组织机构
ORGANIZATIONS

主办单位/ Sponsors：
中国标准化研究院
China National Institute of Standardization
中国空间技术研究院
China Academy of Space Technology
电磁环境效应国家级重点实验室
National Key Laboratory for Electromagnetic Environmental Effects
美国贸易开发署（USTDA）
The United States Trade and Development Agency (USTDA)
美国国家标准协会（ANSI）
American National Standards Institute (ANSI)
美国静电放电协会（ESDA）
Electrostatic Discharge Association (ESDA)

协办单位/ Co-organizers：
北京东方计量测试研究所
Beijing Orient Institute of Measurement and Test
中国电子仪器行业协会防静电装备分会
China's Electronic Instrument Industry Association: Anti-static Equipment Branch
上海防静电工业协会
Shanghai Electrostatic Protection Industry Association

承办单位/Organizers：
贵州师范大学
Guizhou Normal University
中国标准化杂志社
China Standardization Press
《高电压技术》杂志社
High Voltage Engineering

美国贸易开发署（USTDA）
The United States Trade and Development Agency (USTDA)

中国-美国标准与合格评定合作项目（SCCP）
U.S.-China Standards and Conformity Assessment Cooperation Program (SCCP)

ESD-S 第六届静电防护与标准化国际研讨会
6th Electrostatic Protection and Standardization International Conference

会议手册

CONFERENCE MANUAL

2017年11月9日至10日
中国 贵阳
November 9th to 10th, 2017
GUIYANG, CHINA

目录/Content

会议议程

Agenda

美国贸易开发署（USTDA）
中国-美国标准与合格评定合作项目（SCCP）
第六届静电防护与标准化国际研讨会

会议议程

时间、地点:

2017年11月10日
中国贵州省贵阳市贵州师范大学田家炳书院3楼会议厅
贵州省贵阳市宝山北路116号

中国贵州省贵阳市西湖花园大酒店
贵州省贵阳市宝山北路133号

主办单位:

中国标准化研究院
中国空间技术研究院
电磁环境效应国家级重点实验室
美国贸易开发署（USTDA）
美国国家标准协会（ANSI）
美国静电放电协会（ESDA）

协办单位:

北京东方计量测试研究所
中国电子仪器行业协会防静电装备分会
上海防静电工业协会

承办单位:

贵州师范大学
《中国标准化》杂志社
《高电压技术》杂志社

2017 年 11 月 10 日

08:00 - 09:00	**报到注册**
09:00 - 09:20	**欢迎辞**
09:20 - 09:50	**报告题目 1： 中国标准化发展助力静电防护产品质量提升**
	演讲专家：郭德华，研究员
	中国标准化研究院
09:50 - 10:20	**报告题目 2： 我国静电防护技术架构分析与展望**
	演讲专家：季启政，部长，高级工程师
	北京东方计量测试研究所
10:20 - 10:50	**合影、茶歇**
10:50 - 11:40	**报告题目 3：标准存在的问题: 接地和系统水平测试**
	演讲专家：Nathaniel (Nate) Peachey，标准业务部经理
	美国静电放电协会 ESDA
11:40 - 12:00	**现场互动交流**
12:00 - 13:30	**午餐**
13:30 - 14:00	**Topic 4: 非接触静电放电多因素效应与测试标准探讨**
	演讲专家：阮方鸣，教授
	贵州师范大学
14:00 - 14:50	**Topic 5: 设备合格性测试面临的挑战**
	演讲专家：Brett Carn
	Intel 公司，ESDA 董事会成员
14:50 - 15:20	**Topic 6: 空间装备静电起电/放电模拟及防护技术研究**
	演讲专家：原青云，博士
	电磁环境效应国家重点实验室
15:20 - 15:40	**现场互动交流**
15:40 - 16:00	**茶歇**

16:00 - 16:30 **Topic 7: 微型电场传感器技术及应用**

演讲专家：夏善红，研究员

中国科学院电子学研究所

传感技术国家重点实验室

16:30 - 17:00 **Topic 8: 静电放电与二次放电湿度效应研究**

演讲专家：万发雨，教授

南京信息工程大学

17:00 - 17:20 **现场互动交流**

会议结束

U.S.-China Standards and Conformity Assessment Cooperation Program (SCCP)
The United States Trade and Development Agency (USTDA)

The 6th Electrostatic Protection and Standardization International Conference

Agenda

Date/Venue:

November 10, 2017
Guizhou Normal University
No.116, Baoshan North Road, Guiyang, Guizhou, China

West Lake Garden Hotel
No.133, Baoshan North Road, Guiyang, Guizhou, China

Sponsors:

China National Institute of Standardization (CNIS)
China Academy of Space Technology (CAST)
National Key Laboratory for Electromagnetic Environmental Effects
The United States Trade and Development Agency (USTDA)
American National Standards Institute (ANSI)
Electrostatic Discharge Association (ESDA)

Co-organizers:

Beijing Orient Institute of Measurement and Test
China's Electronic Instrument Industry Association Anti-static Equipment Branch
Shanghai Electrostatic Protective Industrial Association

Organizers:

Guizhou Normal University
China Standardization Press
High Voltage Engineering

November 17, 2016

08:00 - 09:00 **Registration**

09:00 - 09:20 **Welcome Address**

09:20 - 09:50 **Topic 1: China standardization development promotes the quality of ESD protection products**

Speaker: Guo Dehua, Researcher

China National Institute of Standardization

9:50 - 10:20 **Topic 2: ESD Protection Technology Architecture of China: Analysis and Prospect**

Speaker: Ji Qizheng, Director, Senior Engineer

Beijing Orient Institute of Measurement and Test

10:20- 10:50 **Coffee break，Group Photo**

10:50 - 11:40 **Topic 3: Issues in Standards: Grounding and System Level Testing**

Speaker: Nathaniel (Nate) Peachey

ESDA Standard business department Manager

11:40 - 12:00 **Interactive Communication**

12:00 - 13:30 **Lunch**

13:30 - 14:00 **Topic 4: Property Discussion on Effect of Multiple Factors in Non-Contact Discharge and Corresponding Standard**

Speaker: Ruan Fangming, Professor

Guizhou Normal University

14:00 - 14:50 **Topic 5: Issues in Standards: Grounding and System Level Testing**

Speaker: Brett Carn

Intel Corporation, Mmember of the ESDA Board of Directors

14:50 - 15:20 **Topic 6: A Study on Space Equipment Electrostatic Electrification/Discharge Simulation and Protection Technology**

Speaker: Dr. Yuan Qingyun**,**

National Key Laboratory for Electromagnetic Environmental Effects

15:20 - 15:40 **Interactive Communication**

15:40 - 16:00 **Coffee break**

16:00 - 16:30 **Topic 7: Miniature electric field sensors and applications**

Speaker: Xia Shanhong, Researcher

State Key Laboratory of Transducer Technology, Institute of Electronics,
Chinese Academy of Science, Beijing, China

16:30 - 17:00 **Topic 8: The effect of humidity on electrostatic discharge and secondary discharge**

Speaker: Dr. Wan Fayu, Professor

Nanjing University of Information Science and Technology

17:00 - 17:20 **Interactive Communication**

The End

主办、协办及承办单位介绍

Sponsor and Organizer Overviews

中国标准化研究院

中国标准化研究院（初名国家科委标准化综合研究所）始建于 1963 年，是直属于国家质量监督检验检疫总局，从事标准化研究的国家级社会公益类科研机构，主要针对我国国民经济和社会发展中全局性、战略性和综合性的标准化问题进行研究。

全院现有职工 500 余人，包括研究员 27 名、博士及博士后 87 名，主要开展标准化发展战略、基础理论、原理方法和标准体系研究。承担节能减排、质量管理、公共安全、视觉健康与安全防护、现代服务、公共管理与政务信息化、信息分类编码、人类工效、食品感官分析等领域标准化研究及相关标准的制修订工作。承担相关领域的全国专业标准化技术委员会、分技术委员会秘书处工作。承担相关标准科学实验、测试等研发及科研成果的推广与应用工作。组织开展能效标识、顾客满意度测评工作，承担地理标志产品保护研究及技术支持工作。负责标准文献资源建设与社会化服务工作，承担国家标准文献共享服务平台运行和标准化基础科学数据资源建设与应用工作。同时，我院的工作直接支撑着国家质量监督检验检疫总局以及国家标准化管理委员会的相关管理职能，包括我国缺陷产品召回管理、国家标准技术审查、全国工业产品生产许可证审查、全国质检中心审查管理等工作。

作为国家级社会公益类科研机构，中国标准化研究院一直致力于积极参与并主导国际组织活动，维护国家利益，承担了国际地理标志网络组织（ORIGIN）副主席职务，承担了国际标准化组织(ISO)的技术委员会副主席、秘书等 13 个关键职务，主持制定 ISO 标准 20 余项。

地址：北京市海淀区知春路 4 号

邮编：100088

http://www.cnis.gov.cn

China National Institute of Standardization

Affiliated with the General Administration of Quality Supervision and Inspection and Quarantine of the People's Republic of China (AQSIQ), China National Institute of Standardization (CNIS) is a non-profit national research body engaging in standardization research. The main responsibilities of CNIS are to conduct all-round, strategic, and comprehensive research of standardization during the development process of economy and society, to research and develop comprehensive fundamental standards, as well as to provide authoritative standards information services. CNIS is poised to provide all-round support in standardization for China's economic development and social progress, to support technical progress, industrial upgrading, and product's quality improvement, and to provide scientific evidence for government policy-making on standardization.

Since its founding in 1963, CNIS has undertaken many national key scientific and research projects. Among them, three important projects of the 10th Five-Year Plan (2000-2005) Key Science and Technology Special Program, namely, Research on Development Strategies for Chinese Technical Standards, Research on Development of China's National Technical Standards System, and Basic Research on and Technological Measures for the Safety Standards of Main Foods, have played important supportive roles for promotion of national standardization. One of our projects, Development of a National Terminology and Graphic Symbol System, has been awarded the State-level Second Prize for Advancement of Science and Technology, the highest prize so far in the field of scientific research on standardization. In addition, many of our projects have been awarded state-level and ministry-level prizes for advancement of science and technology and prizes for key scientific research achievements of the 8th (1990-1995), and 9th (1995-2000) Five-Year Plan periods. Our research has brought about significant influence home and abroad, and has made outstanding contributions to development of China's economic development and the progress of science and technology.

Address：No.4 Zhichun Road, Haidian District, Beijing

Post code：100088

http://www.cnis.gov.cn

中国空间技术研究院

中国空间技术研究院成立于 1968 年，隶属中国航天科技集团公司。经过 40 余年的发展，中国空间技术研究院已成为中国主要的空间技术及其产品研制基地，是中国空间事业最具实力的骨干力量，主要从事空间技术开发、航天器研制，空间领域对外技术交流与合作、航天技术应用等业务。

自 1970 年，中国空间技术研究院先后成功研制并发射了中国第一颗人造地球卫星——东方红一号、实现环月运行的中国首颗月球探测器、实现中国航天员首次空间出舱活动的神舟七号载人飞船等，为中国航天事业发展做出了突出贡献。中国空间技术研究院在北京航天城建成了集系统设计与集成、总装、测试、试验一体化的新型航天器研制生产基地，现在拥有员工 1 万余人，其中包括 8 名两院院士、12 名国家级突出贡献专家和 1700 多名高级专业技术人才。

中国空间技术研究院是我国飞船和卫星的重点研制单位，十分重视电子元器件、单机及整机系统的电磁兼容设计，开展了大量的地面和星上静电防护技术研究工作，并在静电防护管理体系、静电防护技术、防静电系统测试、防静电工作区配置等方面建立了一系列的静电防护院级标准 Q/W 1300~1303-2010，组建了院静电防护管理体系认证委员会和认证中心，在认证中心办公室和审核专家组的协助下，明确了静电防护系统建设与认证管理流程，已经完成对多家院内单位及外协单位开展了静电防护管理体系认证工作，推进了航天领域的静电安全防护进程。

China Academy of Space Technology (CAST)

China Academy of Space Technology (CAST), subordinated to China Aerospace Science and Technology Corporation (CASC), was established on February 20, 1968. Through 44-year development, it has become the main development base for space technology and products in China and the most powerful backbone strength for China’s space endeavor. It is mainly engaged in such fields as development and manufacturing of spacecraft, external exchange and cooperation in space technology, satellite applications, etc. CAST also participates in formulating the state space technology development plans, studies the technological approaches to exploration, exploitation and utilization of outer space, and develops a variety of spacecraft and ground application equipments.

CAST successfully developed and launched china’s first artificial earth satellite. To date, the academy has successfully developed and launched 129 satellites of various kinds and nine Shenzhou spaceships, including scientific and technological test satellites, communications and broadcasting satellites, meteorological satellites, returnable remote sensing satellites and ocean satellites.

CAST has built in Beijing Space City a new spacecraft development and production base which combines system design, assembly, integration, checkout and test in one place. CAST has more than 20,000 staff members, including 8 members of Chinese Academy of Sciences and Chinese Academy of Engineering, 12 national level experts making outstanding contributions, and over 1700 senior specialists. CAST has been making wide contacts with the astronautical companies and space research institutes throughout over a dozen countries and regions.

CAST has engaged in electrostatic field of development of spacecraft and ground application equipments for years, and published series of standards for electrostatic discharge protection management system. It has established certification committee and Electrostatic Discharge Certification of the system, and organized the electrostatic certification of units subordinated to CAST and other co-operation units.

美国贸易开发署（USTDA）

由美国贸易发展署 (USTDA) 提供资助、 美国国家标准协会 (ANSI) 负责协调的美中标准与合格评定合作项目(SCCP) 在以下几个方面为美国和中国相关行业和政府代表提供了一个论坛：

1. 在标准、合格评定以及技术法规等领域的合作;
2. 为促进美中在标准、合格评定以及技术法规等领域的技术交流建立必要的联系;
3. 及时交流关于标准、合格评定以及技术法规等领域的最新议题和发展情况的相关信息

根据 SCCP 项目规定，从 2013 年开始的三年内，ANSI 将在中国协调举办 20 场研讨会。根据美国私营业界相关组织的建议，研讨会内容将覆盖不同的行业和领域。

研讨会的主题将由相关行业组织、ANSI 以及 USTDA 协调选定。

欲了解该项目的更多情况或有意赞助或参与该项目，请访问下列网站：

www.standardsportal.org/us-chinasccp

U.S. Trade and Development Agency

The U.S. Trade and Development Agency (USTDA) helps companies create U.S. jobs through the export of U.S. goods and services for priority development projects in emerging economies. USTDA links U.S. businesses to export opportunities by funding project planning activities, pilot projects, and reverse trade missions while creating sustainable infrastructure and economic growth in partner countries.

美国国家标准学会

American National Standards Institute（ANSI——美国国家标准学会）是由公司、政府和其他成员组成的自愿组织，负责协商与标准有关的活动，审议美国国家标准，并努力提高美国在国际标准化组织中的地位。ANSI 是 IEC 和 ISO 的 5 个常任理事成员之一，也是 4 个理事局成员之一，参加 79%的 ISO/TC 的活动，参加 89%的 IEC/TC 活动。ANSI 是泛美技术标准委员会（COPANT）和太平洋地区标准会议（PASC）的成员。

美国国家标准学会（American National Standards Institute: ANSI）成立于 1918 年。当时，美国的许多企业和专业技术团体，已开始了标准化工作，但因彼此间没有协调，存在不少矛盾和问题。为了进一步提高效率，数百个科技学会、协会组织和团体，均认为有必要成立一个专门的标准化机构，并制订统一的通用标准。1918 年，美国材料试验协会（ASTM）、与美国机械工程师协会（ASME）、美国矿业与冶金工程师协会（ASMME）、美国土木工程师协会（ASCE）、美国电气工程师协会（AIEE）等组织，共同成立了美国工程标准委员会（AESC）。美国政府的三个部（商务部、陆军部、海军部）也参与了该委员会的筹备工作。1928 年，美国工程标准委员会改组为美国标准学会（ASA）。为致力于国际标准化事业和消费品方面的标准化，1966 年 8 月，又改组为美利坚合众国标准学会（USASI）。1969 年 10 月 6 日改成现名：美国国家标准学会（ANSI）。

美国国家标准学会是非赢利性质的民间标准化组织，是美国国家标准化活动的中心，许多美国标准化学协会的标准制修订都同它进行联合，ANSI 批准标准成为美国国家标准，但它本身不制定标准，标准是由相应的标准化团体和技术团体及行业协会和自愿将标准送交给 ANSI 批准的组织来制定，同时 ANSI 起到了联邦政府和民间的标准系统之间的协调作用，指导全国标准化活动，ANSI 遵循自愿性、公开性、透明性、协商一致性的原则，采用 3 种方式制定、审批 ANSI 标准。

ANSI 现有工业学、协会等团体会员约 200 个，公司（企业）会员约 1400 个。领导机构是由主席、副主席及 50 名高级业务代表组成的董事会，行使领导权。董事会闭会期间，由执行委员会行使职权，执行委员会下设标准评审委员会，由 15 人组成。总部设在纽约，卫星办公室设在华盛顿。

American National Standards Institute (ANSI)

As the voice of the U.S. standards and conformity assessment system, the American National Standards Institute (ANSI) empowers its members and constituents to strengthen the U.S. marketplace position in the global economy while helping to assure the safety and health of consumers and the protection of the environment.

The Institute oversees the creation, promulgation and use of thousands of norms and guidelines that directly impact businesses in nearly every sector: from acoustical devices to construction equipment, from dairy and livestock production to energy distribution, and many more. ANSI is also actively engaged in accrediting programs that assess conformance to standards – including globally-recognized cross-sector programs such as the ISO 9000 (quality) and ISO 14000 (environmental) management systems.

ANSI has served in its capacity as administrator and coordinator of the United States private sector voluntary standardization system for more than 90 years. Founded in 1918 by five engineering societies and three government agencies, the Institute remains a private, nonprofit membership organization supported by a diverse constituency of private and public sector organizations.

Throughout its history, ANSI has maintained as its primary goal the enhancement of global competitiveness of U.S. business and the American quality of life by promoting and facilitating voluntary consensus standards and conformity assessment systems and promoting their integrity. The Institute represents the interests of its nearly 1,000 companies, organization, government agency, institutional and international members through its office in New York City, and its headquarters in Washington, D.C.

美国静电放电协会

Electrostatic Discharge Association（ESDA——美国静电放电协会）于 1982 年在美国成立，总部设在纽约，是一个专业的自愿组织，从事静电放电理论和实践研究。其成员从成立初期不到 100 名，发展到遍布全球、总数超过 2,000 名。其领域从仅限于电子元器件的 ESD 影响，拓宽到纺织品、塑料、居室清洁和形象艺术等领域。该协会授权通过标准开发、教育节目、专业书籍、出版物、指南、认证工作和座谈会宣传 ESD 知识。

ESDA 是一个国际化组织，其成员来自 30 多个国家。他们服务于协会标准委员会，在 EOS/ESD 年会上进行技术研讨，并为其它国家的相关组织提供资讯联系。协会已经和不同国家的类似组织建立了正式和非正式联系，正式联系包括日本可靠性中心，新加坡生产力标准部（PSB），日本电子工业协会（EIAJ），德国 ESD 论坛，欧洲的 ESREF，以及巴西的 ABRICEM。

ESDA 的职责是在国际电工委员会（IEC）静电学领域代表美国利益。随着标准领域全球协调性要求的增加，ESD 协会日益受到广泛关注。

Electrostatic Discharge Association (ESDA）

Founded in 1982, the ESD Association (ESDA) is a professional voluntary association dedicated to advancing the theory and practice of electrostatic discharge (ESD) avoidance. From fewer than 100 members, the Association has grown to more than 2,000 members throughout the world. From an initial emphasis on the effects of ESD on electronic components, the Association has broadened its horizons to include areas such as textiles, plastics, web processing, clean-rooms, and graphic arts. To meet the needs of a continually changing environment, the Association is chartered to expand ESD awareness through standards development, educational programs, local chapters, publications, tutorials, certification, and symposia.

Although founded and headquartered in the United States, the ESD Association has a strong international flavor. Its members come from more than 30 countries throughout the world. They serve on Association Standards Committees, present technical papers at the annual EOS/ESD Symposium, and provide the communication links with similar organizations in other countries.

The Association has established informal and formal relationships with similar organizations in various countries. The formal relationships include the Reliability Center of Japan, Productivity Standards Board (PSB) in Singapore, Electronics Industry Association of Japan (EIAJ), ESD Forum of Germany, ESREF in Europe, and ABRICEM in Brazil.

The ESD Association has the responsibility of representing the interest of the United States at the International Electro-technical Commission (IEC) in the area of electrostatics. With the increasing need for global harmonization in the area of standards, the international focus of the ESD Association is vitally important.

北京东方计量测试研究所

北京东方计量测试研究所成立于 1985 年，又称为中国航天科技集团公司第五研究院第五一四研究所，是中国空间技术研究院所属的专业计量测试研究所。

北京东方计量测试研究所是国防科技工业电学一级计量站，是集电磁学、无线电电子学、时间频率、几何量、热学、力学、真空、卫星应用、静电防护和电磁干扰等专业为一体的综合性计量测试研究所，承担着我国国防科技工业、军队系统特别是航天和空间技术领域量值传递和计量校准测试任务，开展计量标准装置和测试设备研制、测量技术和测试方法研究、能力验证和比对、计量人员培训和计量标准考核等工作，同时面向社会提供公正的校准、检测和检验服务。

北京东方计量测试研究所是博士、硕士研究生培养单位，是国家批准的“仪器科学与技术”硕士学位一级学科点。现有博士生导师、硕士生导师、学科带头人后备人员 10 多名，与国内外技术、学术团体有着广泛的接触与联系。

近年来，北京东方计量测试研究所积极开展了航天型号产品相关的静电防护技术研究，承接了多项静电相关的星船地面试验任务，负责起草了中国空间技术研究院的静电防护管理体系院标 Q/W 1300~1303、中国航天科技集团公司静电体系标准 Q/QJA 118~123、国军标 GJB/J 5972-2007《非接触静电电压表校准规范》以及国家标准 GB/T 32304-2015《航天电子产品静电防护要求》等，是航天科技和五院静电防护管理体系的技术支撑单位，已经组织开展了航天科技、航天科工、中电集团、中科院、战略支援部队等多家单位的航天电子产品静电防护管理体系建设和认证工作并收到良好效果。

同时，北京东方计量测试研究所主动搭建静电防护产业化发展生态，具备技术研究、产品检测、物资配货、工程施工、培训咨询、体系认证、产品认证等基础业务服务以及静电防护系统解决方案提供能力，具有国家认监委批复筹建的国家静电防护产品质量监督检验中心、工信部授权的工业（静电防护）产品质量控制和技术评价实验室，是国家认监委授权的国家静电防护产品认证机构，建设了院士专家工作站，通过设立院士工作站静电研究基金等方式，逐步搭建全国性静电专家研究平台，推动我国静电防护技术研究和标准化发展。诚邀各领域专家加入平台，共谋发展！

Beijing Orient Institute of Measurement & Test (BOIMT)

Founded in 1985, Beijing Orient Institute of Measurement & Test (BOIMT) is a metrological institute, subordinated to China Academy of Space Technology (CAST).

BOIMT is tasked with establishing, maintaining and improving measurement standards and conducting research on relevant technologies to achieve more precise measurement. BOIMT plays an important role in every development process of the spacecraft. Each year, BOIMT calibrates approximately 90 thousands set of equipments for CAST.

The calibration services of the institute mainly relate to electromagnetic calibration, radio calibration, time and frequency calibration, geometrical calibration, mechanics calibration (including vacuum calibration), etc. Up until now, BOIMT has established 43 measurement standards, including 14 national-defense primary electrical standards. BOIMT provides essential guard for the accuracy and reliability of quantity values within national-defense system. Especially, it has advanced electrical calibration standards, such as Quantum Hall resistor primary standard and Josephson Voltage primary standard, which have reached the international advanced level.

BOIMT has engaged in electrostatic field for years, and drafted series of standards, for instance, the electrostatic discharge protection management system (Q/W1300-1303), including electrostatic discharge protection management system requirements, technical requirements for electrostatic discharge protection, test requirements for electrostatic discharge protection system and configuration requirements for electrostatic discharge protected area, and the national standard as well, which is Electrostatic discharge protection requirements for aerospace electronic products （GB/T 32304-2015）.What’s more, BOIMT is the technical unit of electrostatic discharge protection, and Electrostatic Discharge Certification of CAST, and initiated the establishment of electrostatic discharge protection management system for such enterprises as China Aerospace Science and Technology Corporation (CASC), China Aerospace Science & Industry Corporation (CASIC), China Electronics Technology Group Corporation (CETGC), Chinese Academy of Science (CAS) and the PLA Strategic Force, which have achieved good results.

At the same time, BOIMT takes the initiative in pursuing the ecological development of electrostatic protection industry, with the systematic solution for electrostatic protection and the ability of technical research, product testing, material distribution, engineering construction, training, consulting, system certification and product certification and other basic services.

BOIMT has been authorized as the unit for anti-static products certification and the quality supervision and inspection center for anti-static products (under-construction) by Certification and Accreditation Administration of the People’s Republic of China (CNCA). Ministry of Industry and Information Technology (MIIT) has also granted BOIMT to the quality control and technical evaluation laboratory for ESD products. Furthermore, by establishing academician workstation and the anti-static research fund along with it, BOIMT has gradually set up a national research platform to promote the development of electrostatic protection technology and standardization in china. Warm welcome experts in all fields to join in this workstation and progress together!

中国电子仪器行业协会防静电装备分会

中国电子仪器行业协会防静电装备分会成立于一九九七年。业务上受国家工业和信息化部相关部门的指导，隶属于中国电子仪器行业协会。是由从事静电与净化控制产业研发、制造、销售、工程施工、检测、培训及应用的相关企事业单位、大专院校、科研院所、业内有关社会团体，以及专家、学者等热心静电与净化控制事业的个人，不受部门和地区限制，自愿组成的全国非盈利性社会团体。本协会经国家民政部批准依法登记，具有社会团体法人资格的社会组织，现有会员单位 280 余家。

协会的宗旨是：为会员单位服务，维护本行业和会员单位的合法权益，贯彻执行国家的政策法律法规，推动防静电装备行业的发展。

防静电装备分会的主要任务包括：

1、协助政府部门制定本行业的技术与产业发展规划；

2、组织行业内外有关单位的联合技术攻关和开发新产品；

3、征集会员单位建议，向政府有关部门反映、沟通情况；

4、组织行业概况调研，制定行规行约；

5、组织并参与制、修定本行业的 GB、GJB、SJ/T 等标准工作；

6、开展技术研究、产品开发、投资项目的论证、评估等咨询服务；

7、开展本行业经营管理业务的培训；

8、利用协会网站组织防静电技术及应用的推广普及，开展市场调研，协助会员单位开拓市场、沟通生产单位与用户之间的联系；

9、开展与国内外有关学术团体、企事业单位、行业协会、信息网及杂志社等联系与合作，组织技术、产品及应用市场等方面的交流，组织国内国际展览会、展示会和技术研讨会等；

10、出版行业刊物《中国防静电》杂志，向政府部门、会员单位、相关用户免费赠阅；

11、根据政府部门委托和会员单位要求，举办其他有关活动。

联系方式：（010）68647410/51246352（电话）（010）68647410（传真），北京市石景山区万达广场 CRD 银座 B-1128 室，100040。网站为 66 防静电网，邮箱 chinaesd@chinaesd.org.cn

China's Electronic Instrument Industry Association

Anti-static Equipment Branch

Anti-static equipment branch is the anti-static equipment industry engaged in scientific research, production and management of enterprises and institutions, not affected by departments and regions limit is composed of voluntary social organizations. Belongs to the Chinese electronic instrument industry association, the association the approval of the ministry of civil affairs shall be registered according to law, have the corporative qualifications of social group, more than 280 members of the existing units.

Association's objective is: for the member unit service and maintain the industry member unit and the lawful rights and interests of the implement state policy laws and regulations, and promote the development of anti-static equipment industry.

Anti-static equipment branch is the government department of anti-static equipment industry to industry management assistant and staff. In the government department and the enterprises and institutions between the bridge and button take effect, to reflect the government enterprises and wishes and requirements, maintain the lawful rights and interests of the industry, assisting the government do a good job in industry management, in business by state ministry of industry and information related departments guidance.

Association tasks include:

Assisting the government department to make the industry technology and industry development planning;

Inside and outside the industry organization of the units concerned joint technology research and development of new products;

Suggestions for the member unit, convey to the government departments, communication circumstance;

An overview of the industry organization investigation, formulate guild regulations HangYao;

Carry out technology research, product development, investment project argumentation, evaluate consulting services;

Participate in making relevant industry standards work;

To carry out the industry management business training;

Use association website organization antistatic technology and application of the popularization and carry out market research, assist member unit to expand the market, communication production unit and the connection between the users;

Development and domestic and foreign related research institutions, enterprises and institutions, industry association, the information network and magazines, etc contact and cooperation, organization technology, product and application market exchanges, organize the domestic and international exhibitions, exhibitions and technical seminars, etc.;

Publishing industry publication national defence in electrostatic magazine, to government departments, the member unit, the related users provide free;

According to the government commission and member unit requirements, hold other relevant activities;

China's electronic instrument industry association anti-static equipment branch address:

Address: Beijing city wanda plaza CRD ginza B - 1128 room

Zip code: 100040

Telephone: (010) 68647410 51246352 fax: (010) 68647410

Web site: 66 antistatic grid

E-mail: chinaesd@chinaesd.org.cn

上海防静电工业协会

上海防静电工业协会 Shanghai Electrostatic Protective Industrial Association（缩写：SEPIA），成立于 2004 年 9 月。本协会是由从事防静电产业的企业、事业单位自愿发起组成的专业性、跨行业、跨地区的非盈利性组织，是上海市一级行业协会，社会团体法人。会员单位主要是覆盖长三角地区的生产防静电服装、地板、包装、耗材、装备设备或有关设计等领域的骨干企业，现有会员单位 105 个,理事单位 22 个。

随着我国信息化建设发展，计算机、通讯、集成电路等行业进入了快速发展期，静电危害问题突出。防静电装备、器材、工具以及防静电环境工程，生产线防静电系统等防静电产业逐步成为先进制造业配套服务的充满活力的新兴产业。由于防静电装备产品有近 100 类，2000 多种，初期生产加工相对容易，部分企业质量管理水平较低，产品生产没有标准，迫切需要加以提高。协会设：标准化委员会、专家委员会等，并投资成立具有独立法人资格的“上海工业静电技术研发服务中心”，负责技术咨询、检测、评估、组织培训、项目开发等。协会有内部季刊《上海防静电工业》。

协会成立以来，已多次牵头组织会员单位参与制定防静电方面国家、行业、地方标准；召开国际、国内有关新技术、新产品研讨会；开展相关知识、技术培训及静电专业职称申报评审等。

协会地址：上海市虹口区车站北路 625 弄 57 号 306 室

邮编：200434

电话：021-65367650

传真：021-65369757

网址：http://www.esdchina.org.cn

电子邮箱：esd_china@esdchina.org.cn

Shanghai Electrostatic Protection Industry Association

Founded in Sep.2004, Shanghai Electrostatic Protection Industry Association (abbr. SEPIA) is a non-profit organization are voluntarily formed by electrostatic protection enterprises and institutions of professionals, cross-trades and cross-regions. SEPIA is a Class A legal body corporate of the industry associations in shanghai and social groups. Members are mainly covered the backbone enterprises of manufacturing and producing anti-static clothing, floors, packages, consumable goods, equipments, devices or related designing,etc. in the areas of the Yangtze River Delta. Currently, SEPIA holds 105 member units, among them 22 are council members.

With the development of the building- of our country's information system, the industries of computer, telecommunication, integrate circuit, etc. have been getting into a speedy developing period, but the issue of the electrostatic hazards has also become prominent to them. Thus, the industries of installation, facility, equipment, tool, environmental engineering, production line system, etc. for electrostatic protection have become vibrant new and rising ones of the Hi-Tech manufacturers with assorted supporting services. Because there were nearly 100 classifiable outfits and 2000 varieties of produts, the production and processing in part of the industries were relatively easy entry at the early stage, the standards of their products' quality control were weak in some manufactures and no criterions could be followed. So it seemed the improvement was in an urgent need.

The Association has set: the Standardization Committee and the Committee of Experts, etc. and invested in establishing a working unit of independent legal personnality " Shanghai Research and Development Service Center for Industrial Electrostatic Technology" , responsible for technical consulting, testing, evaluation, organition, training, project development. SEPIA also has its internal magazing < Shanghai Electrostati Protection Industry >published quarterly.

Since its founding, the Association has taken the leading role in repeatedly organizing its member units involved in fomulating the criterions in the fields of electrostatic protection for the country, the industry and the local; also convening domestic and international conferences and seminars for the related new technologies and new products and launching and developing trainings of technical know-how, also doing jobs on applying, assessing, evaluating and filing electrostatic professional titles, etc.

President: Huang-JianHua Chairman&General Manager of Shanghai Chen-Long International Trade Ltd.,Com.

Address: R306 No.57, Lane625,Road Noth ChenZhan, Shanghai Zip:200434

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Net: http://www.esdchina.org.cn E-mail:esd_china@esdchina.org.cn

贵州师范大学

贵州师范大学地处 有“中国避暑之都”美誉的贵州省省贵阳市，现有宝山、白云和花溪大学城三个校区，占地面积 2800 余亩。有全日制在校学生 3.6 万人，设有 24 个学院、1 所继续教育学院、1 所独立学院。

学校学科综合实力位居贵州省高校第二。现有 4 个一级学科博士学位授权点、16 个一级学科硕士学位授权点、5 个二级学科硕士学位授权点、6 个自主设置二级学科硕士学位授权点，5 个硕士专业学位类别（领域）授权点。学科专业涵盖文、理、工、农学、管理学、艺术学等 11 门类。

学校有教授 302 人、副教授 634 人，有 519 人具有博士学位、996 人具有硕士学位；有 2 个院士工作站、1 个国家工程技术研究中心、1 个国家地方联合工程实验室、1 个国家级大学科技园。2011 年以来，学校共承担省部级以上科研项目 1256 项，经费近 4.87 亿元；获批专利 252 项，出版学术著作 280 部，学术论文被 SCI、EI、ISTP、ISSHP 等收录 4000 余篇。

学校注重对外学术交流与合作研究，先后与美国、英国、葡萄牙、俄罗斯、澳大利亚、日本、韩国、泰国、印度尼西亚、马来西亚、越南、柬埔寨等多个国家和台湾地区的大学与科研机构建立长期合作与交流关系，分别与美国、葡萄牙、俄罗斯、韩国、日本、泰国、印度尼西亚、马来西亚、瑞士等国家和台湾地区的多所大学开展有师生交流项目。

学校历经七十六年风雨，综合实力稳步提升，为推动贵州经济社会发展尤其是基础教育的发展做出了积极贡献。站在新的历史起点上，学校将为加快建设教师教育特色鲜明、多学科协调发展的高水平教学研究型大学而努力奋斗。

Guizhou Normal University

Guizhou normal university (GZNU) is located in Guiyang city of Guizhou province with the reputation of "the summer capital of China". At present, it has three campuses, Baoshan, Baiyun and Huaxi, with a total land area of 187 hectares. There are 36,000 full-time students, with 24 colleges and 1 continuing education college and 1 independent college.

The comprehensive strength of the school discipline ranks second in Guizhou province. It has 4 first-level discipline doctorate authorization centers, 16 first-level discipline master's degree authorization centers, 5 secondary disciplines master's degree authorization centers, 6 secondary disciplines master's degree authorization centers of independent setting field, 5 master's major degree authorization centers. Subject majors include 11 categories such as literature, science, engineering, agriculture, management, and art.

There are 302 professors and 634 associate professors. 519 have doctorate degrees and 996 have master's degrees. There are 2 academician workstations, 1 national engineering and technology research center, 1 national local joint engineering laboratory and 1 national university park of science and technology. Since 2011, GZNU has undertaken 1256 scientific research projects in provincial and ministerial level, with a total of nearly 487 million RMB. It has received 252 patents and 280 academic works. More than 4000 academic papers have been included in SCI, EI, ISTP and ISSHP.

GZNU attaches great importance to intercommunication, and actively conducts academic exchanges with universities and institutions abroad. It has, so far, established long-term links and cooperation with over 40 universities, colleges, and research institutions including America, Britain, Australia, Portugal, Japan, Korea, Thailand, to name a few. Exchange programs in training students and teachers have already been carried out with some universities in Korea, Japan, Thailand and America respectively.

After 76 years of wind and rain, the school has steadily improved its comprehensive strength and made positive contributions to the development of Guizhou economic and social development, especially the education. At the new historical starting point, the school will strive to accelerate the development of the teaching research university of education, a high level teaching and research university with distinctive features and multi-discipline development.

中国标准化杂志社

中国标准化杂志社是由中国标准化协会和中国标准化研究院的全资公司——中国标准科技集团有限公司共同出资的股份制企业。由国家质检总局主管，中国标准化研究院和中国标准化协会共同主办。本着顺应国家新闻出版总署关于中央新闻出版业文化体制改革精神的要求，依据国家新闻出版总署及有关部门规定，经国家质检总局同意，2010 年 9 月，由中国标准化研究院主办的标准科学杂志社(出版刊物为：《标准科学》、《标准生活》、《术语标准化与信息技术》)与中国标准化协会主办的中国标准化杂志社（出版刊物为：《中国标准化》、《China Standardization》）正式合并，2011 年 12 月《术语标准化与信息技术》更名为《产品安全与召回》。现五本杂志涵盖了中国标准化领用领域的政策形势时事政策、发展动态、研究成果、国行标权威发布、标准科技前沿和热点探讨、标准化理论与实践、中国标准化文化历史，以及与百姓生活息息相关的标准知识普及等内容，是目前中国标准化领域最全面、最权威和最具实力的传媒机构。

China Standardization Press

China Standardization Press is a professional media institution in the field of standardization jointly established by China National Institute of Standardization (CNIS) and China Standardization Association (CAS). It is dedicated to be an authoritative media group in China standardization and make great contributions to its development.

China Standardization Press has five journals:

China Standardization (Chinese)

Started in 1958, it is the most influential professional media in China's standardization field.

China Standardization (Overseas)

Started in 2004, it reports the China standardization development in an all-round to the international community, expressing the viewpoints of experts from home and abroad and displaying the standardization culture with Chinese characteristics. It is the only English journal for exchange with overseas standardization organizations.

Standard Science

Started in 1964, it is a core journal in science and technology in China focusing on probing and research of theories of standardization science. It is also a platform for communication of standardization theory and academic exchanges.

Standard Living

Started in 1964, it is a fashionable magazine for science popularization, using popular and easy ways to explain standards, plain and simple language to report news of standardization, and adopting shocking cases to strengthen standards, so as to serve as a standardization guide for common people.

Product Safety and Recall

Started in 1996, it was originally named as Terminology of Standardization and Information Technology. It is professional periodical for introduction of policies, laws, regulations and standards of product safety, analysis of current status and development trend of product safety management at home and abroad, summing up and exchange of experiences in enterprises' product safety management, promotion of product safety technologies, and popularization of product safety knowledge.


高電壓技術
HIGH VOLTAGE ENGINEERING
1975年创刊
主办：国家高电压计量站
中国电机工程学会
出版：中国电力科学研究院
中文核心期刊
美国EI数据库收录
Scopus 数据库收录
《高电压技术》是国内外高电压科技领域具有重要影响力的学术期刊，期刊宗旨为报导高电压及其相关交叉学科研究进展，致力于促进学术交流、引领科技进步。
栏 目
◆ 高电压大功率电力电子与智能输电
◆ 电气绝缘与测试
◆ 输配电设备状态评价与故障诊断
◆ 放电等离子体与脉冲功率
◆ 电磁环境与电磁生物效应
◆ 城市电网智能化
电子邮箱: hve@epri.sgcc.com.cn
在线投稿: http://hve.epri.sgcc.com.cn
gdyjs1975
（欢迎关注）

演讲文稿

Presentations

郭德华

郭德华，博士研究生学历，博士学位，研究员。1987 年 9 月毕业于天津大学精仪系精密仪器专业，获得工学学士学位；1990 年 3 月毕业于天津大学精仪系测试计量技术及仪器专业，获得工学硕士学位；2006 年毕业于中国科学院研究生院，获得管理学博士学位。现工作于中国标准化研究院公共安全标准化研究所，曾赴瑞典接受欧洲标准化知识培训、在美国试验与材料协会（ASTM）访问学习。多年从事标准化研究，具体领域涉及：标准化管理与运行机制、标准情报与标准知识组织、个体防护装备标准化、静电防护标准化，主持和参与国家级和省部级及其他科研与工作项目 30 多项，主编或参与著作或译著 15 部、制定国家标准 10 余项，发表论文 50 余篇，获得国家发明专利 3 项。

Guo Dehua

Guo Dehua, doctoral degree, doctorate, researcher. In September 1987, she graduated from Precision Instrument Major, Department of Precision instrument of Tianjin University with a bachelor's degree in engineering. In March 1990, she graduated from Test Measurement Technology and Instrument Major, Department of Precision instrument of Tianjin University with a master's degree in engineering. In 2006, she graduated from Graduate University of Chinese Academy of Sciences with a doctor's degree in Management Science. She works in Institute of Public Safety Standardization, China National Institute of Standardization now. She had gone to Sweden to accept the European standardization knowledge training, and visited and studied in ASTM. She has been engaged in standardized research for many years and specific areas: standardization management and operation mechanism, standard intelligence and standard knowledge organization, standardization of personal protective equipment and standardization of ESD protection. She hosted and participated in more than 30 national and provincial projects and other research and work projects, and edited or participated in 15 publications or translations, formulated more than 10 national standards, published more than 50 articles and obtained three national invention patents.

中国标准化发展
助力静电防护产品质量提升

中国标准化研究院
公共安全标准化研究所
郭德华
2017年11月10日

内容

1 标准支持质量提升
2 中国标准化发展
3 静电防护标准

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1. 标准支持质量提升

•质量发展纲要（2011-2020）
国发[2012]9号，国务院，2012年2月6日

•消费品标准与质量提升规划（2016—2020年）
国发【2016】68号，国务院，2016年9月6日
改革标准供给体系

•装备制造业标准化和质量提升规划
国质检标联〔2016〕396号
质检总局　国家标准委　工业和信息化部
2016年8月1日
提升装备制造业标准化创新能力

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1. 标准支持质量提升

❖ 中共中央 国务院关于开展质量提升行动的指导意见（2017年9月5日）

产品、工程和服务质量

➢ 加快标准提档升级
改革标准供给体系

➢ 加快国家质量基础设施体系建设
（计量、标准、检验检测、认证认可）
建立政府主导制定的标准与市场自主制定的标准协同发展、协调配套的新型标准体系。

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1. 标准支持质量提升

2017年世界标准日

❖ 主题：标准让城市更智慧
有了国际标准，智慧城市将会更加顺畅、更加一体化地发展。

❖ 中国主题：标准化助力质量提升
牢牢抓住标准这个质量提升的“牛鼻子”，充分发挥和彰显标准化在质量提升中的突出作用。

内容

1 标准支持质量提升
2 中国标准化发展
3 静电防护标准

2. 中国标准化发展

- **深化标准化工作改革方案**
  国发〔2015〕13号），国务院，2015年3月26日
- **国家标准化体系建设发展规划（2016-2020年）**
  国办发〔2015〕89号，2015年12月17日
- **《贯彻实施<深化标准化工作改革方案>重点任务分工(2017-2018年)》**
- **《标准化法》修订**
  - 3月22日，国务院法制办就《中华人民共和国标准化法(修订草案征求意见稿)》公开征求意见
  - 4月24日下午，十二届全国人大常委会第二十七次会议
  - 8月28日上午，十二届全国人大常委会第二十九次会议
- ✓ *国家鼓励学会、协会、商会、联合会、产业技术联盟等社会团体协调相关市场主体共同制定满足市场和创新需要的团体标准。此外，企业可以与其他企业联合制定企业标准。*
- ✓ *标准包括国家标准、行业标准、地方标准和团体标准、企业标准；国家标准分为强制性标准、推荐性标准，行业标准、地方标准是推荐性标准。*

2. 中国标准化发展

- 改革的基本原则共有四项，一是坚持简政放权、放管结合。二是坚持国际接轨、适合国情。三是坚持统一管理、分工负责。四是坚持依法行政、统筹推进。

  把该放的放开放到位，培育发展团体标准，放开搞活企业标准，激发市场主体活力；把该管的管住管好，强化强制性标准管理，保证公益类推荐性标准的基本供给。

- 新型标准体系由政府主导制定的标准和市场自主制定的标准共同构成，改变现行的政府单一供给的标准体系。
- 政府主导制定的标准由6类整合精简为4类，包括：强制性国家标准（将现行的强制性国家标准、行业标准、地方标准整合为新型的强制性国家标准）、 推荐性国家标准、推荐性行业标准、推荐性地方标准；
- 市场自主制定的标准分为团体标准和企业标准。政府主导制定的标准侧重于保基本，市场自主制定的标准侧重于提高竞争力。

2. 中国标准化发展

标准体系

代号：GB、GB/T、GB/Z、GSB、HG、HG/T

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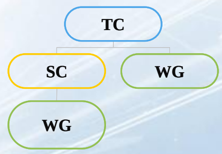
2. 中国标准化发展

- 技术委员会TC （500+）
- 分技术委员会SC （700+）
- 工作组WG



TC/SC成立评估

国家标准立项评估

2. 中国标准化发展

- 培育发展团体标准方面，标准制定主体上，鼓励具备相应能力的学会、协会、商会、联合会等社会组织和产业技术联盟协调相关市场主体共同制定满足市场和创新需要的标准，供市场自愿选用，增加标准的有效供给。在标准管理上，对团体标准不设行政许可，由社会组织和产业技术联盟自主制定发布，通过市场竞争优胜劣汰。

- 在放开搞活企业标准方面，企业根据需要自主制定、实施企业标准。鼓励企业制定高于国家标准、行业标准、地方标准，具有竞争力的企业标准。建立企业产品和服务标准自我声明公开和监督制度，逐步取消政府对企业产品标准的备案管理，落实企业标准化主体责任。

2. 中国标准化发展

- 截至2016年年底，团体标准蓬勃发展，在全国团体标准信息平台注册制定标准的社会团体达到378家，已公布451项团体标准信息；企业标准活力释放，超过6万家企业公开了近25万项标准。
- 国家标准委在2017年工作安排中提出，“培育发展市场自主制定的标准，发展壮大团体标准，深化企业标准管理制度改革。
- 质检总局、国家标准委《关于培育和发展团体标准的指导意见》
- GB/T 20004.1《团体标准化第1部分：良好行为指南》

内容

2. 中国标准化发展

标准化：制定、发布及实施标准的过程

❖ 强制性标准整合精简

❖ 国家重点研发计划：

国家质量基础的共性研究与应用重点专项（NQI专项）

❖ 标准化服务业

关于培育发展的指导意见（送审稿）（2017年8月）

第一批标准化服务业试点项目（2016年11月28日）

2. 中国标准化发展

❖ 强制性标准整合精简工作全面完成（2016年 年初开始）

在11224项强制性国家、行业和地方标准中：

——拟废止的强制性标准为2178项，占总数的19%；

——拟转化为推荐性标准为3657项，占总数的33%；

——拟将多项进行整合为一项的强制性标准为1196项，占总数的11%；

——拟修订的强制性标准为1464项，占总数的13%；

——2729项强制性继续有效，占总数的24%。

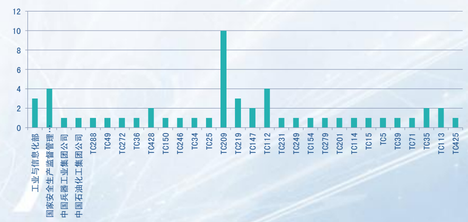
❖ 公示征求意见

❖ **关于印发强制性标准整合精简结论的通知（2017年1月14日）**

- **附件1-强制性标准整合精简结论清单（上册）**
- **附件1-强制性标准整合精简结论清单（下册）**
- **附件2-强制性标准计划项目整合精简**

3 静电防护标准

- 国家标准 51项



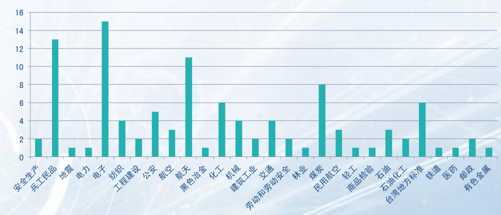
4个归口单位和26个TC，纺织品、服装、个体防护装备、带轮与带

3 静电防护标准

强制性国家标准整合精简

标准号	标准名称	整合精简结论
GB 12014-2009	防静电服	修订
GB 12158-2006	防止静电事故通用导则	与GB 13348-2009 整合为强制性国家标准
GB 12367-2006	涂装作业安全规程　静电喷漆工艺安全	修订
GB 13348-2009	液体石油产品静电安全规程	与GB 12158-2006 整合为强制性国家标准
GB 14773-2007	涂装作业安全规程.静电喷枪及其辅助装置安全技术条件	修订
GB 15607-2008	涂装作业安全规程.粉末静电喷涂工艺安全	
GB 26539-2011	防静电陶瓷砖	转化为推荐性标准
GB 4655-2003	橡胶工业静电安全规程	
GB 50515-2010	导(防)静电地面设计规范	
GB 50611-2010	电子工程防静电设计规范	
GB 50813-2012	石油化工粉体料仓防静电燃爆设计规范	
GB 50944-2013	防静电工程施工与质量验收规范	
GB 4385-1995	防静电鞋、导电鞋 技术要求	废止

3 静电防护标准



106项；28个行业。

标准号	标准名称	整合精简结论
AQ 4115-2011	烟花爆竹防止静电通用导则	修订为强制性国家标准
GA 96-1995	铺地纺织品静电性能参数及测量方法	转化为推荐性标准
HG 2793-1996	工业用导电和抗静电橡胶板	转化为推荐性标准
JT 197-1995	油船静电安全技术要求	修订为强制性国家标准
JT 230-1995	汽车导静电橡胶拖地带	转化为推荐性标准
MT 113-1995	煤矿井下用聚合物制品阻燃抗静电性通用试验方法和判定规则	转化为推荐性标准
MT 379-1995	煤矿用电雷管静电感度测定方法	转化为推荐性标准
MT 449-1995	煤矿用钢丝绳牵引输送带阻燃抗静电性试验方法和判定规则	废止
MT 450-1995	煤矿用钢丝绳芯输送带阻燃抗静电性试验方法和判定规则	废止
MT 520-1995	煤矿雷管生产厂防静电安全规程	废止

China standardization development promotes the quality of ESD protection products

China National Institute of Standardization
Institute of Public Safety Standardization
GUO Dehua
November 10, 2017

Contents

1.Standards support for quality improvement

•Quality Development Plan (2011-2020) G.F. No. [2012]9, the State Council, February 6th, 2012
•Consumer Product Standard and Quality Improvement Plan(2016—2020)
G.F. No. [2016] 68, the State Council, September 6th, 2016
Reform standard supply system
•Standardization and Quality Improvement Plan of Equipment Manufacturing Industry
G.Z.J.B.L No. 〔2016〕 396
Ministry of Quality Control, National Standard Committee, Ministry of Industry and Information Technology
August 1st, 2016
Promoting standardization innovation ability of equipment manufacturing industry

1.Standards support for quality improvement

- **Guiding opinions of the CPC Central Committee and State Council to carry out quality improvement actions (September 5th, 2017)**

Quality of products, engineering and services

- To speed up the upgrading of standards
  To reform standard supply system
- Speed up the construction of national quality infrastructure system
  (Metrology, standards, inspection, certification and accreditation)

Setting up the new standard system that the standard formulated by the government and the standard set up by the market autonomously are in the coordinated development.

1.Standards support for quality improvement

2017 World Standard Day

- **Subject: Standards make cities more intelligent**
  With the international standards, the intelligent cities will have more smooth and more integrated development.
- Chinese subject: Standardization promotes quality improvement
  Firmly grasp the standard which is the key problem of quality improvement, and give full play to highlight the prominent role of standardization in quality improvement.

Contents

2.China standardization development

- **Reform Plan of Deepening the Standardization Work**

  G.F. No. 〔2015〕13, the State Council, March 26, 2015
- **National Standardization System Construction and Development Plan (2016-2020)**

  G.B.F. No. 〔2015〕89, December 17, 2015
- *Implementing the Division of Key Tasks of <Deepening the Reform Plan of Standardization Work> (2017-2018)*
- Revision of *Standardization Law*
  - In March 22nd, the Legislative Affairs Office of the State Council publicly solicited opinions on *the People's Republic of China Standardization Law (Revised Draft)*.
  - On the afternoon of April 24th, the twenty-seventh meeting of the12th NPC Standing Committee
  - In the morning of August 28th, the twenty-ninth meeting of the 12th NPC Standing Committee

✓ ***The State encourages social organizations such as associations, chambers of Commerce, federations, industrial technology alliances to coordinate the relevant market bodies to jointly formulate group standards to meet the needs of the market and innovation. In addition, enterprises can work together with other enterprises to develop enterprise standards.***

✓ ***The standards include national standards, industry standards, local standards, group standards and enterprise standards; national standards are divided into mandatory standards, recommended standards and industry standards; local standards are recommended standards.***

2.China standardization development

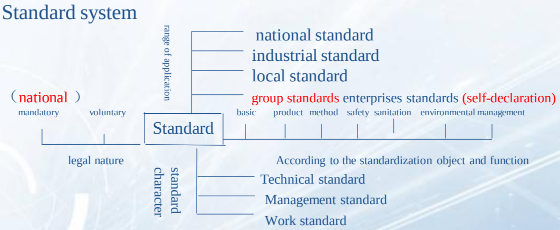
- **The basic principles of reform are four, one is to adhere to streamlining administration, and combing of delegating power and strengthening regulation; two is to keep international integration and be suitable for national conditions. Three is to insist on unified management, division of labor. Four is to insist on administration according to law and make overall plans.**

We should open the right area in place, cultivate the development group standard, release and enliven the enterprise standard, and stimulate the vitality of market subjects; We manage the matter well, strengthen mandatory standards management, and ensure the basic supply of public welfare recommended standards.

- **The new standard system is made up of the government led standards and the standards set by the market independently, which will change the current standard system of the government's single supply.**
- **The government led standards are reduced from 6 types into 4 categories, including: mandatory national standards (the current mandatory national standards, industry standards, local standards are integrated to new mandatory national standards), recommended national standards, recommended industry standards and local standards recommended;**
- **The standards set by the market are divided into group standards and enterprise standards. Government led standards focus on basic, and market independent standards focus on improving competitiveness.**

2.China standardization development

Standard system



Code: GB、GB/T、GB/Z、GSB、HG、HG/T

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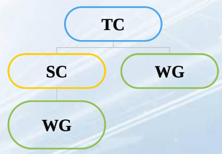
2.China standardization development

- Technical committee TC （500+）
- Sub technical committee SC （700+）
- Working team WG



TC/SC establishment of evaluation
National standard project evaluation

2.China standardization development

- **For developing the group standard and bodies of setting standard, social organizations and industrial technology alliances, such as institute, associations, chambers of Commerce and federations, should be encouraged to coordinate with the related market to formulate the standards required by market and innovation. The standards is for voluntary selection and increasing the effective supply of standards. In the standard management, there is no administrative license for the group standards, and the social organizations and industrial technology alliances independently formulate and release the fittest through competition in the market.**
- **In order to decontrol and enliven enterprise standards, enterprises should make and implement enterprise standards independently according to their own needs. Enterprises shall be encouraged to develop the competitive enterprise standards higher than the national standards, industry standards and local standards. We shall establish the system of self disclosure statement and supervision for enterprise product and service standards. And the record management of government to enterprise product standards shall be phased out, the main responsibility of enterprise standardization shall be implemented.**

2.China standardization development

- By the end of 2016, the group standards have been booming, and 378 social organizations have been registered in the national group standard information platform and set standards, and 451 group standard information have been published;
- In 2017, the National Standard Committee put forward that "cultivating and developing market independent standards, developing and expanding group standards, and deepening the reform of enterprise standard management system".
- *Guiding Opinions on the Cultivation and Development of Group Standards* of AQSIQ and the National Standards Committee
- GB/T 20004.1 *First part of Group standard: Good Behavior Guide*

Contents

2. China standardization development

Standardization: The process of making, releasing and implementing standards

- Integrating and streamlining mandatory standards
- National key research and development plan:

The common research and key application projects on the national quality foundation (NQI project)

- Standardization service industry

Guiding opinions on the cultivation and development (of the Draft) (August 2017)

The first batch of standardized service pilot project (November 28, 2016)

2.China standardization development

- **The work of integrating and streamlining mandatory standards was entirely completed (beginning in 2016)**

In the 11224 mandatory national, industry and local standards:

——2178 mandatory standards to be abolished, accounting for 19% of the total;

——3657 recommended standards to be transferred, accounting for 33% of the total;

——1196 mandatory standards which may integrate a number of items into one item, accounting for 11% of the total;

——1464 mandatory standards to be revised, accounting for 13% of the total;

——2729 mandatory standards which remain to be valid, accounting for 24% of the total;

- **Publicity of asking for opinions**
- **Notice on Issuing the Conclusion of Integrating and Simplifying Mandatory Standards (January 14, 2017)**

·Annex 1- Conclusion list of integrating and streamlining mandatory standards (volume I)

·Annex 1- Conclusion list of integrating and streamlining mandatory standards (volume II)

·Annex 2- Mandatory standard plan project integrating and streamlining

3 ESD protection standards

- 51 NATIONAL STANDARDS

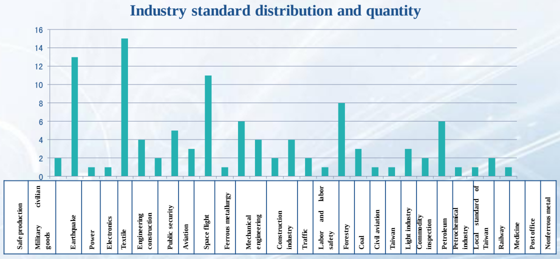
4 focal points and 26 TC, textiles, clothing, personal protective equipment, belt pulley and belt

3 ESD protection standards

Integrating and streamlining national mandatory standards

Standard No.	Standard name	Conclusion of integrating and streamlining
GB 12014-2009	Static protective clothing	Revised
GB 12158-2006	General guideline for preventing electrostatic accidents	Integrated with GB 13348-2009 into mandatory national standards
GB 12367-2006	Safety code for painting--Safety for electrostatic spray painting process	Revised
GB 13348-2009	Safety rules of static electricity with relation to liquid petroleum products	Integrated with GB 12158-2006 into mandatory national standards
GB 14773-2007	Safety regulations for painting operation Safety technical conditions of electrostatic spray gun and its auxiliary device	Revised
GB 15607-2008	Safety regulations for painting operation Process safety of powder electrostatic spraying	
GB 26539-2011	Antistatic ceramic tiles	Translate into recommended standards
GB 4655-2003	Safety rules of static electricity in the rubber industry	
GB 50515-2010	Design code of conductive (antistatic) ground	
GB 50611-2010	Code for design of ESD protection for Electronic Engineering	
GB 50813-2012	Code for design static explosion prevention in petrochemical powders silo	
GB 50944-2013	Code for construction and quality acceptance of antistatic engineering	
GB 4385-1995	Technical requirements for antistatic footwear and conductive footwear	Abolished

3 ESD protection standards



106 items; 28 industries.

3 ESD protection standards

Integrating and streamlining industrial mandatory standards

Standard No.	Standard name	Conclusion of integrating and streamlining
AQ 4115-2011	General guidelines for preventing fireworks and firecrackers from static electricity	Revised to mandatory national standards
GA 96-1995	Electrostatic performance parameters and measurement methods of paving textiles	Translate into recommended standards
HG 2793-1996	Conductive for industrial use and antistatic rubber sheets	Translate into recommended standards
JT 197-1995	Electrostatic safety technique requirement for oil tankers	Revised to mandatory national standards
JT 230-1995	Rubber belt of electrostatic conductivity	Translate into recommended standards
MT 113-1995	Test method and decision rules of electrostatic polymer products' flame retardant and antistatic property under coal mines	Translate into recommended standards
MT 379-1995	Test method of electrostatic sensitivity of electric detonator for coal mines	Translate into recommended standards
MT 449-1995	Test method and decision rules of wire rope conveying flame retardant and antistatic property for coal mines	Abolished
MT 450-1995	Test method and decision rules of wire rope core conveying flame retardant and antistatic property for coal mines	Abolished
MT 520-1995	Antistatic safety regulation of in coal mine detonator factory	Abolished

Thanks！

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季启政

季启政，高级工程师，硕士研究生导师，国家一级注册计量师、国家实验室认可注册评审员、国防实验室认可注册评审员，国家自愿性产品认证检查员，中国计量测试学会高级会员，中国航天科技集团公司静电防护管理体系高级审核员；中国航天科技集团公司第五研究院第五一四研究所静电事业部部长，同时负责国家静电防护产品质量监督检验中心（筹建）、国家静电防护产品认证机构、中国航天科技集团公司静电防护技术中心、中国航天科技集团公司第五研究院静电防护管理体系认证中心办公室运行工作。

长期从事静电防护技术与管理研究，承担了国防、军队、五院多项静电防护检测技术、管理课题研究，是国家标准 GB/T 32304-2015《航天电子产品静电防护要求》、中国航天科技集团公司标准 Q/QJA 118~20-2013《航天电子产品静电防护管理体系系列标准》、中国航天科技集团公司五院标准 Q/W 1300~1303-2010《静电防护管理体系系列标准》主要编写人，作为主要编写人出版专著《电子工业静电防护技术与管理》1 部，发表论文近 50 篇、获得国家发明专利 10 项，获国防科学技术进步一等奖 1 项、中国航天科技集团公司科技进步一等奖 1 项。

作为主创人创建“航天电子产品静电防护管理体系”，该体系在航天工业系统已成功运行、效果显著，并得到了上级高度认可，获得中国航天科技集团公司 2014 年度管理创新优秀成果一等奖、2014 年度国防科技工业企业管理创新成果二等奖、第二十一届全国企业管理现代化创新成果二等奖等荣誉。

Ji Qizheng

Mr. Ji Qizheng, born in 1979, is the senior engineer, the supervisor to master degree candidates, the national first-grade certified metrology engineer, the certified assessor approved by the national laboratory, the certified assessor approved by the national defense laboratory, the inspector of national voluntary products certification, the senior member of Chinese Society for Measurement, the senior assessor of electrostatic protection management system of China Aerospace Science and Technology Corporation and the director of Electrostatic Business Department of No. 514 Research Institute of No. 5 Research Academy of China Aerospace Science and Technology Corporation, and at the same time, he is also in charge of the businesses and works of National Quality Supervision and Inspection Center of Electrostatic Protection Products (being prepared to be established), the national certification authority of electrostatic protection products, Electrostatic Protection Technical Center of China Aerospace Science and Technology Corporation and the office of Electrostatic Protection Management System Certification Center of No. 5 Research Academy of China Aerospace Science and Technology Corporation.

Mr. Ji Qizheng has been being engaged in the research for the electrostatic protection technology and management over a long period of time, and takes on the research work in several research subjects of electrostatic protection detection and testing technology and management of national defense, army and No. 5 Research Academy, and he is the main person for completion of national standard GB/T 32304-2015 “Electrostatic protection requirements for aerospace electronic products”, enterprise standard Q/QJA 118~20-2013 “Series standards of electrostatic protection management system of aerospace electronic products” of China Aerospace Science and Technology Corporation and enterprise standard Q/W 1300~1303-2010 “Series standards of electrostatic protection management system” of No. 5 Research Academy of China Aerospace Science and Technology Corporation. As the main person for completion, he publishes a book on the special subject: “Electrostatic Protection Technology and Management in the Electronic Industry” and publishes 50 academic theses, and he obtains 10 patents for invention of China, and wins a first prize of National Defense Science and

Technology Progress Award and a first prize of Science and Technology Progress Award of China Aerospace Science and Technology Corporation.

As the main person for establishment, he establishes the “Electrostatic Protection Management System of Aerospace Electronic Products”. This system has operated successfully in the aerospace industry system and achieves observably good results, which has been approved thoroughly by the leading body at a higher level, and this system wins the first prize of outstanding achievements award of management innovation in the year of 2014 of China Aerospace Science and Technology Corporation, the second prize of Enterprise Management Innovation Achievements award of National Defense Science and Technology Industry in 2014 and the second prize of 21st National Enterprises’ Management Modernization Innovation Achievements Award.


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我国静电防护技术架构
分析与展望
季启政
2017年11月


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中国航天科技集团公司五院
五一四所
中国航天
单位简介
北京东方计量测试研究所（中国航天科技集团公司五院五一四所）成立于1985年，是中国空间技术研究院所属的专业计量测试研究所，也是国防科技工业电学一级计量站，是集电磁学、无线电电子学、静电防护、卫星应用、真空、环境试验和电磁干扰等专业为一体的综合性计量测试研究所。
北京东方计量测试研究所一直致力于静电防护技术研究，开展静电防护技术基础研究和产品试验相关工作，形成了多项静电防护技术研究成果，并成功应用到航天型号静电防护工作当中。
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资质授权
资质名称
•国家静电防护产品质量监督检验中心（筹建）
•国家静电防护产品认证机构
•工业（静电防护）产品质量控制和技术评价实验室
•电子产品静电防护及应用技术北京市工程实验室
•中国航天科技集团公司静电防护技术中心
•中国空间技术研究院静电防护管理体系认证中心
•中国防静电装备工程施工资格认定证书
•军用校准和测试实验室认可证书
授予单位
•国家认监委 •工信部
•北京发改委 •国防科工局


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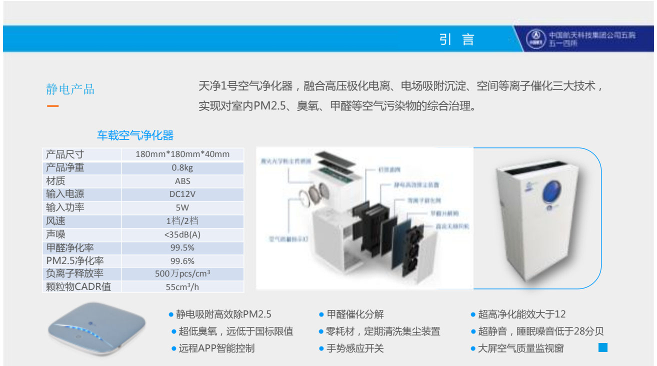
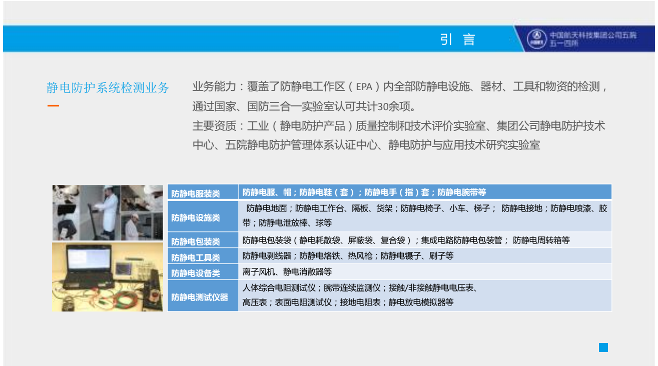
业务概述
检测
与试验能力
静电防护检测
技术安全与环境检测
卫星应用产品（导航）检测
真空检测
节能环保检测
无损检测
环境与可靠性试验
软件评测
目前已经形成了静电防护检测、技术安全与环境检测、节能环保检测、无损检测、环境与可靠性试验、卫星应用产品（导航）检测、软件评测、真空检测等多个检测方向并举的发展格局。


引　言
中国航天科技集团公司五院五一四所
静电产品
天净1号空气净化器，融合高压极化电离、电场吸附沉淀、空间等离子催化三大技术，实现对室内PM2.5、臭氧、甲醛等空气污染物的综合治理。
车载空气净化器
产品尺寸 180mm*180mm*40mm
产品净重 0.8kg
材质 ABS
输入电源 DC12V
输入功率 5W
风速 1档/2档
声噪 <35dB(A)
甲醛净化率 99.5%
PM2.5净化率 99.6%
负离子释放率 500万pcs/cm³
颗粒物CADR值 55cm³/h
静电吸附高效除PM2.5
超低臭氧，远低于国标限值
远程APP智能控制
甲醛催化分解
零耗材，定期清洗集尘装置
手势感应开关
超高净化能效大于12
超静音，睡眠噪音低于28分贝
大屏空气质量监视窗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中国航天科技集团公司五院五一四所
静电防护系统检测业务
业务能力：覆盖了防静电工作区（EPA）内全部防静电设施、器材、工具和物资的检测，通过国家、国防三合一实验室认可共计30余项。
主要资质：工业（静电防护产品）质量控制和技术评价实验室、集团公司静电防护技术中心、五院静电防护管理体系认证中心、静电防护与应用技术研究实验室
防静电服装类 防静电服、帽；防静电鞋（套）；防静电手（指）套；防静电腕带等
防静电设施类 防静电地面；防静电工作台、隔板、货架；防静电椅子、小车、梯子； 防静电接地；防静电喷漆、胶带；防静电泄放棒、球等
防静电包装类 防静电包装袋（静电耗散袋、屏蔽袋、复合袋）；集成电路防静电包装管； 防静电周转箱等
防静电工具类 防静电剥线器；防静电烙铁、热风枪；防静电镊子、刷子等
防静电设备类 离子风机、静电消散器等
防静电测试仪器 人体综合电阻测试仪；腕带连续监测仪；接触/非接触静电电压表、高压表；表面电阻测试仪；接地电阻表；静电放电模拟器等


引　言
中国航天科技集团公司五院五一四所
静电防护系统检测业务
致力于静电防护技术和管理研究，不断提升静电防护测试能力和产品研制能力，围绕型号需求跟踪国际标准，推动静电防护管理体系在五院和集团的建设和认证工作，在静电防护领域形成了集产品和设施检测、体系建设和体系认证咨询、技术和管理人员培训、物资和设备销售、工程设计与施工多项业务于一体的特色能力，为客户提供静电防护系统解决方案。
静电防护系统解决方案构成
技术服务
产品销售
培训咨询
认证服务
工程施工
课题研究
计量监测
标准编制
产品开发
物资供应
系统集成
培训服务
咨询服务
体系认证
产品认证
工程施工
改造维护


引　言
中国航天科技集团公司五院五一四所
研究领域：
静电静电机理研究
静电检测与计量
静电失效机理和敏感度测试
静电危害评价技术
静电防护仪器研制
序号 种类 名称
1 国防课题 静电放电试验装置校准系统
2 国防课题 建立电荷量标准
3 国防课题 防静电屏蔽包装袋检测装置校准方法研究
4 国防课题 非接触式静电电场表和静电电荷分析仪标准装置
5 国防课题 静电电场仪校准装置
6 总装课题 装备静电防护计量测试技术体系研究
7 总装课题 装备静电防护计量测试方法研究
8 总装课题 航天发射场静电电位在线计量技术研究
9 921预研 低轨道航天器空间对接放电研究
编制了国家标准GB/T 32304-2015《航天电子产品静电防护要求》、JJF 1517-2015《非接触式静电电压测量仪校准规范》、集团公司静电防护管理体系系列标准Q/QJA 118~123、五院静电防护管理体系系列标准Q/W 1300~1303等。


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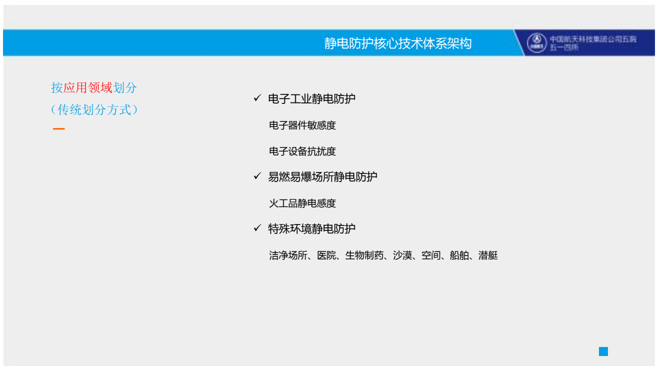
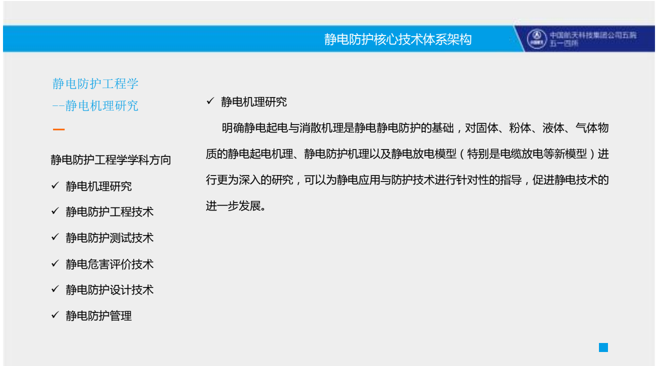
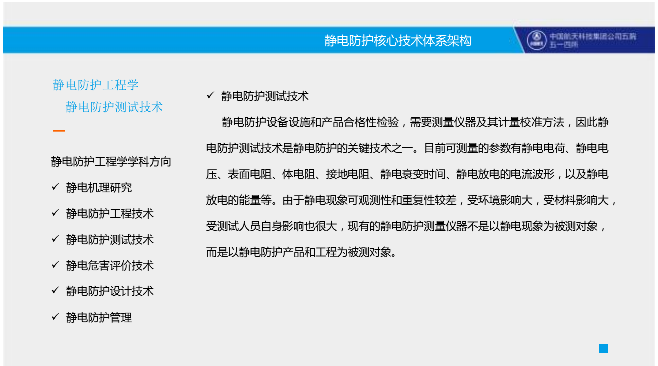
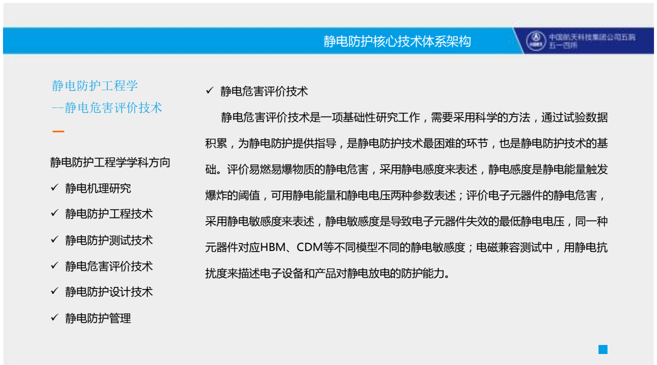

静电防护核心技术体系架构
中国航天科技集团公司五院五一四所
按应用领域划分
（传统划分方式）
✓ 电子工业静电防护
电子器件敏感度
电子设备抗扰度
✓ 易燃易爆场所静电防护
火工品静电感度
✓ 特殊环境静电防护
洁净场所、医院、生物制药、沙漠、空间、船舶、潜艇

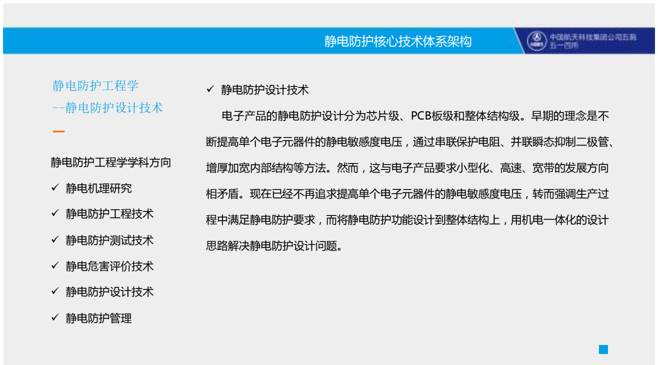

静电防护核心技术体系架构
按技术领域划分：
静电防护工程学学科方向
驱动力：
• 产业发展需要
• 质量提升需要
• 安全保障需要
✓ 静电机理研究
静电起电-消散机理、静电放电模型
✓ 静电防护工程技术
静电防护工程与工艺
✓ 静电防护测试技术
静电防护检测与仪器
✓ 静电危害评价技术
静电失效分析与敏感度
✓ 静电防护设计技术
静电防护材料与产品、静电防护设计
✓ 静电防护管理
静电防护管理与标准

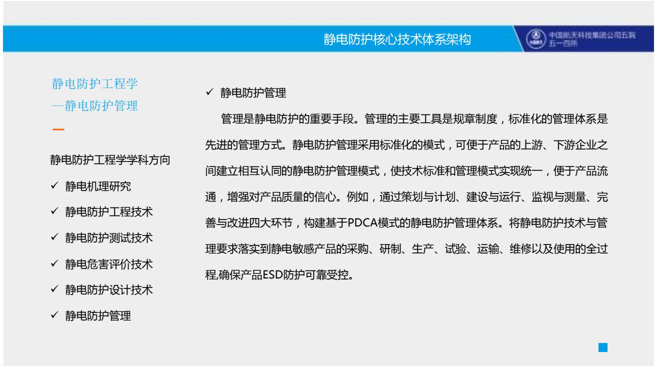

静电防护核心技术体系架构
静电防护工程学
—静电机理研究
静电防护工程学学科方向
✓ 静电机理研究
✓ 静电防护工程技术
✓ 静电防护测试技术
✓ 静电危害评价技术
✓ 静电防护设计技术
✓ 静电防护管理
✓ 静电机理研究
明确静电起电与消散机理是静电静电防护的基础，对固体、粉体、液体、气体物质的静电起电机理、静电防护机理以及静电放电模型（特别是电缆放电等新模型）进行更为深入的研究，可以为静电应用与防护技术进行针对性的指导，促进静电技术的进一步发展。

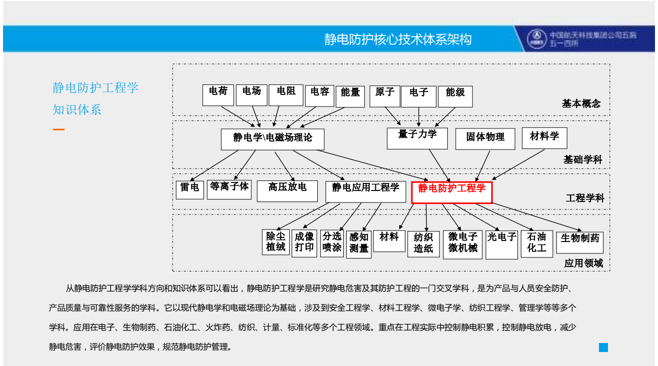

静电防护核心技术体系架构
静电防护工程学
—静电防护工程技术
静电防护工程学学科方向
✓ 静电机理研究
✓ 静电防护工程技术
✓ 静电防护测试技术
✓ 静电危害评价技术
✓ 静电防护设计技术
✓ 静电防护管理
✓ 静电防护工程技术
静电防护工程技术是针对静电起电和静电放电的特点，从静电源和静电危害途径两方面进行静电防护的技术，主要依靠对电阻特性有要求的特殊材料和复合材料，采用泄放、屏蔽、静电中和以及抑制起电的方法，达到静电防护的目的。

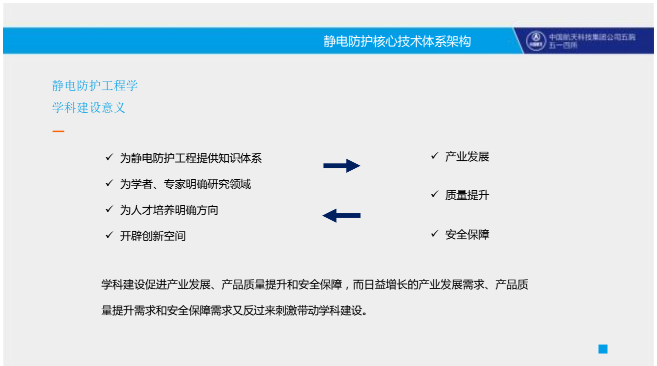

静电防护核心技术体系架构
静电防护工程学
—静电防护测试技术
静电防护工程学学科方向
✓ 静电机理研究
✓ 静电防护工程技术
✓ 静电防护测试技术
✓ 静电危害评价技术
✓ 静电防护设计技术
✓ 静电防护管理
✓ 静电防护测试技术
静电防护设备设施和产品合格性检验，需要测量仪器及其计量校准方法，因此静电防护测试技术是静电防护的关键技术之一。目前可测量的参数有静电电荷、静电电压、表面电阻、体电阻、接地电阻、静电衰变时间、静电放电的电流波形，以及静电放电的能量等。由于静电现象可观测性和重复性较差，受环境影响大，受材料影响大，受测试人员自身影响也很大，现有的静电防护测量仪器不是以静电现象为被测对象，而是以静电防护产品和工程为被测对象。


静电防护核心技术体系架构
静电防护工程学
—静电危害评价技术
静电防护工程学学科方向
✓ 静电机理研究
✓ 静电防护工程技术
✓ 静电防护测试技术
✓ 静电危害评价技术
✓ 静电防护设计技术
✓ 静电防护管理
✓ 静电危害评价技术
静电危害评价技术是一项基础性研究工作，需要采用科学的方法，通过试验数据积累，为静电防护提供指导，是静电防护技术最困难的环节，也是静电防护技术的基础。评价易燃易爆物质的静电危害，采用静电感度来表述，静电感度是静电能量触发爆炸的阈值，可用静电能量和静电电压两种参数表述；评价电子元器件的静电危害，采用静电敏感度来表述，静电敏感度是导致电子元器件失效的最低静电电压，同一种元器件对应HBM、CDM等不同模型不同的静电敏感度；电磁兼容测试中，用静电抗扰度来描述电子设备和产品对静电放电的防护能力。


静电防护核心技术体系架构
静电防护工程学
—静电防护设计技术
静电防护工程学学科方向
✓ 静电机理研究
✓ 静电防护工程技术
✓ 静电防护测试技术
✓ 静电危害评价技术
✓ 静电防护设计技术
✓ 静电防护管理
✓ 静电防护设计技术
电子产品的静电防护设计分为芯片级、PCB板级和整体结构级。早期的理念是不断提高单个电子元器件的静电敏感度电压，通过串联保护电阻、并联瞬态抑制二极管、增厚加宽内部结构等方法。然而，这与电子产品要求小型化、高速、宽带的发展方向相矛盾。现在已经不再追求提高单个电子元器件的静电敏感度电压，转而强调生产过程中满足静电防护要求，而将静电防护功能设计到整体结构上，用机电一体化的设计思路解决静电防护设计问题。


静电防护核心技术体系架构
静电防护工程学
—静电防护管理
静电防护工程学学科方向
✓ 静电机理研究
✓ 静电防护工程技术
✓ 静电防护测试技术
✓ 静电危害评价技术
✓ 静电防护设计技术
✓ 静电防护管理
✓ 静电防护管理
管理是静电防护的重要手段。管理的主要工具是规章制度，标准化的管理体系是先进的管理方式。静电防护管理采用标准化的模式，可便于产品的上游、下游企业之间建立相互认同的静电防护管理模式，使技术标准和管理模式实现统一，便于产品流通，增强对产品质量的信心。例如，通过策划与计划、建设与运行、监视与测量、完善与改进四大环节，构建基于PDCA模式的静电防护管理体系。将静电防护技术与管理要求落实到静电敏感产品的采购、研制、生产、试验、运输、维修以及使用的全过程,确保产品ESD防护可靠受控。


静电防护核心技术体系架构
静电防护工程学
知识体系
电荷
电场
电阻
电容
能量
原子
电子
能级
基本概念
静电学\电磁场理论
量子力学
固体物理
材料学
基础学科
雷电
等离子体
高压放电
静电应用工程学
静电防护工程学
工程学科
除尘植绒
成像打印
分选喷涂
感知测量
材料
纺织造纸
微电子微机械
光电子
石油化工
生物制药
应用领域
从静电防护工程学学科方向和知识体系可以看出，静电防护工程学是研究静电危害及其防护工程的一门交叉学科，是为产品与人员安全防护、产品质量与可靠性服务的学科。它以现代静电学和电磁场理论为基础，涉及到安全工程学、材料工程学、微电子学、纺织工程学、管理学等等多个学科。应用在电子、生物制药、石油化工、火炸药、纺织、计量、标准化等多个工程领域。重点在工程实际中控制静电积累，控制静电放电，减少静电危害，评价静电防护效果，规范静电防护管理。


静电防护核心技术体系架构
静电防护工程学
学科建设意义
✓ 为静电防护工程提供知识体系
✓ 为学者、专家明确研究领域
✓ 为人才培养明确方向
✓ 开辟创新空间
✓ 产业发展
✓ 质量提升
✓ 安全保障
学科建设促进产业发展、产品质量提升和安全保障，而日益增长的产业发展需求、产品质量提升需求和安全保障需求又反过来刺激带动学科建设。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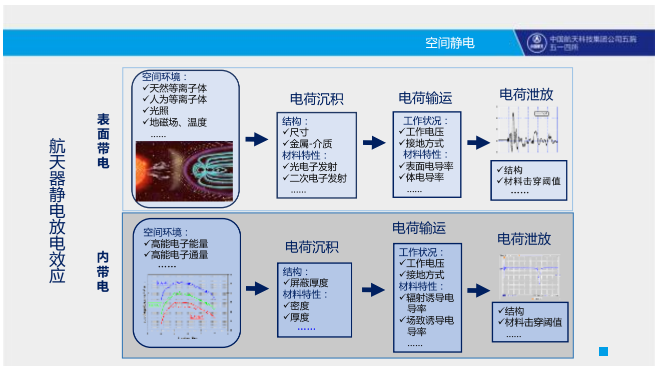
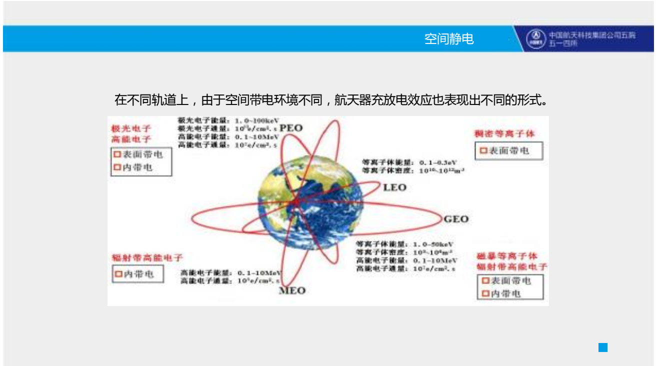
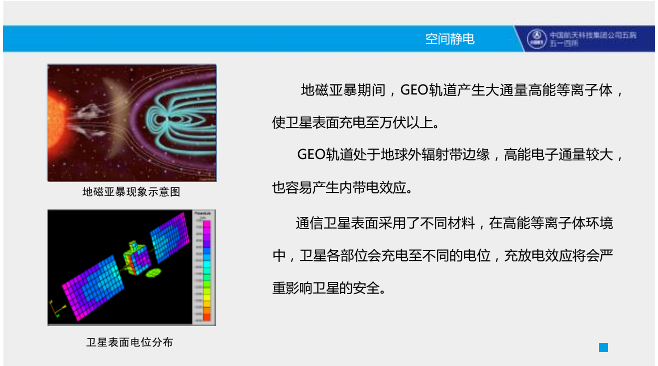
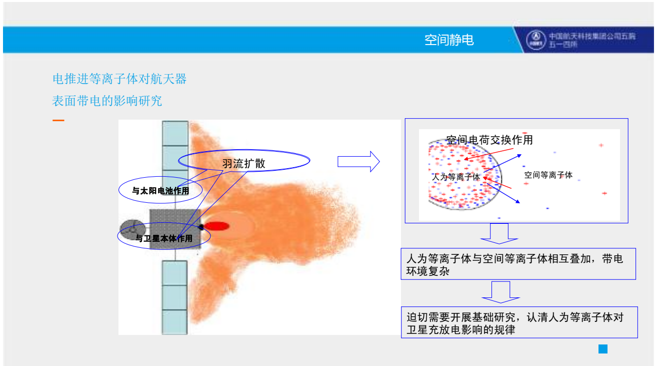
空间静电
总结


空间静电
空间静电—
静电防护核心技术体系的重要组成
作为静电防护核心技术体系架构和静电防护工程学科内容的重要组成部分，空间静电危害及其防护，是空间技术发展与静电防护问题的结合，空间静电问题具有与地面静电问题相通之处，同时又具备其特殊性。

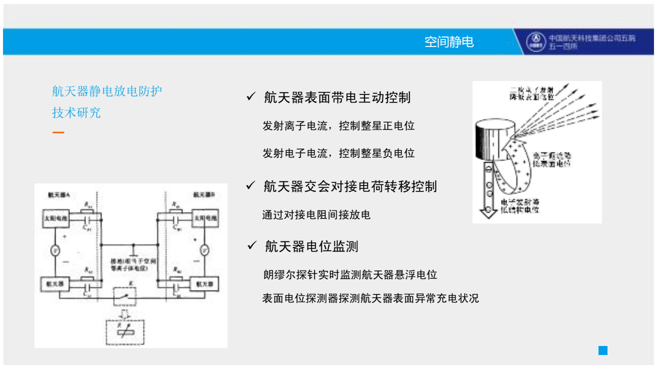

空间静电
航天器静电放电效应
表面带电
空间环境：
✓天然等离子体
✓人为等离子体
✓光照
✓地磁场、温度
……
电荷沉积
结构：
✓尺寸
✓金属-介质
材料特性：
✓光电子发射
✓二次电子发射
……
电荷输运
工作状况：
✓工作电压
✓接地方式
材料特性：
✓表面电导率
✓体电导率
……
电荷泄放
✓结构
✓材料击穿阈值
……
内带电
空间环境：
✓高能电子能量
✓高能电子通量
……
电荷沉积
结构：
✓屏蔽厚度
材料特性：
✓密度
✓厚度
……
电荷输运
工作状况：
✓工作电压
✓接地方式
材料特性：
✓辐射诱导电导率
✓场致诱导电导率
……
电荷泄放
✓结构
✓材料击穿阈值
……


空间静电
在不同轨道上，由于空间带电环境不同，航天器充放电效应也表现出不同的形式。
PEO
LEO
GEO
MEO
□表面带电
□内带电


空间静电
地磁亚暴现象示意图
卫星表面电位分布
地磁亚暴期间，GEO轨道产生大通量高能等离子体，使卫星表面充电至万伏以上。
GEO轨道处于地球外辐射带边缘，高能电子通量较大，也容易产生内带电效应。
通信卫星表面采用了不同材料，在高能等离子体环境中，卫星各部位会充电至不同的电位，充放电效应将会严重影响卫星的安全。


空间静电
电推进等离子体对航天器表面带电的影响研究
羽流扩散
与太阳电池作用
与卫星本体作用
空间电荷交换作用
人为等离子体
空间等离子体
人为等离子体与空间等离子体相互叠加，带电环境复杂
迫切需要开展基础研究，认清人为等离子体对卫星充放电影响的规律


空间静电
空间站舱外航天器静电安全性研究
出舱活动时航天服与空间等离子体相互作用
✓ 等电位连接方式
✓ 自主出舱模式
✓ PIC等离子体模拟计算
保障航天员人身以及航天服内和航天器舱内各设备免于放电危害


空间静电
航天器静电放电防护技术研究
✓ 航天器表面带电主动控制
发射离子电流，控制整星正电位
发射电子电流，控制整星负电位
✓ 航天器交会对接电荷转移控制
通过对接电阻间接放电
✓ 航天器电位监测
朗缪尔探针实时监测航天器悬浮电位
表面电位探测器探测航天器表面异常充电状况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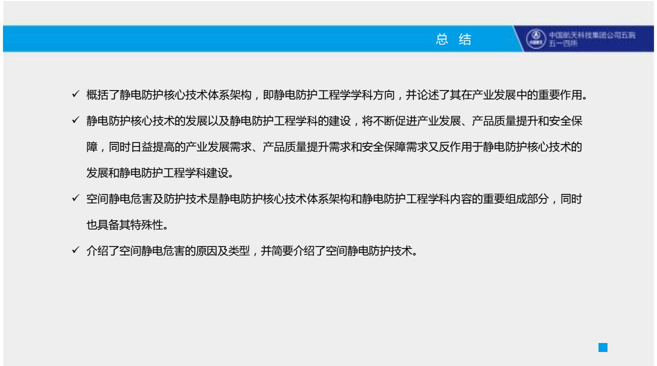
总 结
中国航天科技集团公司五院
五一四所
✓ 概括了静电防护核心技术体系架构，即静电防护工程学学科方向，并论述了其在产业发展中的重要作用。
✓ 静电防护核心技术的发展以及静电防护工程学科的建设，将不断促进产业发展、产品质量提升和安全保障，同时日益提高的产业发展需求、产品质量提升需求和安全保障需求又反作用于静电防护核心技术的发展和静电防护工程学科建设。
✓ 空间静电危害及防护技术是静电防护核心技术体系架构和静电防护工程学科内容的重要组成部分，同时也具备其特殊性。
✓ 介绍了空间静电危害的原因及类型，并简要介绍了空间静电防护技术。


中国航天
期待更多的交流合作
THANKS


ESD Protection Technology
Architecture of China
Analysis and Prospect
Ji Qizheng
November 2017


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Space electrostatic
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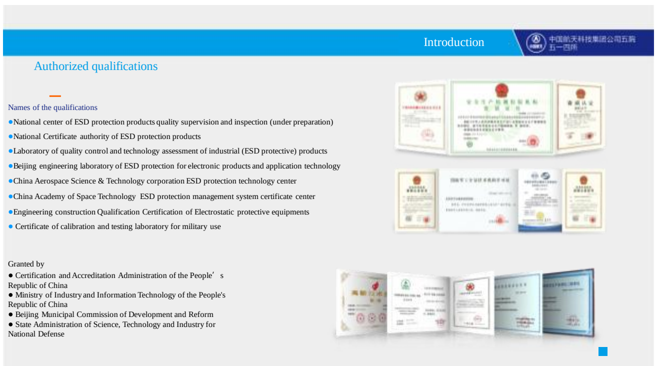
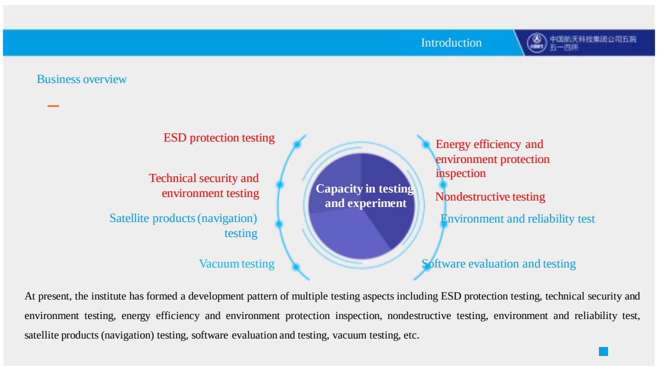
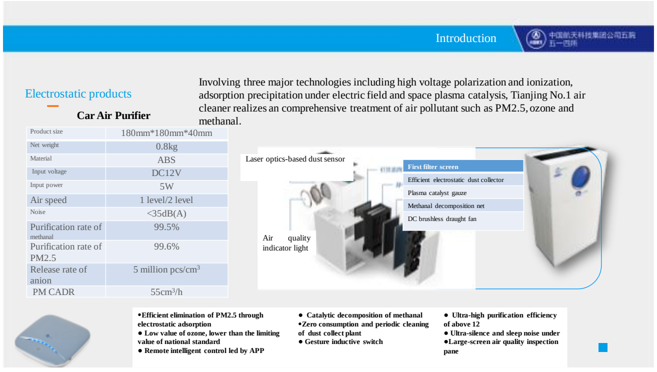
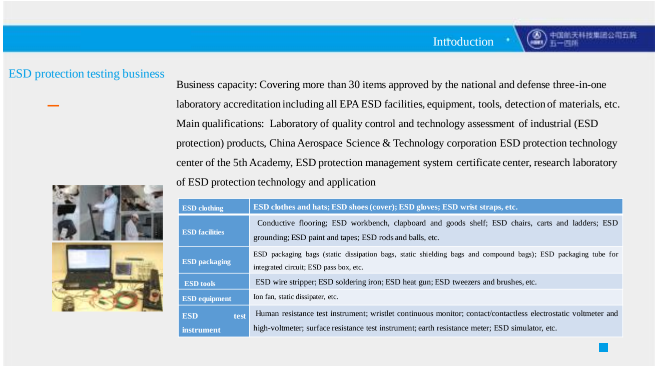
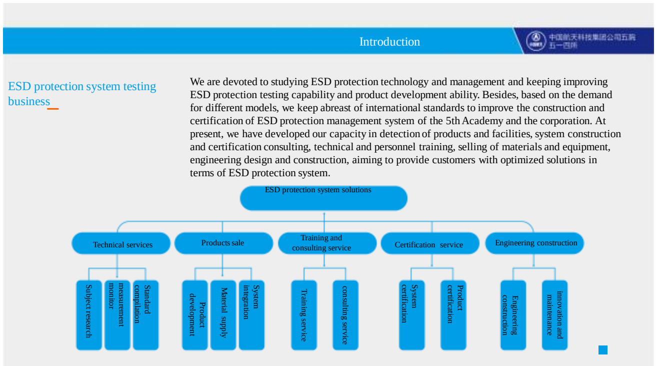
Introduction
About us
Founded in 1985, Beijing Oriental Institute of Measurement and Test (No.514 Institute of the 5th Academy of China Aerospace Science and Technology Corporation) is a measurement and test research institution affiliated to China Academy of Space Technology, also a first-grade electrical metrology station of defense science & technology industry and an integrated measurement and test research institute specializing in electromagnetism, radioelectronics, ESD protection, satellite application, vacuum, environment test, electromagnetic interference, etc.
Beijing Oriental Institute of Measurement and Test has been devoted to studying ESD protection technology including conducting basic research of ESD protection technology and experiment of related products. Now multiple research results it achieved have been successfully applied in the ESD protection work in aerospace engineering.
04

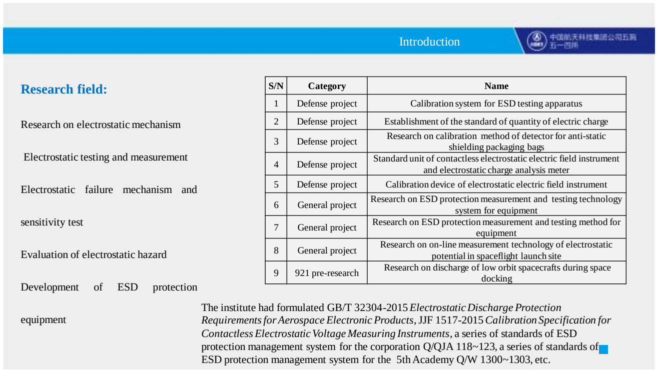

Introduction
Authorized qualifications
Names of the qualifications
●National center of ESD protection products quality supervision and inspection (under preparation)
●National Certificate authority of ESD protection products
●Laboratory of quality control and technology assessment of industrial (ESD protective) products
●Beijing engineering laboratory of ESD protection for electronic products and application technology
●China Aerospace Science & Technology corporation ESD protection technology center
●China Academy of Space Technology ESD protection management system certificate center
●Engineering construction Qualification Certification of Electrostatic protective equipments
● Certificate of calibration and testing laboratory for military use
Granted by
● Certification and Accreditation Administration of the People's Republic of China
● Ministry of Industry and Information Technology of the People's Republic of China
● Beijing Municipal Commission of Development and Reform
● State Administration of Science, Technology and Industry for National Defense


Introduction
Business overview
ESD protection testing
Technical security and environment testing
Satellite products (navigation) testing
Vacuum testing
Capacity in testing and experiment
Energy efficiency and environment protection inspection
Nondestructive testing
Environment and reliability test
Software evaluation and testing
At present, the institute has formed a development pattern of multiple testing aspects including ESD protection testing, technical security and environment testing, energy efficiency and environment protection inspection, nondestructive testing, environment and reliability test, satellite products (navigation) testing, software evaluation and testing, vacuum testing, etc.


Introduction
Electrostatic products
Car Air Purifier
Involving three major technologies including high voltage polarization and ionization, adsorption precipitation under electric field and space plasma catalysis, Tianjing No.1 air cleaner realizes an comprehensive treatment of air pollutant such as PM2.5, ozone and methanal.
Product size 180mm*180mm*40mm
Net weight 0.8kg
Material ABS
Input voltage DC12V
Input power 5W
Air speed 1 level/2 level
Noise <35dB(A)
Purification rate of methanal 99.5%
Purification rate of PM2.5 99.6%
Release rate of anion 5 million pcs/cm³
PM CADR 55cm³/h
Laser optics-based dust sensor
First filter screen
Efficient electrostatic dust collector
Plasma catalyst gauze
Methanal decomposition net
DC brushless draught fan
Air quality indicator light
•Efficient elimination of PM2.5 through electrostatic adsorption
● Low value of ozone, lower than the limiting value of national standard
● Remote intelligent control led by APP
● Catalytic decomposition of methanal
•Zero consumption and periodic cleaning of dust collect plant
● Gesture inductive switch
● Ultra-high purification efficiency of above 12
● Ultra-silence and sleep noise under
•Large-screen air quality inspection pane


Introduction
ESD protection testing business
Business capacity: Covering more than 30 items approved by the national and defense three-in-one laboratory accreditation including all EPA ESD facilities, equipment, tools, detection of materials, etc.
Main qualifications: Laboratory of quality control and technology assessment of industrial (ESD protection) products, China Aerospace Science & Technology corporation ESD protection technology center of the 5th Academy, ESD protection management system certificate center, research laboratory of ESD protection technology and application
ESD clothing ESD clothes and hats; ESD shoes (cover); ESD gloves; ESD wrist straps, etc.
ESD facilities Conductive flooring; ESD workbench, clapboard and goods shelf; ESD chairs, carts and ladders; ESD grounding; ESD paint and tapes; ESD rods and balls, etc.
ESD packaging ESD packaging bags (static dissipation bags, static shielding bags and compound bags); ESD packaging tube for integrated circuit; ESD pass box, etc.
ESD tools ESD wire stripper; ESD soldering iron; ESD heat gun; ESD tweezers and brushes, etc.
ESD equipment Ion fan, static dissipater, etc.
ESD test instrument Human resistance test instrument; wristlet continuous monitor; contact/contactless electrostatic voltmeter and high-voltmeter; surface resistance test instrument; earth resistance meter; ESD simulator, etc.


Introduction
ESD protection system testing business
We are devoted to studying ESD protection technology and management and keeping improving ESD protection testing capability and product development ability. Besides, based on the demand for different models, we keep abreast of international standards to improve the construction and certification of ESD protection management system of the 5th Academy and the corporation. At present, we have developed our capacity in detection of products and facilities, system construction and certification consulting, technical and personnel training, selling of materials and equipment, engineering design and construction, aiming to provide customers with optimized solutions in terms of ESD protection system.
ESD protection system solutions
Technical services
Products sale
Training and consulting service
Certification service
Engineering construction
Subject research
measurement monitor
Standard compilation
Product development
Material supply
System integration
Training service
consulting service
System certification
Product certification
Engineering construction
innovation and maintenance


Introduction
Research field:
Research on electrostatic mechanism
Electrostatic testing and measurement
Electrostatic failure mechanism and sensitivity test
Evaluation of electrostatic hazard
Development of ESD protection equipment
S/N Category Name
1 Defense project Calibration system for ESD testing apparatus
2 Defense project Establishment of the standard of quantity of electric charge
3 Defense project Research on calibration method of detector for anti-static shielding packaging bags
4 Defense project Standard unit of contactless electrostatic electric field instrument and electrostatic charge analysis meter
5 Defense project Calibration device of electrostatic electric field instrument
6 General project Research on ESD protection measurement and testing technology system for equipment
7 General project Research on ESD protection measurement and testing method for equipment
8 General project Research on on-line measurement technology of electrostatic potential in spaceflight launch site
9 921 pre-research Research on discharge of low orbit spacecrafts during space docking
The institute had formulated GB/T 32304-2015 Electrostatic Discharge Protection Requirements for Aerospace Electronic Products, JJF 1517-2015 Calibration Specification for Contactless Electrostatic Voltage Measuring Instruments, a series of standards of ESD protection management system for the corporation Q/QJA 118~123, a series of standards of ESD protection management system for the 5th Academy Q/W 1300~1303, etc.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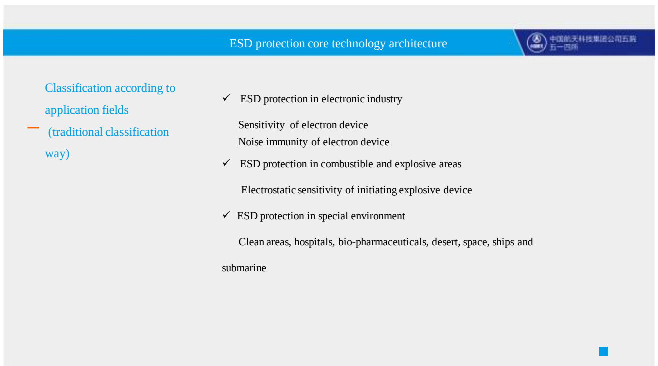
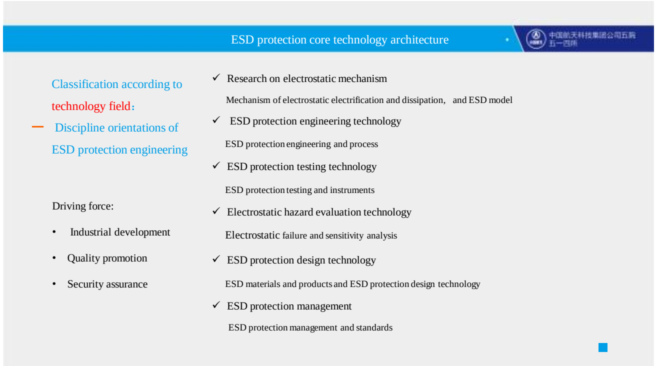
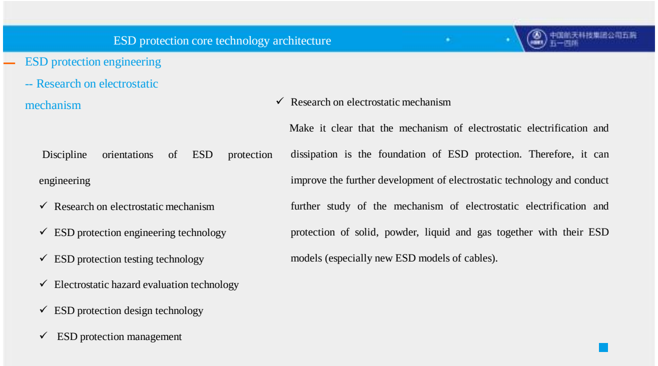
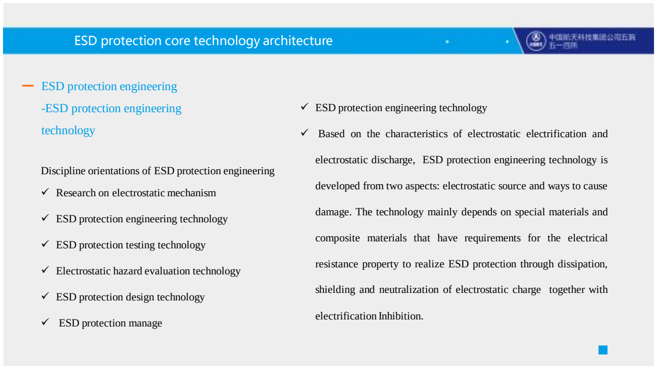
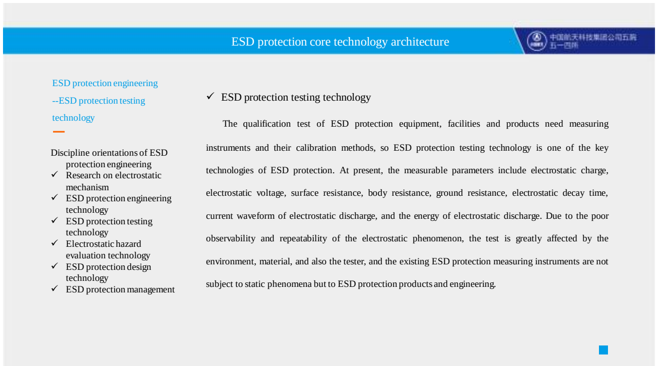
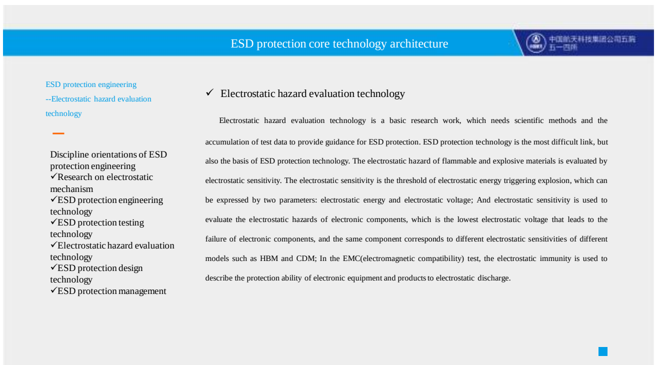

ESD protection core technology architecture
Classification according to application fields (traditional classification way)
✓ ESD protection in electronic industry
Sensitivity of electron device
Noise immunity of electron device
✓ ESD protection in combustible and explosive areas
Electrostatic sensitivity of initiating explosive device
✓ ESD protection in special environment
Clean areas, hospitals, bio-pharmaceuticals, desert, space, ships and submarine

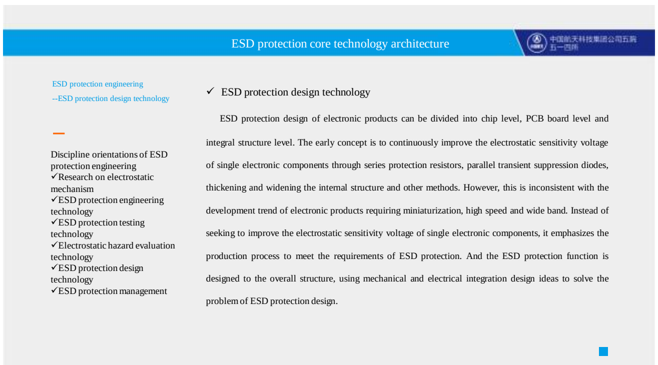

ESD protection core technology architecture
Classification according to technology field:
Discipline orientations of ESD protection engineering
Driving force:
• Industrial development
• Quality promotion
• Security assurance
✓ Research on electrostatic mechanism
Mechanism of electrostatic electrification and dissipation, and ESD model
✓ ESD protection engineering technology
ESD protection engineering and process
✓ ESD protection testing technology
ESD protection testing and instruments
✓ Electrostatic hazard evaluation technology
Electrostatic failure and sensitivity analysis
✓ ESD protection design technology
ESD materials and products and ESD protection design technology
✓ ESD protection management
ESD protection management and standards

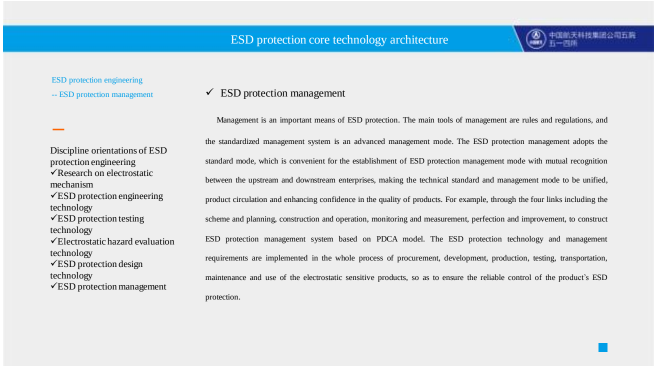

ESD protection core technology architecture
ESD protection engineering
-- Research on electrostatic mechanism
Discipline orientations of ESD protection engineering
✓ Research on electrostatic mechanism
✓ ESD protection engineering technology
✓ ESD protection testing technology
✓ Electrostatic hazard evaluation technology
✓ ESD protection design technology
✓ ESD protection management
✓ Research on electrostatic mechanism
Make it clear that the mechanism of electrostatic electrification and dissipation is the foundation of ESD protection. Therefore, it can improve the further development of electrostatic technology and conduct further study of the mechanism of electrostatic electrification and protection of solid, powder, liquid and gas together with their ESD models (especially new ESD models of cables).

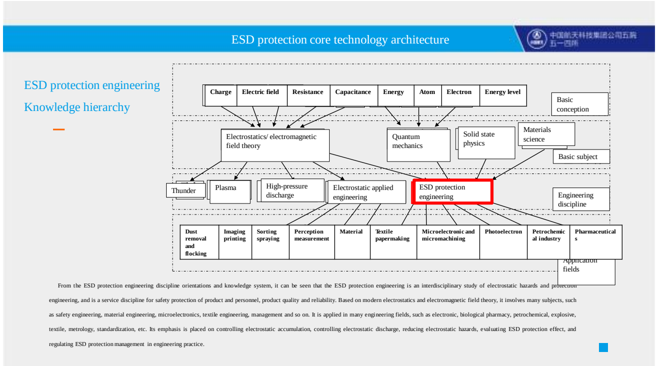

ESD protection core technology architecture
ESD protection engineering
-ESD protection engineering technology
Discipline orientations of ESD protection engineering
✓ Research on electrostatic mechanism
✓ ESD protection engineering technology
✓ ESD protection testing technology
✓ Electrostatic hazard evaluation technology
✓ ESD protection design technology
✓ ESD protection manage
✓ ESD protection engineering technology
✓ Based on the characteristics of electrostatic electrification and electrostatic discharge, ESD protection engineering technology is developed from two aspects: electrostatic source and ways to cause damage. The technology mainly depends on special materials and composite materials that have requirements for the electrical resistance property to realize ESD protection through dissipation, shielding and neutralization of electrostatic charge together with electrification Inhibition.

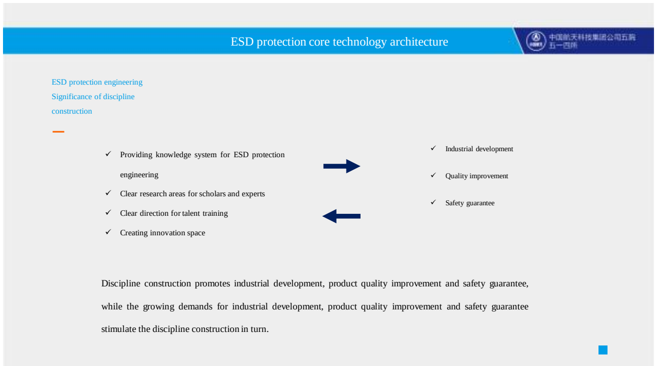

ESD protection core technology architecture
ESD protection engineering
--ESD protection testing technology
Discipline orientations of ESD protection engineering
✓ Research on electrostatic mechanism
✓ ESD protection engineering technology
✓ ESD protection testing technology
✓ Electrostatic hazard evaluation technology
✓ ESD protection design technology
✓ ESD protection management
✓ ESD protection testing technology
The qualification test of ESD protection equipment, facilities and products need measuring instruments and their calibration methods, so ESD protection testing technology is one of the key technologies of ESD protection. At present, the measurable parameters include electrostatic charge, electrostatic voltage, surface resistance, body resistance, ground resistance, electrostatic decay time, current waveform of electrostatic discharge, and the energy of electrostatic discharge. Due to the poor observability and repeatability of the electrostatic phenomenon, the test is greatly affected by the environment, material, and also the tester, and the existing ESD protection measuring instruments are not subject to static phenomena but to ESD protection products and engineering.


ESD protection core technology architecture
ESD protection engineering
--Electrostatic hazard evaluation technology
Discipline orientations of ESD protection engineering
✓Research on electrostatic mechanism
✓ESD protection engineering technology
✓ESD protection testing technology
✓Electrostatic hazard evaluation technology
✓ESD protection design technology
✓ESD protection management
✓ Electrostatic hazard evaluation technology
Electrostatic hazard evaluation technology is a basic research work, which needs scientific methods and the accumulation of test data to provide guidance for ESD protection. ESD protection technology is the most difficult link, but also the basis of ESD protection technology. The electrostatic hazard of flammable and explosive materials is evaluated by electrostatic sensitivity. The electrostatic sensitivity is the threshold of electrostatic energy triggering explosion, which can be expressed by two parameters: electrostatic energy and electrostatic voltage; And electrostatic sensitivity is used to evaluate the electrostatic hazards of electronic components, which is the lowest electrostatic voltage that leads to the failure of electronic components, and the same component corresponds to different electrostatic sensitivities of different models such as HBM and CDM; In the EMC(electromagnetic compatibility) test, the electrostatic immunity is used to describe the protection ability of electronic equipment and products to electrostatic discharge.


ESD protection core technology architecture
ESD protection engineering
--ESD protection design technology
Discipline orientations of ESD protection engineering
✓Research on electrostatic mechanism
✓ESD protection engineering technology
✓ESD protection testing technology
✓Electrostatic hazard evaluation technology
✓ESD protection design technology
✓ESD protection management
✓ ESD protection design technology
ESD protection design of electronic products can be divided into chip level, PCB board level and integral structure level. The early concept is to continuously improve the electrostatic sensitivity voltage of single electronic components through series protection resistors, parallel transient suppression diodes, thickening and widening the internal structure and other methods. However, this is inconsistent with the development trend of electronic products requiring miniaturization, high speed and wide band. Instead of seeking to improve the electrostatic sensitivity voltage of single electronic components, it emphasizes the production process to meet the requirements of ESD protection. And the ESD protection function is designed to the overall structure, using mechanical and electrical integration design ideas to solve the problem of ESD protection design.


ESD protection core technology architecture
ESD protection engineering
-- ESD protection management
Discipline orientations of ESD protection engineering
✓Research on electrostatic mechanism
✓ESD protection engineering technology
✓ESD protection testing technology
✓Electrostatic hazard evaluation technology
✓ESD protection design technology
✓ESD protection management
✓ ESD protection management
Management is an important means of ESD protection. The main tools of management are rules and regulations, and the standardized management system is an advanced management mode. The ESD protection management adopts the standard mode, which is convenient for the establishment of ESD protection management mode with mutual recognition between the upstream and downstream enterprises, making the technical standard and management mode to be unified, product circulation and enhancing confidence in the quality of products. For example, through the four links including the scheme and planning, construction and operation, monitoring and measurement, perfection and improvement, to construct ESD protection management system based on PDCA model. The ESD protection technology and management requirements are implemented in the whole process of procurement, development, production, testing, transportation, maintenance and use of the electrostatic sensitive products, so as to ensure the reliable control of the product's ESD protection.


ESD protection core technology architecture
ESD protection engineering
Knowledge hierarchy
Charge
Electric field
Resistance
Capacitance
Energy
Atom
Electron
Energy level
Basic conception
Electrostatics/ electromagnetic field theory
Quantum mechanics
Solid state physics
Materials science
Basic subject
Thunder
Plasma
High-pressure discharge
Electrostatic applied engineering
ESD protection engineering
Engineering discipline
Dust removal and flocking
Imaging printing
Sorting spraying
Perception measurement
Material
Textile papermaking
Microelectronic and micromachining
Photoelectron
Petrochemical industry
Pharmaceuticals
Application fields
From the ESD protection engineering discipline orientations and knowledge system, it can be seen that the ESD protection engineering is an interdisciplinary study of electrostatic hazards and protection engineering, and is a service discipline for safety protection of product and personnel, product quality and reliability. Based on modern electrostatics and electromagnetic field theory, it involves many subjects, such as safety engineering, material engineering, microelectronics, textile engineering, management and so on. It is applied in many engineering fields, such as electronic, biological pharmacy, petrochemical, explosive, textile, metrology, standardization, etc. Its emphasis is placed on controlling electrostatic accumulation, controlling electrostatic discharge, reducing electrostatic hazards, evaluating ESD protection effect, and regulating ESD protection management in engineering practice.


ESD protection core technology architecture
ESD protection engineering
Significance of discipline construction
✓ Providing knowledge system for ESD protection engineering
✓ Clear research areas for scholars and experts
✓ Clear direction for talent training
✓ Creating innovation space
✓ Industrial development
✓ Quality improvement
✓ Safety guarantee
Discipline construction promotes industrial development, product quality improvement and safety guarantee, while the growing demands for industrial development, product quality improvement and safety guarantee stimulate the discipline construction in turn.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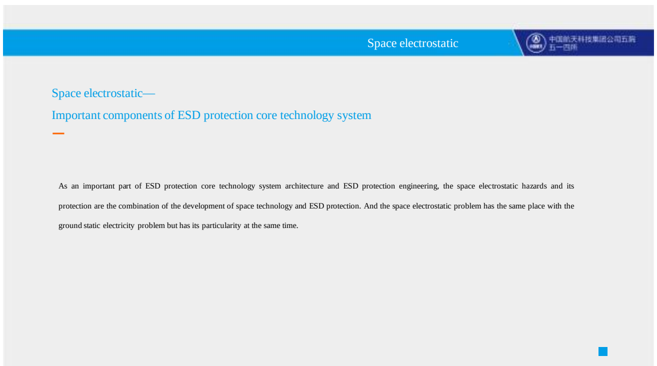
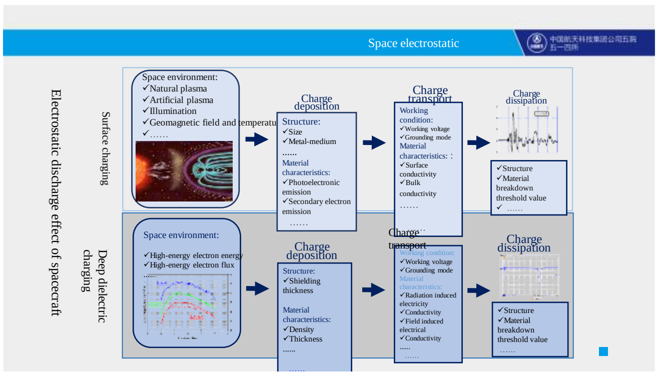
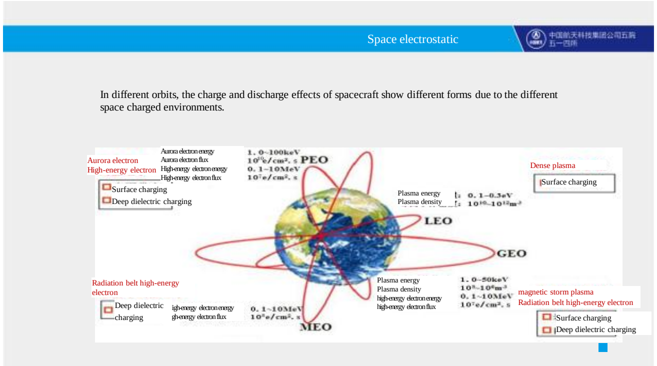
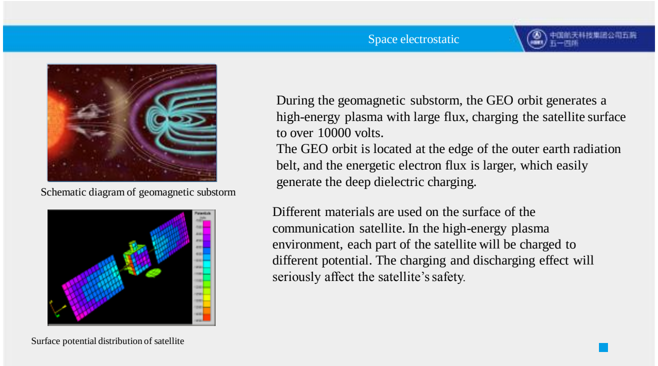
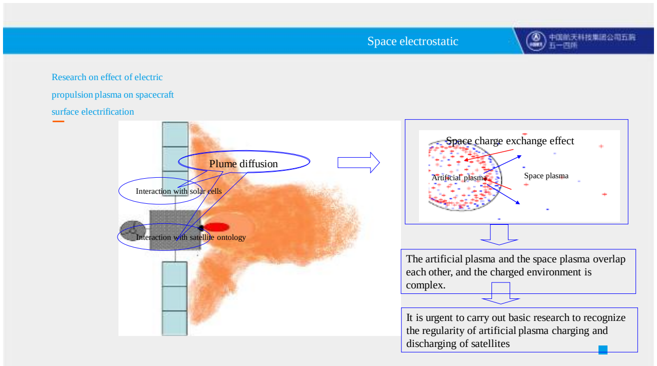
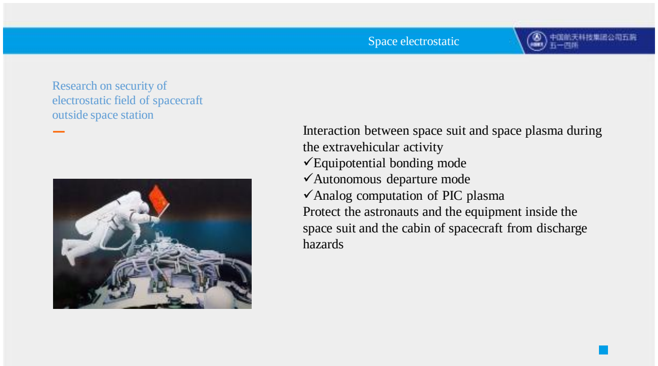

Space electrostatic
Space electrostatic—
Important components of ESD protection core technology system
As an important part of ESD protection core technology system architecture and ESD protection engineering, the space electrostatic hazards and its protection are the combination of the development of space technology and ESD protection. And the space electrostatic problem has the same place with the ground static electricity problem but has its particularity at the same time.

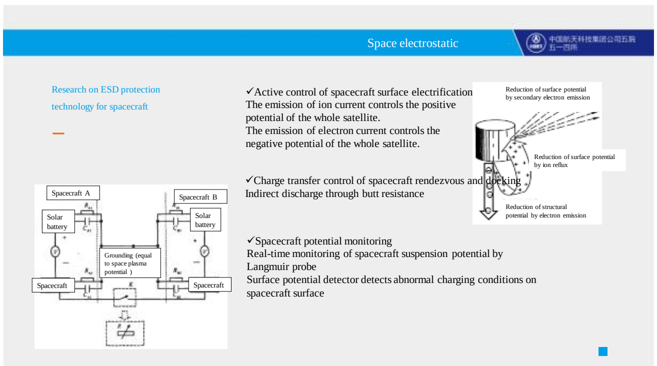

Space electrostatic
Electrostatic discharge effect of spacecraft
Surface charging
Space environment:
✓Natural plasma
✓Artificial plasma
✓Illumination
✓Geomagnetic field and temperatu
✓……
Charge deposition
Structure:
✓Size
✓Metal-medium
......
Material characteristics:
✓Photoelectronic emission
✓Secondary electron emission
……
Charge transport
Working condition:
✓Working voltage
✓Grounding mode
Material characteristics: :
✓Surface conductivity
✓Bulk conductivity
……
Charge dissipation
✓Structure
✓Material breakdown threshold value
✓ ……
Deep dielectric charging
Space environment:
✓High-energy electron energy
✓High-energy electron flux
......
Charge deposition
Structure:
✓Shielding thickness
Material characteristics:
✓Density
✓Thickness
......
Charge transport
Working condition:
✓Working voltage
✓Grounding mode
Material characteristics:
✓Radiation induced electricity
✓Conductivity
✓Field induced electrical
✓Conductivity
......
Charge dissipation
✓Structure
✓Material breakdown threshold value
……


Space electrostatic
In different orbits, the charge and discharge effects of spacecraft show different forms due to the different space charged environments.
Aurora electron
High-energy electron
Surface charging
Deep dielectric charging
PEO
LEO
GEO
MEO
Dense plasma
Surface charging
Radiation belt high-energy electron
Deep dielectric charging
magnetic storm plasma
Radiation belt high-energy electron
Surface charging
Deep dielectric charging


Space electrostatic
Schematic diagram of geomagnetic substorm
Surface potential distribution of satellite
During the geomagnetic substorm, the GEO orbit generates a high-energy plasma with large flux, charging the satellite surface to over 10000 volts.
The GEO orbit is located at the edge of the outer earth radiation belt, and the energetic electron flux is larger, which easily generate the deep dielectric charging.
Different materials are used on the surface of the communication satellite. In the high-energy plasma environment, each part of the satellite will be charged to different potential. The charging and discharging effect will seriously affect the satellite's safety.


Space electrostatic
Research on effect of electric propulsion plasma on spacecraft surface electrification
Plume diffusion
Interaction with solar cells
Interaction with satellite ontology
Space charge exchange effect
Artificial plasma
Space plasma
The artificial plasma and the space plasma overlap each other, and the charged environment is complex.
It is urgent to carry out basic research to recognize the regularity of artificial plasma charging and discharging of satellites


Space electrostatic
Research on security of electrostatic field of spacecraft outside space station
Interaction between space suit and space plasma during the extravehicular activity
✓Equipotential bonding mode
✓Autonomous departure mode
✓Analog computation of PIC plasma
Protect the astronauts and the equipment inside the space suit and the cabin of spacecraft from discharge hazards


Space electrostatic
Research on ESD protection technology for spacecraft
✓Active control of spacecraft surface electrification
The emission of ion current controls the positive potential of the whole satellite.
The emission of electron current controls the negative potential of the whole satellite.
✓Charge transfer control of spacecraft rendezvous and docking
Indirect discharge through butt resistance
✓Spacecraft potential monitoring
Real-time monitoring of spacecraft suspension potential by Langmuir probe
Surface potential detector detects abnormal charging conditions on spacecraft surface
Spacecraft A
Spacecraft B
Solar battery
Solar battery
Grounding (equal to space plasma potential)
Spacecraft
Spacecraft
Reduction of surface potential by secondary electron emission
Reduction of surface potential by ion reflux
Reduction of structural potential by electron emission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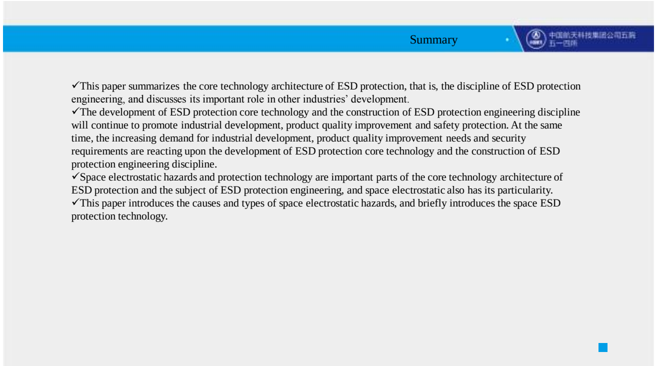
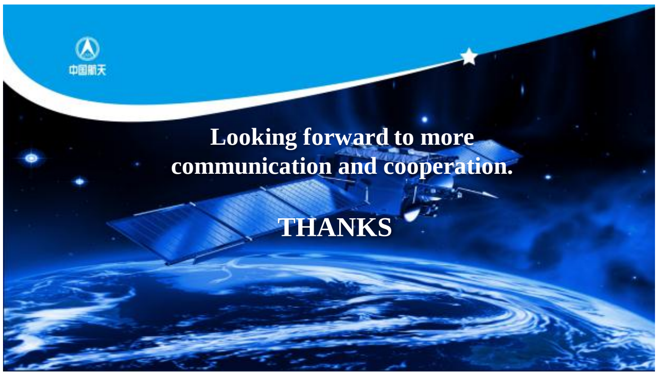

Summary
中国航天科技集团公司五院
五一四所
✓This paper summarizes the core technology architecture of ESD protection, that is, the discipline of ESD protection engineering, and discusses its important role in other industries' development.
✓The development of ESD protection core technology and the construction of ESD protection engineering discipline will continue to promote industrial development, product quality improvement and safety protection. At the same time, the increasing demand for industrial development, product quality improvement needs and security requirements are reacting upon the development of ESD protection core technology and the construction of ESD protection engineering discipline.
✓Space electrostatic hazards and protection technology are important parts of the core technology architecture of ESD protection and the subject of ESD protection engineering, and space electrostatic also has its particularity.
✓This paper introduces the causes and types of space electrostatic hazards, and briefly introduces the space ESD protection technology.


中国航天
Looking forward to more communication and cooperation.
THANKS

纳撒尼尔 ·皮奇

纳撒尼尔·皮奇（Nathaniel Peachey） 1994 年在林肯市的内布拉斯加大学获得博士学位，然后在洛斯阿拉莫斯国家实验室被授予董事资助的博士后奖学金。 1996 年，他在科罗拉多斯普林斯加入了 Atmel 公司。在之后的几年中，皮奇博士在 Atmel 公司担任过多个职位，包括工艺工程师、技术开发工程师、设备工程师、电路设计工程师。从 2003 年他开始专注于 ESD 防护和 I / O 设计问题。

2005 年皮奇博士担任 RF Micro Devices 公司新成立的 ESD 设计组的工程经理。在担任此职务期间，他负责为 RFMD 设计的所有技术（包括硅和砷化镓）提供 ESD 防护研发。除了对芯片的保护，他还领导发展和改进了射频天线 ESD 防护，是 IEEE 高级会员。

皮奇博士撰写和合作撰写了超过 30 篇技术期刊论文。他还提交了 14 个专利，已被授权或等待授权。皮奇博士 2009 年首次当选 ESD 协会理事会的理事。他曾在教育委员会任职，担任第一业务部经理。2011 年，他担任 ESDA 的标准业务部经理，负责 ESDA 有关器件测试和工厂标准的制定和更新。在他任职期间，皮奇博士帮助推进了与 JEDEC 的联合标准的制定工作。

Nathaniel (Nate) Peachey

Nathaniel (Nate) Peachey received his Ph.D. in Physical Chemistry in 1994 from the University of Nebraska–Lincoln and then was awarded a Director's Funded Postdoctoral Fellowship at the Los Alamos National Laboratory (Los Alamos, NM) where he studied thin-film membranes for gas separation. In 1996, he joined Atmel Corporation in Colorado Springs as a thin-films process engineer. Over the next several years Dr. Peachey held various positions at Atmel including process engineer, technology development engineer, device engineer, and circuit design engineer. In 2003, he began focusing exclusively on ESD protection and I/O circuit design issues.

In 2005 Dr. Peachey accepted the position of engineering manager for the newly formed ESD design group at RF Micro Devices. In this capacity, he was responsible for the development of ESD protection for all the technologies that RFMD designed in including both silicon and GaAs. Besides on-chip protection he led the development and improvement of the RF antenna ESD protection. In 2015 RFMD and Triquint Semiconductor merged to form Qorvo Inc. and Dr. Peachey continued his ESD and management responsibilities in the new company. Also in 2015 Dr. Peachey added the responsibility of Corporate ESD Program Manager to his responsibilities. In this capacity, he is responsible to guide the ESD control program for Qorvo as well as oversee annual audits of assembly facilities.

Dr. Peachey has authored and coauthored over 30 technical journal submissions. He has also submitted 14 patents that have either been granted or are pending. He was also asked to author a chapter on ESD and EOS failure mechanisms and reliability for the 2015 textbook "Electrostatic Discharge Protection: Advances and Applications" edited by Professor Juin J. Liou. Dr. Peachey is also a Senior Member of the IEEE.

In 2009 Dr. Peachey was elected to the Board of Directors for the ESD Association. He has been involved in various activities within ESDA. In 2011, he was appointed to the position of Manager for the Standards Business Unit for the ESD Association. In this capacity, he is responsible to oversee the development and updating of both the device testing and the factory standards documents for the ESD Association. During his tenure as Standards Business Unit Manager, Dr. Peachey has helped to drive the development of joint standards with JEDEC.

标准存在的问题：接地和系统水平测试

ESDA/CNIS 会议, 中国贵阳
Nathaniel Peachey
2017年11月10日

标准存在的问题:

接地和系统水平测试

摘要

该PPT将讨论关于即将开始对ANSI/ESD S6.1接地标准进行重新审查的工作，并将该标准作为模版使用，写入新的文件，这将使该标准在亚洲有更广泛的适用性。接地是成功的ESD控制程序的核心，这就使得这些工作特别重要。

第二个即将讨论的议题是继续对测试标准的讨论。虽然HBM和CDM标准适用于设备和组件，但是IEC 61000-4-2标准仅适用于终端电子产品。然而，有一种趋势将该测试推给原件制造商。该讨论将包含如何正确使用IEC 61000-4-2标准，以及如何正确使用电子产品RF端口特别保护的高水平原则。该讨论还将强调如何将这些设计原则用于电缆放电的系统端口。

标准存在的问题

大纲

I. ANSI/ESD S6.1 接地标准介绍
II. 接地在中国的注意事项
III. 亚洲接地工作组

IV. IEC61000-4-2 标准的使用和滥用
V. 电子产品RF端口保护的设计问题
VI. 全球放电问题以及他们对产品造成的威胁
VII. 总结

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VII. 总结

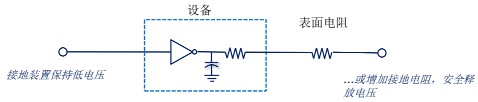
接地介绍

接地 ➡ **ESD**控制的基本要素

- 从建筑物和交流接地开始，必须保持与地面牢固相连。
- 许多电子原件对电压敏感，即使是小的直流电压差。
- 在为有效的等电位接地方案奠定基础方面，标准非常重要。
- 有效的ESD控制程序随后将被实施，一旦实施，ESD敏感元件将被成功制造和组装。

接地介绍

工厂的ESD 控制



在工厂，对ESD敏感元件的基本防护是:

1. 连接到地面，使电压最小(<100V) 或
2. 增加表面地租，使得逐渐增加的电压可以被安全释放。

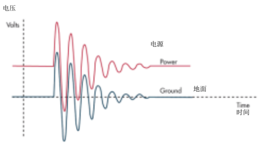
在任何情况下，接地是有效进行ESD防护的关键

接地中的问题

什么可能出错…

- 一种常见的接地方法是用4欧姆的电阻将ESD接地与交流接地或设备接地分开。
- 连接到地线时可能会发生瞬变。如果ESD和交流接地之间的电阻存在差异，地线之间会产生电压电位差。

- 电源与地面耦合会导致瞬变。
- 其他设备地线的“噪音”也会导致瞬变。



接地时存在的问题

考虑一个例子…

- 假设线路电压有一个临时的10V电压。
- 同时假设设备和ESD接地之间有一个4 Ω的电阻，并且在设备接地与地面之间有一个1 Ω的电阻。

$$V = V_{eq}\frac{R_1}{R_1 + R_2}$$

因此，电阻器另一端的电压是2V。因此在两个接地之间存在8V的电压差。

带有足够电流的8V电压差能够轻易损坏ESD-敏感设备！！

标准中存在的问题

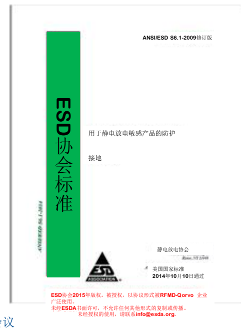
大纲

I. ANSI/ESD S6.1 接地标准介绍
II. 接地在中国的注意事项
III. 亚洲接地工作组
IV. IEC61000-4-2 标准的使用和滥用
V. 电子产品RF端口保护的设计问题
VI. 全球放电问题以及他们对产品造成的威胁
VII. 总结

接地注意事项

ANSI/ESD S6.1

- 该文件是在北美洲严格执行的规范。
- 但是，该文件讨论的原则通常普遍适用于ESD防护区域（EPA）的接地。
- 尽管如此，实际上需要一个适用于EPA的更加国际化的ESD接地文件资料。
- 这将不会对目前的接地文件进行重大修改。
- 但是…必须认真地制定更具国际适用性的文件。

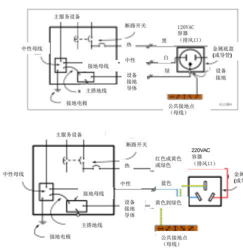


接地注意事项

ANSI/ESD S6.1之外

将对与图表有关的改变做出调整

例如…

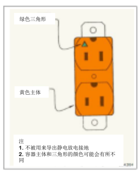


接地注意事项

ANSI/ESD S6.1之外

将会更多涉及其他变化

- 隔离接地插座在5.3.2部分进行讨论
- 这个图表，当然仅适用于北美洲
- 将需要了解中国的等效电路是什么



接地电阻的公共接地点

- ANSI/ESD S6.1规定公共接地点(CPG)到交流接地的电阻必须小于1欧姆。
- 在中国，允许低压电源是4欧姆或更小。许多工厂执行4欧姆的限制。

术语的定义

- 根据ANSI/ESD S6.1，接地端通过一个大于1欧姆的电阻与交流电源或地面连接，被称为“辅助接地”。
- 在中国，这被称为“独立接地”或“特殊接地”。

接地注意事项

ANSI/ESD S6.1之外

其他改变…

- 参考文件需包含北美国家电气规范**(ANSI/NFPA 70)**之外的参考
- 需要用国际（亚洲）条款和限制条件规定辅助接地（独立或特殊接地）。目前的**S6.1**符合美国国家电气规范**NFPA 70**。

标准——定义

标准不是旨在解决问题事项的“教授艺术”。
相反，标准是规定限制条件，描述与之相关的问题事项要求的官方文件。
（关于接地…）通过访问旨在解释该系统如何构建的文献可以获得构建满足标准要求的接地系统所需的专业知识。

2017年ESDA/CNIS会议　13

标准中存在的问题

大纲

I. ANSI/ESD S6.1 接地标准介绍
II. 接地在中国的注意事项
III. 亚洲接地工作组
IV. IEC61000-4-2 标准的使用和滥用
V. 电子产品RF端口保护的设计问题
VI. 全球放电问题以及他们对产品造成的威胁
VII. 总结

2017年ESDA/CNIS会议　14

亚洲接地工作组

目前状态

- 工作组已经成立。
- 已指定中国的工作组主席。
- 已经举行了几次工作组会议，开始行动。
- 已向ESD协会TAS委员会提交工作报告。
- 一旦工作报告获得批准，将开始新文件的工作。这将是ANSI / ESD S6.1的配套文件，但是会更加国际化，特别是能够覆盖中国的情况。

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亚洲接地工作组

发展计划

- 由于该文件不是符合北美洲情况的文件，它必须是超过ANSI认证的文件。
- 一旦文件被编写、审查并由ESD协会发行，该文件需向IEC委员会提交。
- 然后工作组以及ESD协会需将文件提交给IEC委员会审查、发行。

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标准中存在的问题

大纲

I. ANSI/ESD S6.1 接地标准介绍
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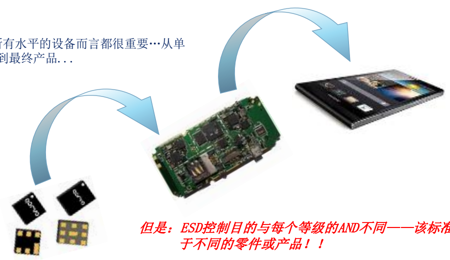
VII. 总结

2017年ESDA/CNIS会议　17

IEC 61000-4-2 系统水平

系统水平与设备水平

ESD防护对所有水平的设备而言都很重要…从单个组件到板到最终产品...



但是：ESD控制目的与每个等级的AND不同——该标准适用于不同的零件或产品！！

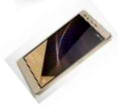
2017年ESDA/CNIS会议　18

IEC 61000-4-2 系统水平

ESD 测试标准

- 设备等级防护的目的是仅在制造和组装阶段提供保护。
- 设备测试是在部件切断电源的情况下进行的。
- 根据ANSI/ESDA/JEDEC JS-001 (HBM)和ANSI/ESDA/JEDEC JS-002 (CDM)进行设备测试。

- 组装和感应场ESD威胁都需要进行插板等级防护…在外部端口。
- 插板（系统）等级测试是在部件通电的情况下完成的。
- 根据IEC 61000-4-2接触放电进行测试。



- 终端产品需进行整体系统等级防护。
- 系统等级测试是在部件通电的情况下完成的。
- 根据IEC 61000-4-2接触放电和空气放电进行测试。

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IEC 61000-4-2的滥用

对设备级组件强加系统等级要求

- 一些OEM开始对设备供应商施加系统等级要求。
- 预计这将提高最终产品的质量。
- 实际上，这能够降低ESD的稳健性和产品性能！！

设备系统等级要求的重要性

- 设备尺寸大得令人无法接受。
- 性能可能会显著下降，特别是在射频和高速数码的应用方面。
- 由于ESD防护不能转到电路板最有效的位置上，防护实际上可能会更糟。
- 不允许板级设计人员存在灵活性。

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IEC 61000-4-2 系统等级

设备等级和系统等级要求的正确应用

ANSI/ESDA/JEDEC JS-001 HBM
ANSI/ESDA/JEDEC JS-002 CDM　—适用于→　**设备**

IEC 61000-4-2
IEC 61000-4-5
其他系统等级测试　—适用于→　**线路板和最终产品**

当设备按照设备等级ESD规范进行设计时:

- 他们可以在ANSI/ESD S20.20标准工厂被安全组装成产品。
- 它向板级设计人员提供了灵活性空间，可以将系统级ESD防护和高性能产品需要的调整能力最大化。

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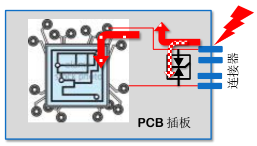
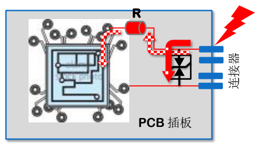
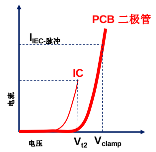
IEC 61000-4-2 系统水平

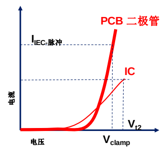
设备和系统水平ESD 协调设计







- 正确定位PCB二极管和电路等级ESD防护是最佳系统级防护所必需的。
- 这是通过首先对电路等级和插板等级ESD防护组件进行描述实现的。



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标准中存在的问题

大纲

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射频天线防护

平衡装置水平和系统等级要求

- 天线端口防护是设备装置和系统等级要求平衡的良好例证。
- 一些OEM开始要求对天线设备组件进行系统级保护。

除了系统级ESD防护，插板设计人员必须关注:
射频调整
配错（导致发生瞬变）
插入损耗
线性
等等…

如果整个IEC防护是针对内部设备组件进行的，对所有性能和耐久性要求的调整和优化没有灵活性！

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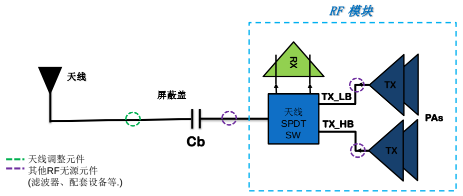
射频天线防护

基本的天线RF模块组件原理图



- ❑ IEC接触放电测试将在天线上进行。预计能够承受8kV IEC的接触放电测试。
- ❑ 为了能够承受ESD测试，必须将防护元件放置在PCB插板的天线上或RF模块的天线上，或两个地方都放置。

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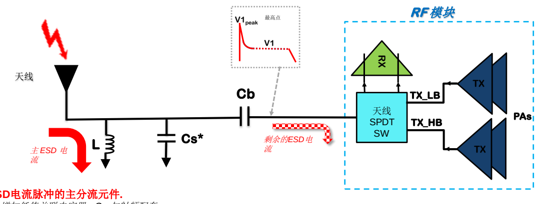
射频天线防护

基本的天线端口保护 ➡ 分流指示器



L = ESD电流脉冲的主分流元件.
*可能会增加低值并联电容器，Cs, 与射频配套.

产生高残余电流和电压，v1(t)这会产生内部故障！
- ➢ 触发/过冲电压, V1峰值 >100V

L < 20nH 需要进行ESD防护.但是，这导致射频性能问题!
它可将高插入损耗(IL)添加到天线上。

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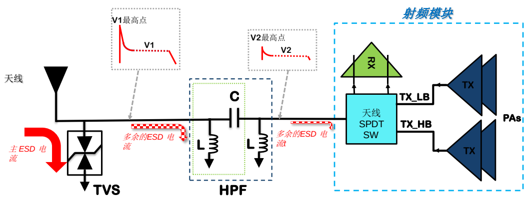
射频天线防护

理想的ESD保护方案 ➡ 二阶段方法



第一阶段:
ESD电流脉冲的主分流器
产生多余的电压脉冲，v1(t)
限制电压，V1< 20V
触发/过冲电压, V1峰值 <50V
=> TVS（二极管、火花隙、电容器）

第二阶段:
进一步降低残余的电压脉冲，v2(t)
限制电压，V2< 10V
触发/过冲电压, V2峰值<20V
=> HPF (第二个或第三个命令)

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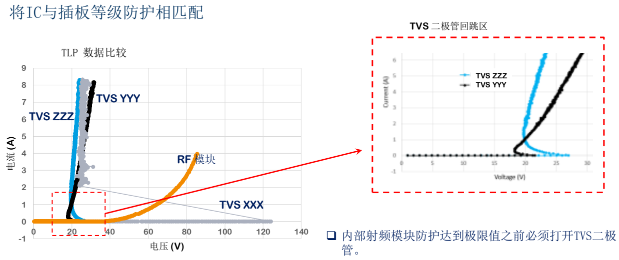
射频天线防护

将IC与插板等级防护相匹配



- ❑ 内部射频模块防护达到极限值之前必须打开TVS二极管。
- ❑ 如果这些防护等级没有进行适当的匹配（协同设计），将会导致故障。

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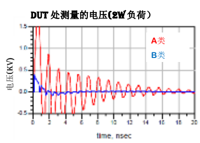
射频天线防护

ESD保护装置在电路板上的放置

例 A:
TVS 在微波传输带的后面 (靠近 DUT)

例B:
TVS在微波传输带的前面 (在天线端口)

- ❑ 理想的TVS位置是在天线外端口
  =>残流电压的最低水平
- ❑ 如果正确放置在PCB上，TVS设备应该能够覆盖ESD能量的99%
- ❑ 注：如果TVS设备在射频模块内部，将没有机会“调整”ESD防护，达到最佳性能。



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标准中存在的问题

大纲

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II. 接地需在中国考虑的事项
III. 亚洲接地工作组
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VI. 全球放电问题以及他们对产品造成的威胁
VII. 总结

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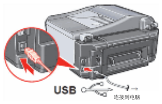
电缆放电

其他系统水平威胁

- 电缆放电对电子产品而言是另一个系统水平威胁。
- 通过USB与其他电缆连接的扩散装置成了一个更大的问题。

- 由于手持设备和无线设备通常在连接时没有接地，这些设备使问题更加严重。在这种情况下，电缆及设备的电荷和地电位都是未知的。
- 防止破坏电缆放电的防御线是:
  1. 接地优先或屏蔽优先的连接器
  2. 屏蔽电缆。
- 但是，这不是防止电缆放电的唯一防护要求！



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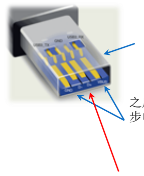
电缆放电

接地/屏蔽优先连接



- 但是，如果在连接之前，所有的线路和屏蔽都是带电的…屏蔽和GND将在敏感数据线之前放电。
- 数据线最后放电。这就从数据线到已经连接好的设备产生了短暂的脉冲放电。
- 整个过程在正常情况下，ESD未防护区域发生。因此，几千伏特的静电荷是未知的。

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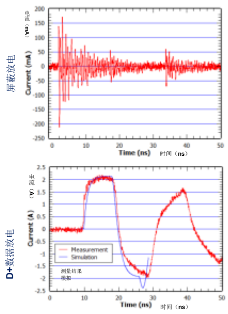
电缆放电

CDE事件的风险评估

试验:

- USB-3个电缆（3米）被充电至1000V。
- 首次与防护罩连接时，电缆放电。
- 1到2毫秒之后，D+数据线被连接并放电。
- *D+数据线在大约20ns的持续时间内释放了2.2A脉冲。*
- **通常情况下，在非ESD安全环境中，充电1000V不是极限值。**



Wolfgang Stadler, Josef Niemesheim, Andreas Stadler, Sebastian Koch, Harald Gossner, "电缆放电事件的风险评估", 2016年Tucson AZ.EOS/ESD专题研讨会的学术进展

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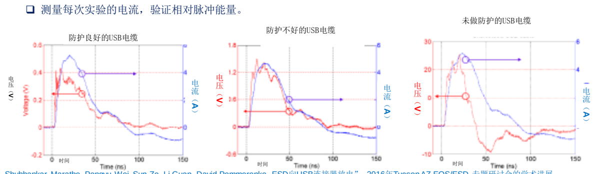
电缆放电

ESD向USB连接器放电

- 第一次实验，将一个1.8m USB-2个电缆连接到"设备"（PCB接地）一端，然后用另一端的ESD枪进行脉冲。
- 使用不同的电缆:
  1. 防护良好的USB电缆
  2. 防护欠佳的USB电缆
  3. 未做防护的USB电缆
- ESD枪被通电至2kV，然后向USB电缆开口端放电。
- 测量每次实验的电流，验证相对脉冲能量。



Shubhankar Marathe, Pengyu Wei, Sun Ze, Li Guan, David Pommerenke, ESD向USB连接器放电", 2016年Tucson AZ.EOS/ESD 专题研讨会的学术进展

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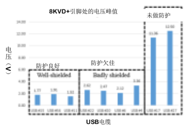
电缆放电

ESD 向USB连接器放电

- 在第二次实验中，同样1.8m USB-2个电缆在连接到设备上之前被通电。然后他们被连接到设备上，被测量放电电压。
- 再一次使用不同的电缆:
  1. 防护良好的USB电缆
  2. 防护欠佳的USB电缆
  3. 未做防护的USB电缆
- ESD枪被通电至8kV，然后向未连接的USB电缆开口端放电。
- 然后测量插入期间D+数据线的电压。

- 结果:
  1. 在电缆放电期间，防护对降低电压而言很重要。
  2. 在电缆放电时降低电压方面，即使是防护欠佳的电缆也明显优于未做防护的电缆。



SHUBHANKAR MARATHE, PENGYU WEI, SUN ZE, LI GUAN, DAVID POMMERENKE, ESD向USB连接器放电", 2016年TUCSON AZ.EOS/ESD 专题研讨会的学术进展

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电缆放电

经验教训

1. 对电缆正确充分的防护可以减少对电子产品电缆放电威胁的电压威胁。
2. 即使是正确防护的电缆，电缆放电对连接到电子设备上的通讯电缆而言，仍然是一个风险。
3. 必须对线路板进行正确的电缆放电防护，使其能够承受预计将影响电子设备的最高等级的电缆放电威胁。
4. 正常情况下预计，如果电子设备通过IEC 61000-4-2，4级（8kV接触放电，15kV空气放电），那么连接到电缆的端口可以在现场被安全使用。

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标准问题

总结

- 接地是维持EPA，安全处理ESD敏感设备的基础。国际化的接地标准需要明确说明接地和接地系统要求。
- 需要了解设备和系统级ESD压力，以便设计优良的产品。但是希望设备提供系统级ESD防护是不切实际的，对设备和系统级ESD防护的协调设计能够提供更有效和更稳健的设计。
- 射频天线端口防护为如何实施这些协调设计原则提供了一个很好的例子。这也是一个好的模型，说明了要求设备组件并入IEC保护类型的局限性。
- 特别对手持设备而言，电缆放电一直是一个关注点。对这些电缆的正确防护是控制CDE临时电压的关键。更进一步讲，必须对连接器提供防护，减轻现场的电缆放电风险。

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Issues in Standards: Grounding and System Level Testing

ESDA/CNIS Conference, Giuyang China
Nathaniel Peachey
November 10, 2017

Issues in Standards:

Grounding and System Level Testing

Abstract

This presentation will discuss the work that is beginning where the ANSI/ESD S6.1 Grounding Standard is being revisited and used as a template to write a new document that will have broader applicability in Asia. The centrality of grounding to a successful ESD control program makes this work particularly important.

The second topic that will be discussed is a continuation of the testing standard discussion. While the HBM and CDM Standards are applicable to devices and components, the IEC 61000-4-2 Standard is intended for final electronic products only. However, there is a tendency to push this testing back onto the component manufacturers. This discussion will cover the proper use of the IEC 61000-4-2 Standard as well as some high level principles about protecting particularly RF ports in electronic products. The discussion will also address how these design principles are applicable to cable discharge events at system ports.

Issues in Standards

Outline

I. Introduction to ANSI/ESD S6.1 Grounding Standard
II. Considerations for Grounding in China
III. The Asian Grounding Working Group

IV. Uses and Misuses of the IEC61000-4-2 Standard
V. Issues in Designing RF Port Protection for Electronic Products
VI. Cable Discharge Events and their Threat to Products
VII. Summary

Issues in Standards

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V. Issues in Designing RF Port Protection for Electronic Products
VI. Cable Discharge Events and their Threat to Products
VII. Summary

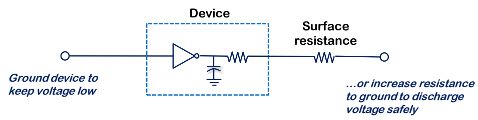
Introduction to Grounding

Grounding ⟶ *the fundamental element of ESD control*

- Starting with the building and AC ground, solid connections to ground must be maintained.
- Many electronic parts are sensitive to voltage even small DC voltage differentials.
- Standards are important to provide a foundation for an effective equipotential grounding scheme.
- The effective ESD control program can then be implemented where ESD-sensitive parts can be successfully manufactured and assembled.

Introduction to Grounding

ESD control in the factory



In the factory the primary protection for ESD sensitive parts is:

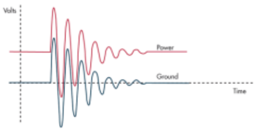
1. Connectivity to ground so that voltage is minimized (<100V) or
2. Increasing surface resistance so that voltage that does build up can be safely discharged.

In either case, grounding remains the key to effective ESD protection

Problems in Grounding

What can go wrong…

- One ground approach that is common is to have 4 ohms of resistance separating the ESD ground from the AC or equipment ground.
- There can be transients that couple onto the ground line. If there are resistance differences between ESD and AC grounds, a *voltage potential difference* can result between the grounds.
- Transients can result from coupling across power to ground.
- These can also result from "noise" on the ground line from other equipment.



Problems in Grounding

Consider an example…

- Assume that there is a 10V transient on the line voltage.
- Also assume that there is a 4 Ω resistance between equipment and ESD grounds and 1 Ω resistance to earth ground from equipment ground.

$$V = V_{eq}\frac{R_1}{R_1 + R_2}$$

So the voltage on the other side of the resistor is 2V. So there is 8V difference between the 2 grounds!

An 8V differential with sufficient current can easily damage an ESD-sensitive device!!

Issues in Standards

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Considerations for Grounding

ANSI/ESD S6.1

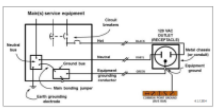
- This document is, strictly applied, North America specific.
- However, the principles discussed in the document are generally universally applicable to ground in an ESD Protected Area (EPA).
- In spite of this, what is needed is an ESD grounding document that applies to the EPA that is more international in nature.
- This may not involve a major revision of the current grounding document.
- But…the development of a more internationally applicable document must be done carefully.

Considerations for Grounding

Beyond ANSI/ESD S6.1

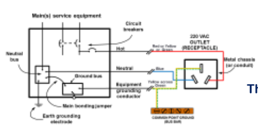
Some changes will be adjustments having to do with figures

For example…



This figure…

Becomes



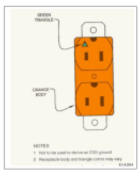
This figure

Considerations for Grounding

Beyond ANSI/ESD S6.1

Other changes will be more involved

- Isolated ground receptacles are discussed in Section 5.3.2
- This, of course, is a figure that applies only to North America.
- Will need to understand what the equivalent circuit is in China.



Common Point Ground to Ground Resistance

- ANSI/ESD S6.1 specifies that resistance from common point ground (CPG) to AC ground must be less than 1 ohm.
- For China, 4 ohms or less is allowed for low voltage power. This 4 ohm limit is observed in many factories.

Definitions of Terms

- In ANSI/ESD S6.1, the ground that is connected to AC or earth ground through a resistance greater than 1 ohm is called an "auxiliary ground".
- In China this is known as an "independent ground" or a "special ground".

Considerations for Grounding

Beyond ANSI/ESD S6.1

Other Changes…

- Referenced documents will need to include other references than the North American National Electric Code (ANSI/NFPA 70).
- Auxiliary Ground (independent or special ground) will need to be defined and specified in international (Asian) terms and limits. The current S6.1 follows and calls out the NFPA 70 of the US National Electric Code.

Standard – A Definition

- A Standard is NOT a document intended to "teach the art" of the subject matter being addressed.
- Rather, a Standard is an official document that specifies limits and describes the requirements for the subject matter to which it pertains.
- (For grounding…) Gaining the expertise required to build a grounding system that meets the Standard is done by accessing literature that is intended to explain how this system is built.

Issues in Standards

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Asia Grounding Working Group

Current status

- The working group has been established.
- A working group chair in China has been identified.
- There have been a few working group meetings to get the activities started.
- A work statement has been submitted to the ESD Association TAS committee.
- Once the work statement has been approved, work on a new document will begin. This would be a companion document to ANSI/ESD S6.1 but would be more international, particularly covering the China situation.

Asia Grounding Working Group

Development plans

- Since this document is NOT a document that pertains to the North America situation, it must be more than an ANSI certified document.
- Once the document has been written, reviewed, and released by the ESD Association, is should be submitted to the IEC committee.
- The working group along with the ESD Association should then submit the document to the IEC committee for their review and release.

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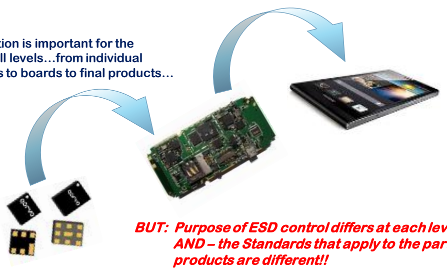
IEC 61000-4-2 System Level

System Level vs. Device Level

ESD protection is important for the devices at all levels…from individual components to boards to final products…



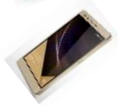
BUT: Purpose of ESD control differs at each level AND – the Standards that apply to the parts or products are different!!

IEC 61000-4-2 System Level

ESD testing Standards

- Device level protection is intended to protect during manufacturing and assembly only.
- Device testing is done with the part powered off.
- Devices are tested to the ANSI/ESDA/JEDEC JS-001 (HBM) and ANSI/ESDA/JEDEC JS-002 (CDM).

- Board level protection is required for both assembly and field ESD threats…at ports that are external.
- Board (system) level testing is done with the part powered up.
- Testing is done using IEC 61000-4-2 contact discharge.



- Entire system level protection is required for the final product.
- System level testing is done with the part powered up.
- Testing is done using IEC 61000-4-2 contact discharge AND air discharge.

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Misuse of IEC 61000-4-2

Imposing system level requirements on device level components

- Some OEM's are beginning to impose system level requirements onto device suppliers.
- The expectation is that this will improve the quality of the final product.
- In fact, this can degrade both ESD robustness and performance of the product!!

Consequences of System Level Requirements for Devices

- Device size grows unacceptably large.
- Performance may be degraded significantly, particularly for RF and high speed digital applications.
- Protection may actually be worse since the ESD protection cannot be moved to the most effective position on the board.
- Allows no flexibility for the board level designer.

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IEC 61000-4-2 System Level

Proper application of device level and system level requirements

ANSI/ESDA/JEDEC JS-001 HBM
ANSI/ESDA/JEDEC JS-002 CDM — Applies to → DEVICES

IEC 61000-4-2
IEC 61000-4-5
Other system level tests — Applies to → Boards and Final Products

When devices are designed to device level ESD specifications:

- They can be safely assembled into a product in an ANSI/ESD S20.20 compliant factory.
- It provides the board level designer the flexibility to maximize both system level ESD protection and the tuning capability required for a high performance product.

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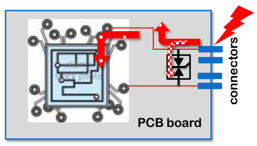
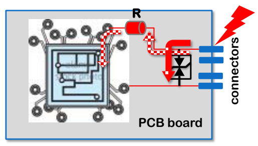
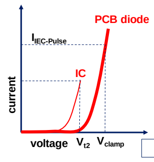
IEC 61000-4-2 System Level

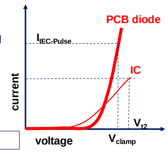
Device and system level ESD co-design







- Properly targeting the PCB diode and the circuit level ESD protection is necessary for optimal system level protection.
- This is done by first characterizing both the circuit level and board level ESD protection components.



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Issues in Standards

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RF Antenna Protection

Balancing device level and system level requirements

- Antenna port protection is a good illustration of the balance between device and system level requirements.
- Some OEM's are beginning to request system level protection on antenna device components.

In addition to system level ESD protection, the board designer must be concerned about:

- *RF tuning*
- *Mismatch (resulting in transients)*
- *Insertion loss*
- *Linearity*
- *And so forth…*

If the entire IEC protection is inside the device component, no flexibility remains for tuning and optimizing ALL performance and ruggedness requirements!

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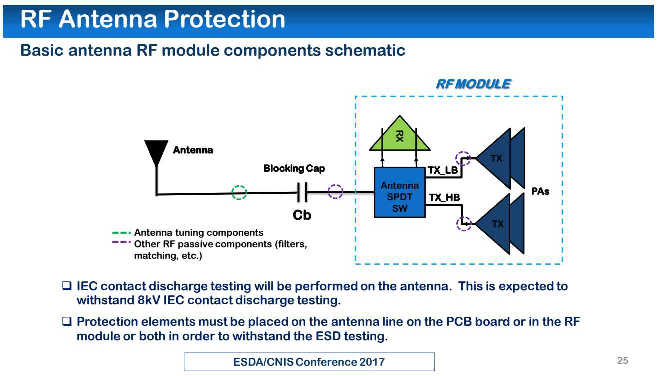
RF Antenna Protection
Basic antenna RF module components schematic
RF MODULE
Antenna
Blocking Cap
Cb
RX
TX
TX_LB
TX_HB
Antenna SPDT SW
PAs
Antenna tuning components
Other RF passive components (filters, matching, etc.)
IEC contact discharge testing will be performed on the antenna. This is expected to withstand 8kV IEC contact discharge testing.
Protection elements must be placed on the antenna line on the PCB board or in the RF module or both in order to withstand the ESD testing.
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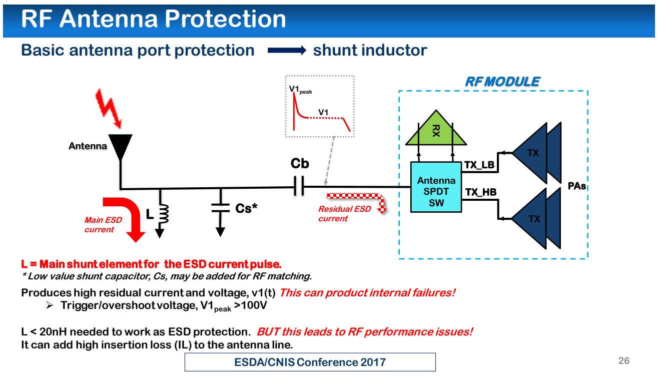
RF Antenna Protection
Basic antenna port protection shunt inductor
RF MODULE
V1peak
V1
Antenna
Cb
Cs*
L
Main ESD current
Residual ESD current
RX
TX
TX_LB
TX_HB
Antenna SPDT SW
PAs
L = Main shunt element for the ESD current pulse.
* Low value shunt capacitor, Cs, may be added for RF matching.
Produces high residual current and voltage, v1(t) This can product internal failures!
Trigger/overshoot voltage, V1peak >100V
L < 20nH needed to work as ESD protection. BUT this leads to RF performance issues!
It can add high insertion loss (IL) to the antenna line.
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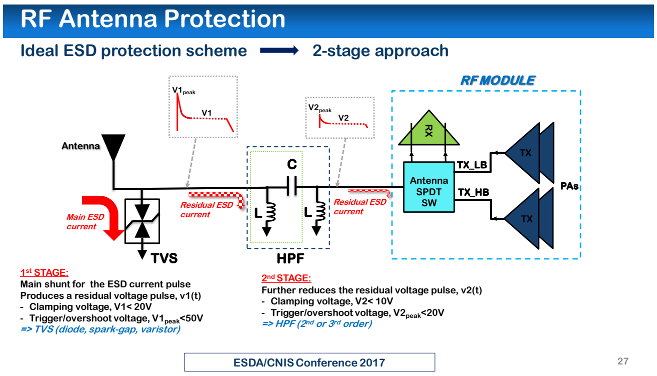
RF Antenna Protection
Ideal ESD protection scheme 2-stage approach
RF MODULE
V1peak
V1
V2peak
V2
Antenna
C
L
Main ESD current
Residual ESD current
TVS
HPF
RX
TX
TX_LB
TX_HB
Antenna SPDT SW
PAs
1st STAGE:
Main shunt for the ESD current pulse
Produces a residual voltage pulse, v1(t)
- Clamping voltage, V1< 20V
- Trigger/overshoot voltage, V1peak<50V
=> TVS (diode, spark-gap, varistor)
2nd STAGE:
Further reduces the residual voltage pulse, v2(t)
- Clamping voltage, V2< 10V
- Trigger/overshoot voltage, V2peak<20V
=> HPF (2nd or 3rd order)
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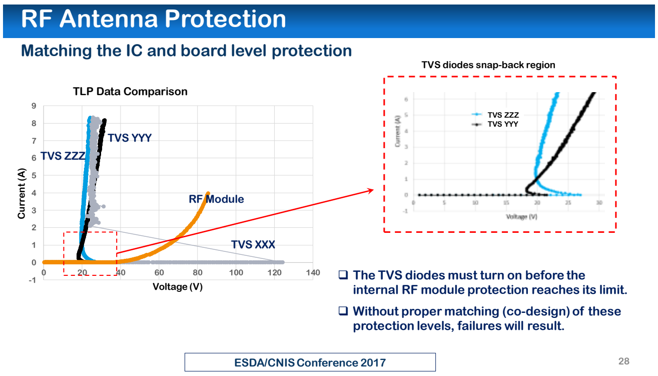
RF Antenna Protection
Matching the IC and board level protection
TLP Data Comparison
TVS diodes snap-back region
TVS ZZZ
TVS YYY
RF Module
TVS XXX
Current (A)
Voltage (V)
The TVS diodes must turn on before the internal RF module protection reaches its limit.
Without proper matching (co-design) of these protection levels, failures will result.
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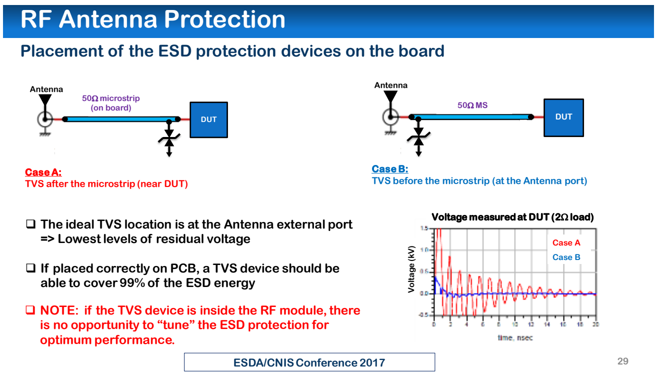
RF Antenna Protection
Placement of the ESD protection devices on the board
Antenna
50Ω microstrip (on board)
DUT
50Ω MS
Case A:
TVS after the microstrip (near DUT)
Case B:
TVS before the microstrip (at the Antenna port)
Voltage measured at DUT (2Ω load)
Case A
Case B
Voltage (kV)
time, nsec
The ideal TVS location is at the Antenna external port => Lowest levels of residual voltage
If placed correctly on PCB, a TVS device should be able to cover 99% of the ESD energy
NOTE: if the TVS device is inside the RF module, there is no opportunity to "tune" the ESD protection for optimum performance.
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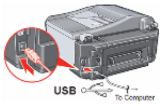
Cable Discharge Events

Other system level threats

- Cable discharge events are another system level threat to electronic products.
- With the proliferation of devices that are connected by USB and other cables, this becomes a larger concern.
- Hand-held and wireless devices exacerbate the problem since these are normally not connected to earth ground when being connected. In these cases, the charge and ground potential of both the cable and the device are unknown.
- Lines of defense to prevent damaging cable discharge are:
  1. Ground-first or shield-first connectors
  2. Shielding of cables.
- However, this is NOT the only protection needed to protect against cable discharge events!



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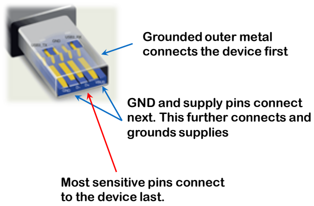
Cable Discharge Events

Ground/shielding first connections



- But, if all lines and shielding are charged before connection…shielding and GND will be discharged before the sensitive data lines.
- Data lines are then discharged last. This creates a transient pulse discharge from the data lines to the device to which it has been connected.
- The entire process occurs in a normal, ESD unprotected area. Thus static charges of several thousand volts is not uncommon.

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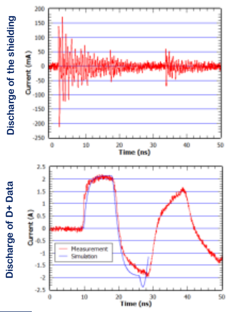
Cable Discharge Events

Risk assessment of CDE events

Experiment:

- USB-3 cable (3 meters) was charged up to 1000V.
- Cable was discharged by first contacting the shield.
- 1 to 2 milliseconds later, the D+ data line was contacted and discharged.
- *D+ Data line discharges a 2.2A pulse of approximately 20ns in duration.*
- **1000V of charging is NOT extreme in a normal, non-ESD safe environment.**



Wolfgang Stadler, Josef Niemesheim, Andreas Stadler, Sebastian Koch, Harald Gossner, " Risk Assessment of Cable Discharge Events", Proceedings of the EOS/ESD Symposium 2016, Tucson AZ.

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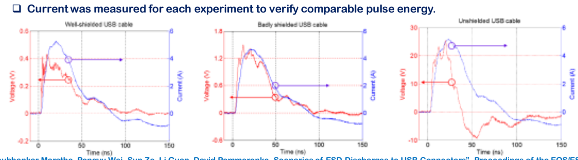
Cable Discharge Event

ESD discharges into USB connectors

- In the first experiment, a 1.8m USB-2 cable was connected to a “device” (PCB ground) on one end and then pulsed with an ESD gun on the other.
- Differing cables were used:
  1. Well-shielded USB cable
  2. Poorly shielded USB cable
  3. Unshielded USB cable
- The ESD gun was charged to 2kV and then discharged into the open end of the USB cable.
- Current was measured for each experiment to verify comparable pulse energy.



Shubhankar Marathe, Pengyu Wei, Sun Ze, Li Guan, David Pommerenke, Scenarios of ESD Discharges to USB Connectors”, Proceedings of the EOS/ESD Symposium 2016, Tucson AZ.

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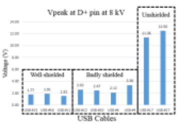
Cable Discharge Events

ESD discharges into USB connectors

- In the second experiment, the same 1.8m USB-2 cables were charge up prior to being connected to a device. They were then connected to the device and the discharge voltage measured
- Again the different cables used were:
  1. Well-shielded USB cable
  2. Poorly shielded USB cable
  3. Unshielded USB cable
- The ESD gun was charged to 8kV and then discharged into the open end of the unconnected USB cable.
- The voltage was then measured from the D+ data line during the plug-in event.

- RESULT:
  1. Shielding is important for reduction of voltage during a CDE event.
  2. Even poor shielding is significantly better than an unshielded cable to reduce the voltage of the CDE event.



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Cable Discharge Events

Lessons Learned

1. Proper and sufficient shielding of cables can reduce the voltage threat of the CDE threat to electronic products.
2. Even for properly shielded cables, CDE events are a risk for communication cables that are connected into an electronic device.
3. Proper ESD protection must be supplied on board to withstand the highest level of ESD threat anticipated to impact the electronic devices.
4. It is normally expected that if the electronic device passes IEC 61000-4-2 level 4 (8kV contact discharge, 15kV air discharge), then the ports into which cables are connected should be safe for use in the field.

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Issues in Standards

Summary

- Grounding is foundational to maintaining an EPA where handling ESD sensitive devices can be done safely. An international grounding standard is needed to specify the requirements for grounding and grounding systems.
- Device and system level ESD stressing needs to be understood to design superior final products. While expecting devices to supply system level ESD protection is not practical, co-design of device and system level ESD protection can provide more efficient and robust designs.
- RF antenna port protection is a good example of how to implement these co-design principles. It is also a good model to illustrate the limitations of requiring device components to incorporate the IEC type of protection.
- Cable discharge events continue to be a concern particularly for hand-held devices. Proper shielding of these connecting cables is critical to controlling the voltage of the CDE transient. Further, protection must be provided on the connectors to mitigate the risk of CDE events in the field.

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阮方鸣

阮方鸣教授，贵州师范大学教授，北京邮电大学工学博士，博士生导师，日本名名古屋工业大学访问研究员；国际电子电器工程师学会高级会员(IEEE Senior Member)，亚太环境电磁学学术会议 (Asia- Pacific International Conference on Environment Electromagnetics 2012, 2015) 程序技术委员会委员，国家自然科学基金同行评议专家，国家基础电子元器件质量检验中心专家，中国通信学会电磁兼容委员会委员，中国电子学会高级会员，中国通信学会高级会员，IEEE 大数据分会会员。

作为电磁兼容研究领域的中国学者，应邀出席在欧美国家召开的多次一流电磁兼容学术会议，主要有：

2009年8月美国奥斯汀国际电子电器工程师学会电磁兼容年会(2009IEEE EMC, Austin, US),

2009年1月 瑞士苏黎世国际电磁兼容学术会议(2009 Zurich International Conference on EMC, Jan14-17, Zurich, Switzerland)

2011年9月英国约克大学召开的欧洲第10届国际电磁兼容学术会议(EMC Europe2011, York University, UK)，

2013年5月澳大利亚墨尔本亚太国际电磁兼容学术会议(2013 APEMC, Melbourne, Australia),

2012年9月意大利罗马欧洲第10届国际电磁兼容学术会议(EMC Europe2012, Rome, Italy),

2010年9月波兰弗罗茨瓦夫第9届欧洲国际电磁兼容学术会议(EMC Europe2010, Wroclaw, Poland),

2006年12月日本名古屋工业大学亚洲国际电磁兼容学术会议(2006ASEMC, Nagoya, Japan)

2014年9月瑞典哥德堡欧洲国际电磁兼容学术会议(EMC Europe 2014, Gothenburg, Sweden, Sept 1-4, 2014)

获2015年贵州省科技进步三等奖（第一获奖人），获首届贵州省高等学校科学研究优秀成果(科学技术)自然科学奖三等奖（第一获奖人）、贵州省第二届（第一获奖人）和第四届（第二获奖人）自然科学优秀学术论三等奖各一次。

以第一作者和通信作者发表学术论文83篇；主持完成和在研国家级、省市级科研项目13项；获得国家授权发明专利、实用新型专利各一项，合作出版学术译著一部。

应邀为 ICCC (世界通信大会)， APEMC(亚太国际电磁兼容学术会议)， 通信学报，电子与信息学报，物理学报，Chinese Physics B, China Communication, 天津大学学报、吉林大学学报等审稿人。

Ruan Fangming

Ruan Fangming received his BS degree in electronic engineering in July, 1982 from Guizhou University of China, received MA degree in education in July, 2006 from Guizhou Normal University of China, and received PhD Eng. degree in electromagnetic fields and electromagnetic waves in July, 2009 from Beijing University of Post and Telecommunication. He was with Liupanshui Normal College from Aug., 1982 to Feb., 2000 as an instructor and an associate professor (since 1997). In Mar., 2000 he moved to Guizhou Normal University of China. From Sept., 2004 through Sept 2005 he worked as a visiting scholar in Fujiwara Electromagnetic Environment Lab of Nagoya Institute of Technology, Japan, engaged in properties research of micro-gap electrostatic discharge. Since Dec., 2006 he has been a full professor in Guizhou Normal University. Dr. Ruan is a senior member of China Institute of Electronics (CIE), a senior member of China Institute of Communication (CIC). On Nov., 2015 Dr. Ruan was awarded IEEE senior membership.

Dr. Ruan has published more than 80 papers in academic journals and academic conferences, completed as the research team leader 11 research projects supported by national or provincial government of China, and was the inventor of 3 patents. Dr. Ruan was electromagnetic compatibility (EMC) commission member of CIC, and was a TPC member of CEEM'2012 and CEEM'2015 (Asia-Pacific Conference on Environment Electromagnetics).

Dr. Ruan was awarded 2015 Guizhou Province Third Prize of Science and Technology Advancement(with title "Mechanism and correlative properties research of electrode moving speed effect in short-gap electrostatic discharge "), and 2014 Third Prize of Science and Technology Advancement of Guizhou Universities and Colleges(with title "Mechanism research of short-gap electrostatic discharge properties"). Presently Prof. Ruan is an advisor of graduates in Guizhou University and in Guizhou Normal University, having 10 graduate students, and teaching graduate level classes on RF and microwave technology, principles and design of electromagnetic compatibility (EMC), and TeraHertz technology.

非接触静电放电多因素效应与测试标准探讨

阮方鸣 教授

贵州师范大学

纲要

- 研究背景
- 电极移动速度效应
- 气体压强影响
- 温度湿度影响
- 新型ESD测试系统
- 测试标准的考虑
- 结语

研究背景

在工业生产和日常生活中，非接触静电放电是真实而大量存在的。电国际电工委员会(IEC) 制定了接触放电测试的国际标准，但是非接触静电放电的测试标准至今仍为空白。

非接触静电放电的性质，受多种环境因素的影响，包括气体压强、电极移动速度、温度、湿度、靶和电极材料等。

研究背景

- 静电放电造成损失　500亿美元/年

IEC　CCC　IEEE →

静电放电测试标准？

非接触型ESD--- No！

接触型ESD --- Yes

多因素中---电极移动速度效应/1987提出*

人体-金属 静电放电参数显著变化

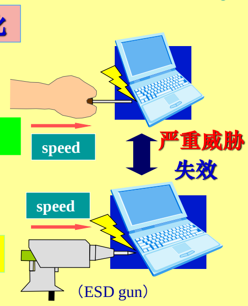
强影响

电极向靶的移动速度

强影响

静电放电模拟器的放电参数

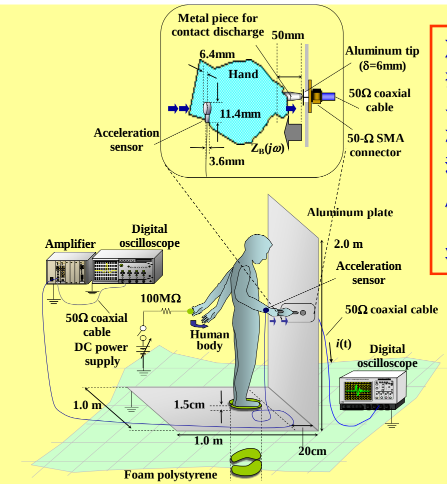
机 理 寻 找 --- ？



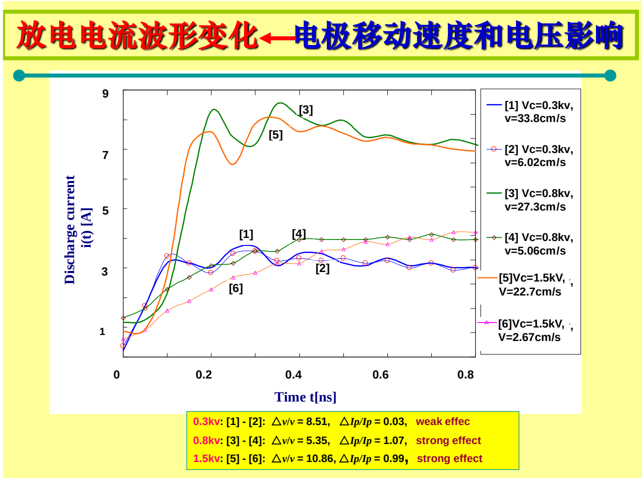
* B Daout H Ryser etc: The Correlation of Rising Slope and Speed of Approach in ESD Tests[C]. Proceedings of the 12th Int. Zurich Symp., 1987, pp.467–474

电极移动速度效应

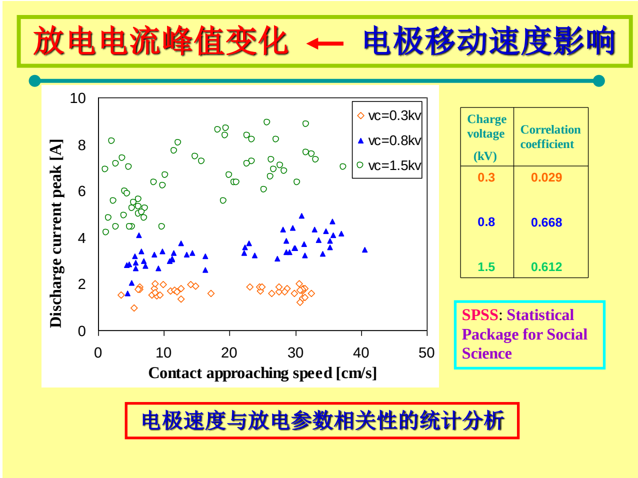
关键因素



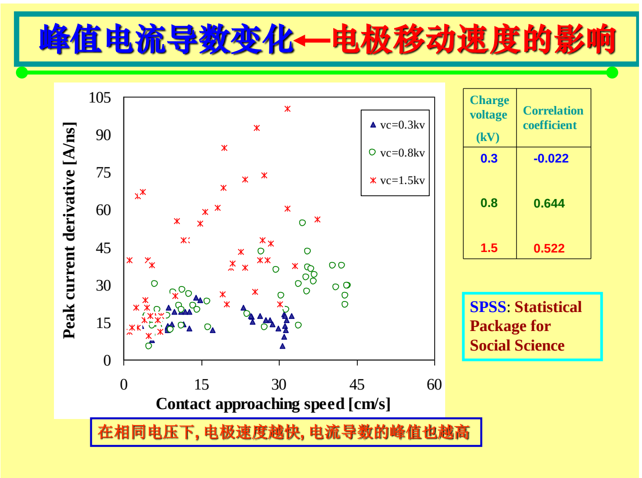
放电参数与电极运动速度的同步测量



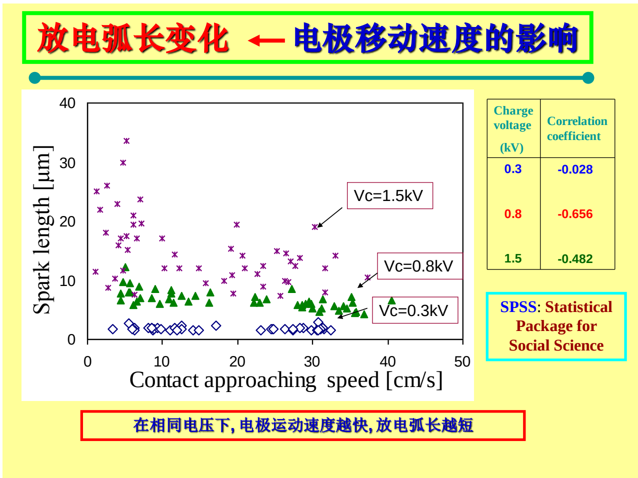
放电电流波形变化←电极移动速度和电压影响
Discharge current i(t) [A]
Time t[ns]
[1] Vc=0.3kv, v=33.8cm/s
[2] Vc=0.3kv, v=6.02cm/s
[3] Vc=0.8kv, v=27.3cm/s
[4] Vc=0.8kv, v=5.06cm/s
[5]Vc=1.5kV, V=22.7cm/s
[6]Vc=1.5kV, V=2.67cm/s
0.3kv: [1] - [2]: △v/v = 8.51, △Ip/Ip = 0.03, weak effec
0.8kv: [3] - [4]: △v/v = 5.35, △Ip/Ip = 1.07, strong effect
1.5kv: [5] - [6]: △v/v = 10.86, △Ip/Ip = 0.99, strong effect



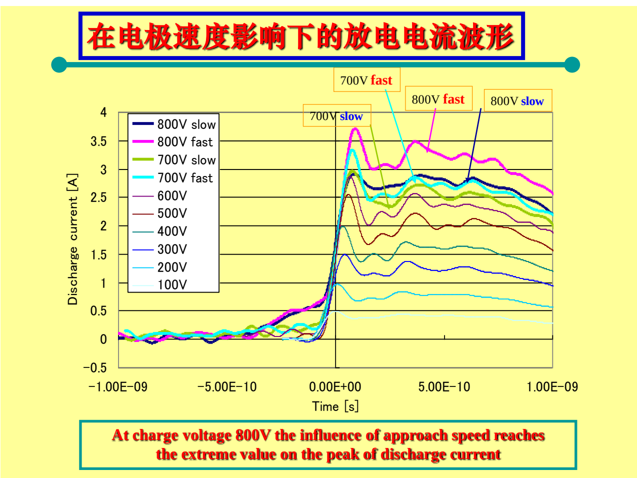
放电电流峰值变化 ← 电极移动速度影响
Discharge current peak [A]
Contact approaching speed [cm/s]
vc=0.3kv
vc=0.8kv
vc=1.5kv
Charge voltage (kV)
Correlation coefficient
0.3 0.029
0.8 0.668
1.5 0.612
SPSS: Statistical Package for Social Science
电极速度与放电参数相关性的统计分析



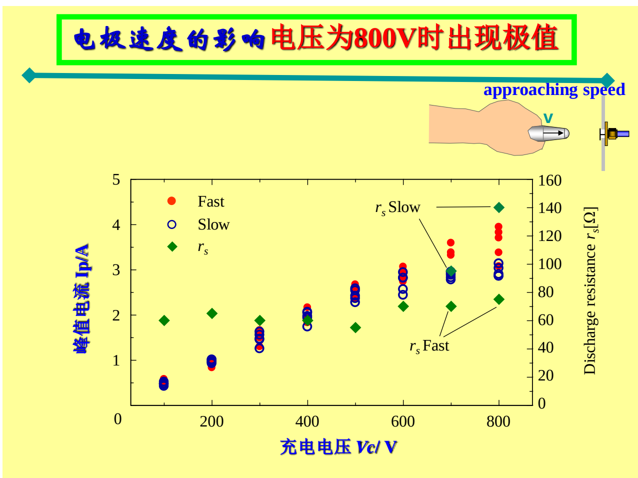
峰值电流导数变化←电极移动速度的影响
Peak current derivative [A/ns]
Contact approaching speed [cm/s]
vc=0.3kv
vc=0.8kv
vc=1.5kv
Charge voltage (kV)
Correlation coefficient
0.3 -0.022
0.8 0.644
1.5 0.522
SPSS: Statistical Package for Social Science
在相同电压下, 电极速度越快, 电流导数的峰值也越高



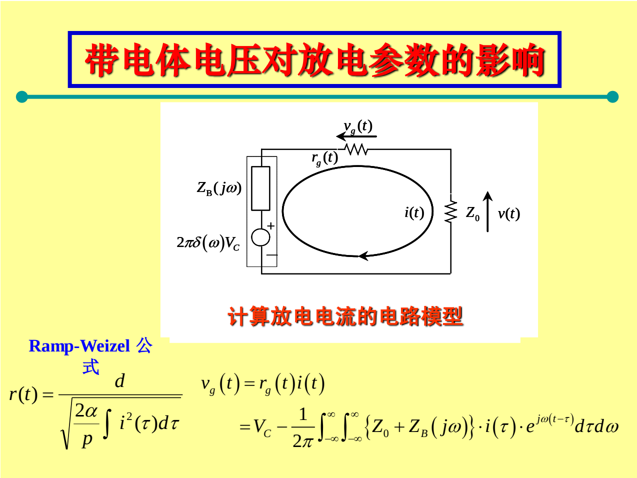
放电弧长变化 ← 电极移动速度的影响
Spark length [μm]
Contact approaching speed [cm/s]
Vc=1.5kV
Vc=0.8kV
Vc=0.3kV
Charge voltage (kV)
Correlation coefficient
0.3 -0.028
0.8 -0.656
1.5 -0.482
SPSS: Statistical Package for Social Science
在相同电压下, 电极运动速度越快, 放电弧长越短

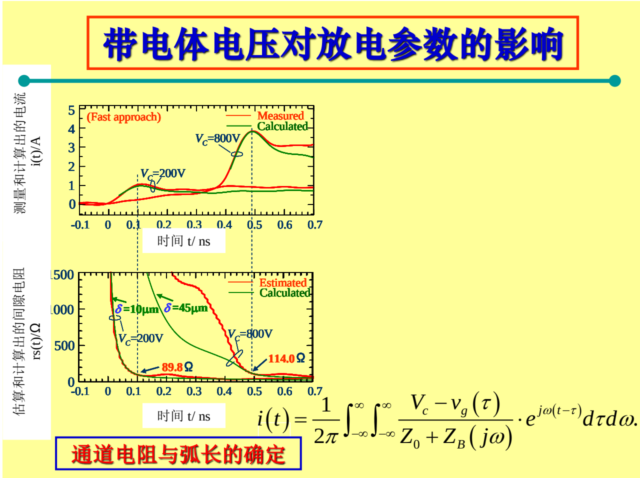


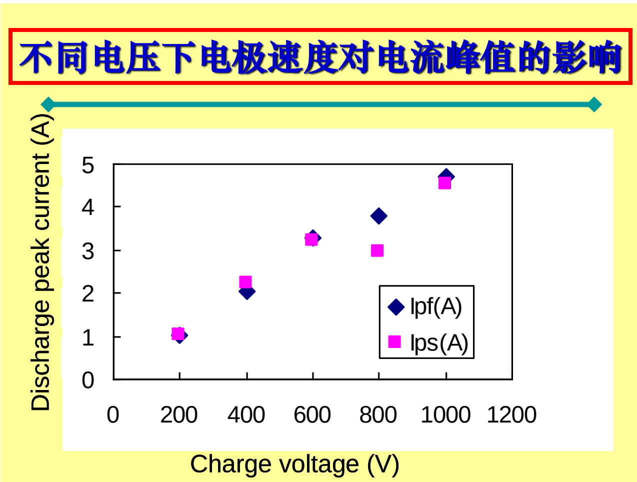
在电极速度影响下的放电电流波形
Discharge current [A]
Time [s]
800V slow
800V fast
700V slow
700V fast
600V
500V
400V
300V
200V
100V
At charge voltage 800V the influence of approach speed reaches the extreme value on the peak of discharge current

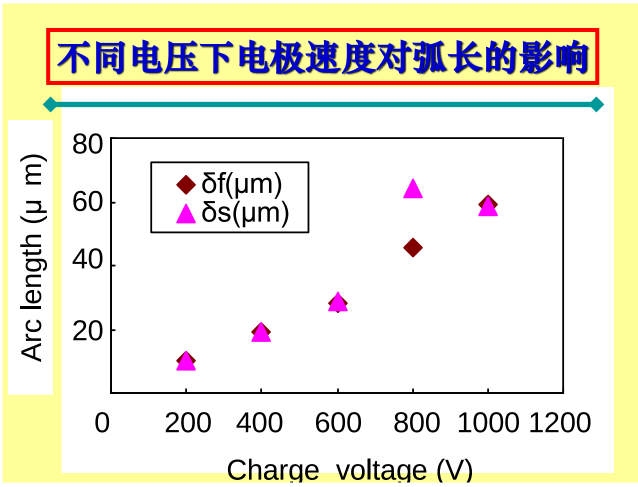


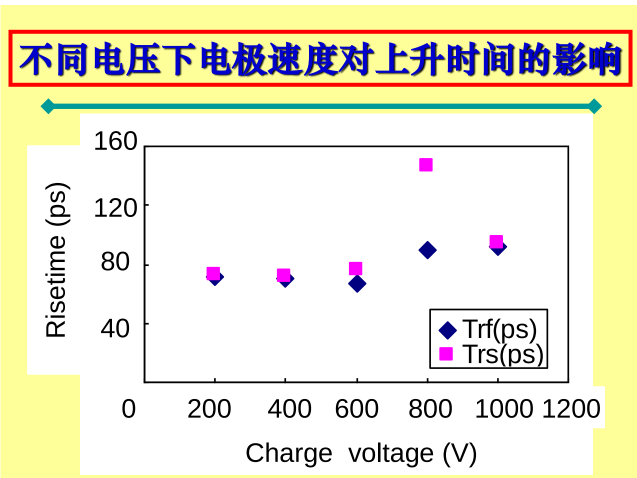
电极速度的影响电压为800V时出现极值
approaching speed
v
峰值电流 Ip/A
Discharge resistance r_s[Ω]
Fast
Slow
r_s
r_s Slow
r_s Fast
充电电压 Vc/ V

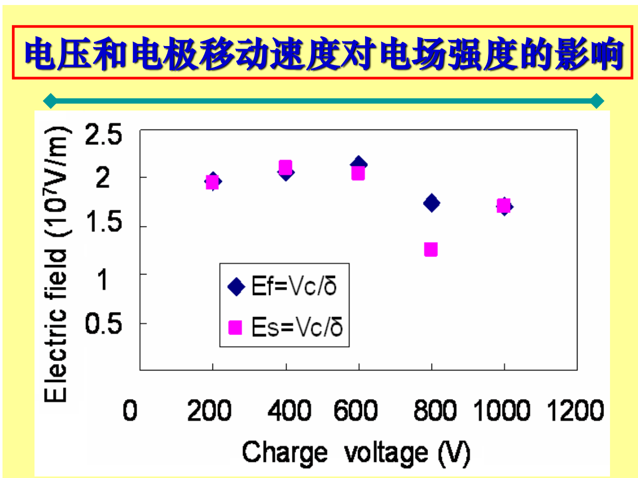

带电体电压对放电参数的影响
计算放电电流的电路模型
Ramp-Weizel 公式
$r(t)=\dfrac{d}{\sqrt{\frac{2\alpha}{p}\int i^2(\tau)d\tau}}$
$v_g(t)=r_g(t)i(t)$
$=V_C-\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\{Z_0+Z_B(j\omega)\}\cdot i(\tau)\cdot e^{j\omega(t-\tau)}d\tau d\omega$


带电体电压对放电参数的影响
测量和计算出的电流 i(t)/A
(Fast approach)
Measured
Calculated
时间 t/ ns
估算和计算出的间隙电阻 rs(t)/Ω
Estimated
Calculated
89.8Ω
114.0Ω
$i(t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{V_c-v_g(\tau)}{Z_0+Z_B(j\omega)}\cdot e^{j\omega(t-\tau)}d\tau d\omega.$
通道电阻与弧长的确定

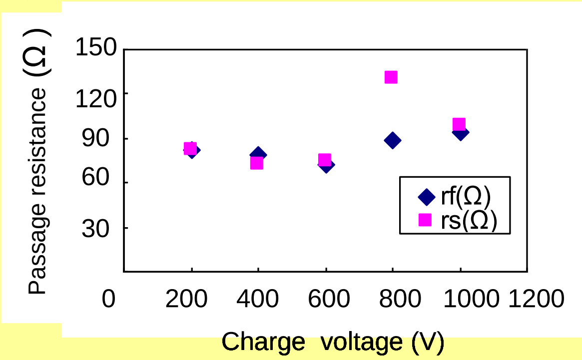

不同电压下电极速度对电流峰值的影响
Discharge peak current (A)
Ipf(A)
Ips(A)
Charge voltage (V)


不同电压下电极速度对弧长的影响
Arc length (μ m)
δf(μm)
δs(μm)
Charge voltage (V)


不同电压下电极速度对上升时间的影响
Risetime (ps)
Trf(ps)
Trs(ps)
Charge voltage (V)


电压和电极移动速度对电场强度的影响
Electric field (10^7V/m)
Ef=Vc/δ
Es=Vc/δ
Charge voltage (V)

不同电压和电极速度对间隙电阻的影响



在不同电压和速度下的放电参数

- 在带电电压为0.3kV时，放电参数与电极运动速度几乎没有关系。
- 在带电电压为 0.8kV时 电极运动速度对放电电流峰值的影响非常明显。
- 带电电压为1.5kV 时，电极运动速度对放电参数的影响大于Vc=0.3kV时的影响而小于Vc=0.8kV的影响。

放电电流参数与电极运动速度的相关系数及统计分析

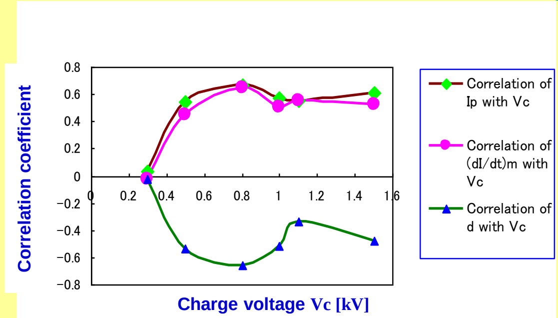
Table 1　Correlation coefficients with contact moving speed for different charge voltages

V_C [kV]	Correlation coefficients: Current peak		Max Rising slope		Spark length	
0.3	0.029	NS	-0.022	NS	-0.028	NS
0.5	0.544	**	0.452	**	-0.532	**
0.8	0.668	**	0.644	**	-0.656	**
1.0	0.572	**	0.511	**	-0.516	**
1.1	0.555	**	0.557	**	-0.338	*
1.5	0.612	**	0.522	**	-0.482	**

NS --- no significant correlation;　* --- $p < 0.05$　** --- $p < 0.01$

SPSS: Statistical Package for Social Science

电极速度效应随电压变化临界现象分析



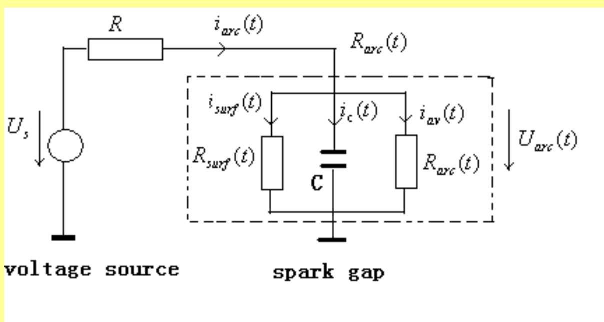
相关系数与电压的关系

电极速度效应随电压变化临界现象分析

表 5-1 小间隙放电的三类参数设置范围

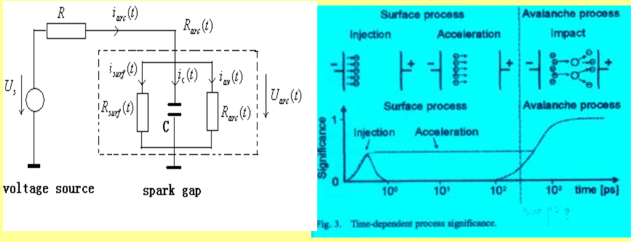
参数范围	1	2	3
放电间隙(μm)	<10	20-80	80-100
上升时间(ps)	<40	300-600	<350
击穿电压(V)	<700	700-2000	>1500
场强(kV/mm)	>50-100	25-75	<8-35
放电波形	无台阶	有台阶	无台阶
阴极影响	有	无	无
阳极影响	无	有	有
气压影响	无	有	有
所属过程	表面	表面和雪崩	雪崩

电极速度效应随电压变化临界现象分析

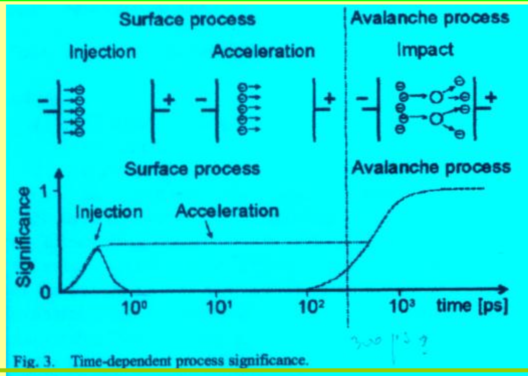


小间隙放电模型的推进

2. 发现静电放电的电压引起放电参数出现临界值现象，并用理论进行了成功的阐释，修正完善了小间隙放电模型。

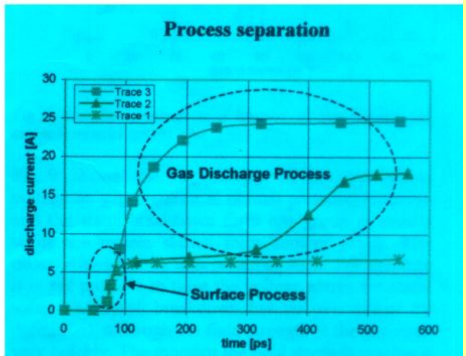


小间隙静电放电模型的分析



Short-gap Electrostatic Discharge Model

用小间隙静电放电模型的分析

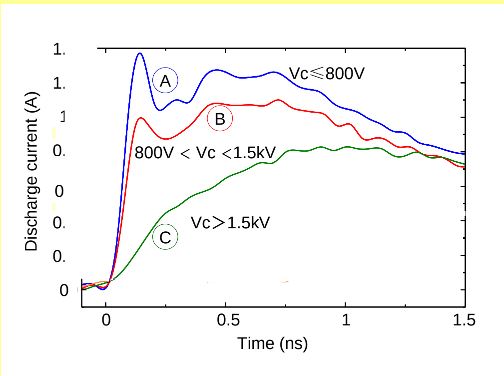


Short-gap Electrostatic Discharge Model

电极速度效应随电压变化临界现象分析

出现临界现象的原因在于：**800V**的电压是表面过程向气体电子雪崩过程转变的关键点。在这个点附近，表面过程和电子雪崩过程同时起作用。电压低于**800V**，放电过程的特性主要由表面过程决定；电压高于**800V**，表面过程影响下降，放电过程则主要由电子雪崩过程所决定。这样，就造成了在**800V**时，电极的快速移动速度引起放电参数变化所产生的特殊临界现象。

在不同电压影响下的放电电流波形分类



电极速度效应随电压变化临界现象分析

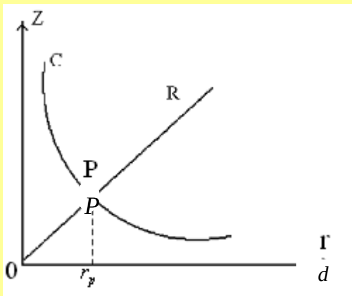


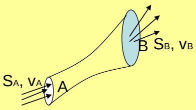
图5.3.4 放电通道电阻R、极间分布电容C与放电间隙 *d* 的关系示意图

流体力学原理 用于电极移动速度效应分析

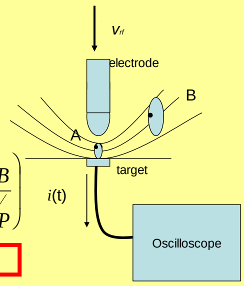
作为一种流体，空气运动遵循流体力学的基本原理和规律。应用流体力学中的连续性原理和Bernoulli定理，分析放电间隙内部压强与间隙外部压强，在电极移动速度下所产生的差别，可以从理论上给出一种对放电参数电极移动速度效应产生机理新的解释。

电极移动速度影响研究

电极移动速度效应与气体压强变化关系的模型



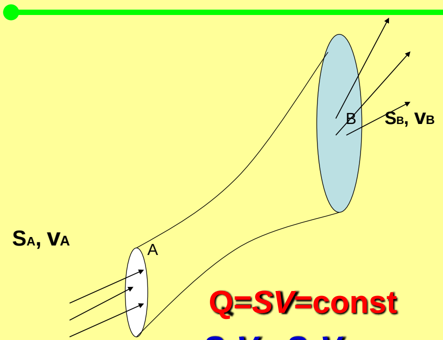
SAVA=SBVB=const



$$i = i_0 e^{\alpha d} \qquad \frac{\alpha}{P} = A\exp\left(\frac{-B}{E/P}\right)$$

Townsend 放电理论

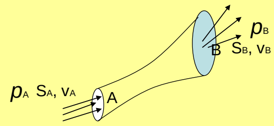
流体力学的基本原理---连续性方程



Q=SV=const

$S_A V_A = S_B V_B = const$

流体力学的基本原理---Bernoulli 方程

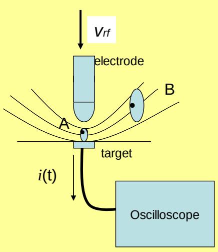


$$p_B - p_A = \frac{1}{2}\rho(v_A^2 - v_B^2) + \rho g(h_A - h_B)$$

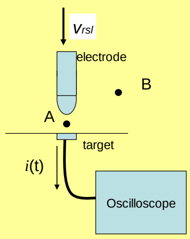
$$p_B + \rho g h_B + \frac{1}{2}\rho v_B^2 = p_A + \rho g h_A + \frac{1}{2}\rho v_A^2$$

$$p + \rho g y + \frac{1}{2}\rho v^2 = const.$$

流体力学原理分析极移动速度效应



(a)电极快速移动有流管形成，导致$P_A<P_B$



(b)电极静止和低速移动没有流管形成，$P_A=P_B$

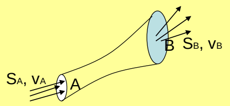
流体力学原理分析极移动速度效应

$$p_A = p_B - \frac{1}{2}\rho\left[\left(\frac{S_B}{S_A}\right)^2 - 1\right]v_B^{\ 2}$$

$$\left[\left(\frac{S_B}{S_A}\right)^2 - 1\right] > 0$$

$$p_A < p_B$$

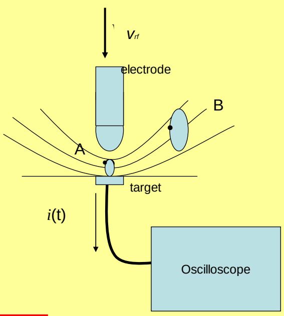
气体压强变化对电极移动速度效应影响



$S_A V_A = S_B V_B = const$

$$i = i_0 e^{\alpha d}$$

$$\frac{\alpha}{P} = A\exp\left(\frac{-B}{E/P}\right)$$



Townsend 放电理论

气体压强变化影响下电极移动速度效应

在小间隙放电模型中，电子的迁移速度v_e与气体压强p有密切关系

$$i(t)_{av} = C\frac{dV}{dt} + eN_0\frac{v_e}{d}\exp\left(\int_0^t \alpha(\xi)v_e(\xi)d\xi\right) \quad (3.2.15)$$

$$i(t)_{surf} = \frac{4}{9}\varepsilon_0\sqrt{\frac{2e}{m_e}}\cdot\frac{S_n(t)\cdot V(t)^{\frac{3}{2}}}{(d - v_e(t)\cdot t)^2}K[\alpha(t)] \quad (3.2.19)$$

$$\alpha = Ap\exp\left(-\frac{Bp}{E}\right)$$

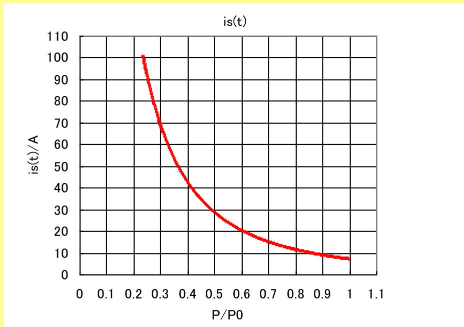
气体压强影响下电极极速度效应

$$v_e(t) = C\cdot\left(\frac{E}{p}\right)^{\frac{1}{2}}$$

$$C = 3.3\times10^6\frac{cm^{3/2}torr^{1/2}}{sV^{1/2}}$$

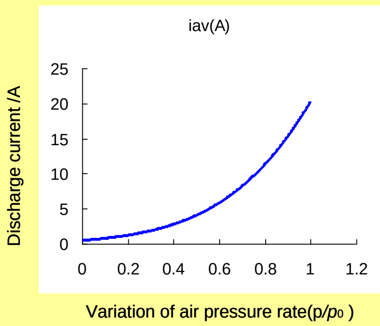
依据上面各式和已知相关参数，可以初步估算在气体压强变化影响下，放电电流的变化情况，结果如下面两个图所示

气体压强影响下电极极速度效应



随着气体压强的减小，表面过程中的放电电流迅速增加

气体压强影响下电极极速度效应



随着气体压强的减小，气体电子雪崩过程中的放电电流迅速减小

电极速度效应机理的数值分析

考虑电极移动速度改变放电间隙内压强，同时改变两电极间电容大小进而改变两极间电场强度，可以由极间电容表达式

$$C = \frac{S}{4\pi kd} \quad (4.3.14)$$

出发，结合(4.3.11), (4.3.12)和小间隙静电放电模型的有关参量，可以推得放电电流表达式为：

$$i(t) = \frac{dQ(t)}{dt} = i_0\exp\left[(d_0 - V_h t)AP\exp\left(\frac{-BpS}{4\pi kQ(t)}\right)\right] \quad (4.3.15)$$

电极速度效应机理的数值分析

$$i(t)=\frac{dQ}{dt}=i_0\exp\left[\begin{array}{l}(d_0-V_h t)A\left(p_B-\frac{1}{2}\rho\left(1-\left(\frac{1}{100}\right)^2\right)V_h^2\right)\bullet\\ \bullet\exp\left(\frac{-\left(p_B-\frac{1}{2}\rho\left(1-\left(\frac{1}{100}\right)^2\right)V_h^2\right)BS}{4\pi kQ(t)}\right)\end{array}\right]$$

电极移动速度效应机理的数值分析

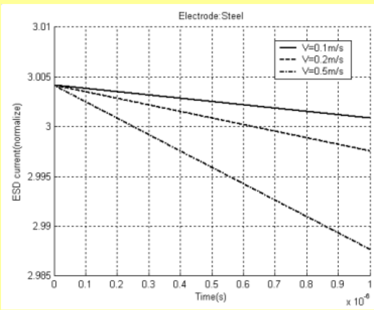
$$\frac{dQ}{dt}=\exp\left[\begin{array}{l}(10^{-4}-V_h t)A\left(10^5-0.65^2V_h^2\right)\cdot\\ \cdot\exp\left(\frac{-\left(10^5-0.65^2V_h^2\right)B\times 0.035\times 10^{-13}}{Q(t)}\right)\end{array}\right]$$

$d_0=10^{-4}m$　$V_h=0.1m/s, 0.2m/s, 0.5m/s$　$p_B=10^5$ Pa，

$\rho=1.293\text{kg/m}^3$　$S=4\times10^{-6}m^2$　$\varepsilon=\frac{1}{36\pi}\times10^{-9}F/m$

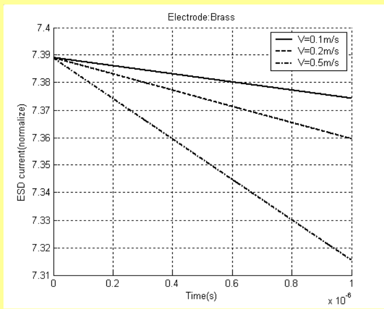
$k=8.9\times10^9$　Nm^2/C^2

电极移动速度效应机理的数值分析



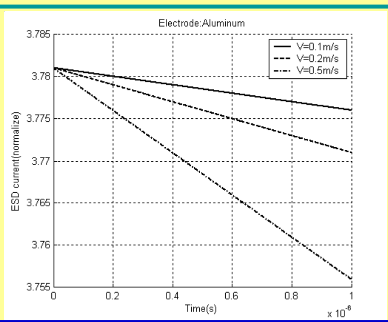
电极移动速度对放电电流的影响（不锈钢电极）

电极移动速度效应机理的数值分析



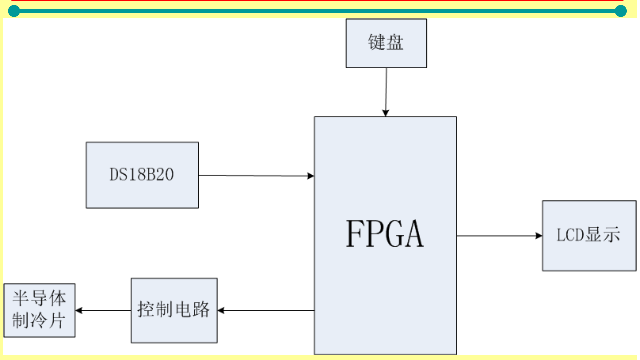
电极移动速度对放电电流的影响（铜电极）

电极移动速度效应机理的数值分析



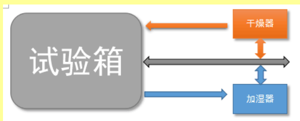
电极移动速度对放电电流的影响（铝电极）

温度控制的设计 ---为新ESD 测试系统

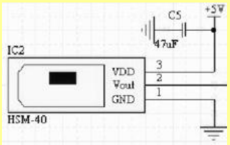


系统框图

湿度控制的设计----为新ESD 测试系统



湿度控制模块



湿度传感器接口电路

新型ESD测试平台设计

不同因素影响的检验

比较：Missouri 科技大学David Pommerenke的静电放电测试装置 (1995)

40 *D. Pommerenke/Journal of Electrostatics 36 (1995) 31–54*

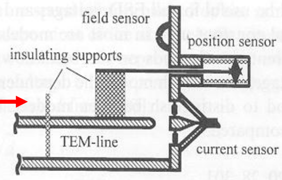


Fig. 7. Set-up for the measurement of arc length, speed of approach and discharge current.

缺点：(1) 高速向靶运动可能造成仪器损坏
（2）环境开放，不同因素难以精确控制

电极移动速度效应机理的实验验证

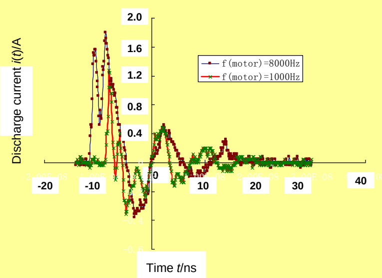


Fig6 Comparison of two electrode speeds in ESD events

电极移动速度效应机理的实验验证

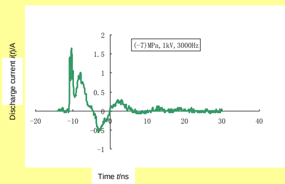


Fig7 Discharge current with comparatively high gas pressure in ESD

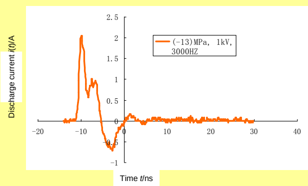
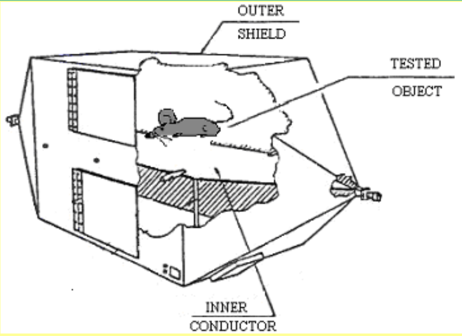


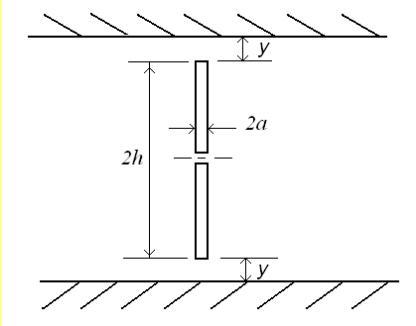
Fig8 Discharge current with comparatively low gas pressure in ESD

计算人体生物电阻抗的算法



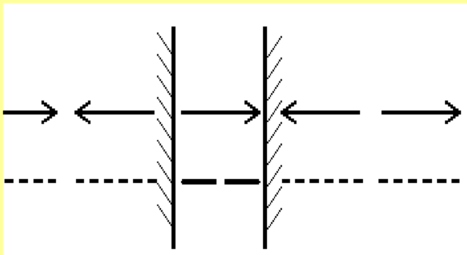
电磁波辐射系统结构示意图

计算人体生物电阻抗的算法



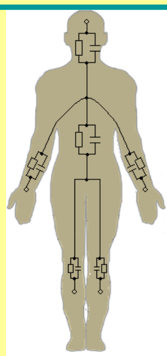
校正天线的设置

计算人体生物电阻抗的算法



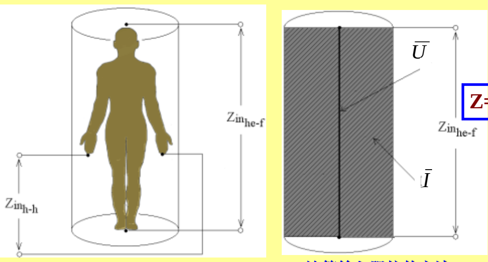
电磁波的镜像反射效应

计算人体生物电阻抗的算法



人体的等效电路

计算人体生物电阻抗的算法

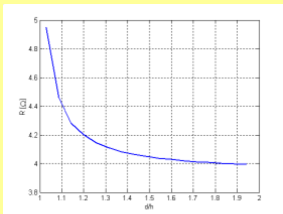


$Z=\overline{U}/\overline{I}$

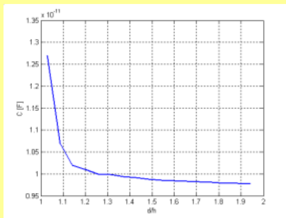
输入输出端子的选择　　计算输入阻抗的方法

用人体的柱体模型计算阻抗

计算人体生物电阻抗的算法



(a) 电阻



(b) 电容

置于横电磁波小室中柱体模型的计算结果

结 语

分析研究非接触静电放电多因素效应，探索静电放电参数在不同因素作用下的变化规律，有着重要的理论意义和实际应用价值。基于已经取得的研究成果，进一步进行深入和拓展的研究，取得新的进展和成就，为非接触静电放电抗扰度测试国际标准的提出建立，提供有益的理论和技术参考依据。

谢谢大家！

Property Discussion on Effect of Multiple Factors in Non-Contact Discharge and Corresponding Standard

Ruan Fangming Prof Ph D

Guizhou Normal University

Outline

- Back Ground
- Effect of Electrode Moving
- Influence of Gas Pressure
- Influence of Temperature & Humidity
- New Test System of ESD
- Initial Discussion on Standard of Non-Contact ESD Test
- Conclusion

Back Ground

Electrostatic Discharge (ESD) is serious threat of various electronic system and instrument in aerospace and astronomic, industry, and defence. International Electrotechnical Commission has made test standards of contact ESD, but till now no standards made for non-contact ESD which taken with large amount place in reality situation.

Multiple factors have effect on non-contact discharge results, included gas pressure, electrode moving speed, temperature, humidity, material of electrode.

Back Ground

- Losses Caused by ESD:

~ USD 500 million / Year

IEC CCC IEEE →

Test Standard

Contact ESD --- Yes

Non-Contact ESD ?

--- No !

Effect on ESD Parameters of Electrode Moving Speed / proposed in 1987*

Phenomenon:

Distinctive Variation of Parameters in Human-Metal ESD

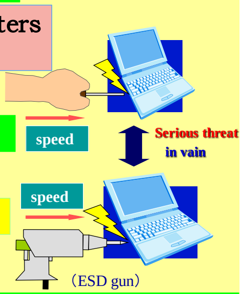
Strong Impact on

Velocity of Electrode to Target

Strong Impact on

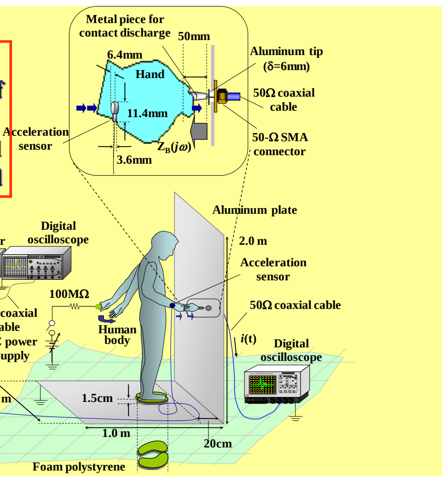
Discharge Parameters of ESD Gun

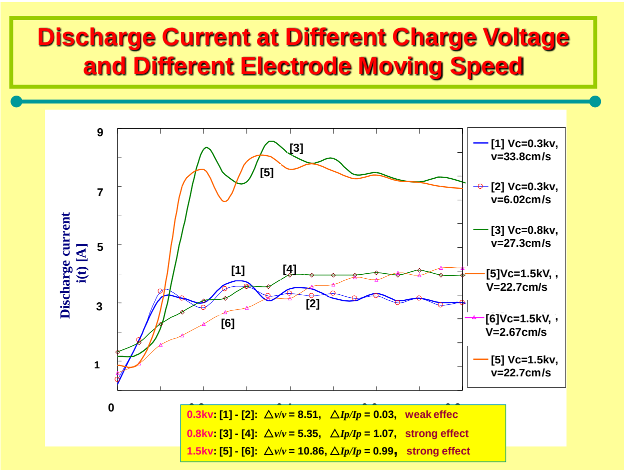
Mechanism ? On the way

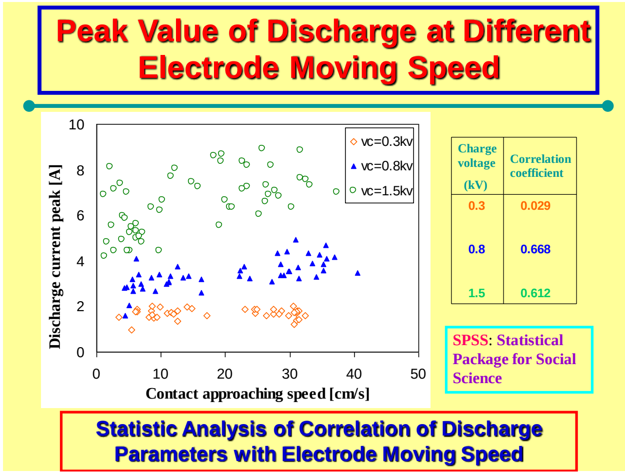


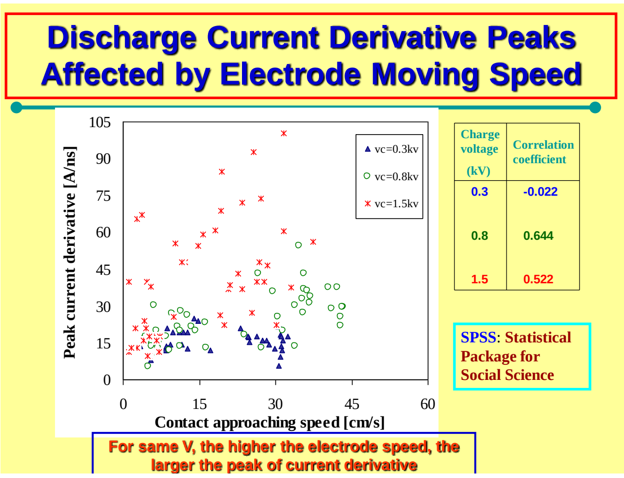
* B Daout H Ryser etc: The Correlation of Rising Slope and Speed of Approach in ESD Tests[C]. Proceedings of the 12th Int. Zurich Symp., 1987, pp.467–474

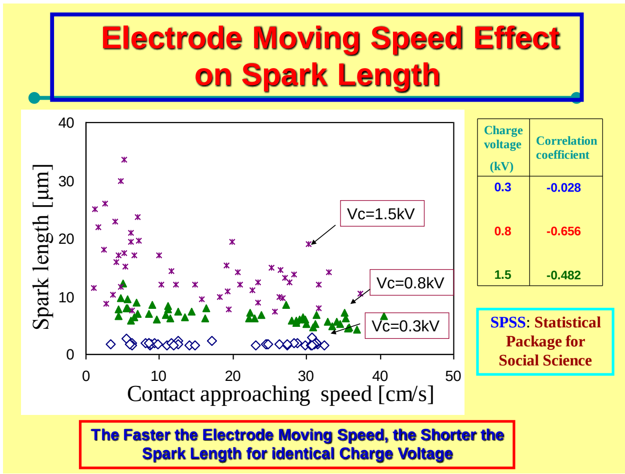
Simultaneous Measurement of Discharge Parameters and Electrode Speed

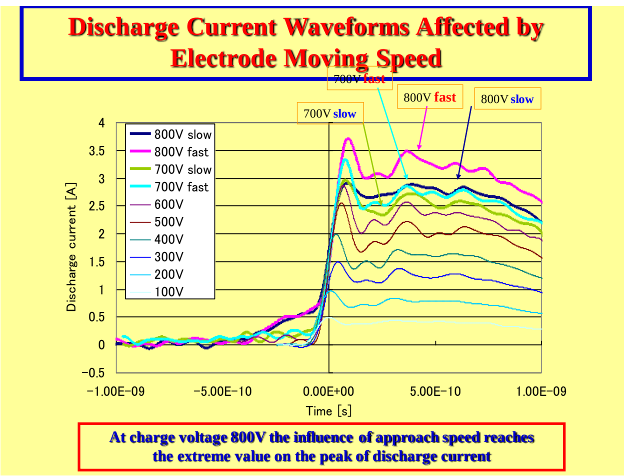


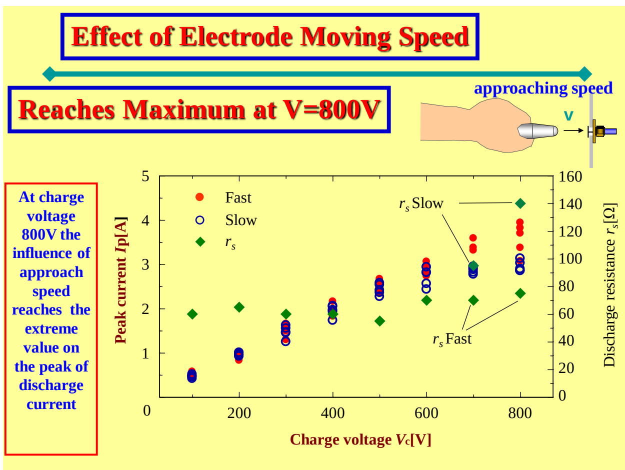

Discharge Current at Different Charge Voltage and Different Electrode Moving Speed
Discharge current i(t) [A]
[1] Vc=0.3kv, v=33.8cm/s
[2] Vc=0.3kv, v=6.02cm/s
[3] Vc=0.8kv, v=27.3cm/s
[5]Vc=1.5kV, V=22.7cm/s
[6]Vc=1.5kV, V=2.67cm/s
[5] Vc=1.5kv, v=22.7cm/s
0.3kv: [1] - [2]: △v/v = 8.51, △Ip/Ip = 0.03, weak effec
0.8kv: [3] - [4]: △v/v = 5.35, △Ip/Ip = 1.07, strong effect
1.5kv: [5] - [6]: △v/v = 10.86, △Ip/Ip = 0.99, strong effect

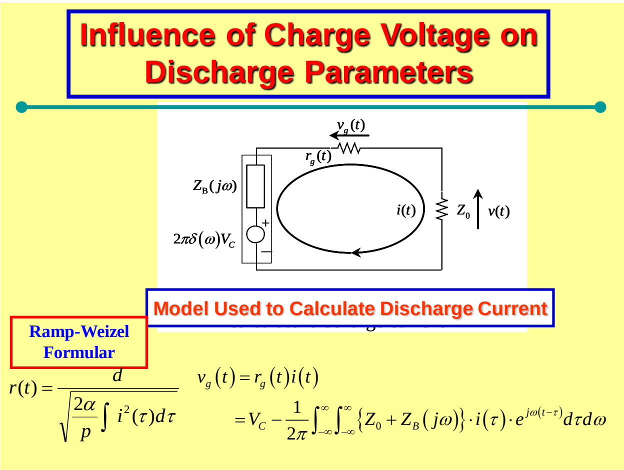

Peak Value of Discharge at Different Electrode Moving Speed
Discharge current peak [A]
Contact approaching speed [cm/s]
vc=0.3kv
vc=0.8kv
vc=1.5kv
Charge voltage (kV) | Correlation coefficient
0.3 | 0.029
0.8 | 0.668
1.5 | 0.612
SPSS: Statistical Package for Social Science
Statistic Analysis of Correlation of Discharge Parameters with Electrode Moving Speed

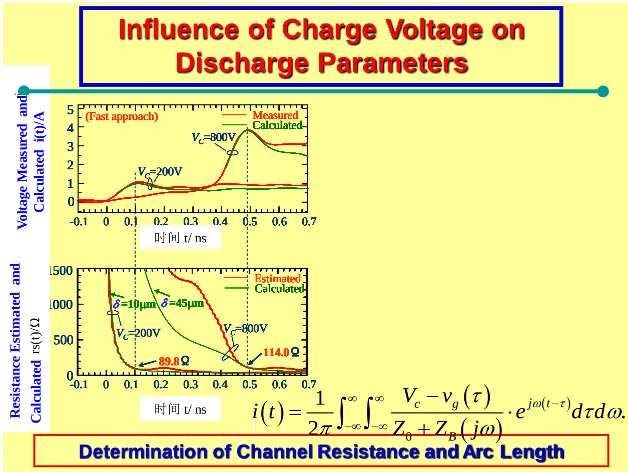

Discharge Current Derivative Peaks Affected by Electrode Moving Speed
Peak current derivative [A/ns]
Contact approaching speed [cm/s]
vc=0.3kv
vc=0.8kv
vc=1.5kv
Charge voltage (kV) | Correlation coefficient
0.3 | -0.022
0.8 | 0.644
1.5 | 0.522
SPSS: Statistical Package for Social Science
For same V, the higher the electrode speed, the larger the peak of current derivative

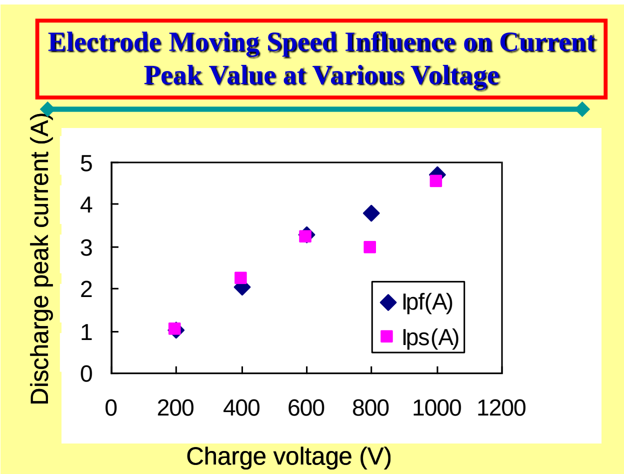

Electrode Moving Speed Effect on Spark Length
Spark length [µm]
Contact approaching speed [cm/s]
Vc=1.5kV
Vc=0.8kV
Vc=0.3kV
Charge voltage (kV) | Correlation coefficient
0.3 | -0.028
0.8 | -0.656
1.5 | -0.482
SPSS: Statistical Package for Social Science
The Faster the Electrode Moving Speed, the Shorter the Spark Length for identical Charge Voltage

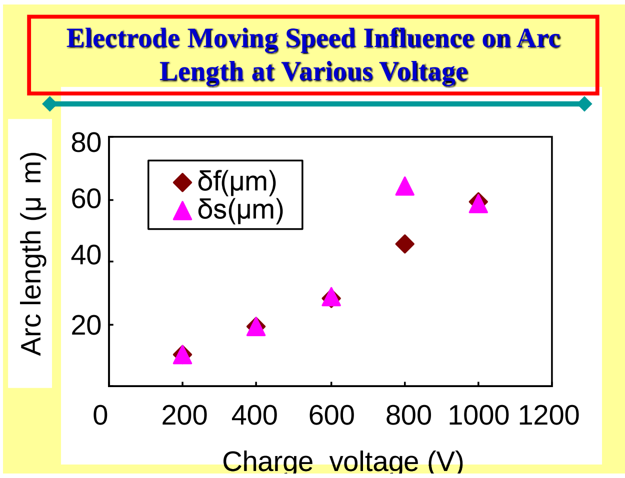

Discharge Current Waveforms Affected by Electrode Moving Speed
700V fast
800V fast
800V slow
700V slow
800V slow
800V fast
700V slow
700V fast
600V
500V
400V
300V
200V
100V
Discharge current [A]
Time [s]
At charge voltage 800V the influence of approach speed reaches the extreme value on the peak of discharge current

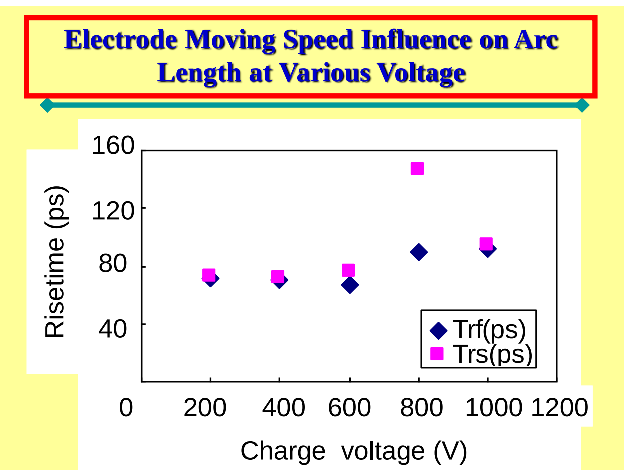

Effect of Electrode Moving Speed
Reaches Maximum at V=800V
approaching speed
v
At charge voltage 800V the influence of approach speed reaches the extreme value on the peak of discharge current
Fast
Slow
r_s
r_s Slow
r_s Fast
Peak current Ip[A]
Discharge resistance r_s[Ω]
Charge voltage Vc[V]

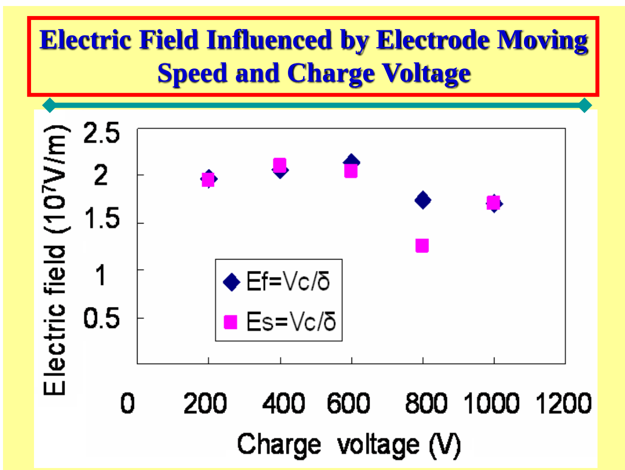

Influence of Charge Voltage on Discharge Parameters
$v_g(t)$
$r_g(t)$
$Z_B(j\omega)$
$2\pi\delta(\omega)V_C$
$i(t)$
Z_0
$v(t)$
Model Used to Calculate Discharge Current
Ramp-Weizel Formular
$r(t)=\frac{d}{\sqrt{\frac{2\alpha}{p}\int i^2(\tau)d\tau}}$
$v_g(t)=r_g(t)i(t)$
$=V_C-\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\{Z_0+Z_B(j\omega)\}\cdot i(\tau)\cdot e^{j\omega(t-\tau)}d\tau d\omega$


Influence of Charge Voltage on Discharge Parameters
Voltage Measured and Calculated i(t)/A
(Fast approach)
Measured
Calculated
V_C=800V
V_C=200V
时间 t/ ns
Resistance Estimated and Calculated rs(t)/Ω
Estimated
Calculated
δ=10μm
δ=45μm
V_C=200V
V_C=800V
89.8Ω
114.0Ω
时间 t/ ns
$i(t)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{V_c-v_g(\tau)}{Z_0+Z_B(j\omega)}\cdot e^{j\omega(t-\tau)}d\tau d\omega.$
Determination of Channel Resistance and Arc Length

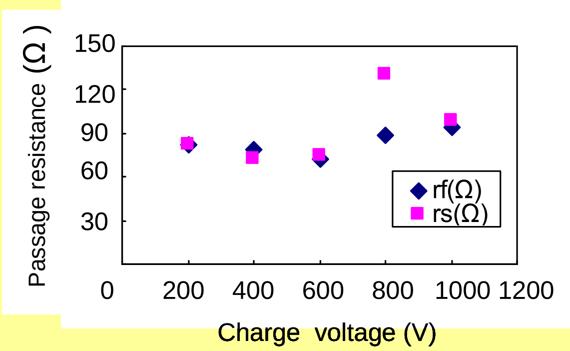

Electrode Moving Speed Influence on Current Peak Value at Various Voltage
Discharge peak current (A)
Ipf(A)
Ips(A)
Charge voltage (V)


Electrode Moving Speed Influence on Arc Length at Various Voltage
Arc length (μ m)
δf(μm)
δs(μm)
Charge voltage (V)


Electrode Moving Speed Influence on Arc Length at Various Voltage
Risetime (ps)
Trf(ps)
Trs(ps)
Charge voltage (V)


Electric Field Influenced by Electrode Moving Speed and Charge Voltage
Electric field (10^7V/m)
Ef=Vc/δ
Es=Vc/δ
Charge voltage (V)

Passage Resistance Affected by Electrode Moving Speed and Charge Voltage



Discharge Parameters Imposed by Electrode Moving Speed and Charge Voltage

- Discharge parameters affected by electrode moving speed have little change at charge voltage 0.3kV.
- Electrode moving speed have distinctive effect on discharge current peak value when charge voltage is 0.8kV.
- Influence on discharge parameters by electrode moving speed, as Vc >1.5kV, larger than that caused by Vc=0.3kV, and less than that by Vc =0.8kV.

Correlation and Statistic Analysis between Discharge Parameters and Electrode Moving Speed

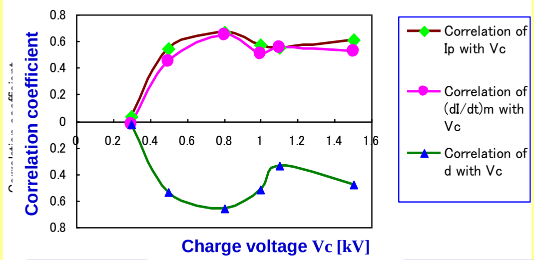
Table 1 Correlation coefficients with contact moving speed for different charge voltages

V_C [kV]	Correlation coefficients: Current peak		Max Rising slope		Spark length	
0.3	0.029	NS	-0.022	NS	-0.028	NS
0.5	0.544	**	0.452	**	-0.532	**
0.8	0.668	**	0.644	**	-0.656	**
1.0	0.572	**	0.511	**	-0.516	**
1.1	0.555	**	0.557	**	-0.338	*
1.5	0.612	**	0.522	**	-0.482	**

NS --- no significant correlation; * --- $p < 0.05$ ** --- $p < 0.01$

SPSS: Statistical Package for Social Science

Effect Analysis of Discharge Parameter Threshold Phenomenon with Charge Voltage



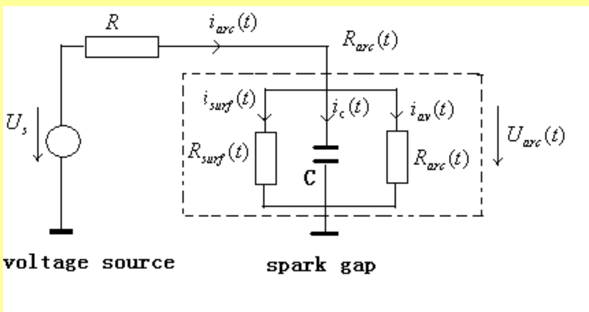
Correlation Coefficient with Charge Voltage

Threshold Phenomenon of Electrode Moving Speed Effect Change with Charge Voltage

表 5-1 小间隙放电的三类参数设置范围

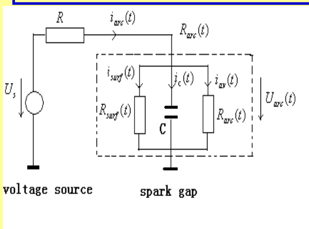
参数范围	1	2	3
放电间隙(μm)	<10	20-80	80-100
上升时间(ps)	<40	300-600	<350
击穿电压(V)	<700	700-2000	>1500
场强(kV/mm)	>50-100	25-75	<8-35
放电波形	无台阶	有台阶	无台阶
阴极影响	有	无	无
阳极影响	无	有	有
气压影响	无	有	有
所属过程	表面	表面和雪崩	雪崩

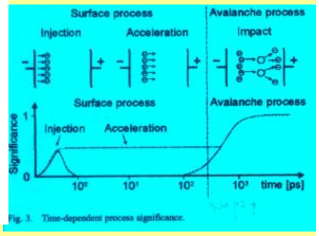
Threshold Phenomenon of Electrode Moving Speed Effect Change with Charge Voltage



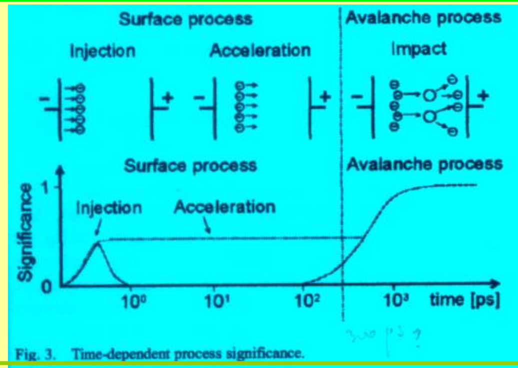
Effect research of Electrode moving speed

Discovering Phenomenon of Parameters Threshold Resulted from Charge Voltage Change, and Giving Theoretic Illustration on the Mechanism, Revised and Made Performance of Short-gap ESD Model



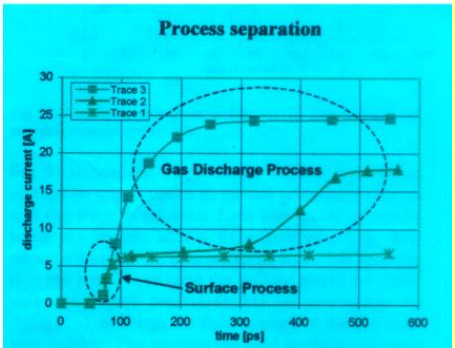


Analysis of Short-gap ESD Model



Short-gap Electrostatic Discharge Model

Threshold Phenomenon Analysis with Short-gap ESD Model

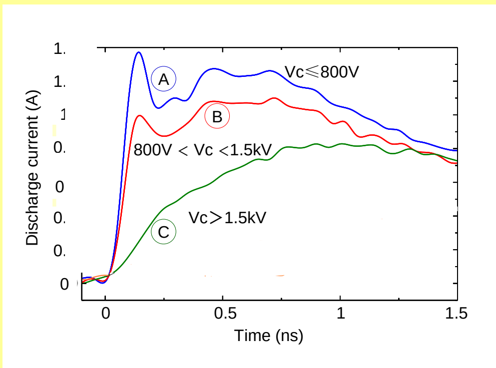


Short-gap Electrostatic Discharge Model

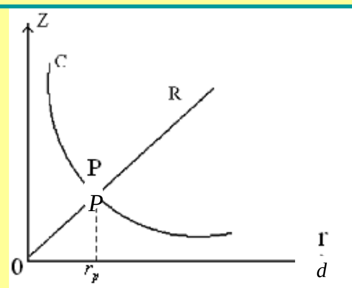
Threshold Phenomenon of Electrode Moving Speed Effect Change with Charge Voltage

The cause is that surface process transfers to avalanche process, shown key point at Vc=800V. Both surface process and avalanche acted at Vc=800V. For Vc＜800V，ESD event mainly determined by surface process； as Vc＞800V influence of surface process decrease and ESD event dominated by avalanche process. Special threshold phenomenon of electrode moving effect, hence, produced by comprehensive action of surface process and avalanche process.

Sorts of Discharge Current to Various Charge Voltage



Threshold Phenomenon of Electrode Moving Speed Effect Change with Charge Voltage



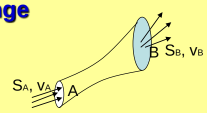
Relationship of channel resistance R, distributive capacitance and discharge gap

Fluid Mechanics Principles Used to Analyze Electrode Moving Speed Effect

Air flow motion, as a kind of fluid, follows the basic theorems, principles and laws in fluid mechanics. Analysis was given based on principle of continuity and Bernoulli theorem and discussion of gas press difference between inner and outer gap, obtained a new theoretical description on mechanism of electrode moving speed on discharge parameters.

Effect research of Electrode moving speed

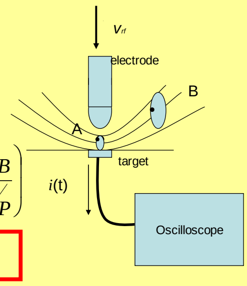
A Model was proposed to describe effect on Parameters of Electrode Speed via Gas Pressure Change



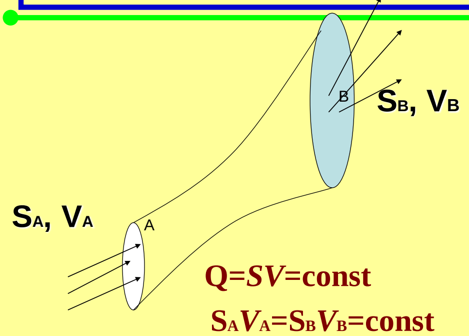
$S_A V_A = S_B V_B = const$

$$i = i_0 e^{\alpha d} \qquad \frac{\alpha}{P} = A\exp\left(\frac{-B}{E/P}\right)$$

Townsend Theory of Gas Discharge



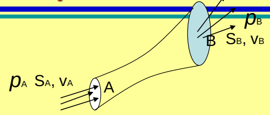
Continuity Equation---A Basic Principle in Fluid Mechanics



$Q = SV = const$

$S_A V_A = S_B V_B = const$

Bernoulli Equation--- Another Basic Principle in Fluid Mechanics

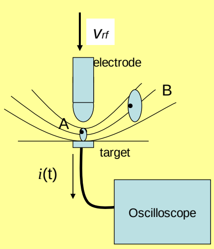


$$p_B - p_A = \frac{1}{2}\rho(v_A^2 - v_B^2) + \rho g(h_A - h_B)$$

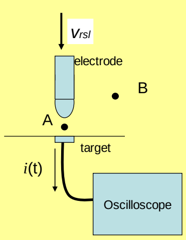
$$p_B + \rho g h_B + \frac{1}{2}\rho v_B^2 = p_A + \rho g h_A + \frac{1}{2}\rho v_A^2$$

$$p + \rho g y + \frac{1}{2}\rho v^2 = const.$$

Gas Pressure Has Strong Influence on Electrode Moving Speed Effect



(a) Fluid tube formed when $P_A < P_B$



(b) No fluid tube formed for, $P_A = P_B$

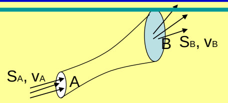
Mechanism Analysis of Electrode Moving Speed Effect on Discharge Parameters

$$p_A = p_B - \frac{1}{2}\rho\left[\left(\frac{S_B}{S_A}\right)^2 - 1\right] v_B^{\,2}$$

$$\left[\left(\frac{S_B}{S_A}\right)^2 - 1\right] > 0$$

$$p_A < p_B$$

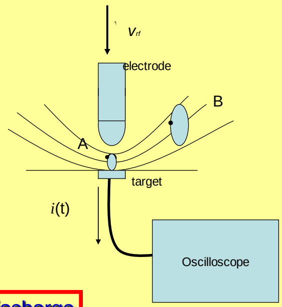
Electrode Moving Speed Effect Analyzed with Fluid Mechanics Principles



$S_A V_A = S_B V_B = const$

$$i = i_0 e^{\alpha d}$$

$$\frac{\alpha}{P} = A\exp\left(\frac{-B}{E/P}\right)$$



Townsend Theory of Gas Discharge

Numerous Analysis of Electrode Moving Speed Effect on Discharge Parameters

Electron moving speed v_e has strong correlation with gas pressure p *in short-gap ESD*

$$i(t)_{av} = C\frac{dV}{dt} + eN_0\frac{v_e}{d}\exp\left(\int_0^t \alpha(\xi)v_e(\xi)d\xi\right) \quad (3.2.15)$$

$$i(t)_{surf} = \frac{4}{9}\varepsilon_0\sqrt{\frac{2e}{m_e}}\cdot\frac{S_n(t)\cdot V(t)^{\frac{3}{2}}}{(d - v_e(t)\cdot t)^2}K[\alpha(t)] \quad (3.2.19)$$

$$\alpha = Ap\exp\left(-\frac{Bp}{E}\right)$$

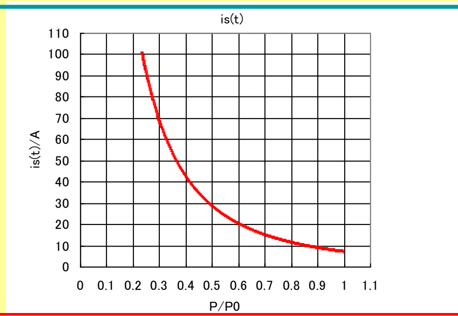
Gas Pressure Variation Impacting on Electrode Moving Speed Effect

$$v_e(t) = C\cdot\left(\frac{E}{p}\right)^{\frac{1}{2}}$$

$$C = 3.3\times10^6\,\frac{cm^{3/2}torr^{1/2}}{sV^{1/2}}$$

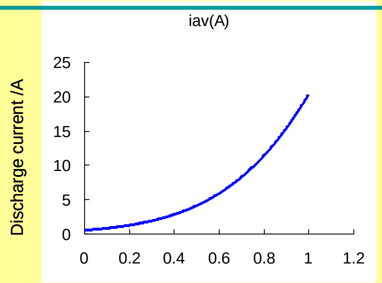
Discharge current variation situation, based on formulas above and parameters relative, can be estimated according to gas pressure variation, seeing in two figures blow

Gas Pressure Variation Impacting on Electrode Moving Speed Effect



Discharge current in surface process increase much with gas pressure decreased

Gas Pressure Variation Impacting on Electrode Moving Speed Effect



Discharge current in surface process decrease rapidly with gas pressure increase

Numerous Analysis of Electrode Moving Speed Effect on Discharge Parameters

With consideration gas pressure changed by electrode moving speed, and electrical field strength varied by capacitance between two poles, the formula below is used to describe capacitance between two poles

$$C = \frac{S}{4\pi kd} \quad (4.3.14)$$

And hence deduct , combined (4.3.11), (4.3.12) ,discharge current formula as following

$$i(t) = \frac{dQ(t)}{dt} = i_0\exp\left[(d_0 - V_h t)AP\exp\left(\frac{-BpS}{4\pi kQ(t)}\right)\right] \quad (4.3.15)$$

Numerous Analysis of Electrode Moving Speed Effect

$$i(t)=\frac{dQ}{dt}=i_0\exp\left[\begin{array}{l}(d_0-V_h t)A\left(p_B-\frac{1}{2}\rho\left(1-\left(\frac{1}{100}\right)^2\right)V_h^2\right)\\ \bullet\exp\left(\frac{-\left(p_B-\frac{1}{2}\rho\left(1-\left(\frac{1}{100}\right)^2\right)V_h^2\right)BS}{4\pi kQ(t)}\right)\end{array}\right]$$

Numerous Analysis of Electrode Moving Speed Effect

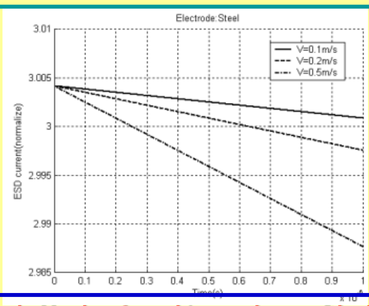
$$\frac{dQ}{dt}=\exp\left[\begin{array}{l}(10^{-4}-V_h t)A\left(10^5-0.65^2V_h^2\right)\cdot\\ \cdot\exp\left(\frac{-\left(10^5-0.65^2V_h^2\right)B\times 0.035\times 10^{-13}}{Q(t)}\right)\end{array}\right]$$

$d_0=10^{-4}m$　$V_h=0.1m/s, 0.2m/s, 0.5m/s$　$p_B=10^5$ Pa，

$\rho=1.293\text{kg/m}^3$　$S=4\times 10^{-6}m^2$　$\varepsilon=\frac{1}{36\pi}\times 10^{-9}F/m$

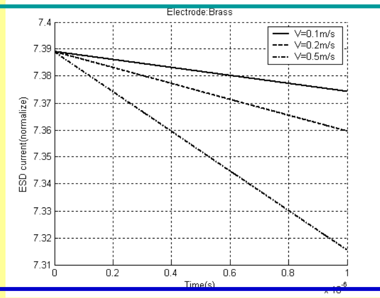
$k=8.9\times 10^9$ Nm²/C²

Numerous Analysis of Electrode Moving Speed Effect



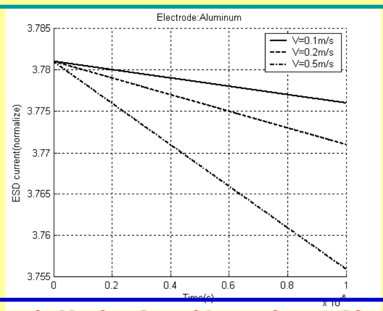
Electrode Moving Speed Impacting on Discharge Current (Stainless steel electrode)

Numerous Analysis of Electrode Moving Speed Effect



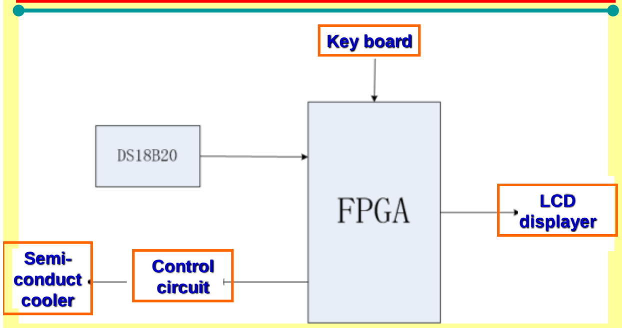
Electrode Moving Speed Impacting on Discharge Current(Cu electrode)

Numerous Analysis of Electrode Moving Speed Effect

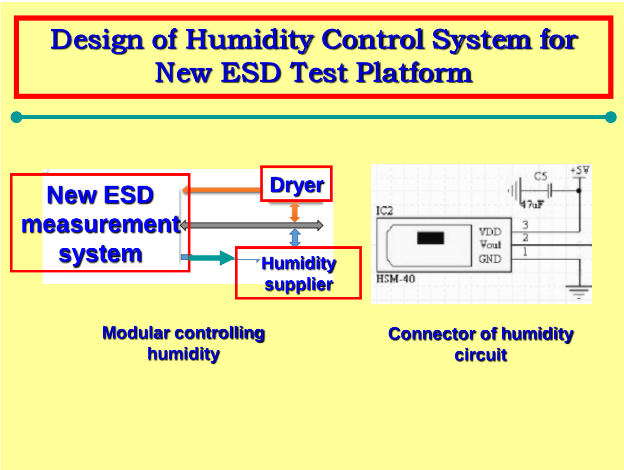


Electrode Moving Speed Impacting on Discharge Current(Al electrode)

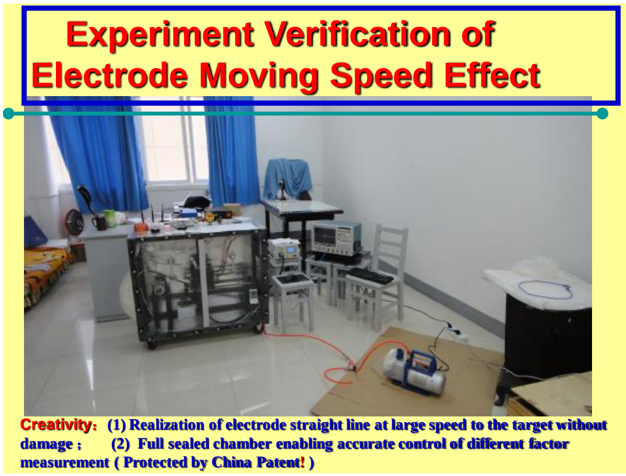
Design of Temperature Control System for New ESD Test Platform

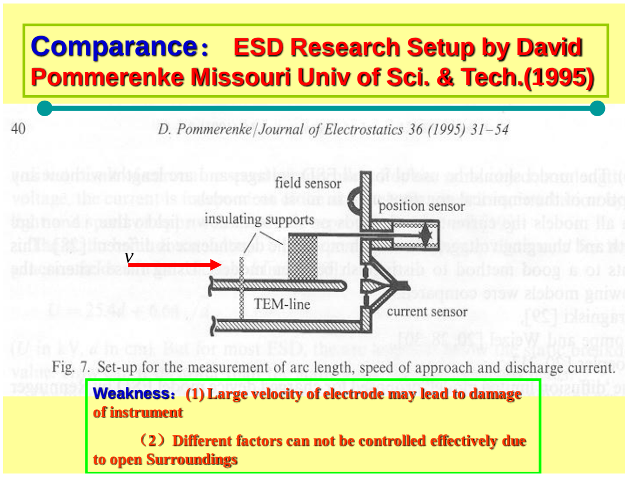


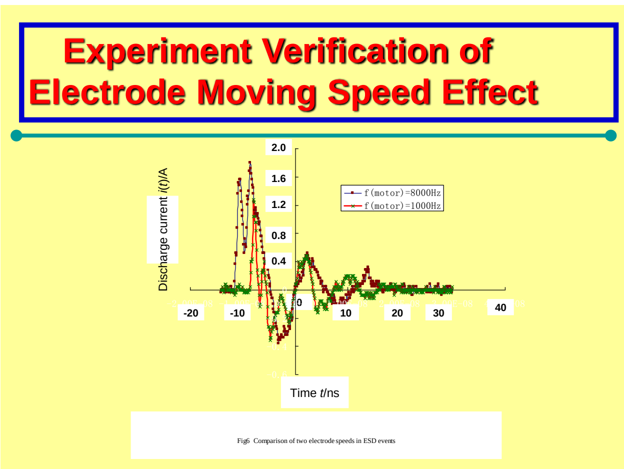
Block diagram system

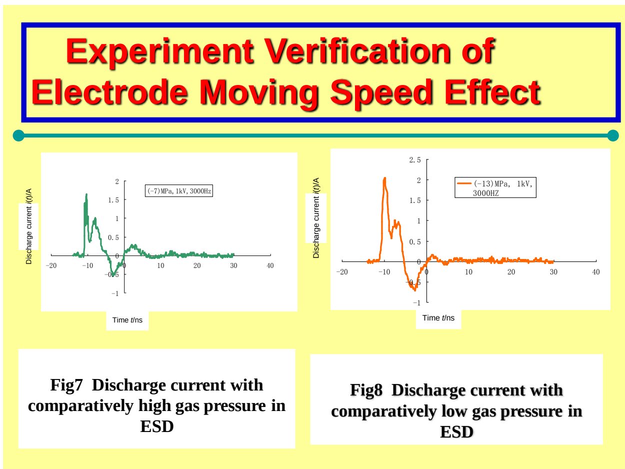

Design of Humidity Control System for New ESD Test Platform
New ESD measurement system
Dryer
Humidity supplier
IC2
HSM-40
VDD
Vout
GND
C5
47uF
+5V
Modular controlling humidity
Connector of humidity circuit

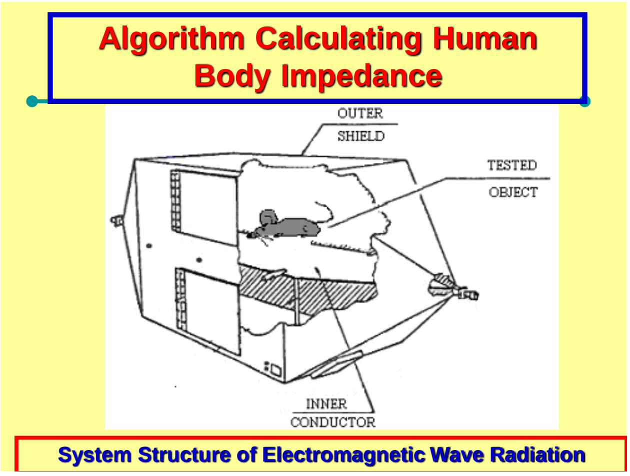

Effect research of Electrode moving speed
Invented a New System for Research of Multi Factor Effect on Discharge Parameters, Providing Solution to Important Two Difficult Problems in ESD Expertise
Hints: (1) Realization of Real Line Motion without Damage of Instrument when Moving Electrode at Large Velocity to Target
(2) Perform Sealed Box Making Possible Effective Control of Various Factor Impacting on Discharge Parameters (Chinese Patent No. : ZL201310017269.6)

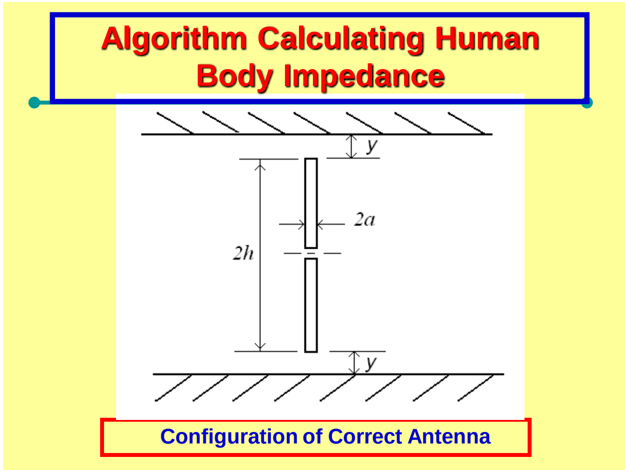

Experiment Verification of Electrode Moving Speed Effect
Creativity: (1) Realization of electrode straight line at large speed to the target without damage ; (2) Full sealed chamber enabling accurate control of different factor measurement (Protected by China Patent!)

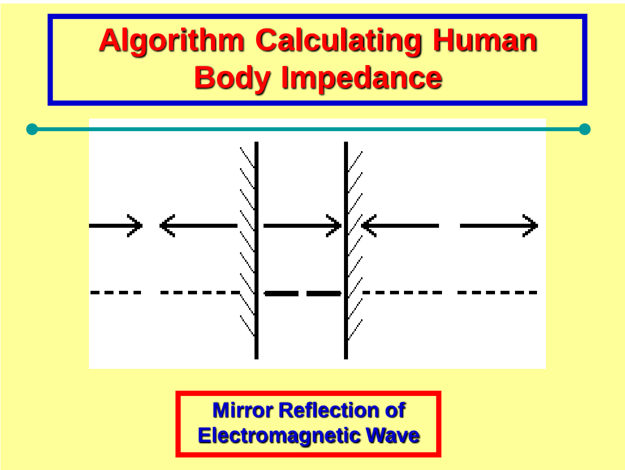

Comparance: ESD Research Setup by David Pommerenke Missouri Univ of Sci. & Tech.(1995)
40
D. Pommerenke/Journal of Electrostatics 36 (1995) 31–54
field sensor
position sensor
insulating supports
V
TEM-line
current sensor
Fig. 7. Set-up for the measurement of arc length, speed of approach and discharge current.
Weakness: (1) Large velocity of electrode may lead to damage of instrument
（2）Different factors can not be controlled effectively due to open Surroundings

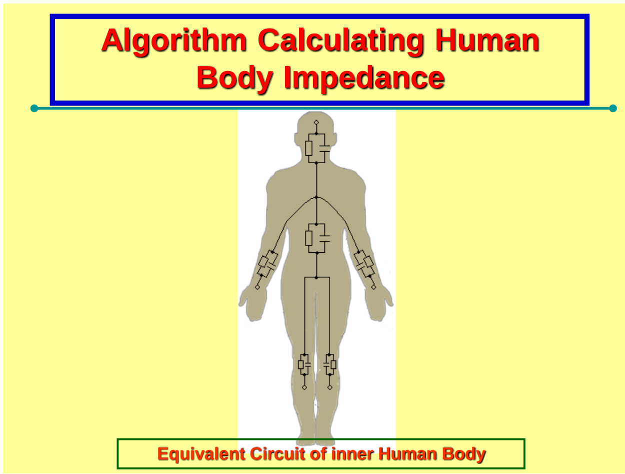

Experiment Verification of Electrode Moving Speed Effect
Discharge current i(t)/A
2.0
1.6
1.2
0.8
0.4
0
-20
-10
10
20
30
40
f(motor)=8000Hz
f(motor)=1000Hz
Time t/ns
Fig6 Comparison of two electrode speeds in ESD events

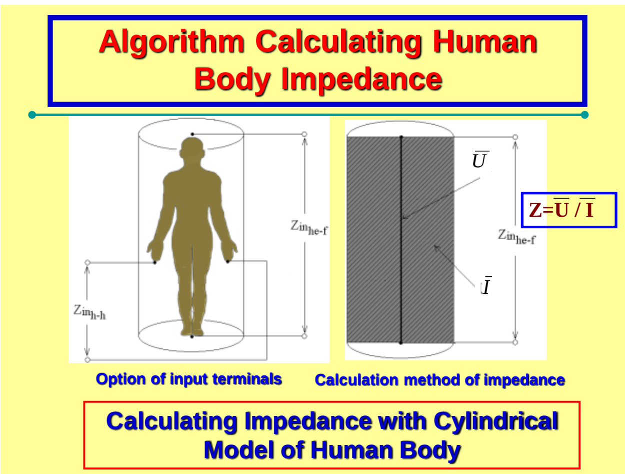

Experiment Verification of Electrode Moving Speed Effect
Discharge current i(t)/A
Time t/ns
(-7)MPa, 1kV, 3000Hz
(-13)MPa, 1kV, 3000HZ
Fig7 Discharge current with comparatively high gas pressure in ESD
Fig8 Discharge current with comparatively low gas pressure in ESD

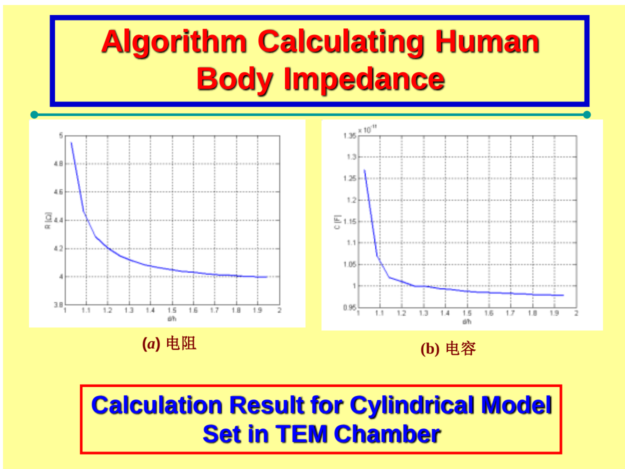

Algorithm Calculating Human Body Impedance
OUTER SHIELD
TESTED OBJECT
INNER CONDUCTOR
System Structure of Electromagnetic Wave Radiation


Algorithm Calculating Human Body Impedance
y
2a
2h
y
Configuration of Correct Antenna


Algorithm Calculating Human Body Impedance
Mirror Reflection of Electromagnetic Wave


Algorithm Calculating Human Body Impedance
Equivalent Circuit of inner Human Body


Algorithm Calculating Human Body Impedance
Zin_he-f
Zin_h-h
U
I
Zin_he-f
Z=U / I
Option of input terminals
Calculation method of impedance
Calculating Impedance with Cylindrical Model of Human Body


Algorithm Calculating Human Body Impedance
(a) 电阻
(b) 电容
Calculation Result for Cylindrical Model Set in TEM Chamber

Conclusion

Test standards of non-contact electrostatic discharge need to consider effect of multiple factors. Deep investigation of non-contact ESD may provide benefit theoretical and technical suggestion to proposal of ESD test standards.

Tank You Very Much for Your Attention!

布雷特 ·卡恩

布雷特 ·卡恩最初于 1999 年加入英特尔公司，是企业质量网络的首席工程师。他在英特尔积极从事设备静电防护的工作。在此方面，Brett 在英特尔 ESD 理事会就任要职，监督全球所有英特尔站点的器件级 ESD 和闭锁测试，定义所有内部测试规范，检查所有英特尔 ESD 设计规则，监督/定义全球所有英特尔产品的 ESD 目标水平并领导许多产品的后硅 ESD 调试。近几年来，Brett 也积极参与解决 EOS 挑战。

在加入英特尔之前，他曾在莱迪思半导体工作了 13 年，在那里他于 20 世纪 90 年代初开始从事 ESD 相关工作。自 2007 年以来，Brett 一直是 ESD 目标级别工业委员会的成员，并帮助撰写了几篇白皮书，并且是最后四个白皮书的主编。 Brett 是 ESDA 的积极成员，也是 ESDA 董事会的现任成员。 Brett 还是 ESDA 教育委员会的成员，负责监督所有在线培训，并且是技术和咨询支持委员会（TAS）现任主席以及 ESDA 几个工作组的成员。布雷特于 1986 年从波特兰州立大学获得电气工程学士学位。

Brett Carn

Brett Carn initially joined Intel Corporation in 1999 and is a principal engineer in the Corporate Quality Network. He has actively worked in the field of device level ESD at Intel. In that role, Brett chairs the Intel ESD Council overseeing component level ESD & Latchup testing across all Intel sites worldwide, defining all internal test specifications, reviewing all Intel ESD design rules, overseeing/defining the ESD target levels for all Intel products worldwide and leading post silicon ESD debug on many products. In more recent years Brett has also been actively involved with addressing EOS challenges. Prior to joining Intel, he worked for Lattice Semiconductor for 13 years where he started working on ESD in the early 1990s. Since 2007, Brett has been a member of the Industry Council on ESD Target Levels and has helped author several whitepapers as well as been the lead editor on the last four whitepapers. Brett is an active member of the ESDA and a current member of the ESDA Board of Directors. Brett is also a member of the ESDA Education Council, overseeing all online training, and is the current chair of the Technical and Advisory Support Committee (TAS) and a member of several ESDA working groups. Brett received his BS in electrical engineering from Portland State University in 1986.

ESD 设备合格性测试面临的挑战

ESDA/CNIS 会议，中国贵阳
Brett Carn
2017年11月10日

摘要

该PPT将讨论目前的人体模型 (HBM) ANSI/ESDA/JEDEC JS-001 和充电装置模型(CDM) ANSI/ESDA/JEDEC JS-002 的测试标准. 长期以来需要对HBM和CDM测试标准方面的产业结构进行调整。JS-001 和 JS-002 在满足校准要求方面已经做了很多努力。本次讨论将回顾目前的JS-001 和 JS-002 标准发生的显著变化，并将探讨如何在遵守当前标准的前提下应对行业内的挑战。这些挑战将给集成电路元件ESD阈值的评估工作带来重大风险。本次讨论也将回顾由ESD协会发布的目前的ESD路线图，并强调对正确的ESD合格性测试的日益增长的迫切需求。

背景

背景 – 人体模型(HBM)

- 对所有组件进行ESD测试的最古老的测试方法可追溯到19世纪60年代
- HBM规范说明最初是由 MIL-STD定义的
- 最后一次修订MIL-STD 是在1989年，而在此时， ESDA 和JEDEC 都制定了行业标准
  – JEDEC 首次发行标准是在1996年， ESDA首次发行标准是在1998年
- 2010年ESDA 和JEDEC的首个联合规范发布，即ANSI/ESDA/JEDEC JS-001
- JS-001 不断发展为未来的ESD测试挑战，这一问题已被确定并纳入文件中

背景 – 充电装置模型(CDM)

- 对CDM 最初的工作开始于19世纪70年代
- 19世纪80年代末/90年代初对首个商业用测试装置进行了介绍
  – 该系统是我们今天非插座固定（电场诱导）CDM系统的早期版本
- ESDA 和JEDEC 各自的标准是在19世纪90年代中/晚期针对这些测试系统制定的
- 2014 年，针对CDM 的首个联合标准由ESDA 和 JEDEC发布，即 ANSI/ESDA/JEDEC JS-002
- JS-002 不断发展，重点解决非插座固定CDM测试系统面临的独特挑战

背景 – 行业验收– JS-001

- 在 JS-001 发布之前，存在由许多组织颁布的标准 (ESDA, JEDEC, AEC, JEITA, IEC)
- 随着ANSI/ESDA/JEDEC JS-001的发布, 业内一致认可JS-001， 并被ESDA, JEDEC, JEITA, AEC 和IEC 采用
- 统一使用一个规范标准是确保整个行业测试过程一致，测试结果一致的关键

在解释说明JS-001 方面依然面临挑战- 下面将会进行更详细的讨论

背景– 行业验收– JS-002

- 在JS-002发布之前，存在由许多组织颁布的标准 (ESDA, JEDEC, AEC, JEITA, IEC)
  – 一些标准机构与ESDA一致, 其他标准机构与JEDEC一致
  – 但是每种方法都提供了有价值的信息 –多个标准的存在不能很好地服务于这个行业
- 随着2014年ANSI/ESDA/JEDEC JS-002 的发布, 已经开始进行产业调整
  – 这对产业调整至关重要
  – IEC 已经采用，AEC预计将在2017年采用，JEITA仍在进行调查研究

JS-002标志着与以前所有的规范标准存在重大区别–理解是正确运用规范的关键

ESD 设备合格性测试面临的挑战

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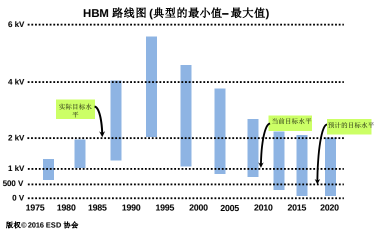
ESD 路线图[1]

1本章节信息可登录下列网站查询www.esda.org
https://www.esda.org/standards/complimentary-downloads/view/1869

HBM ESD 路线图



- HBM目标水平一直在稳步下降
- 水平下降是由于IO性能的提高
- 先进的技术节点也驱动了HBM性能的降低

ESD 设备合格性测试面临的挑战

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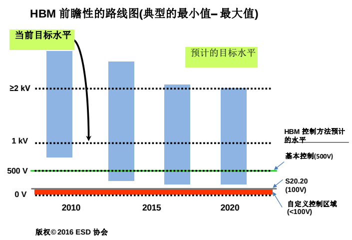
HBM ESD 路线图



- 分开观察2010年和以后各年
- 展望2020年及以后各年，在目标水平范围内没有预期的重大变化
- 注: 生产控制低于100V 时将面临挑战

ESD 设备合格性测试面临的挑战

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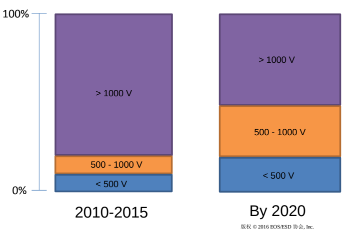
HBM ESD 路线图



- 虽然到2020年，该范围可能不会有重大变化，但预计集成电路目标水平的分布将发生变化
- 这将推动我们在如何处理制造业ESD控制方面面临的挑战
- 这也将带动确保正确进行合格性测试方面的需求

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我们必须为制造业提供正确的信息

ESD 设备合格性测试面临的挑战

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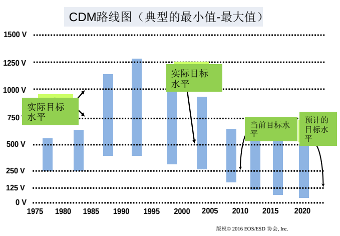
CDM ESD 路线图



- CDM目标水平一直在稳步下降
- 是什么推动了这种下降?
  – IO 性能方面的进步
  – 由于将更多功能集成到一个IC中，导致更大的IC包
- 先进的技术节点也推动了CDM性能的下降

ESD 设备合格性测试面临的挑战

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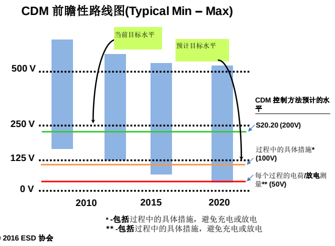
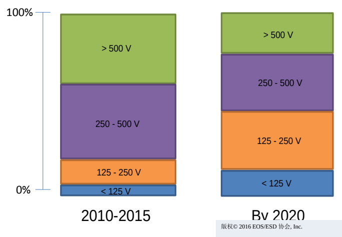
CDM ESD 路线图



- 分开观察2010年和以后各年
- 预计2020年，CDM较低的目标水平会下降
- 注:生产控制低于50V 时将面临严峻的挑战

CDM ESD 路线图



- 虽然到2020年，该范围可能不会有重大变化，但预计集成电路目标水平的分布将发生变化
- 这将推动我们在如何处理制造业ESD控制方面面临的挑战
- 我们需要确保满足JS-002，并且坚持JS-002 的要求也将至关重要

我们必须为制造业提供正确的信息

总结 – 路线图

- 虽然到2020年， HBM 和 CDM的目标水平范围可能不会发生令人瞩目的变化，预计ICs 目标水平的分布将呈下降趋势
- 利用JS-001 和 JS-002 规范标准对集成电路进行精准测试的需求将至关重要

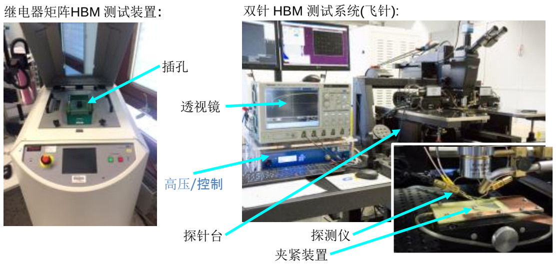
作为一个标准组织，我们必须确保对规范说明的理解是清楚明确的

JS-001 测试的详细信息

HBM 测试系统

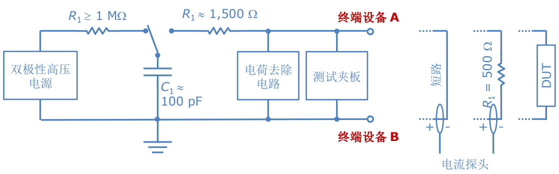
继电器矩阵HBM 测试装置:

双针 HBM 测试系统(飞针):



人体模型简化电路

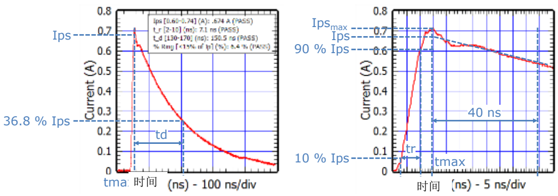
- 带负荷的简化的HBM模拟装置ANSI/ESDA/JEDEC JS-001 (以下简称JS-001) (图 1)



请谨记: 终端设备 A = 脉冲/压力, 终端设备 B = 地面

HBM波形验证– 短波

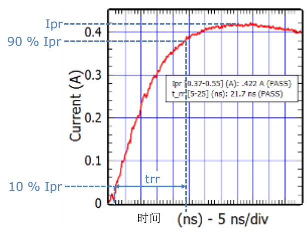
- 参数符合JS-001: Ips (计算出的), Ips_{max}, tr, td



ESD 设备合格性测试面临的挑战 19

HBM 波形验证– 500 欧姆负载

- 参数符合JS-001: Ipr, trr (增加的 "r" 表示 500 Ω 电阻)



ESD 设备合格性测试面临的挑战 20

HBM 波形验证– 参数

- JS-001定义的参数 (表 1):

电压水平(V)	短路的I峰值 Ipr (A)	500 Ω 的 I峰值 Ipr (A)	短路上升时间 tr (ns)	500 Ω 上升时间 trr (ns)	短路的衰减时间 td (ns)	最大振铃电流 I_R (A)
50 (可选的)	0.027–0.040	N/A	2.0–10	N/A	130–170	Ips的15 %
125 (可选的)	0.075–0.092	N/A	2.0–10	N/A	130–170	Ips的15 %
250	0.15–0.18	N/A	2.0–10	N/A	130–170	Ips的15 %
500	0.30–0.37	N/A	2.0–10	N/A	130–170	Ips的15 %
1000	0.60–0.73	0.37–0.55	2.0–10	5.0–25	130–170	Ips的15 %
2000	1.20–1.47	N/A	2.0–10	N/A	130–170	Ips的15 %
4000	2.40–2.93	1.50–2.20	2.0–10	5.0–25	130–170	Ips的15 %
8000 (可选的)	4.80–5.87	N/A	2.0–10	N/A	130–170	Ips的15 %

介绍50 V 的水平，为路线图做准备!

ESD 设备合格性测试面临的挑战 21

HBM 测试面临的挑战#1

- 波形验证
- 大多数HBM测试系统是以“基于继电器”的连接系统为基础
  - 基于继电器的系统产生前端脉冲和后缘脉冲风险
  - 对这些问题失败的理解和检查会导致错误的分配，降低HBM通过集成电路的水平

不正确的水平可能会导致制造业增加不必要的 ESD 控制

ESD 设备合格性测试面临的挑战 22

HBM 测试面临的挑战#2 – 引脚的类别

JS-001 要求将所有的引脚分类到定义组中的其中一类:

- 非连接引脚:
  - 一个封装的互连(引脚, 凸块或球块) 不与模具进行电连接。
- 电源引脚:
  - 电源引脚是向电路提供电流的引脚。电源引脚通常不传输信息。
    备注:为了进行ESD测试，电源和接地引脚被当作电源引脚。
- 非电源引脚:
- 所有未分类到电源引脚中的或无连接的引脚都是非电源引脚 ("信号引脚" 或 "IO引脚")。这包括诸如输入、输出、计时、控制、地址、数据等引脚。大多数非电源引脚发送或接收信息。

ESD 设备合格性测试面临的挑战 23

HBM 测试面临的挑战#2 –引脚的类别

- JS-001 介绍了2个表格，规定了进行HBM测试所需的引脚组合
  - 这些表格被定为表2A 和表2B
- 表 2B 代表追溯到最原始的MIL-STD测试方法的传统引脚组合
- 表2A 代表进行准确的HBM测试（消除了表2A中的一些风险）的最新引脚组合（之后将进行讨论）

ESD 设备合格性测试面临的挑战 24

HBM 测试 JS-001 表 2B

引脚组合的组号	连接到终端设备B的引脚	连接到终端设备A的引脚 (单引脚，每次测试一个)
1	电源引脚组1	除电源引脚组1之外的每个电源引脚
		每个非电源引脚
2	电源引脚组2	除电源引脚组2之外的每个电源引脚
		每个非电源引脚
...	...	...
N	电源引脚组N	除电源引脚组N之外的每个电源引脚
		每个非电源引脚
N+1	所有非电源引脚, 排除 PUT	每个非电源引脚 (如PUT)

电源
非电源引脚
所有其他受压的引脚
“IO 测试”

ESD 设备合格性测试面临的挑战 25

HBM 测试 JS-001 表 2A

引脚组合的组号	连接到终端设备B的引脚	连接到终端设备A的引脚 (单引脚，每次测试一个)
1	电源引脚组1	除电源引脚组1之外的每个电源引脚
		与电源1关联的 每个非电源引脚
...	...	...
N	电源引脚组N	除电源引脚组N之外的每个电源引脚
		与电源N关联的 每个非电源引脚
N+1	每个耦合非电源引脚对中的一个引脚，一次一对引脚	耦合非电源引脚对中其他引脚

电源
非电源引脚
“IO 测试”

ESD 设备合格性测试面临的挑战 26

表2A 中的 “关联” 之谜

- 根据 JS-001, 如果发生下列情况之一，非电源引脚（典型的I/O 引脚）与电源引脚组关联
  - 电源引脚组输出的电流 (即VDDIO) 是连接到非电源引脚的电路运行所必需的
  - 非电源引脚组和电源引脚组之间存在一个寄生路径 (如VCC电源引脚组中的漏极开路式非电源引脚连接到附近的良好的隔离环N)
- 每个非电源引脚至少于一个电源引脚组相关联，特殊情况下与两个组相关联 (VDDIO 和 VSS)

与产品设计相关的知识是根据表2A的要求正确进行测试所必不可少的!

ESD 设备合格性测试面临的挑战 27

HBM 测试 JS-001 表 2A 和表2 B –阈值的区别

- 尽管在理论上，根据表2A和表2B，HBM测试应得出相同的阈值， 但是并非总会出现相同或相似的结果; 例如:
  - 表2B中的极端超限应力可导致消耗和劣化，导致不切实际的低阈值– 表2A中的引脚对被减少，产生较高（更多相关领域）的阈值（有意的）
  - 表 2A 中的IO测试比表2B中的测试更为关键，并且可以给出截然不同的结果 (不计划隐藏表2B测试中的弱点)

ESD 设备合格性测试面临的挑战 28

总结 – HBM

- JS-001 是在HBM测试方面进行行业调整迈出的重要一步
- 但是，规范中的某些部分可能会使普通用户引起混淆
  - 波形验证
  - 引脚组合

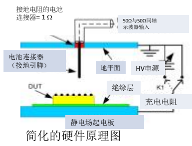
这种混淆会导致对集成电路原件不准确的HBM阈值水平预测

ESD 设备合格性测试面临的挑战 29

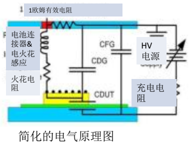
JS-002 测试的详细信息[1]

1该部分信息也发表于：
A. Righter, B. Carn “关注新的 ANSI/ESDA/JEDEC JS-002 CDM 测试标准”, 符合2017年9月的版本

CDM 背景



简化的硬件原理图

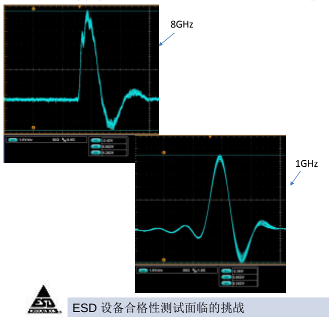


简化的电气原理图

实例测试系统

- 电场感应CDM 示意图
- 设备通过静电场起电板的电压充电，并且单个引脚/球块作为接近DUT的电池连接器放电

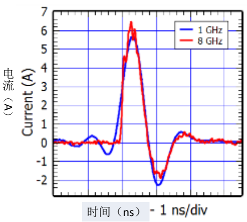
CDM 背景 – JEDEC JESD22-C101 波形



- 介绍一种铁氧体满足以前的规格，为了满足FWHM 要求，当有很高的BW观察范围时，引入了很明显的铃声(1 GHz时不会看到)

新**ESDA/JEDEC** 的关键重点与 **CDM** 规范 **ANSI/ESDA/JEDEC JS-002-2014 (JS-002)** 一起，正在去除铁氧体，提高响铃声

CDM 背景 – 范围 BW 的依赖关系



- JESD22-C101 仅在1 GHz 时要求进行波纹验证
- 真实的波纹实际上比1 GHz 范围内可以捕获到的波纹更快，并且该范围对真实的波纹进行了过滤
- 真实的波纹有更高的峰值电流，更快的Tr，并且使用高BW范围(>6 GHz)测量时会减少FWHM
- 这就导致当使用旧规范时，依据BW范围[1]的校准测试系统会发生变异

JS-002的关键重点是介绍使用高BW范围 (>6 GHz)检查波形的要求，以看到“真正的”峰值电流

CDM –JS-002中的波形验证频率

- 工具的初始认证或任何周期性的再认证
  - 进行再认证的最长期限是一年
    - 对系统的任何服务/维修也会驱动再认证
  - 必须使用如表2所示的**高频带宽度 (BW) 示波器** 规范，并且在两个极性中同时使用大型/小型验证模块验证所有参数是否均满足在5个测试条件(TCs), – 参照附录G进行调整
- 每季度进行认证
  - 使用1 GHz 或高BW 示波器,在两个极性中同时使用大型/小型验证模块，验证表1或表2中的所有参数是否均满足在5个测试条件(TCs), –参照附录G进行调整
    - 如果可能，建议使用高BW范围

JS-002的关键重点: 说明何时使用高BW/低 BW示波器

CDM –波形验证表

- 注意峰值电流范围的重点
- 为了达到目标峰值电流范围可调整场板电压
- 在每个测试条件下需要对所有的参数进行检查
- JS-002增加的附录为如何完成波形验证提供了2个选择

表1. 1GHz带宽示波器的CDM波形特征

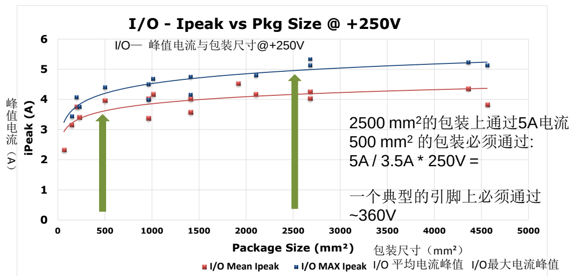
1GHz带宽示波器		测试条件									
		TC 125		TC 250		TC 500		TC 750		TC 1000	
验证模块	Sym.	小	大	小	大	小	大	小	大	小	大
峰值电流	Ip	1.0-1.6	1.9-3.2	2.1-3.1	4.2-6.3	4.4-5.9	9.1-12.3	6.6-8.9	13.7-18.5	8.8-11.9	18.3-24.7
上升时间	Tr	<350	<450	<350	<450	<350	<450	<350	<450	<350	<450
半峰全宽 (ps)	FWHM	325-725	500-1000	325-725	500-1000	325-725	500-1000	325-725	500-1000	325-725	500-1000
负脉冲信号 (A，最大，第二个峰值)	I_{p2}	<70% Ip	<50% Ip	<70% Ip	<50% Ip	<70% Ip	<50% Ip	<70% Ip	<50% Ip	<70% Ip	<50% Ip

表2 高带宽（> = 6GHz）示波器的CDM波形特征

6GHz带宽示波器		测试条件									
		TC 125		TC 250		TC 500		TC 750		TC 1000	
验证模块	Sym.	小	大	小	大	小	大	小	大	小	大
峰值电流	Ip	1.4-2.3	2.3-3.8	2.9-4.3	4.8-7.3	6.1-8.3	10.3-13.9	9.2-12.4	15.5-20.9	12.2-16.5	20.6-27.9
上升时间	Tr	<250	<350	<250	<350	<250	<350	<250	<350	<250	<350
半峰全宽	FWHM	250-600	450-900	250-600	450-900	250-600	450-900	250-600	450-900	250-600	450-900
负脉冲信号 (A，最大，第二个峰值)	I_{p2}	<70% Ip	<50% Ip	<70% Ip	<50% Ip	<70% Ip	<50% Ip	<70% Ip	<50% Ip	<70% Ip	<50% Ip

理解场板电压/峰值电流的关系非常重要

CDM – 峰值电流取决于包装尺寸



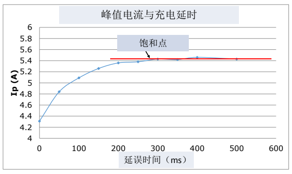
2500 mm²的包装上通过5A电流
500 mm² 的包装必须通过:
5A / 3.5A * 250V =

一个典型的引脚上必须通过
~360V

依赖图表对理解CDM ESD路线图中的风险至关重要

CDM –完全充电装置

- 问题描述:为了能够充足电，大包需要超过最小延期
- 在JS-002中添加程序，确定最小的充电延期时间



- 使用大型验证模块或设备（假设的），对最小延误时间和较长延误时间下的放电峰值电流进行描述
- 如果最小延误时间下的峰值电流低于较长延误时间下的峰值电流；需要合适的延误时间描述，如左图图表所示

JS-002的关键重点: 必须确保组件充满电

CDM – 未来的CDM 测试

- 电场感应CDM测试是今天主要的测试方法
  - 火花电阻在低电压情况下会产生严重的误差
- 电压水平的下降会限制电场感应测试的使用
- 使用ESDA/JEDEC JWG对2种方法进行评估
- CCDM –CDM
  - TR 发布于2016 年–可被设计成现有放电波形的形状
  - – SP 计划在2018年初发布
  - 直接接触法消除波形中的火花变化
  - 用于低电压CDM测试的可替代方法
  - cc-TLP –电容耦合传输线脉冲
  - 该方法已经存在一段时间了
  - 可能与目前的放电波形不完全匹配
  - 晶圆级表征技术的好选择

CDM路线图将驱动JS-002的其他改变/改进

总结 - CDM

- JS-002 是首个CDM 联合测试标准
- 下列改变对本规范至关重要:
  - 不存在铁氧体（电感器）的硬件
  - 高BW (>6GHz)的情况下的验证波形要求，以及关于多久检查一次的要求
  - 确保元件正确充电
  - 了解峰值电流以及它与场板电压和包装尺寸之间的关系

没有正确的理解，将无法正确应用JS-002

总结

- ANSI/ESDA/JEDEC JS-001 和 JS-002 标志着在对组件ESD测试进行行业调整方面迈出了重要的一步
  - 如果公司未使用/遵守这些规范标准，该公司将没有资格在半导体行业中处于领先地位
  - 预期的ESD路线图变化将推动对准确进行ESD测试的迫切要求
  - 今天，仍有许多公司不计划遵守该规范说明——不是故意不遵守——而是由于缺乏对规范的理解

ESD协会的培训可以帮助确保联合标准的一致性

备份数据库

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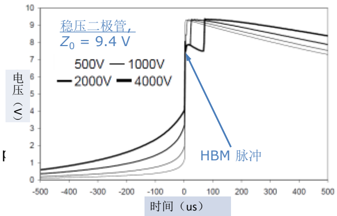
ESD 设备合格性测试面临的挑战 43

HBM 波形验证– 预脉冲

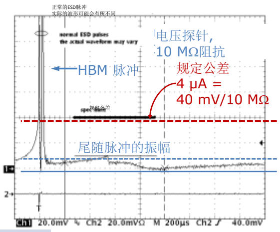
- 在实际HBM应力脉冲之前，HBM 测试装置可能引起电压升高→ 预脉冲 → 会导致"人为" 故障 [2]
- 预脉冲电压水平取决于测试装置
- 测量: 在100 µs/div 时，通过DUT或通过稳压二极管 (Z_0 = 8–10 V) 测量电流
- 注:
  - 无限制规定 – 如果确定了预脉冲，p 必须评估产品风险!
  - 10 k 的分流器可降低预脉冲



ESD 设备合格性测试面临的挑战 44

HBM 波形验证– 尾随脉冲

- HBM测试仪器在真实的HBM应力脉冲之后，可产生虚假的（"尾随"）脉冲电流 →由于过电压会导致故障[3]
- 测量设置: 在终端设备A和终端设备B之间设置10 kΩ 分流器和并联的稳压二极管(Z_0 = 6–15 V)
- 测量1 ms 内(200 µs/div)通过稳压管的电压
- 必须验证正电流和负电流
- 限制值: <4 µA @ 4,000 V



ESD 设备合格性测试面临的挑战 45

HBM 引脚集合– 电源引脚组

- 用电阻小于3 Ω 的金属将电源引脚连接到芯片或组件上，形成一个"电源引脚组"
  - "3 Ω 标准"必须通过可靠的设备文件进行验证或者必须通过测量进行验证（但是，由于存在寄生电阻，可能不太容易进行测量）
  - 如果电阻不能被测量，或者电阻是未知的，每个引脚必须被看作是单独的电源引脚组
- 未通过金属连接到其他电源引脚上的电源引脚形成他们自己的电源引脚组
- 每个电源引脚必须属于且仅属于一个电源引脚组

ESD 设备合格性测试面临的挑战 46

HBM 测试 JS-001 表 2B –应力策略

- 选择全部*N* 电源引脚组(请谨记,接地引脚组也是电源引脚组!), 将电源引脚组分成 1 到 *N*
- 选择第一个电源引脚组并将其连接到终端设备B – 分别将 所有的 其他电源引脚与非电源引脚连接到终端设备A，并对其施加压力!(不对未连接的施加压力!)
  备注: 未连接到终端设备A或B的引脚是不固定的
- 继续将第2个用于第N个引脚组，并将其连接到终端设备B –分别将 所有的 其他电源引脚与非电源引脚连接到终端设备A，并对其施加压力!(不对未连接的施加压力!)
- 分别将每个非电源引脚连接到终端设备A，使其承受来自通常连接到终端设备B上的所有其他非电源引脚的压力 ("IO 测试")

ESD 设备合格性测试面临的挑战 47

HBM 测试 JS-001 表 2A – 应力策略

- 选择所有的*N* 电源引脚组，并将电源引脚组分成1到*N* 类
- 选择第一个电源引脚组，将其连接到终端设备B上– 分别将 所有的 其他电源引脚和与电源1相关的所有非电源引脚 连接到终端设备A 并对其施加压力
- 继续将第2个用于第N个引脚组，并将其连接到终端设备B–分别将 所有的 其他电源引脚和与该电源组相关的所有非电源引脚 连接到终端设备A 并对其施加压力
- 连接每个耦合的非电源引脚对中的一个引脚，并将其连接到终端设备B – 将该耦合非电源引脚对的其他引脚连接到终端设备A并对其施加压力，一次一个引脚对 ("I/O 测试")

表2A 规定了所需引脚对组合的最小集合!

ESD 设备合格性测试面临的挑战 48

HBM 测试 JS-001 表 2A – 测试策略

- 总体来讲，根据表2A“最低要求的引脚组合”可被分解为:
  - 一个“矩阵测试”(供电测试)
  - 一个“域内测试”(所有与一个电源相关的非电源引脚抵抗该电源的压力，非电源引脚组+电源 引脚可被视为“域”) – 与表 2B不同
  - IO 测试
- 建议: 不同不同的设备进行矩阵测试、域内测试和IO 测试
  → 在发生故障时，可能的放电路径和导致故障的机械装置可以被很容易地缩小。

ESD 设备合格性测试面临的挑战　49

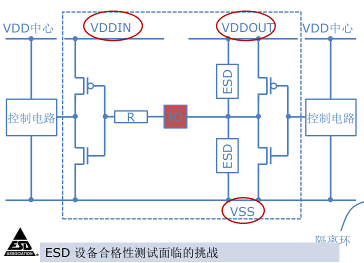
HBM 测试 JS-001 表 2A:耦合非电源引脚对

- 根据JS-001:两个引脚有一个预期的直流电流路径(例如传递闸极或电阻)
- 耦合引脚对举例(见JS-001附录D)
  - USB 数据引脚(如D+/D-)
  - PCI数据引脚(如, TXN/TXP, RXN, RXP)
  - 晶体引脚对(如, XTALOUT, XTALIN)
  - 差分放大器输入, LNA 输入/输出
- 注: 表2B 和 表 2A 的IO 测试可以交换，比如，如果
  - 耦合引脚对是未知的，必须使用表2B的IO测试
  - 有太多的耦合引脚对，可使用表2B的IO测试

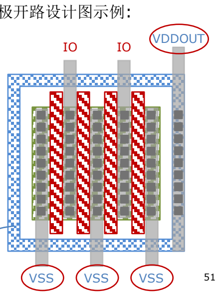
ESD 设备合格性测试面临的挑战　50

“关联”之谜– 例 (1)

I/O pad的典型示意图:

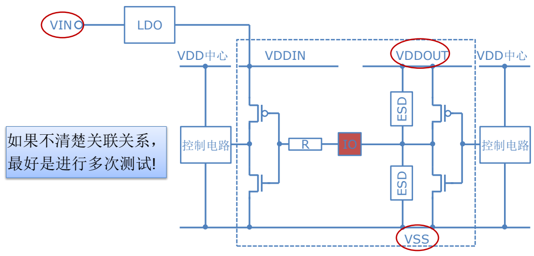


漏极开路设计图示例:



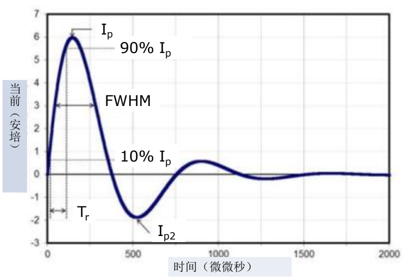
ESD 设备合格性测试面临的挑战　51

“关联”之谜– 例 (2)



ESD 设备合格性测试面临的挑战　52

CDM –波形参数



ESD 设备合格性测试面临的挑战　53

ESD Device Qualification Testing Challenges

ESDA/CNIS Conference, Guiyang China
Brett Carn
November 10, 2017

ABSTRACT

This presentation will discuss the current human body model (HBM) ANSI/ESDA/JEDEC JS-001 and charged device model (CDM) ANSI/ESDA/JEDEC JS-002 test standards. There has long been a need to align the Industry on HBM and CDM testing standards. JS-001 and JS-002 have gone a long way to meet that alignment need. The discussion will review significant changes in the current JS-001 and JS-002 standards and will pursue the challenges within the Industry with adherence to the present standards. These challenges can result in significant risk to the assessment of the ESD threshold of integrated circuit components. This discussion will also review the current ESD roadmap published by the ESD Association and how this highlights the ever increasing critical need for correct ESD qualification testing.

Background

Background – Human Body Model (HBM)

- The oldest of all component ESD testing methods, with work starting back in the 1960's
- The HBM specification was originally defined by the MIL-STD
- The last revision of the MIL-STD was in 1989 at which point the ESDA and JEDEC both developed Industry standards
  - First standards released by JEDEC in 1996 and ESDA in 1998
- In 2010 the first joint specification from the ESDA and JEDEC was released as ANSI/ESDA/JEDEC JS-001
- JS-001 continues to evolve as future ESD testing challenges are identified and incorporated into the document

Background – Charged Device Model (CDM)

- Initial work on CDM start in the 1970's
- The first commercial testers were introduced in the late 1980s / early 1990s
  - The systems were the early versions of the non-socketed (field-induced) CDM systems we have today
- Separate standards from both the ESDA and JEDEC followed around these test systems in the mid/late 1990s
- In 2014 the first joint standard for CDM was released by the ESDA and JEDEC as ANSI/ESDA/JEDEC JS-002
- JS-002 continues to evolve, focusing on the unique challenges of a non-socketed CDM test system

Background – Industry Acceptance – JS-001

- Previous to the release of JS-001 there were standards from many organizations (ESDA, JEDEC, AEC, JEITA, IEC)
- With the release of ANSI/ESDA/JEDEC JS-001, the Industry has aligned on JS-001 with adoption by ESDA, JEDEC, JEITA, AEC and IEC
- Aligning on one specification has been critical to ensuring consistent testing and consistent results across the Industry

Challenges still exist in interpretation of JS-001 - this will be discussed in more detail

Background – Industry Acceptance – JS-002

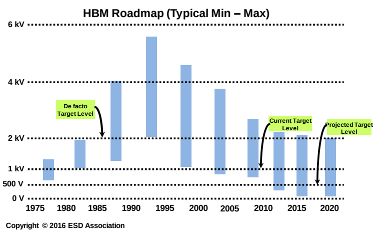
- Previous to the release of JS-002 there were standards from many organizations (ESDA, JEDEC, AEC, JEITA, IEC)
  - Some standards bodies aligned with ESDA, others with JEDEC
  - While each method provides valuable information – the presence of multiple standards does not serve the Industry well
- With the release of ANSI/ESDA/JEDEC JS-002 in 2014, Industry alignment has started
  - This is vital to alignment of the Industry
  - IEC adoption has been completed with AEC adoption expected in 2017, JEITA is still in investigation

JS-002 represents a significant departure from all previous specifications – understanding is critical to apply the specification correctly

ESD Roadmaps[1]

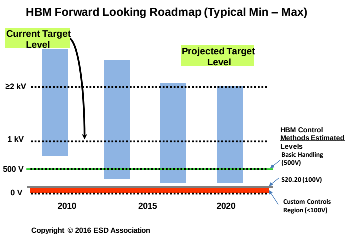
[1]Information in this section can be found at www.esda.org
https://www.esda.org/standards/complimentary-downloads/view/1869

HBM ESD Roadmap



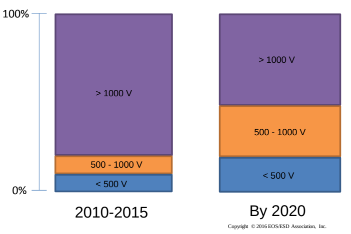
- HBM target levels have been steadily dropping
- Reduction in levels is a result of increases in IO performance
- Advanced technology nodes also driving reductions in HBM performance

HBM ESD Roadmap



- Isolating look at 2010 and beyond
- Not anticipating a significant change in the *range* of target levels looking forward to the year 2020 and beyond
- Note: manufacturing controls become challenged below 100V

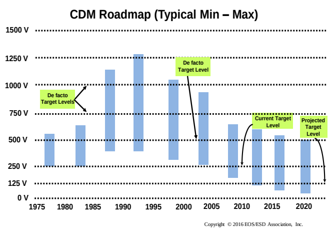
HBM ESD Roadmap



- Though the *range* may not significantly change by the year 2020, it is anticipated that the *distribution* of target levels for integrated circuits will change
- This will drive challenges in how we handle ESD controls in manufacturing
- This will also drive the need for ensuring the qualification testing is done properly

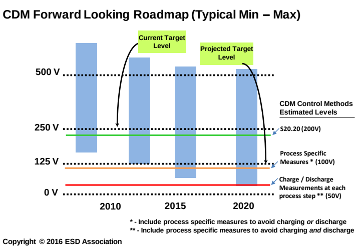
We must supply the correct information to manufacturing

CDM ESD Roadmap



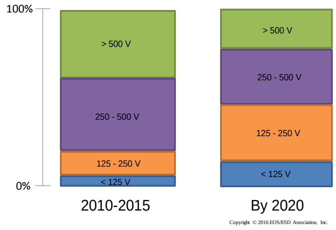
- CDM target levels have been steadily dropping
- What is driving this reduction?
  - Advances in IO performance
  - Larger IC packages as a result of packing more functionality into one IC
- Advanced technology nodes also driving reductions in CDM performance

CDM ESD Roadmap



- Isolating look at 2010 and beyond
- Expecting a reduction in the lower target level for CDM in 2020
- Note: manufacturing controls become significantly challenged below 50V

CDM ESD Roadmap



- Though the *range* may not significantly change by the year 2020, it is anticipated that the *distribution* of target levels for integrated circuits will change
- This will drive challenges in how we handle ESD controls in manufacturing
- The need to ensure compliance to JS-002 and to adhere to the requirements of JS-002 will be critical

We must supply accurate information to manufacturing

Summary - Roadmaps

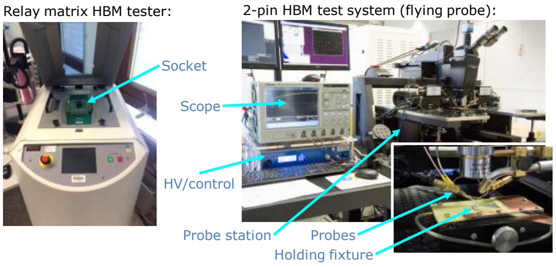
- Though the *range* of HBM and CDM target levels may not dramatically change by the year 2020 it is anticipated the *distribution* of target levels for ICs will trend downward
- The need for accurate testing of integrated circuits utilizing JS-001 and JS-002 specifications will be critical

As a standards organization, we must ensure understanding of the specifications is clear

JS-001 Testing Details

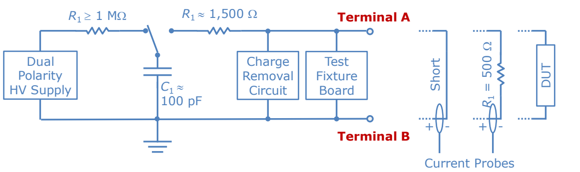
HBM Test Systems

Relay matrix HBM tester: 2-pin HBM test system (flying probe):



Human Body Model Simplified Circuit

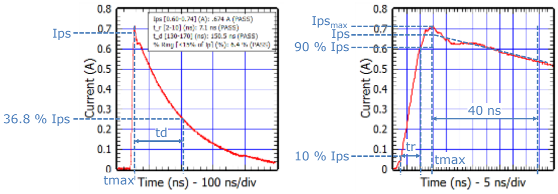
- Simplified HBM simulator with loads according to ANSI/ESDA/JEDEC JS-001 (referred to from this point on as JS-001) (Figure 1)



Remember: Terminal A = pulse/stress, Terminal B = ground

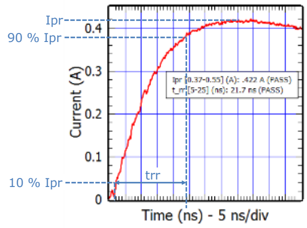
HBM Waveform Verification – Short

- Parameters according to JS-001: Ips (calculated), Ips_{max}, tr, td



HBM Waveform Verification – 500 Ohm Load

- Parameters according to JS-001: Ipr, trr (added "r" denotes 500 Ω resistor)



HBM Waveform Verification – Parameters

- Parameters defined in JS-001 (Table 1):

Voltage Level (V)	Ipeak for short Ips (A)	Ipeak for 500 Ω Ipr (A)	Rise Time for Short tr (ns)	Rise Time for 500 Ω trr (ns)	Decay Time for short td (ns)	Maximum Ringing Current I_R (A)
50 (optional)	0.027– 0.040	N/A	2.0–10	N/A	130–170	15 % of Ips
125 (optional)	0.075– 0.092	N/A	2.0–10	N/A	130–170	15 % of Ips
250	0.15–0.18	N/A	2.0–10	N/A	130–170	15 % of Ips
500	0.30–0.37	N/A	2.0–10	N/A	130–170	15 % of Ips
1000	0.60–0.73	0.37–0.55	2.0–10	5.0–25	130–170	15 % of Ips
2000	1.20–1.47	N/A	2.0–10	N/A	130–170	15 % of Ips
4000	2.40–2.93	1.50–2.20	2.0–10	5.0–25	130–170	15 % of Ips
8000 (optional)	4.80–5.87	N/A	2.0–10	N/A	130–170	15 % of Ips

50 V level introduced to prepare for the roadmap!

HBM Testing Challenge #1

- Waveform verification
  - Most HBM test systems are based on a "relay based" connection system
  - Relay based systems create risks of both pre pulses as well as trailing pulses
  - Failure to understand and check for these issues can result in incorrectly assigning *reduced* HBM passing levels to an integrated circuit

Incorrect levels can potentially result in requiring un-needed additional ESD controls in manufacturing

HBM Testing Challenge #2 – Pin Classifications

JS-001 requires all pins to be classified into one of the defined groups:
- No-connect pins:
  - A package interconnect (pin, bump or ball) that is not electrically connected to a die.
- Supply pins:
  - A supply pin is any pin that provides current to a circuit. Supply pins typically transmit no information.
    Remark: For the purpose of ESD testing, power and ground pins are treated as supply pins.
- Non-supply pins:
  - All pins not categorized as supply pins or no connects are non-supply pins ("signal pins" or "IO pins"). This includes pins such as input, output, clocks, controls, address, data ... Most non-supply pins transmit or receive information.

HBM Testing Challenge #2 – Pin Classifications

- JS-001 introduces 2 tables to define the pin combinations required for HBM test
  - These tables are identified as Table 2A and Table 2B
- Table 2B represents the legacy pin combinations, dating back to the original MIL-STD test method
- Table 2A represents the latest pin combinations for accurate HBM testing without some of the risks of Table 2A (to be discussed later)

HBM Testing JS-001 Table 2B

Pin Combination Set Number	Pin(s) Connected to Terminal B	Pin Connected to Terminal A (Single Pins, tested one at a time)
1	Supply Pin Group 1	Every Supply Pin except pins of Supply Pin Group 1
		Every Non-Supply Pin
2	Supply Pin Group 2	Every Supply Pin except pins of Supply Pin Group 2
		Every Non-Supply Pin
...	...	...
N	Supply Pin Group N	Every Supply Pin except pins of Supply Pin Group N
		Every Non-Supply Pin
N+1	All Non-supply Pins, except PUT	Each Non-Supply Pin (as the PUT)

Supplies
Non-supply pins
All other stressed pins
"IO test"

HBM Testing JS-001 Table 2A

Pin Combination Set Number	Pin(s) Connected to Terminal B	Pin Connected to Terminal A (Single Pins, tested one at a time)
1	Supply Pin Group 1	Every Supply Pin except pins of Supply Pin Group 1
		Every Non-Supply Pin associated with Supply 1
...	...	...
N	Supply Pin Group N	Every Supply Pin except pins of Supply Pin Group N
		Every Non-Supply Pin associated with Supply N
N+1	One Pin of Each Coupled Non-Supply Pin Pair, one pair at a time	The other pin of the Coupled Non-Supply Pin Pair

Supplies
Non-supply pins
"IO test"

The Mystery of "Association" in Table 2A

- Per JS-001, a non-supply pin (typically an I/O pin) is *associated* with a supply pin group if either
  - The current from the supply pin group (i.e., VDDIO) is required for the function of the electrical circuit(s) that connect to that non-supply pin
  - A parasitic path exists between non-supply and supply pin group (e.g., open-drain type non-supply pin to a VCC supply pin group that connects to a nearby N-well guard ring).
- Each non-supply pin is *associated* with at least one supply pin group, typically with two (VDDIO and VSS)

The knowledge of associations in the product design is essential for testing according to Table 2A correctly!

HBM Testing JS-001 Table 2A and Table 2 B – Threshold Differences

- Although ideally HBM testing according to Table 2A and Table 2B should give the same thresholds, identical or even similar results cannot always be expected; examples:
  - Extreme overstressing in Table 2B could lead to wear-out and degradation and to unrealistic low thresholds – pin pairs are reduced in Table 2A and could yield to a higher (more field-relevant) threshold (intentional)
  - IO test of Table 2A is far more critical than in Table 2B and could give significantly different results (not intended to hide weakness in test according to Table 2B)

Summary - HBM

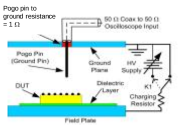
- JS-001 is a significant step forward in aligning the Industry on HBM testing
- However, there are areas within the specification that can cause confusion to the average user
  - Waveform verification
  - Pin combinations

This confusion can lead to incorrect HBM threshold level predictions for IC components

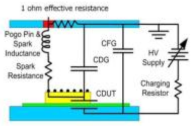
JS-002 Testing Details[1]

[1]Information in this section is also published in:
A. Righter, B. Carn "A Look at the New ANSI/ESDA/JEDEC JS-002 CDM Test Standard", *In Compliance* Sept 2017 Issue

CDM Background



Simplified Hardware Schematic

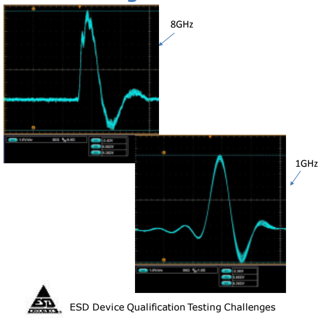


Simplified Electrical Schematic

Example test systems

- Field-induced CDM schematic shown
- A device is charged through a voltage applied to the field plate and a single pin/ball is discharged as the pogo pin approaches the DUT

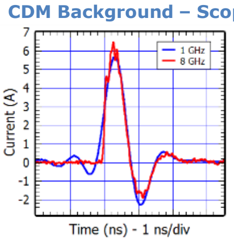
CDM Background – JEDEC JESD22-C101 waveform



- Introduction of a ferrite to meet previous specs to meet FWHM requirements introduces significant ringing when viewed with a high BW scope (not seen at 1 GHz)

A key focus of the new ESDA/JEDEC joint CDM specification ANSI/ESDA/JEDEC JS-002-2014 (JS-002) is to remove the ferrite to improve ringing

CDM Background – Scope BW Dependency



- JESD22-C101 called for waveform verification at 1 GHz only
- The true waveform is actually faster than what can be captured on a 1 GHz scope and the scope filters the true waveform
- The true waveform has a higher Ipeak, faster Tr and reduced FWHM when measured with a high BW scope (>6 GHz)
- This created variability in calibrating test systems based on the BW of the scope [1] when using the old specifications

A key focus of JS-002 is to introduce requirements for checking waveforms using a high BW (>6 GHz) scope to see the "real" Ipeak

CDM – Waveform Verification Frequency in JS-002

- At initial qualification of the tool or during any periodic requalification
  - Requalification should be at a maximum period of 1 yr
    - Requalification could also be driven by any service/repair of the system
  - *Must* use the **high bandwidth (BW) oscilloscope** specifications as shown in *Table 2* and verify that all parameters are met at each of the 5 test conditions (TCs), using both the large/small verification module at both polarities – make adjustments as per Annex G
- Verification every quarter
  - Using either a 1 GHz or high BW oscilloscope, verify that all parameters in Table 1 or 2 are met at each of the 5 TCs, using both the large/small verification module at both polarities – make adjustments as per Annex G
    - It is recommended to use a high BW scope here if possible

A key focus of JS-002: clarify when to use high BW/low BW oscilloscope

CDM – Waveform Verification Tables

- Note focus on Ipeak ranges
- Field plate voltage is adjusted in order to hit the target Ipeak ranges
- Full parameter checks required at each test condition
- Annex added to JS-002 to offer 2 options for how to complete the waveform verification

Table 1. CDM Waveform Characteristics for a 1 GHz Bandwidth Oscilloscope

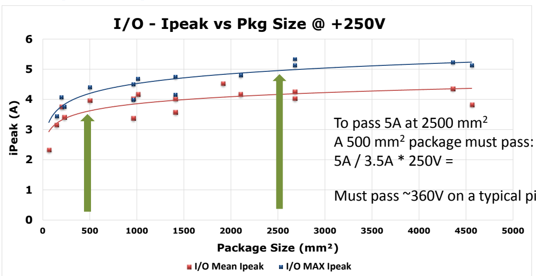
1 GHz BW Oscilloscope		Test Condition									
		TC 125		TC 250		TC 500		TC 750		TC 1000	
Verification Module	Sym.	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large
Peak Current (A)	Ip	1.0-1.6	1.9-3.2	2.1-3.1	4.2-6.3	4.4-5.9	9.1-12.3	6.6-8.9	13.7-18.5	8.8-11.9	18.3-24.7
Rise time (ps)	Tr	<350	<450	<350	<450	<350	<450	<350	<450	<350	<450
Full width at half maximum (ps)	FWHM	325-725	500-1000	325-725	500-1000	325-725	500-1000	325-725	500-1000	325-725	500-1000
Undershoot (A, max. 2nd peak)	Ip₂	<70% Ip	<50% Ip	<70% Ip	<50% Ip	<70% Ip	<50% Ip	<70% Ip	<50% Ip	<70% Ip	<50% Ip

Table 2. CDM Waveform Characteristics for a High Bandwidth (>= 6 GHz) Oscilloscope

>= 6 GHz BW Oscilloscope		Test Condition									
		TC 125		TC 250		TC 500		TC 750		TC 1000	
Verification Module	Sym.	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large
Peak Current (A)	Ip	1.4-2.3	2.3-3.8	2.9-4.3	4.8-7.3	6.1-8.3	10.3-13.9	9.2-12.4	15.5-20.9	12.2-16.5	20.6-27.9
Rise time (ps)	Tr	<250	<350	<250	<350	<250	<350	<250	<350	<250	<350
Full width at half maximum (ps)	FWHM	250-600	450-900	250-600	450-900	250-600	450-900	250-600	450-900	250-600	450-900
Undershoot (A, max. 2nd peak)	Ip₂	<70% Ip	<50% Ip	<70% Ip	<50% Ip	<70% Ip	<50% Ip	<70% Ip	<50% Ip	<70% Ip	<50% Ip

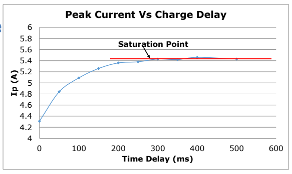
Understanding the field plate voltage/Ipeak relationship is important

CDM – Ipeak Dependence on Package Size



Dependence graphs are critical for understanding risks in CDM ESD Roadmap

CDM – Fully Charging the Device



- **Problem statement**: Large packages may require more than the minimum delay in order to fully charge
- Procedure added to JS-002 to determine minimum charge delay
- Using large verification module or a device (ideal), characterize the discharge Ipeak at minimum delay and longer delay times
- If Ipeak at minimum delay is lower than Ipeak at longer delay times; a characterization of the appropriate delay is needed such as shown on the figure on the left

A key focus of JS-002: must ensure component is fully charged

CDM – Future of CDM Testing

- Field Induced CDM testing is the dominate test method today
  - Spark resistance creates significant error at low voltages
- Reduction in voltage levels will limit the use of field induced testing
- 2 methods being evaluated by the ESDA/JEDEC JWG
  - CCDM – Contact CDM
    - TR published in 2016 – can be designed to shape of existing discharge waveform – SP in progress for early 2018 release
    - Contact method removes spark variation in waveform
    - Possible alternative method for low voltage CDM testing
  - cc-TLP – Capacitive coupled transmission line pulse
    - Approach has been around for awhile
    - May not completely match present discharge waveforms
    - Good option as a wafer level characterization technique

The CDM roadmap will drive additional changes / improvements in JS-002

Summary - CDM

- JS-002 represents the first joint CDM test specification
- Critical to this specification are the following changes:
  - Hardware without existence of a ferrite (inductance)
  - Requirement to verify waveform at high BW (>6GHz) and how often to check
  - Ensure correct charging of the component
  - Understand Ipeak and it's relationship to field plate voltage and to package size

Without the correct understanding, JS-002 can be applied incorrectly

Summary

- ANSI/ESDA/JEDEC JS-001 and JS-002 represent a significant step forward in aligning the Industry on component ESD testing
  - If a company is not using/following these specifications they are not positioned to lead within the semiconductor Industry
- Anticipated ESD roadmap changes will drive a critical need for accurate ESD testing
- Today, there are companies who are not following the specifications as intended – not on purpose – but due to a lack of understanding

Training through the ESD Association can help to ensure alignment to the joint standards

BACKUP

References (1)

Standards:

ANSI/ESDA/JEDEC JS-001-2017: *"ESDA/JEDEC Joint Standard for Electrostatic Discharge Sensitivity Testing – Human Body Model (HBM) – Component Level"*, 2017. www.esda.org

ANSI/ESDA/JEDEC JS-002-2014: *"ESDA/JEDEC Joint Standard for Electrostatic Discharge Sensitivity Testing – Charged Device Model (CDM) - Device Level"*, 2014. www.esda.org

ANSI/ESD S5.3.1-2009: *"Electrostatic Discharge Sensitivity Testing – Charged Device Model (CDM) - Component Level"*, 2009. www.esda.org

JEDEC JESD22-C101F: *"Field-Induced Charged-Device Model Test Method for Electrostatic-Discharge-Withstand Thresholds of Microelectronic Components"*, 2013. www.jedec.org

ANSI/ESD S20.20-2014: *"Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)"*, 2014. www.esda.org

IEC 61340-5-1 (2007-09) Ed. 1.0: *"Electrostatics – Part 5-1: Protection of electronic devices from electrostatic phenomena – General requirements"*, 2007. – Update to be expected in 2016. www.iec.ch

White Papers Industry Council (available for download e.g. www.esda.org/documents):

Industry Council on ESD Target Levels, White Paper 1: *"A Case for Lowering Component Level HBM/MM ESD Specifications and Requirements. Revision 3.0"*, Sept 2011.

Industry Council on ESD Target Levels, White Paper 2: *"A Case for Lowering Component Level CDM ESD Specifications and Requirements. Revision 2.0"*, Apr. 2010.

References (2)

Publications:

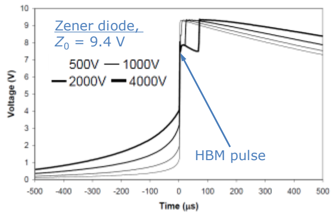
[1] Smedes, T.; Polewski, M.; van IJzerloo, A.; Lefebvre, J.L.; Dekker, M., *"Pitfalls for CDM calibration procedures"*, Proc. EOS/ESD Symposium 2010, 341.

[2] Etherton, M.; Axelrod, V.; Meuse, T.; Miller, J.W.; Marom, H., *"HBM ESD failures caused by a parasitic pre-discharge current spike"*, Proc. EOS/ESD Symposium 2008, 30.

[3] Meuse, T.; Ting, Larry; Schichl, J.; Barrett, R.; Bennett, D.; Cline, R.; Duvvury, C.; Hopkins, M.; Kunz, H.; Leiserson, J.; Steinhoff, R., *"Formation and suppression of a newly discovered secondary EOS event in HBM test systems"*, Proc. EOS/ESD Symposium 2004, 1.

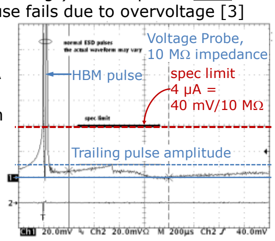
HBM Waveform Verification – Pre-pulse

- HBM testers may cause a voltage rise before the actual HBM stress pulse → pre-pulse → can cause "artificial" fails [2]
- Level of pre-pulse voltage depends on tester
- Measurement: measure current through DUT or through a Zener diode (Z_0 = 8–10 V) at 100 µs/div
- NOTE:
  - There is no limit defined – if pre-pulse determined, product risk must be assessed!
  - The 10 k shunt can reduce the pre-pulse.



HBM Waveform Verification – Trailing Pulse

- HBM testers may have spurious ("trailing") current pulses after the actual HBM stress pulse → can cause fails due to overvoltage [3]
- Measurement set-up: 10 kΩ shunt and parallel Zener diode (Z_0 = 6–15 V) between Terminal A and Terminal B
- Measure voltage across Zener with 1 ms time scale (200 µs/div)
- Positive and negative currents must be verified
- Limit: <4 µA @ 4,000 V



HBM Pin Grouping – Supply Pin Groups

- Supply pins that are connected on chip or on package level by a metal with a resistance of less than 3 Ω, form a "supply pin group"
  - "3 Ω criterion" must either be verified by reliable device documentation or must be verified by measurements (however, measurements may not be easily possible due to parasitic resistances)
  - If the resistance cannot be measured or is not known, each pin has to be treated as separate supply pin group
- Supply pins which are not connected to any other supply pin by metal, form their own supply pin group
- Each supply pin must be a member of one and only one supply pin group

HBM Testing JS-001 Table 2B – Stress Strategy

- Select all *N* supply pin groups (remember, ground pin groups are also supply pin groups!), sort the supply pin groups from 1 to *N*
- Select the 1st supply pin group and connect it to Terminal B – connect all other supply pins and non-supply pins individually to Terminal A and stress it (no stressing of no-connects!)
  Remark: Pins not connected to Terminal A or B are left floating
- Continue with 2nd to *N*th pin group and connect it to Terminal B – connect all other supply pins and non-supply pins individually to Terminal A and stress it (no stressing of no-connects!)
- Connect each non-supply pin individually to Terminal A and stress it against all other non-supply pins commonly connected to Terminal B ("IO test")

HBM Testing JS-001 Table 2A – Stress Strategy

- Select all *N* supply pin groups and sort the supply pin groups 1 to *N*
- Select the 1st supply pin group and connect it to Terminal B – connect all other supply pins and all non-supply pins associated to Supply 1 individually to Terminal A and stress it
- Continue with 2nd to *N*th pin group and connect it to Terminal B – connect all other supply pins and all non-supply pins associated to this supply group individually to Terminal A and stress it
- Connect one pin of each coupled non-supply pin pair and connect it to Terminal B – connect the other pin of the coupled non-supply pin pair to Terminal A and stress it, one pin pair at a time ("I/O Test")

Table 2A defines the minimum set of required pin pair combinations!

HBM Testing JS-001 Table 2A – Test Strategy

- In general, the "minimum required pin combination set" according to Table 2A can be split into:
  - A "matrix test" (supply test)
  - An "intra-domain test" (all non-supply pins associated to one supply are stressed against this supply, the group of non-supply pins + supply pin could be seen as "domain") – difference to Table 2B
  - IO test
- Recommendation: Use different set of devices for matrix test, intra-domain test, and IO test
  → in case of failures, the possible discharge path and the mechanism causing the failure can be easily narrowed-down

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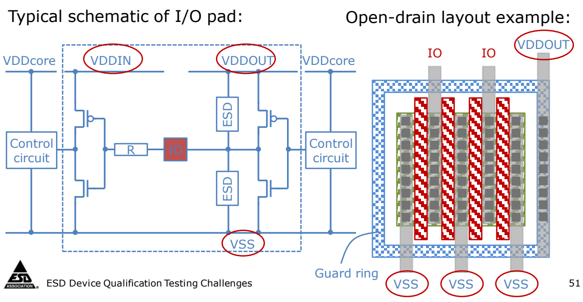
HBM Testing JS-001 Table 2A: Coupled Non-Supply Pin Pairs

- Per JS-001: Two pins that have an intended direct current path (such as a pass gate or resistors)
- Examples for coupled pin pairs (see Annex D of JS-001)
  - USB data pins (e.g., D+/D-)
  - PCI data pins (e.g., TXN/TXP, RXN, RXP)
  - Crystal pin pairs (e.g., XTALOUT, XTALIN)
  - Differential amplifier inputs, LNA inputs/outputs
- Note: IO test of Table 2B and Table 2A can be exchanged, e.g., if
  - Coupled pin pairs are unknown, IO test of Table 2B has to be used
  - Too many coupled pin pairs exist, IO test of Table 2B may be used

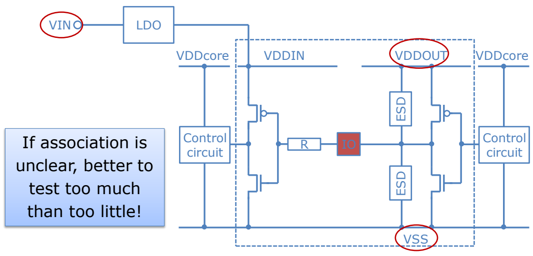
ESD Device Qualification Testing Challenges 50

The Mystery of "Association" – Examples (1)



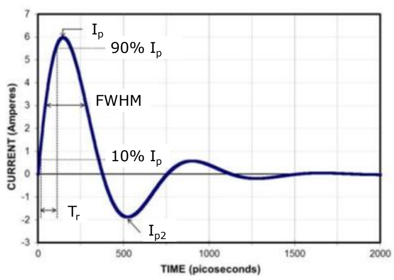
ESD Device Qualification Testing Challenges 51

The Mystery of "Association" – Examples (2)



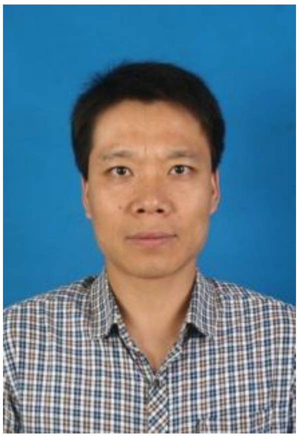
ESD Device Qualification Testing Challenges 52

CDM – Waveform Parameters



ESD Device Qualification Testing Challenges 53

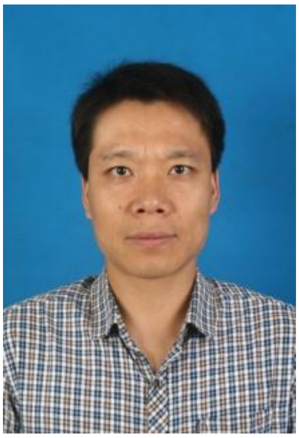
原青云



原青云，男，1979－，博士，全国电磁兼容标准化技术委员会高频现象分技术委员会委员，ISO/IEC 工作组（TC 77/SC 77B/MT12）专家。2003 年毕业于军械工程学院计算机应用专业，获学士学位；2006 年毕业于军械工程学院武器系统与运用工程专业，获硕士学位；2010 年毕业于军械工程学院武器系统与运用工程专业，获博士学位，师从刘尚合院士。

主持、参与和完成包括国防 973、国家自然科学基金、“十二五”装备预研基金等课题 16 项，获军队科技进步一等奖 1 项、二等奖 2 项，受理/授权国家发明专利 12 项，发表学术论文 40 余篇，主编/参编著作 2 部。研究方向为装备静电安全性研究，主要包括 ESD 抗扰度测试、静电理论、静电测试、静电防护等。

Yuan Qingyun



Yuan Qingyun, male, 1979 -, doctor, commissioner of high frequency phenomena sub-technical committee, National electromagnetic compatibility standardization technical committee, expert of ISO/IEC （TC 77/SC 77B/MT12）workgroup. In 2003, he graduated from Computer Applications Major, Ordnance Engineering College with a baccalaureate; in 2006, he graduated from Weapon System and Application Engineering Major, Ordnance Engineering College with a master's degree. In 2010, he graduated from Weapon System and Application Engineering Major, Ordnance Engineering College with a doctorate. He studied under Academician Liu Shanghe.

He chaired, participated in and completed 16 projects including national defense 973, national natural science foundation, "the 12th Five-Year Plan" equipment and advanced research fund, etc , won 1 first prize of military science and technology progress, 2 second prizes, accepted / authorized 12 national invention patents, published over 40 academic papers, edited/participated in 2 works.

The research direction is the study of equipment electrostatic safety, mainly including ESD immunity test, electrostatic theory, electrostatic test, ESD protection, etc.

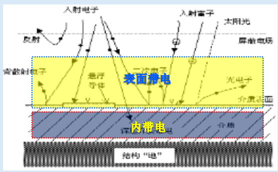
空间装备静电起电/放电模拟及防护技术研究

原青云
电磁环境效应国家重点实验室
2017.11.10 贵州·贵阳

汇报内容

- 航天器静电起电/放电效应的危害
- 空间装备带电环境地面模拟及测试技术
- 空间装备静电防护技术

航天器静电起电/放电效应的危害



航天器静电起电/放电效应，是指航天器在空间轨道运行时，与空间等离子体、高能电子和太阳辐射等环境相互作用而发生的静电电荷积累及泄放过程，又被称为航天器带电效应。

航天器静电起电/放电效应的危害

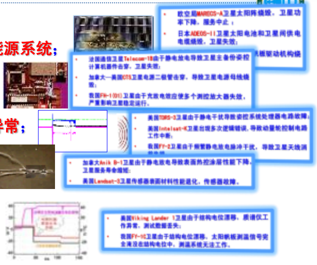
航天器静电起电/放电效应通常会造成灾难性故障，严重威胁航天器在轨安全运行。

- 2007年NASA统计了4家权威机构数据库，表明在国外发生的326起空间环境引发的卫星故障中，起电/放电效应占54.2%。
- 2012年日本统计了起电/放电效应引起的空间环境异常为54%（161/298）。

国外空间环境故障的比例图

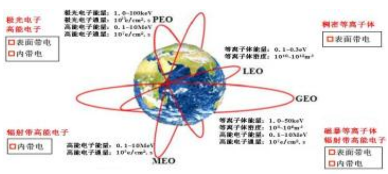
航天器静电起电/放电效应的危害

- 造成供配电系统短路，破坏航天器能源系统；
- 击穿元器件，破坏航天器电子系统；
- 产生电磁脉冲干扰，造成电路工作异常；
- 击穿功能材料，影响材料性能；
- 导致结构电位漂移，影响测量系统；
- ··· ···



航天器静电起电/放电效应的危害

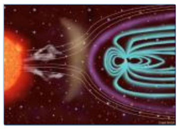
在不同轨道上，由于空间带电环境不同，航天器静电起电/放电效应也表现出不同的形式。



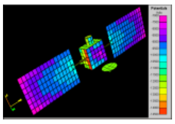
航天器静电起电/放电效应的危害

□ GEO轨道静电起电/放电效应

地磁亚暴期间，GEO轨道产生大通量高能等离子体，使航天器表面充电至万伏以上。



地磁亚暴现象示意图



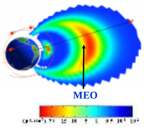
卫星表面电位分布

我国的新型通信和气象等卫星表面采用了不同材料，在高能等离子体环境中，卫星各部位会充电至不同的电位，起电/放电效应将会严重影响卫星的安全。

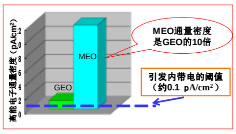
航天器静电起电/放电效应的危害

□ MEO轨道静电起电/放电效应

MEO处于地球外辐射带内侧，是空间辐射环境最恶劣的地球轨道，其电子能量最高可达10MeV，高能电子通量是GEO轨道的10倍以上，导致航天器内带电效应严重。



MEO轨道空间辐射环境



我国的大部分二代导航卫星处于MEO轨道，其空间高能电子引起的卫星内带电效应突出，将严重影响卫星研制和在轨组网。

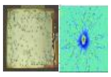
航天器静电起电/放电效应的危害

□ LEO轨道静电起电/放电效应

LEO带电环境为稠密低温等离子体，当它与航天器高压太阳电池阵作用时，太阳电池收集大量电子，导致结构电位漂移，诱发静电放电。

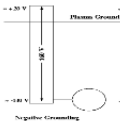
交会对接产生放电

舱外活动中宇航员生命安全



热控涂层击穿

太阳电池击穿



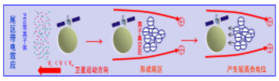
国际空间站在等离子体中的充电电位

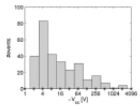
我国的空间站采用了100V以上高压太阳电池阵，与空间稠密等离子体作用后，将造成热控涂层击穿、太阳电池击穿和交会对接放电，危及舱外活动中宇航员生命安全。

航天器静电起电/放电效应的危害

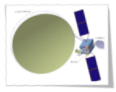
□ PEO轨道静电起电/放电效应

在PEO轨道（高倾角LEO），卫星速度大于离子速度而远小于电子速度，在尾部形成的离子"真空"区。同时，极区存在高能大通量的极光沉降电子，由于缺乏离子中和，大尺寸卫星尾部表面会形成较高的负电位，该现象称为尾区带电效应。





freja卫星带电事件统计结果



高分辨对地观测卫星

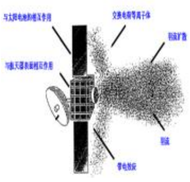
我国未来的高分辨对地观测卫星将采用大尺寸天线等部件，尾区带电效应将严重影响卫星电子系统的在轨安全。

航天器静电起电/放电效应的危害

□电推进产生等离子体诱发静电起电/放电效应

航天器采用电推进技术后，电推进将产生低能稠密人为等离子体，与空间等离子体（高能稀薄）存在较大差异，从而影响航天器带电环境和表面充电电位。

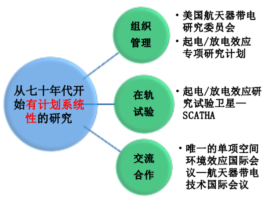
我国未来多型卫星将会采用电推进技术，空间等离子体与人为等离子体相互叠加，将使卫星带电环境更加复杂。



电推进产生等离子体与航天器作用示意图

空间装备带电环境地面模拟及测试技术

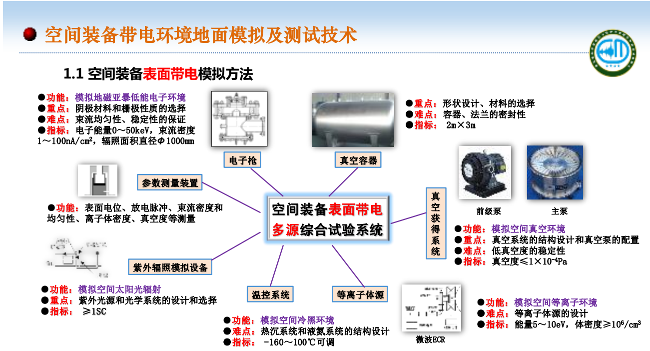
国外十分重视航天器静电起电/放电效应的研究



SCATHA
带电技术试验卫星

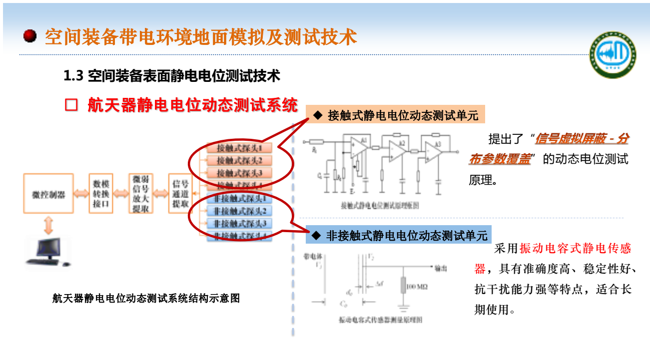
带电技术国际会议论文集

空间装备带电环境地面模拟及测试技术
空间带电环境地面模拟装置
美国CEETC3
美国AZTech
美国REEF
法国SIRENE
法国SEMIRAMIS
日本武藏工业大学
VS
兰州510所
中科院空间科学与应用研究中心
兰州510所
电磁环境效应国家重点实验室
国外
国内



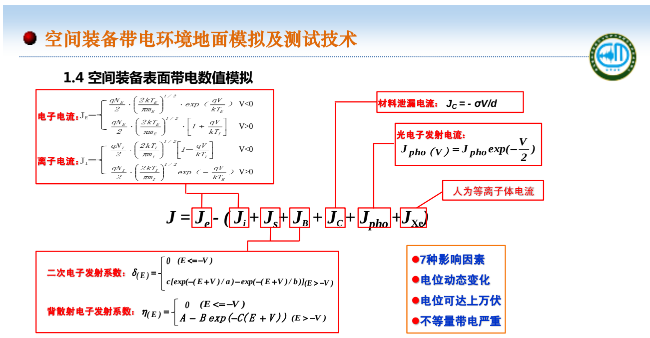
空间装备带电环境地面模拟及测试技术
1.1 空间装备表面带电模拟方法
空间装备表面带电多源综合试验系统
电子枪
真空容器
参数测量装置
紫外辐照模拟设备
温控系统
等离子体源
真空获得系统
前级泵
主泵
微波ECR

空间装备带电环境地面模拟及测试技术
1.2 空间介质内带电模拟方法
空间介质内带电试验系统
电子加速器
真空容器+屏蔽体
参数测量装置
温控系统
真空获得系统
前级泵
主泵

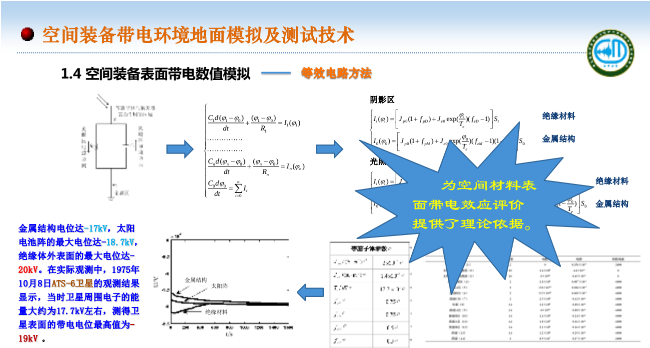


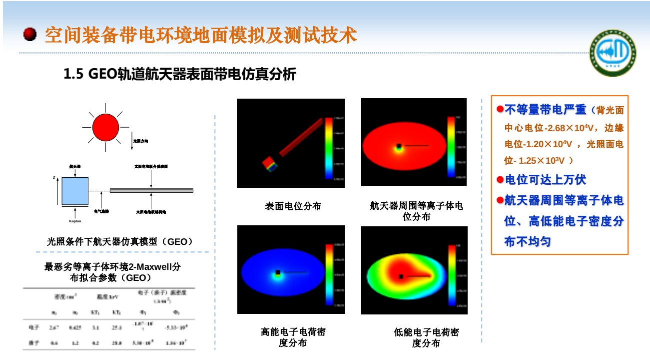
空间装备带电环境地面模拟及测试技术
1.3 空间装备表面静电电位测试技术
航天器静电电位动态测试系统
接触式静电电位动态测试单元
非接触式静电电位动态测试单元
提出了“信号虚拟屏蔽-分布参数匹配”的动态电位测试原理。
采用振动电容式静电传感器，具有准确度高、稳定性好、抗干扰能力强等特点，适合长期使用。
航天器静电电位动态测试系统结构示意图

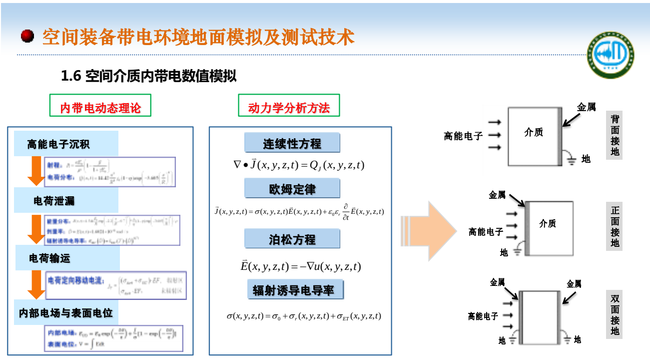
空间装备带电环境地面模拟及测试技术
1.3 空间装备表面静电电位测试技术
航天器静电电位动态测试系统
航天器静电电位动态测试系统结构示意图
响应带宽：直流~1 kHz

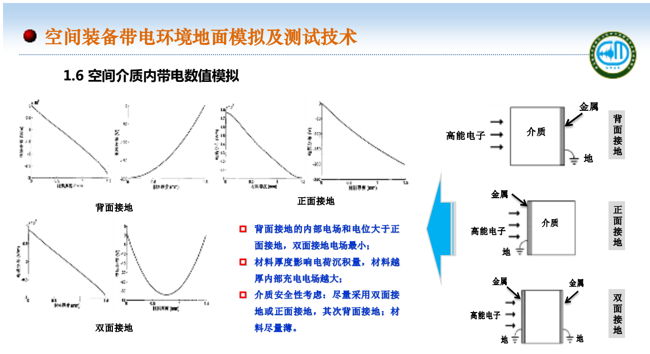


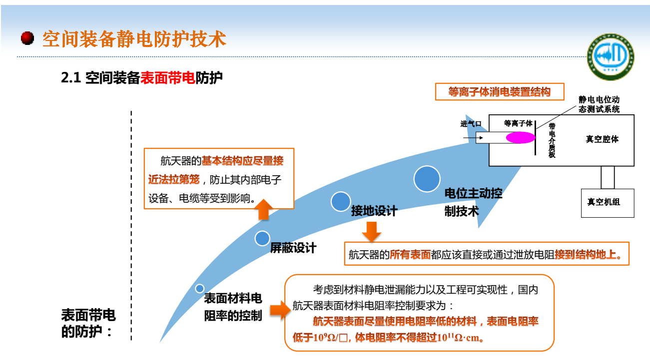
空间装备带电环境地面模拟及测试技术
1.4 空间装备表面带电数值模拟
电子电流
离子电流
材料泄漏电流：Jc = - σV/d
光电子发射电流
人为等离子体电流
二次电子发射系数
背散射电子发射系数
7种影响因素
电位动态变化
电位可达上万伏
不等量带电严重

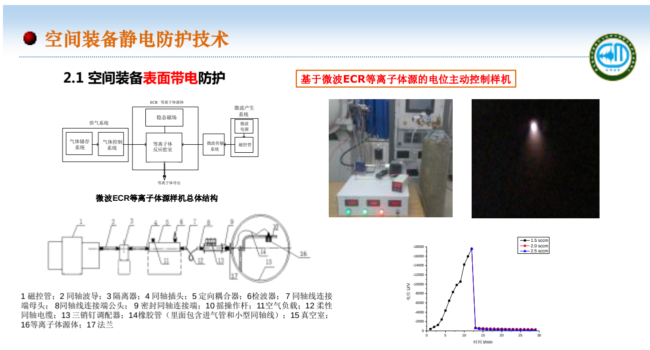

空间装备带电环境地面模拟及测试技术
1.4 空间装备表面带电数值模拟
等效电路方法
阴影区
绝缘材料
金属结构
为空间材料表面带电效应评价提供了理论依据。
金属结构电位达-17kV，太阳电池阵的最大电位达-18.7kV，绝缘体外表面的最大电位达-20kV。在实际观测中，1975年10月8日ATS-6卫星的观测结果显示，当时卫星周围电子的能量大约为17.7kV左右，测得卫星表面的带电电位最高值为-19kV。

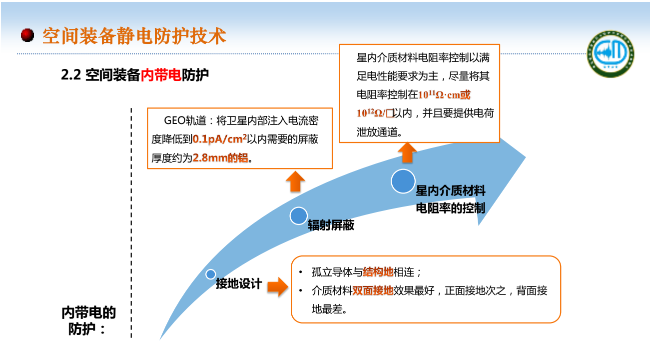

空间装备带电环境地面模拟及测试技术
1.5 GEO轨道航天器表面带电仿真分析
光照条件下航天器仿真模型（GEO）
最恶劣等离子体环境2-Maxwell分布拟合参数（GEO）
表面电位分布
航天器周围等离子体电位分布
高能电子电荷密度分布
低能电子电荷密度分布
●不等量带电严重（背光面中心电位-2.68×10⁴V，边缘电位-1.20×10⁴V，光照面电位-1.25×10⁴V）
●电位可达上万伏
●航天器周围等离子体电位、高低能电子密度分布不均匀

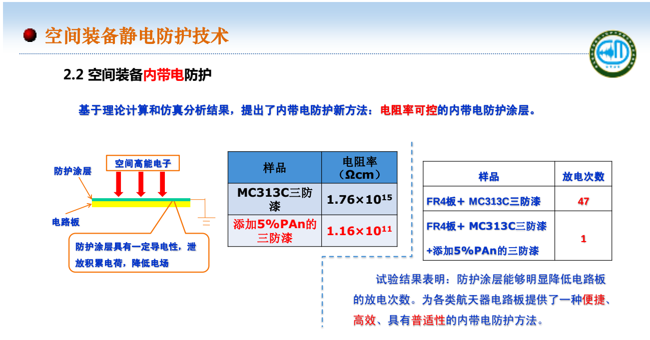

空间装备带电环境地面模拟及测试技术
1.6 空间介质内带电数值模拟
内带电动态理论
动力学分析方法
高能电子沉积
电荷泄漏
电荷输运
内部电场与表面电位
连续性方程
欧姆定律
泊松方程
辐射诱导电导率
高能电子
介质
金属
地
背面接地
正面接地
双面接地


空间装备带电环境地面模拟及测试技术
1.6 空间介质内带电数值模拟
背面接地
正面接地
双面接地
背面接地的内部电场和电位大于正面接地，双面接地电场最小；
材料厚度影响电荷沉积量，材料越厚内部充电电场越大；
介质安全性考虑：尽量采用双面接地或正面接地，其次背面接地；材料尽量薄。
高能电子
介质
金属
地
背面接地
正面接地
双面接地

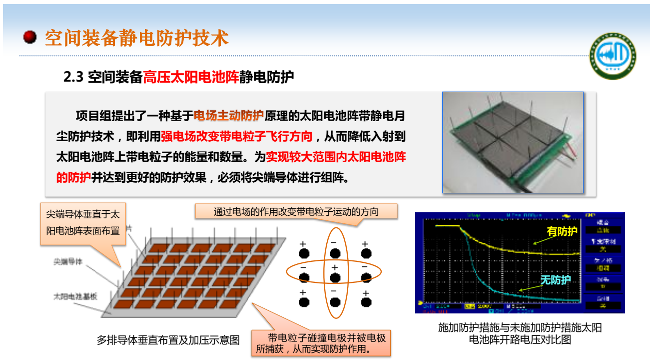

空间装备静电防护技术
2.1 空间装备表面带电防护
等离子体消电装置结构
静电电位动态测试系统
等离子体
进气口
真空腔体
真空机组
航天器的基本结构应尽量接近法拉第笼，防止其内部电子设备、电缆等受到影响。
电位主动控制技术
接地设计
屏蔽设计
航天器的所有表面都应该直接或通过泄放电阻接到结构地上。
表面材料电阻率的控制
考虑到材料静电泄漏能力以及工程可实现性，国内航天器表面材料电阻率控制要求为：
航天器表面尽量使用电阻率低的材料，表面电阻率低于10⁹Ω/□，体电阻率不得超过10¹¹Ω·cm。
表面带电的防护：

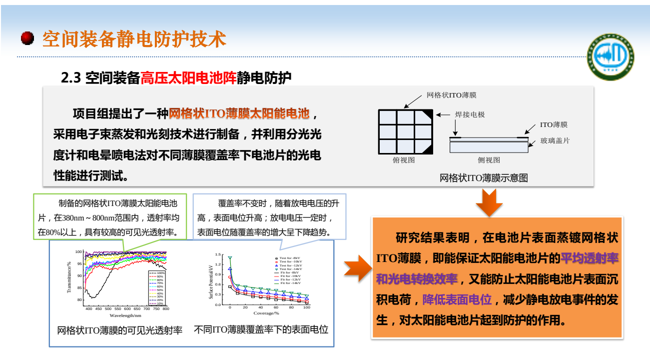

空间装备静电防护技术
2.1 空间装备表面带电防护
基于微波ECR等离子体源的电位主动控制样机
微波ECR等离子体源样机总体结构


空间装备静电防护技术
2.2 空间装备内带电防护
星内介质材料电阻率控制以满足电性能要求为主，尽量将其电阻率控制在10¹¹Ω·cm或10¹²Ω/□以内，并且要提供电荷泄放通道。
GEO轨道：将卫星内部注入电流密度降低到0.1pA/cm²以内需要的屏蔽厚度约为2.8mm的铝。
星内介质材料电阻率的控制
辐射屏蔽
接地设计
孤立导体与结构地相连；
介质材料双面接地效果最好，正面接地次之，背面接地最差。
内带电的防护：


空间装备静电防护技术
2.2 空间装备内带电防护
基于理论计算和仿真分析结果，提出了内带电防护新方法：电阻率可控的内带电防护涂层。
防护涂层
空间高能电子
电路板
防护涂层具有一定导电性，泄放积累电荷，降低电场
样品
电阻率（Ωcm）
MC313C三防漆
1.76×10¹⁵
添加5%PAn的三防漆
1.16×10¹¹
样品
放电次数
FR4板+ MC313C三防漆
47
FR4板+ MC313C三防漆+添加5%PAn的三防漆
1
试验结果表明：防护涂层能够明显降低电路板的放电次数。为各类航天器电路板提供了一种便捷、高效、具有普适性的内带电防护方法。


空间装备静电防护技术
2.3 空间装备高压太阳电池阵静电防护
高压太阳电池阵表面ESD模拟试验
典型放电脉冲波形
高压太阳阵样品表面产生ESD比较随机，主要发生在汇流条、互连片以及电池边缘。
试验显示，没有保护措施的高压太阳电池阵表面产生ESD的电压阈值为500V，产生二次放电的电压阈值为70V。
高压太阳电池阵表面二次放电模拟试验
二次放电时电池串之间击穿瞬间
样品电池A与电池B之间的Kapton 基底材料热解为导电碳化层，电池A和电池B的PN结被击穿短路。


空间装备静电防护技术
2.3 空间装备高压太阳电池阵静电防护
项目组提出了一种基于电场主动防护原理的太阳电池阵带静电月尘防护技术，即利用强电场改变带电粒子飞行方向，从而降低入射到太阳电池阵上带电粒子的能量和数量。为实现较大范围内太阳电池阵的防护并达到更好的防护效果，必须将尖端导体进行组阵。
尖端导体垂直于太阳电池阵表面布置
通过电场的作用改变带电粒子运动的方向
多排导体垂直布置及加压示意图
带电粒子碰撞电极并被电极所捕获，从而实现防护作用。
有防护
无防护
施加防护措施与未施加防护措施太阳电池阵开路电压对比图


空间装备静电防护技术
2.3 空间装备高压太阳电池阵静电防护
项目组提出了一种网格状ITO薄膜太阳能电池，采用电子束蒸发和光刻技术进行制备，并利用分光光度计和电晕喷电法对不同薄膜覆盖率下电池片的光电性能进行测试。
网格状ITO薄膜
焊接电极
ITO薄膜
玻璃盖片
俯视图
侧视图
网格状ITO薄膜示意图
制备的网格状ITO薄膜太阳能电池片，在380nm～800nm范围内，透射率均在80%以上，具有较高的可见光透射率。
覆盖率不变时，随着放电电压的升高，表面电位升高；放电电压一定时，表面电位随着覆盖率的增大呈下降趋势。
网格状ITO薄膜的可见光透射率
不同ITO薄膜覆盖率下的表面电位
研究结果表明，在电池片表面蒸镀网格状ITO薄膜，即能保证太阳能电池片的平均透射率和光电转换效率，又能防止太阳能电池片表面沉积电荷，降低表面电位，减少静电放电事件的发生，对太阳能电池片起到防护的作用。

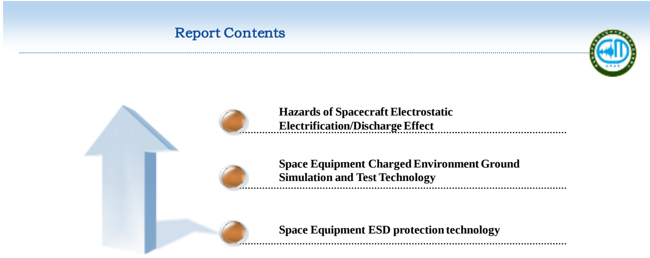

空间装备静电防护技术
2.3 空间装备高压太阳电池阵静电防护
在进行太阳电池阵设计时，优化太阳电池阵电路布置方式，使相邻电池之间电位低于二次放电的阈值电压，可以有效抑制二次放电的发生。
100V
50V
相邻太阳电池串间的电压为50V
单串太阳阵电池组件结构
电路总电流为4A
三并太阳阵电池组件结构
串电流为1.4A
设计上保证电池串得到的有用电流不足以维持电弧，才能避免由于长时间放电而引起的材料热解。

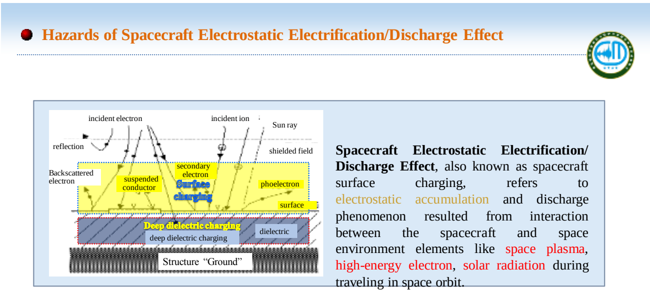
结束语

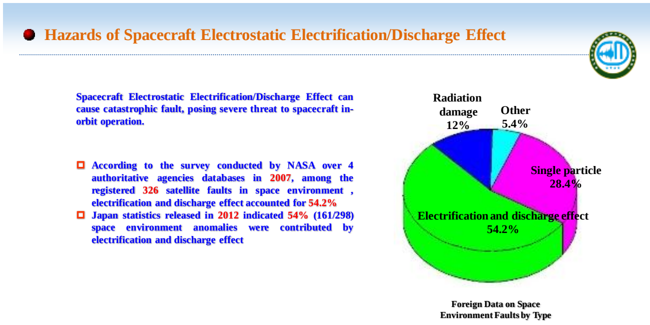
影响空间装备静电起电/放电效应的因素众多，机理复杂，在带电环境地面模拟和静电防护方面的研究相对薄弱。虽然近年来实验室在地面模拟和防护方法方面取得了一系列成果，但要彻底解决空间装备静电起电/放电问题，还需要深入开展相关的基础理论、模拟方法和防护技术研究。

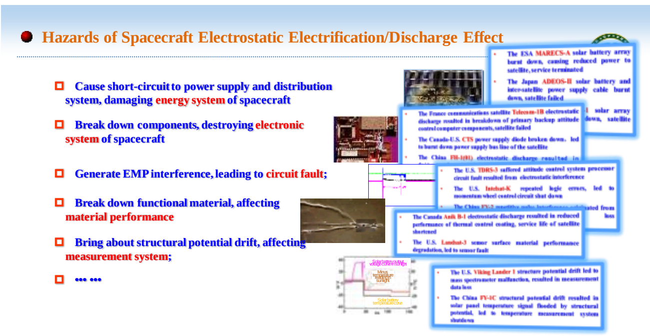
汇报结束，谢谢！

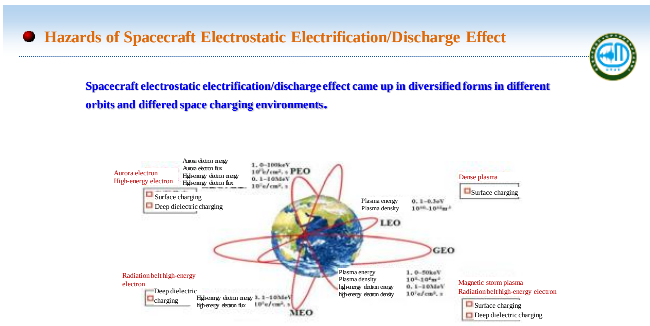

A Study on Space Equipment Electrostatic Electrification/Discharge Simulation and Protection Technology
YUAN Qingyun
State Key Laboratory of Electromagnetic Environment Effects
Nov. 10 2017
Guiyang·Guizhou

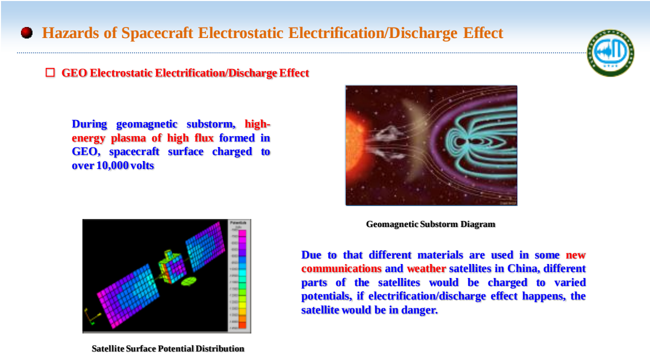

Report Contents
Hazards of Spacecraft Electrostatic Electrification/Discharge Effect
Space Equipment Charged Environment Ground Simulation and Test Technology
Space Equipment ESD protection technology

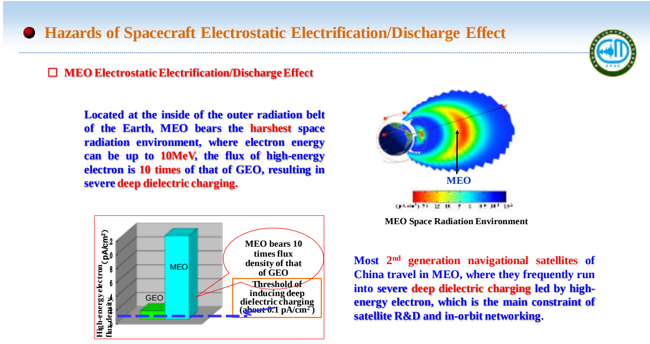

Hazards of Spacecraft Electrostatic Electrification/Discharge Effect
incident electron
incident ion
Sun ray
reflection
shielded field
Backscattered electron
suspended conductor
secondary electron
Surface charging
phoelectron
surface
Deep dielectric charging
deep dielectric charging
dielectric
Structure "Ground"
Spacecraft Electrostatic Electrification/ Discharge Effect, also known as spacecraft surface charging, refers to electrostatic accumulation and discharge phenomenon resulted from interaction between the spacecraft and space environment elements like space plasma, high-energy electron, solar radiation during traveling in space orbit.

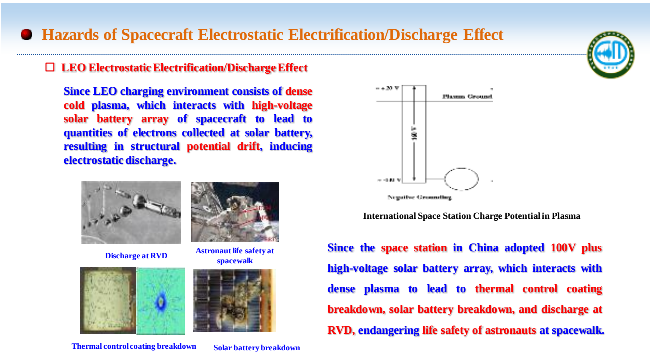

Hazards of Spacecraft Electrostatic Electrification/Discharge Effect
Spacecraft Electrostatic Electrification/Discharge Effect can cause catastrophic fault, posing severe threat to spacecraft in-orbit operation.
According to the survey conducted by NASA over 4 authoritative agencies databases in 2007, among the registered 326 satellite faults in space environment, electrification and discharge effect accounted for 54.2%
Japan statistics released in 2012 indicated 54% (161/298) space environment anomalies were contributed by electrification and discharge effect
Radiation damage 12%
Other 5.4%
Single particle 28.4%
Electrification and discharge effect 54.2%
Foreign Data on Space Environment Faults by Type

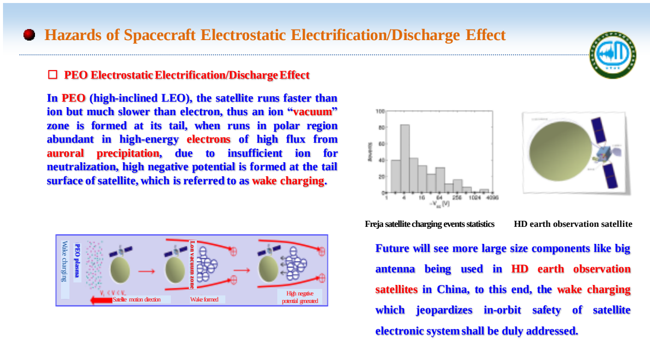

Hazards of Spacecraft Electrostatic Electrification/Discharge Effect
Cause short-circuit to power supply and distribution system, damaging energy system of spacecraft
Break down components, destroying electronic system of spacecraft
Generate EMP interference, leading to circuit fault;
Break down functional material, affecting material performance
Bring about structural potential drift, affecting measurement system;
••• •••
The ESA MARECS-A solar battery array burnt down, causing reduced power to satellite, service terminated
The Japan ADEOS-II solar battery and inter-satellite power supply cable burnt down, satellite failed
The France communications satellite Telecom-1B electrostatic discharge resulted in breakdown of primary backup attitude control computer components, satellite failed
The Canada-U.S. CTS power supply diode broken down, led to burnt down power supply bus line of the satellite
The U.S. TDRS-3 suffered attitude control system processor circuit fault resulted from electrostatic interference
The U.S. Intelsat-K repeated logic errors, led to momentum wheel control circuit shut down
The Canada Anik B-1 electrostatic discharge resulted in reduced performance of thermal control coating, service life of satellite shortened
The U.S. Landsat-3 sensor surface material performance degradation, led to sensor fault
The U.S. Viking Lander 1 structure potential drift led to mass spectrometer malfunction, resulted in measurement data loss
The China FY-1C structural potential drift resulted in solar panel temperature signal flooded by structural potential, led to temperature measurement system shutdown

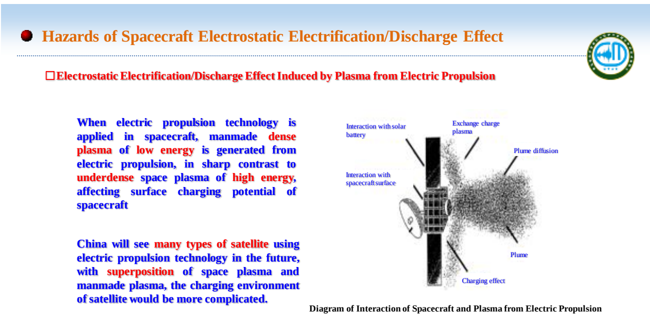

Hazards of Spacecraft Electrostatic Electrification/Discharge Effect
Spacecraft electrostatic electrification/discharge effect came up in diversified forms in different orbits and differed space charging environments.
Aurora electron
High-energy electron
Surface charging
Deep dielectric charging
PEO
Dense plasma
Surface charging
LEO
GEO
Radiation belt high-energy electron
Deep dielectric charging
Magnetic storm plasma
Radiation belt high-energy electron
Surface charging
Deep dielectric charging
MEO

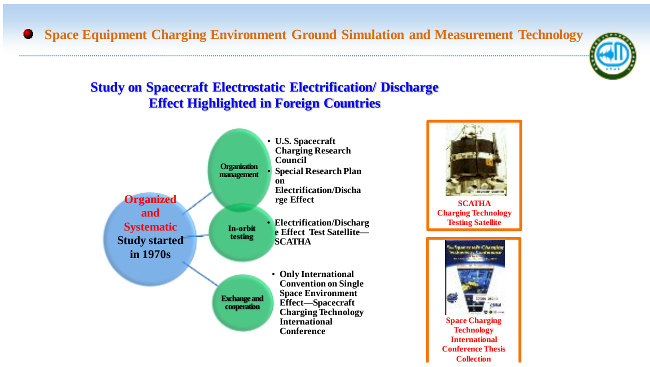

Hazards of Spacecraft Electrostatic Electrification/Discharge Effect
GEO Electrostatic Electrification/Discharge Effect
During geomagnetic substorm, high-energy plasma of high flux formed in GEO, spacecraft surface charged to over 10,000 volts
Geomagnetic Substorm Diagram
Satellite Surface Potential Distribution
Due to that different materials are used in some new communications and weather satellites in China, different parts of the satellites would be charged to varied potentials, if electrification/discharge effect happens, the satellite would be in danger.

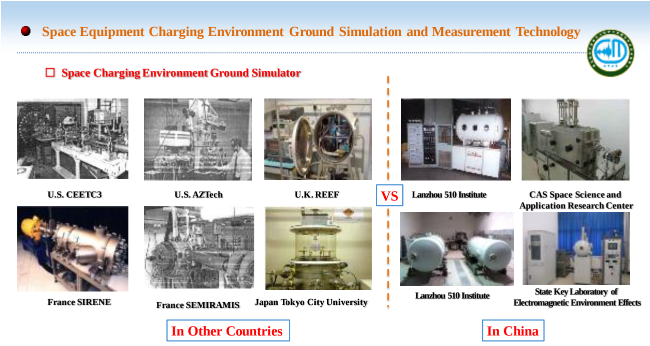

Hazards of Spacecraft Electrostatic Electrification/Discharge Effect
MEO Electrostatic Electrification/Discharge Effect
Located at the inside of the outer radiation belt of the Earth, MEO bears the harshest space radiation environment, where electron energy can be up to 10MeV, the flux of high-energy electron is 10 times of that of GEO, resulting in severe deep dielectric charging.
MEO
MEO Space Radiation Environment
High-energy electron flux density (pA/cm²)
MEO
GEO
MEO bears 10 times flux density of that of GEO
Threshold of inducing deep dielectric charging (about 0.1 pA/cm²)
Most 2nd generation navigational satellites of China travel in MEO, where they frequently run into severe deep dielectric charging led by high-energy electron, which is the main constraint of satellite R&D and in-orbit networking.

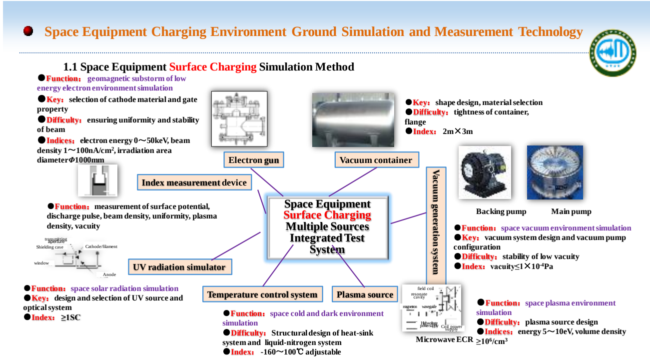

Hazards of Spacecraft Electrostatic Electrification/Discharge Effect
LEO Electrostatic Electrification/Discharge Effect
Since LEO charging environment consists of dense cold plasma, which interacts with high-voltage solar battery array of spacecraft to lead to quantities of electrons collected at solar battery, resulting in structural potential drift, inducing electrostatic discharge.
Plasma Ground
Negative Grounding
International Space Station Charge Potential in Plasma
Discharge at RVD
Astronaut life safety at spacewalk
Thermal control coating breakdown
Solar battery breakdown
Since the space station in China adopted 100V plus high-voltage solar battery array, which interacts with dense plasma to lead to thermal control coating breakdown, solar battery breakdown, and discharge at RVD, endangering life safety of astronauts at spacewalk.

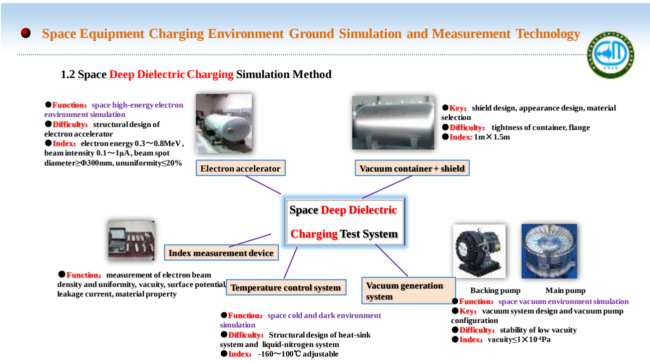

Hazards of Spacecraft Electrostatic Electrification/Discharge Effect
PEO Electrostatic Electrification/Discharge Effect
In PEO (high-inclined LEO), the satellite runs faster than ion but much slower than electron, thus an ion "vacuum" zone is formed at its tail, when runs in polar region abundant in high-energy electrons of high flux from auroral precipitation, due to insufficient ion for neutralization, high negative potential is formed at the tail surface of satellite, which is referred to as wake charging.
Freja satellite charging events statistics
HD earth observation satellite
Future will see more large size components like big antenna being used in HD earth observation satellites in China, to this end, the wake charging which jeopardizes in-orbit safety of satellite electronic system shall be duly addressed.

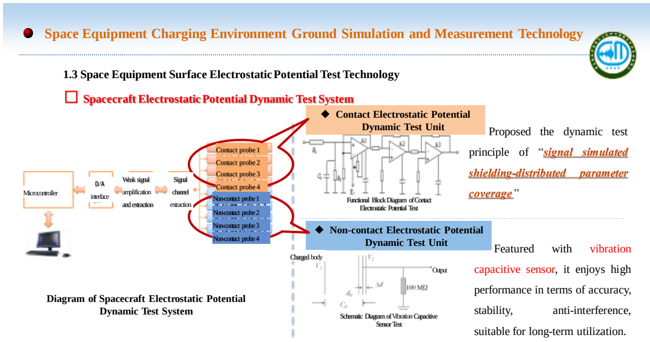

Hazards of Spacecraft Electrostatic Electrification/Discharge Effect
Electrostatic Electrification/Discharge Effect Induced by Plasma from Electric Propulsion
When electric propulsion technology is applied in spacecraft, manmade dense plasma of low energy is generated from electric propulsion, in sharp contrast to underdense space plasma of high energy, affecting surface charging potential of spacecraft
China will see many types of satellite using electric propulsion technology in the future, with superposition of space plasma and manmade plasma, the charging environment of satellite would be more complicated.
Interaction with solar battery
Exchange charge plasma
Plume diffusion
Interaction with spacecraft surface
Plume
Charging effect
Diagram of Interaction of Spacecraft and Plasma from Electric Propulsion

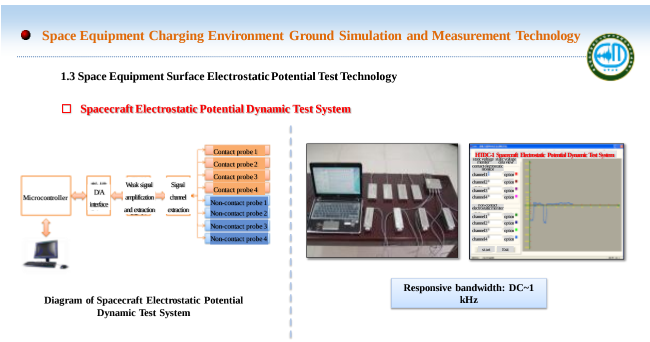

Space Equipment Charging Environment Ground Simulation and Measurement Technology
Study on Spacecraft Electrostatic Electrification/ Discharge Effect Highlighted in Foreign Countries
Organized and Systematic Study started in 1970s
Organization management
In-orbit testing
Exchange and cooperation
U.S. Spacecraft Charging Research Council
Special Research Plan on Electrification/Discharge Effect
Electrification/Discharge Effect Test Satellite—SCATHA
Only International Convention on Single Space Environment Effect—Spacecraft Charging Technology International Conference
SCATHA Charging Technology Testing Satellite
Space Charging Technology International Conference Thesis Collection

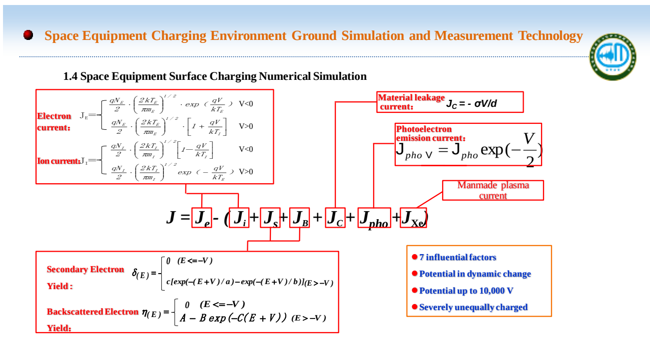

Space Equipment Charging Environment Ground Simulation and Measurement Technology
Space Charging Environment Ground Simulator
U.S. CEETC3
U.S. AZTech
U.K. REEF
VS
Lanzhou 510 Institute
CAS Space Science and Application Research Center
France SIRENE
France SEMIRAMIS
Japan Tokyo City University
Lanzhou 510 Institute
State Key Laboratory of Electromagnetic Environment Effects
In Other Countries
In China

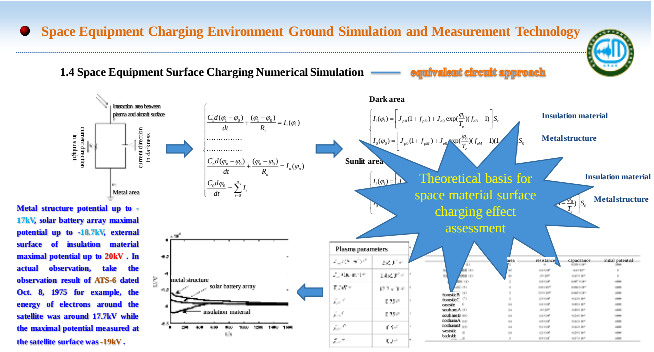

Space Equipment Charging Environment Ground Simulation and Measurement Technology
1.1 Space Equipment Surface Charging Simulation Method
Function: geomagnetic substorm of low energy electron environment simulation
Key: selection of cathode material and gate property
Difficulty: ensuring uniformity and stability of beam
Indices: electron energy 0~50keV, beam density 1~100nA/cm², irradiation area diameter Φ1000mm
Electron gun
Vacuum container
Key: shape design, material selection
Difficulty: tightness of container, flange
Index: 2m×3m
Index measurement device
Function: measurement of surface potential, discharge pulse, beam density, uniformity, plasma density, vacuity
Space Equipment Surface Charging Multiple Sources Integrated Test System
Vacuum generation system
Backing pump
Main pump
Function: space vacuum environment simulation
Key: vacuum system design and vacuum pump configuration
Difficulty: stability of low vacuity
Index: vacuity≤1×10⁻⁴Pa
UV radiation simulator
Function: space solar radiation simulation
Key: design and selection of UV source and optical system
Index: ≥1SC
Temperature control system
Plasma source
Function: space cold and dark environment simulation
Difficulty: Structural design of heat-sink system and liquid-nitrogen system
Index: -160~100℃ adjustable
Microwave ECR
Function: space plasma environment simulation
Difficulty: plasma source design
Indices: energy 5~10eV, volume density ≥10⁶/cm³

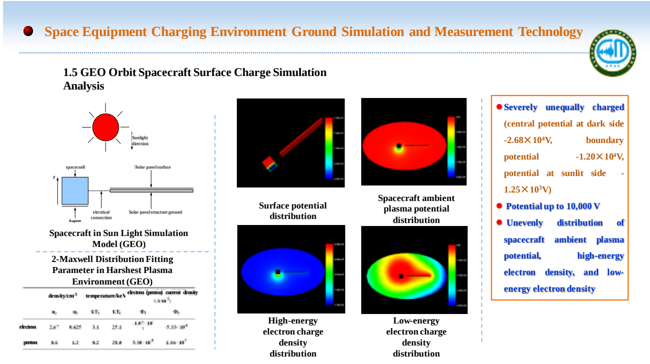

Space Equipment Charging Environment Ground Simulation and Measurement Technology
1.2 Space Deep Dielectric Charging Simulation Method
Function: space high-energy electron environment simulation
Difficulty: structural design of electron accelerator
Index: electron energy 0.3~0.8MeV, beam intensity 0.1~1μA, beam spot diameter≥Φ300mm, ununiformity≤20%
Electron accelerator
Key: shield design, appearance design, material selection
Difficulty: tightness of container, flange
Index: 1m×1.5m
Vacuum container + shield
Space Deep Dielectric Charging Test System
Index measurement device
Function: measurement of electron beam density and uniformity, vacuity, surface potential, leakage current, material property
Temperature control system
Vacuum generation system
Backing pump
Main pump
Function: space cold and dark environment simulation
Difficulty: Structural design of heat-sink system and liquid-nitrogen system
Index: -160~100℃ adjustable
Function: space vacuum environment simulation
Key: vacuum system design and vacuum pump configuration
Difficulty: stability of low vacuity
Index: vacuity≤1×10⁻⁴Pa

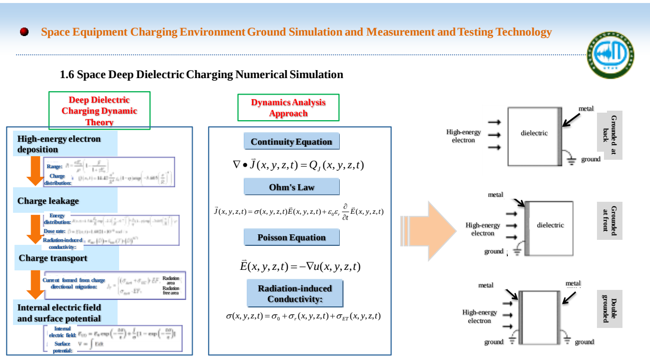

Space Equipment Charging Environment Ground Simulation and Measurement Technology
1.3 Space Equipment Surface Electrostatic Potential Test Technology
Spacecraft Electrostatic Potential Dynamic Test System
Contact Electrostatic Potential Dynamic Test Unit
Microcontroller
D/A interface
Weak signal amplification and extraction
Signal channel extraction
Contact probe 1
Contact probe 2
Contact probe 3
Contact probe 4
Non-contact probe 1
Non-contact probe 2
Non-contact probe 3
Non-contact probe 4
Functional Block Diagram of Contact Electrostatic Potential Test
Proposed the dynamic test principle of "signal simulated shielding-distributed parameter coverage"
Non-contact Electrostatic Potential Dynamic Test Unit
Featured with vibration capacitive sensor, it enjoys high performance in terms of accuracy, stability, anti-interference, suitable for long-term utilization.
Schematic Diagram of Vibration Capacitive Sensor Test
Diagram of Spacecraft Electrostatic Potential Dynamic Test System

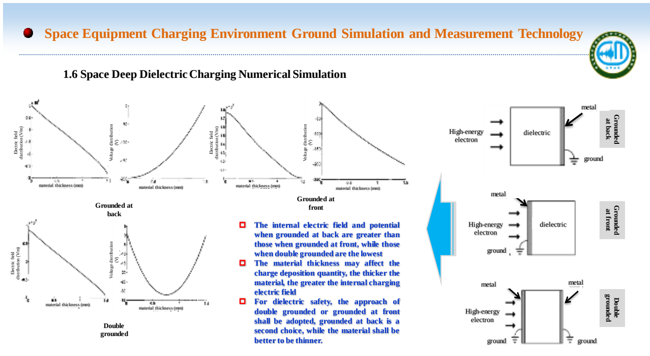

Space Equipment Charging Environment Ground Simulation and Measurement Technology
1.3 Space Equipment Surface Electrostatic Potential Test Technology
Spacecraft Electrostatic Potential Dynamic Test System
Microcontroller
D/A interface
Weak signal amplification and extraction
Signal channel extraction
Contact probe 1
Contact probe 2
Contact probe 3
Contact probe 4
Non-contact probe 1
Non-contact probe 2
Non-contact probe 3
Non-contact probe 4
Diagram of Spacecraft Electrostatic Potential Dynamic Test System
Responsive bandwidth: DC~1 kHz

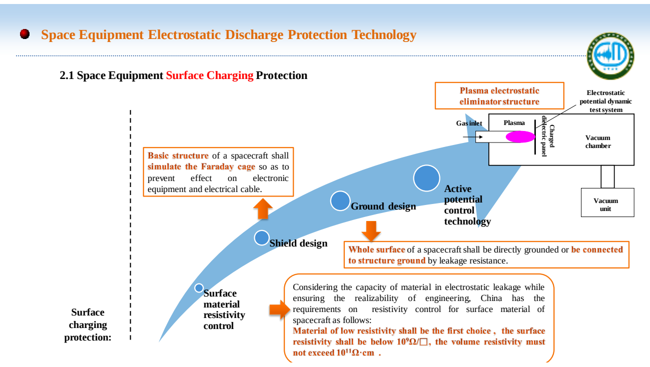

Space Equipment Charging Environment Ground Simulation and Measurement Technology
1.4 Space Equipment Surface Charging Numerical Simulation
Electron current:
Ion current:
Material leakage current: $J_C = -\sigma V/d$
Photoelectron emission current:
Manmade plasma current
$J = J_e - (J_i + J_s + J_B + J_C + J_{pho} + J_{Xe})$
Secondary Electron Yield:
Backscattered Electron Yield:
7 influential factors
Potential in dynamic change
Potential up to 10,000 V
Severely unequally charged

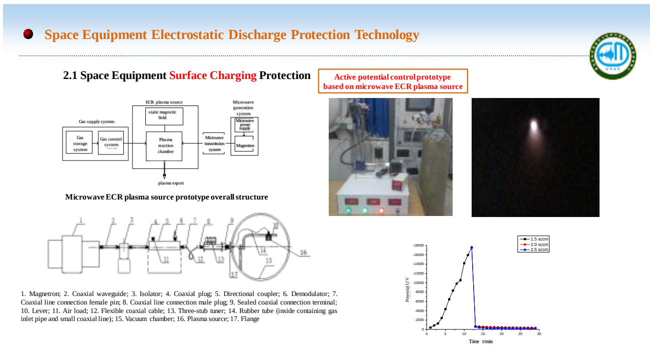

Space Equipment Charging Environment Ground Simulation and Measurement Technology
1.4 Space Equipment Surface Charging Numerical Simulation —— equivalent circuit approach
Dark area
Sunlit area
Insulation material
Metal structure
Theoretical basis for space material surface charging effect assessment
Metal structure potential up to -17kV, solar battery array maximal potential up to -18.7kV, external surface of insulation material maximal potential up to 20kV. In actual observation, take the observation result of ATS-6 dated Oct. 8, 1975 for example, the energy of electrons around the satellite was around 17.7kV while the maximal potential measured at the satellite surface was -19kV.
metal structure
solar battery array
insulation material
Plasma parameters

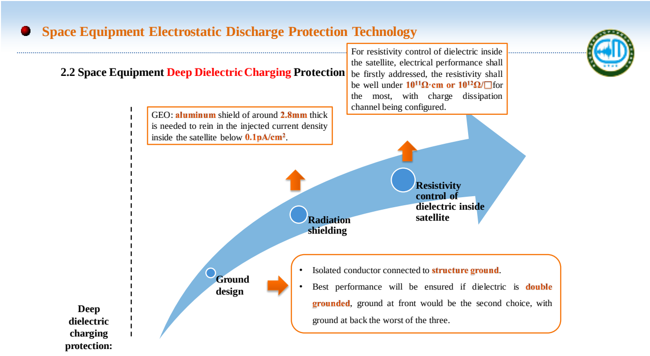

Space Equipment Charging Environment Ground Simulation and Measurement Technology
1.5 GEO Orbit Spacecraft Surface Charge Simulation Analysis
Spacecraft in Sun Light Simulation Model (GEO)
2-Maxwell Distribution Fitting Parameter in Harshest Plasma Environment (GEO)
Surface potential distribution
Spacecraft ambient plasma potential distribution
High-energy electron charge density distribution
Low-energy electron charge density distribution
Severely unequally charged (central potential at dark side -2.68×10⁴V, boundary potential -1.20×10⁴V, potential at sunlit side -1.25×10³V)
Potential up to 10,000 V
Unevenly distribution of spacecraft ambient plasma potential, high-energy electron density, and low-energy electron density

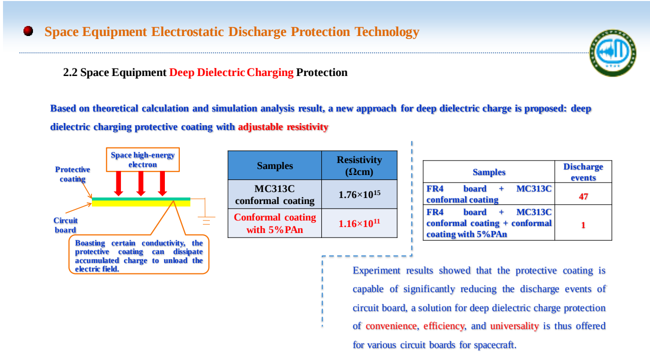

Space Equipment Charging Environment Ground Simulation and Measurement and Testing Technology
1.6 Space Deep Dielectric Charging Numerical Simulation
Deep Dielectric Charging Dynamic Theory
Dynamics Analysis Approach
High-energy electron deposition
Charge leakage
Charge transport
Internal electric field and surface potential
Continuity Equation
Ohm's Law
Poisson Equation
Radiation-induced Conductivity:
High-energy electron
dielectric
metal
ground
Grounded at back
Grounded at front
Double grounded

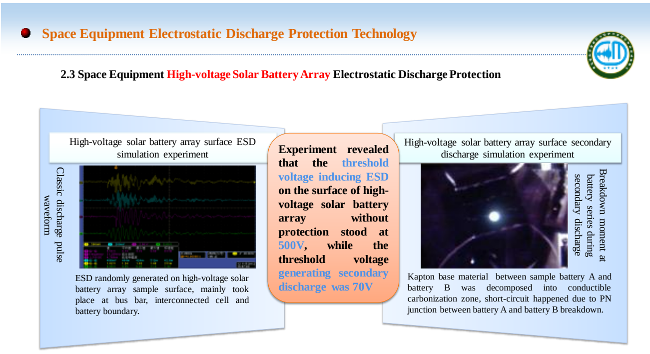

Space Equipment Charging Environment Ground Simulation and Measurement Technology
1.6 Space Deep Dielectric Charging Numerical Simulation
Grounded at back
Grounded at front
Double grounded
The internal electric field and potential when grounded at back are greater than those when grounded at front, while those when double grounded are the lowest
The material thickness may affect the charge deposition quantity, the thicker the material, the greater the internal charging electric field
For dielectric safety, the approach of double grounded or grounded at front shall be adopted, grounded at back is a second choice, while the material shall be better to be thinner.
High-energy electron
dielectric
metal
ground

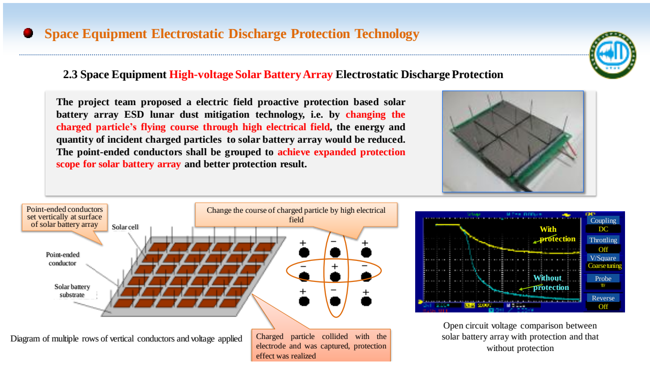

Space Equipment Electrostatic Discharge Protection Technology
2.1 Space Equipment Surface Charging Protection
Plasma electrostatic eliminator structure
Electrostatic potential dynamic test system
Gas inlet
Plasma
Charged dielectric panel
Vacuum chamber
Vacuum unit
Basic structure of a spacecraft shall simulate the Faraday cage so as to prevent effect on electronic equipment and electrical cable.
Ground design
Active potential control technology
Shield design
Whole surface of a spacecraft shall be directly grounded or be connected to structure ground by leakage resistance.
Surface material resistivity control
Surface charging protection:
Considering the capacity of material in electrostatic leakage while ensuring the realizability of engineering, China has the requirements on resistivity control for surface material of spacecraft as follows:
Material of low resistivity shall be the first choice, the surface resistivity shall be below 10⁹Ω/□, the volume resistivity must not exceed 10¹¹Ω·cm.

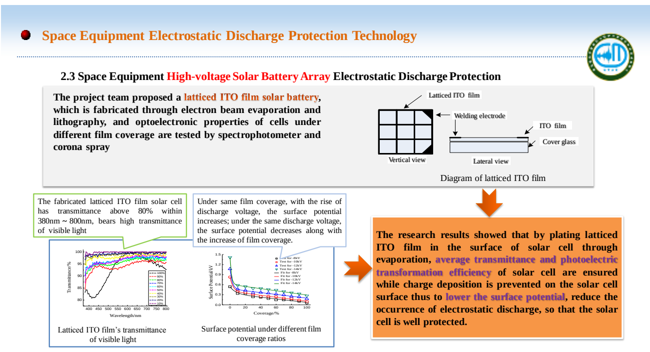

Space Equipment Electrostatic Discharge Protection Technology
2.1 Space Equipment Surface Charging Protection
Active potential control prototype based on microwave ECR plasma source
Microwave ECR plasma source prototype overall structure
1. Magnetron; 2. Coaxial waveguide; 3. Isolator; 4. Coaxial plug; 5. Directional coupler; 6. Demodulator; 7. Coaxial line connection female pin; 8. Coaxial line connection male pin; 9. Sealed coaxial connection terminal; 10. Lever; 11. Air load; 12. Flexible coaxial cable; 13. Three-stub tuner; 14. Rubber tube (inside containing gas inlet pipe and small coaxial line); 15. Vacuum chamber; 16. Plasma source; 17. Flange
Time /min

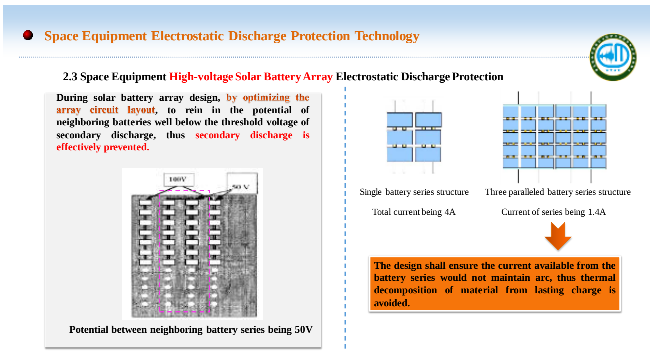

Space Equipment Electrostatic Discharge Protection Technology
2.2 Space Equipment Deep Dielectric Charging Protection
For resistivity control of dielectric inside the satellite, electrical performance shall be firstly addressed, the resistivity shall be well under 10¹¹Ω·cm or 10¹³Ω/□for the most, with charge dissipation channel being configured.
GEO: aluminum shield of around 2.8mm thick is needed to rein in the injected current density inside the satellite below 0.1pA/cm².
Resistivity control of dielectric inside satellite
Radiation shielding
Ground design
Deep dielectric charging protection:
Isolated conductor connected to structure ground.
Best performance will be ensured if dielectric is double grounded, ground at front would be the second choice, with ground at back the worst of the three.

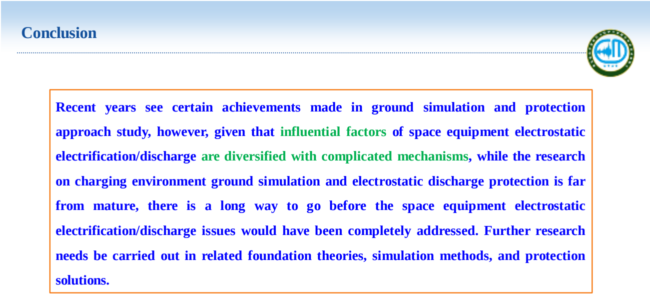

Space Equipment Electrostatic Discharge Protection Technology
2.2 Space Equipment Deep Dielectric Charging Protection
Based on theoretical calculation and simulation analysis result, a new approach for deep dielectric charge is proposed: deep dielectric charging protective coating with adjustable resistivity
Protective coating
Space high-energy electron
Circuit board
Boasting certain conductivity, the protective coating can dissipate accumulated charge to unload the electric field.
Samples | Resistivity (Ωcm)
MC313C conformal coating | 1.76×10¹⁵
Conformal coating with 5%PAn | 1.16×10¹¹
Samples | Discharge events
FR4 board + MC313C conformal coating | 47
FR4 board + MC313C conformal coating + conformal coating with 5%PAn | 1
Experiment results showed that the protective coating is capable of significantly reducing the discharge events of circuit board, a solution for deep dielectric charge protection of convenience, efficiency, and universality is thus offered for various circuit boards for spacecraft.


Space Equipment Electrostatic Discharge Protection Technology
2.3 Space Equipment High-voltage Solar Battery Array Electrostatic Discharge Protection
High-voltage solar battery array surface ESD simulation experiment
Classic discharge pulse waveform
ESD randomly generated on high-voltage solar battery array sample surface, mainly took place at bus bar, interconnected cell and battery boundary.
Experiment revealed that the threshold voltage inducing ESD on the surface of high-voltage solar battery array without protection stood at 500V, while the threshold voltage generating secondary discharge was 70V
High-voltage solar battery array surface secondary discharge simulation experiment
Breakdown moment at battery series during secondary discharge
Kapton base material between sample battery A and battery B was decomposed into conductible carbonization zone, short-circuit happened due to PN junction between battery A and battery B breakdown.


Space Equipment Electrostatic Discharge Protection Technology
2.3 Space Equipment High-voltage Solar Battery Array Electrostatic Discharge Protection
The project team proposed a electric field proactive protection based solar battery array ESD lunar dust mitigation technology, i.e. by changing the charged particle's flying course through high electrical field, the energy and quantity of incident charged particles to solar battery array would be reduced. The point-ended conductors shall be grouped to achieve expanded protection scope for solar battery array and better protection result.
Point-ended conductors set vertically at surface of solar battery array
Solar cell
Point-ended conductor
Solar battery substrate
Change the course of charged particle by high electrical field
Diagram of multiple rows of vertical conductors and voltage applied
Charged particle collided with the electrode and was captured, protection effect was realized
With protection
Without protection
Open circuit voltage comparison between solar battery array with protection and that without protection


Space Equipment Electrostatic Discharge Protection Technology
2.3 Space Equipment High-voltage Solar Battery Array Electrostatic Discharge Protection
The project team proposed a latticed ITO film solar battery, which is fabricated through electron beam evaporation and lithography, and optoelectronic properties of cells under different film coverage are tested by spectrophotometer and corona spray
Latticed ITO film
Welding electrode
ITO film
Cover glass
Vertical view
Lateral view
Diagram of latticed ITO film
The fabricated latticed ITO film solar cell has transmittance above 80% within 380nm ~ 800nm, bears high transmittance of visible light
Under same film coverage, with the rise of discharge voltage, the surface potential increases; under the same discharge voltage, the surface potential decreases along with the increase of film coverage.
Latticed ITO film's transmittance of visible light
Surface potential under different film coverage ratios
The research results showed that by plating latticed ITO film in the surface of solar cell through evaporation, average transmittance and photoelectric transformation efficiency of solar cell are ensured while charge deposition is prevented on the solar cell surface thus to lower the surface potential, reduce the occurrence of electrostatic discharge, so that the solar cell is well protected.


Space Equipment Electrostatic Discharge Protection Technology
2.3 Space Equipment High-voltage Solar Battery Array Electrostatic Discharge Protection
During solar battery array design, by optimizing the array circuit layout, to rein in the potential of neighboring batteries well below the threshold voltage of secondary discharge, thus secondary discharge is effectively prevented.
100V
50V
Potential between neighboring battery series being 50V
Single battery series structure
Total current being 4A
Three paralleled battery series structure
Current of series being 1.4A
The design shall ensure the current available from the battery series would not maintain arc, thus thermal decomposition of material from lasting charge is avoided.


Conclusion
Recent years see certain achievements made in ground simulation and protection approach study, however, given that influential factors of space equipment electrostatic electrification/discharge are diversified with complicated mechanisms, while the research on charging environment ground simulation and electrostatic discharge protection is far from mature, there is a long way to go before the space equipment electrostatic electrification/discharge issues would have been completely addressed. Further research needs be carried out in related foundation theories, simulation methods, and protection solutions.


End of the report, thanks！

夏善红

1983、1986、1994 年分别在清华大学无线电电子学系、中国科学院电子学研究所、英国剑桥大学工程系电子工程专业获得学士、硕士、博士学位。1990 年获得英国皇家学会 Royal Fellowship，2002 年获得美国加州大学伯克利分校 Berkeley Scholarship。曾担任传感技术联合国家重点实验室主任、中国科学院电子学研究所副所长、“十五”国家 863 计划微机电系统（MEMS）重大专项总体专家组成员、“十一五”国家 863 计划先进制造技术领域专家组成员、国家自然科学基金委员会信息科学部专家评审组成员、中国电子学会电子线路与系统分会主任、第十六届固态传感器执行器与微系统国际会议（Transducers’2011）大会主席兼国际指导委员会主席等。

目前任中国科学院电子学研究所研究员、博士生导师、所学术委员会和学位委员会委员，973 项目首席科学家，中国电子学会会士、理事、敏感技术分会副主任、电路与系统分会副主任，中国仪器仪表学会理事、传感器分会副理事长、微纳器件与系统技术分会常务理事，中国微米纳米技术学会常务理事等。

多年从事传感器与微系统技术研究。作为项目负责人，先后承担国家自然科学基金、973、863 等二十余项国家级科研项目，发表论文三百余篇，获得中国发明专利三十余项。在电场传感器、微传感器集成芯片系统（SOC）等方面取得多项创新研究成果，获北京市科学技术奖一等奖、三等奖各一项。

Xia Shanhong

Shanhong Xia got her bachelor, master and doctor degree respectively from Tsinghua University, Chinese academy of sciences and University of Cambridge, UK in 1983, 1986, and 1994. She was awarded the Royal Fellowship in 1990 and Berkeley Scholarship in 2002. She once served as the director of state key laboratory of transducer technology, deputy director of the institute of electronics, Chinese Academy of Sciences. She was a member of the MEMS for "10th five-year plan" national 863 program and the advanced manufacturing technology experts' group for "11th five-year plan" national 863 program. She worked for national natural science foundation, information sciences review panel. She directed electronic circuit and system branch of China electronic institute. She chaired the 16th solid-state sensor, actuator and Microsystems international conference, and served as the concurrent president of the international steering committee.

Now she is a researcher at the institute of electronics, Chinese academy of sciences, where she works as a doctoral tutor, and a member of the academic committee and the academic degrees committee. Besides, she is a 973 project's chief scientist, director of China electronics missionaries, deputy director of sensitive technology branch, and circuits and systems branch. Also, she is named as the director of the institute of instrumentation, deputy director of the Sensors' branch, standing director of micro-nano devices and systems technology, and the Chinese society of micron nanotechnology.

She has dedicated herself on sensor and microsystem technology for years. As the project leader, she has undertaken more than 20 national-level research projects, such as national natural science fund, 973, 863, etc. And she has published over three hundred papers and 30 more patents were granted. She has made great achievements in the field of electric field sensor and microsensor integrated chip system (SOC), and won the first and third prize of Beijing science and technology award.

ESD-S 第六届静电防护与标准化国际研讨会
6th Electrostatic Protection and Standardization International Conference

微型电场传感器技术及应用

夏善红

◆中国科学院电子学研究所 传感技术国家重点实验室
◆北京中科飞龙传感技术有限责任公司

报告提纲

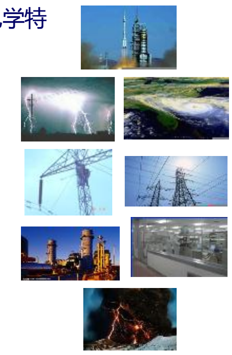
- ❑研究背景
- ❑关键技术
- ❑应用情况
- ❑总结展望

报告提纲

- ❑研究背景
- ❑关键技术
- ❑应用情况
- ❑总结展望

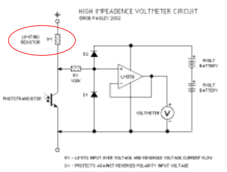
应用背景

❑电场是科技和生产活动中必要的电学特性参量。
- ➢航空航天
  - ✓飞行器发射安全条件保障
- ➢气象
  - ✓雷电预警
  - ✓大气电学研究
- ➢电网
  - ✓绝缘子缺陷检测
  - ✓非接触式电压检测
- ➢工业
  - ✓静电测量
- ➢科学研究
  - ✓火山喷发
  - ✓地震预测
- ➢……



高阻式静电压仪

❑ 常用于接触式测量静电/电压
- ❑ 接触过程中发生电荷转移
- ❑ 测量结果随时间衰减

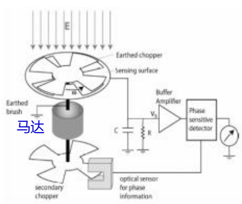


工作原理

现有产品

场磨式电场仪

❑ 场磨式电场仪常用于测量地面大气电场或静电。



工作原理

Kleinwachter EFM-122, 德国

CS110, 美国

现有产品

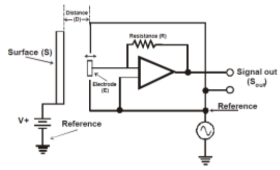
空中电场传感器

❑ 探针式　　❑ 双球式

❑ 场磨式　　❑ 三维旋叶式

振动电容式静电计

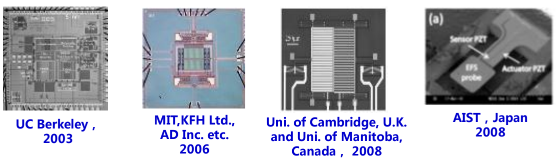
❑ 振动电容式静电计用于非接触式静电/电压检测
- ❑ 含有裸露可动部件
- ❑ 测试距离短

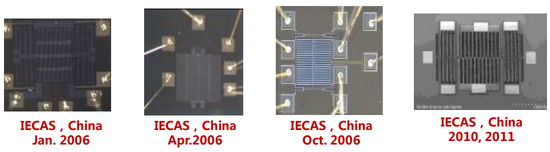


工作原理

现有产品

MEMS电场传感器

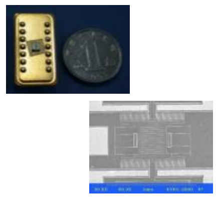




MEMS电场传感器

❑ 优点
- ➢ 体积小、空间分辨率高、功耗低、成本低；
- ➢ 无裸露可动部件，稳定性好，可靠性高；
- ➢ 安装简单，易于维护

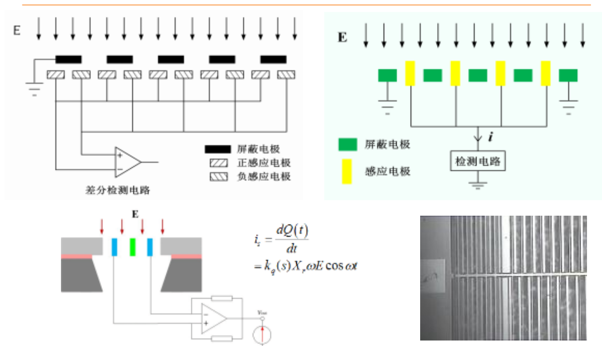
❑ MEMS电场传感器
- ➢ 芯片尺寸
- ➢ 5×5×1mm³
- ➢ 可批量化制备



报告提纲

- ❑ 研究背景
- ❑ 关键技术
- ❑ 应用情况
- ❑ 总结展望

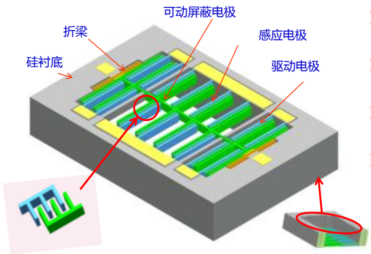
工作原理



Photograph of the structure

敏感结构设计

❑敏感结构分辨力为目前可查询报道最好水平。



- 共面电极
  - 电场感应效率高
- 梳齿状感应电极
  - 提升灵敏度
- 对称差分结构
  - 提升信噪比
- 镂空衬底结构
  - 提升品质因数，避免结构粘连

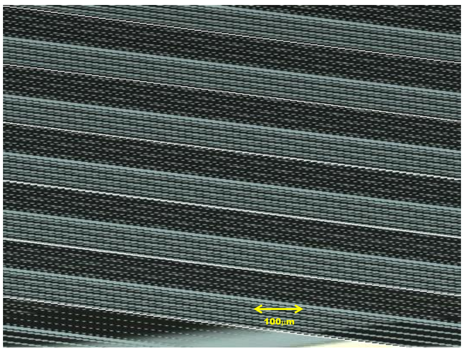
中国科学院电子学研究所 中科飞龙

制备工艺

❑在实验室建立了小批量生产工艺流程规范。

中国科学院电子学研究所 中科飞龙

敏感结构振动视频

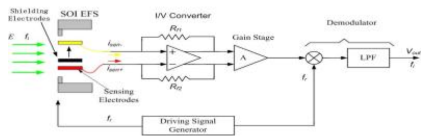


中国科学院电子学研究所 中科飞龙

信号处理电路及测试结果

✓峰值提取法

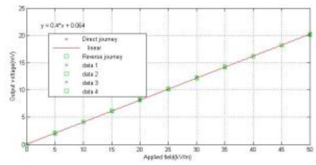
✓低噪声预处理电路



✓ 测量结果

✓ 精度Precision: 优于5%

✓ 分辨力 Resolution: 优于15V/m



中国科学院电子学研究所 中科飞龙

报告提纲

❑研究背景

❑关键技术

❑应用情况

❑总结展望

中国科学院电子学研究所 中科飞龙

环境适应性测试报告

❑环境适应性测试

❑电磁兼容测试

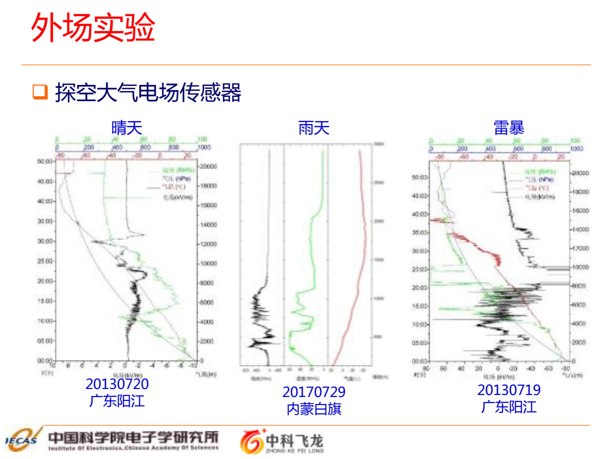
北京第三检测中心

江苏省电子信息产品质量监督检验研究中国赛宝（江苏）实验室(CEPREI)

国家电子计算机质量监督检验中心(NCTC)

中国科学院电子学研究所 中科飞龙

外场实验
地面大气电场仪
MEMS atmospheric electric field sensor
Campbell CS110
中科院电子所 观测场地
MEMS 电场传感器
Campbell CS110
20140605
晴天
MEMS 电场传感器
Campbell CS110
20140610
雷暴
中国科学院电子学研究所
中科飞龙



外场实验
探空大气电场传感器
晴天
雨天
雷暴
20130720
广东阳江
20170729
内蒙白旗
20130719
广东阳江
中国科学院电子学研究所
中科飞龙

应用情况
产品已成功应用于卫星发射基地。
酒泉
太原
西昌
文昌
中国科学院电子学研究所
中科飞龙

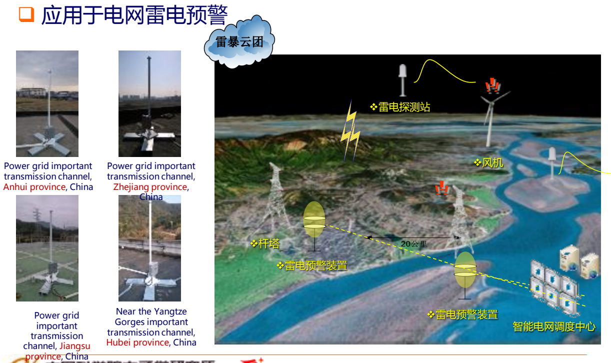
地面大气电场仪
卫星发射基地
山西太原
海南文昌
四川西昌
甘肃酒泉
中国科学院电子学研究所
中科飞龙

探空大气电场传感器
卫星发射基地
传感器
四川西昌
甘肃酒泉
山西太原
海南文昌
中国科学院电子学研究所
中科飞龙

应用
电网
合肥市
常州市
宜昌市
武汉市
杭州市
温州市
中国科学院电子学研究所
中科飞龙

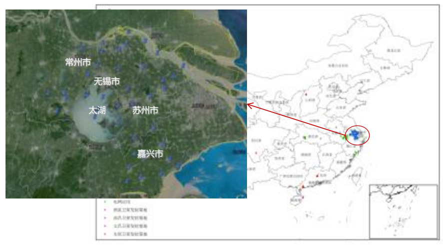
地面大气电场仪

- 应用于电网雷电预警



应用

- 气象



地面大气电场仪

- 气象观测

探空大气电场传感器

- 气象观测

探空大气电场传感器

- 分布式三维大气电场探测系统

应用 Applications

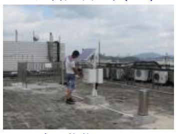
- 石油石化

石油石化

❑ 广石化

广石化聚丙烯（二）

广石化生产调度指挥中心



广石化化工区01

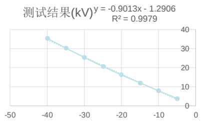
广石化化工区02

石油石化

❑ 静电检测

MEMS非接触式手持静电仪

主要优势：
- ✓ 全密封，无裸露可动部件；
- ✓ 精度高，优于1%；
- ✓ 易批量化制备、成本低；
- ✓ 测试距离远。

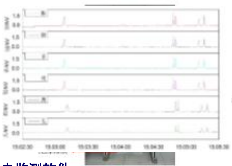


石油石化

❑ 静电检测
- ➢MEMS非接触式静电安全检测门
- ➢可测量人体头、肩、臂、手、腿、脚部位带电大小

人体带电监测软件

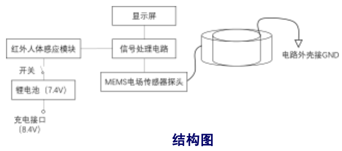
结构图



标定

石油石化

❑ 静电检测
- ➢非接触式静电安全检测释放球
  - ➢非接触式静电主动探测



结构图

探空大气电场传感器

❑ 机载大气电场探测
- ➢人工影响天气作业

陕西榆林

无人机

陕西西安

运12

报告提纲

- ❑ 研究背景
- ❑ 关键技术
- ❑ 应用情况
- ❑ 总结展望

总结展望

- 本项目成功研制了基于MEMS技术的电场传感器；
- 传感器测试性能优异；
- 目前已经在航天、电网、石油石化、气象等领域成功应用；
- 根据应用需求，将研制更多产品类型。

中国科学院电子学研究所 Institute Of Electronics, Chinese Academy Of Sciences　中科飞龙 ZHONG KE FEI LONG

ESD-S 第六届静电防护与标准化国际研讨会
6th Electrostatic Protection and Standardization International Conference

谢谢

中国科学院电子学研究所 Institute Of Electronics, Chinese Academy Of Sciences　中科飞龙 ZHONG KE FEI LONG

ESD-S 第六届静电防护与标准化国际研讨会
6th Electrostatic Protection and Standardization International Conference

Miniature electric field sensors and applications

Shanhong Xia

- State Key Laboratory of Transducer Technology, Institute of Electronics, Chinese Academy of Science, Beijing, China
- Beijing Tflying Transducer Technology Co., Ltd. Beijing, China

OUTLINE

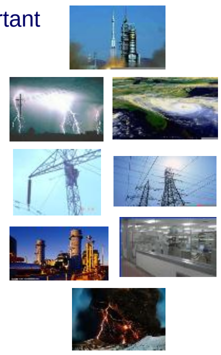
- ❑ Introduction
- ❑ Principle, design and fabrication
- ❑ Test and applications
- ❑ Summary

OUTLINE

- ❑ Introduction
- ❑ Principle, design and fabrication
- ❑ Test and applications
- ❑ Summary

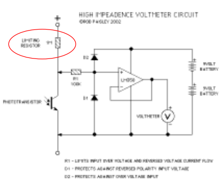
Needs for Electric Field Sensors

- ❑ Electric field measurement is important in many applications.
  - ➢ Aeroacoustic and astronautic fields
    - ✓ Satellite and spacecraft safety launching
  - ➢ Atmospheric science
    - ✓ Advance warning of lightning
    - ✓ Research on space charge distribution
  - ➢ Power grid
    - ✓ Detection for defect of insulators
    - ✓ Non-contact voltage measurement
  - ➢ Industry
    - ✓ Electrostatic discharge prevention, et al.
  - ➢ Researches
    - ✓ Volcano eruption triggered lightning
    - ✓ Earthquake prediction
  - ➢ ……



High impedance voltmeter

- High impedance voltmeter is commonly used for measuring voltage by contact.

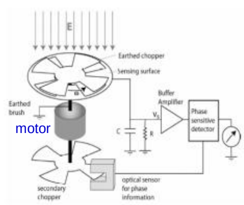


Working principle

Commercial products

Electric field mill

- Field mill is commonly used for atmospheric electric field measurement on the ground, or electrostatic charge.



Working principle of field mill

Kleinwachter EFM-122, Germany

CS110, USA

Commercial field mill products

Atmospheric Electric Field Sounding

- Induction probe
- Dual-sphere

CETP, France   New Mexico Tech,

Developed by National Space Science Center, CAS, China

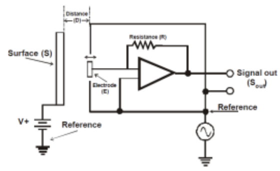
- Field mill
- 3D electric field sensor

Field mill used by NASA for airborne electric field measurement

Balloon-borne 3D atmospheric electric field sensor developed by IECAS, China

Electrostatic Meter

- Electrostatic meter is commonly used for electrostatic charge/voltage measurement.



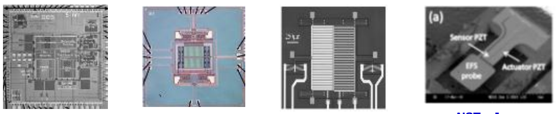
Working principle

TREK Model325, USA

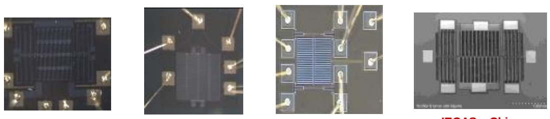
SIMCO FMX-002,Japan   Monroe 282IS, USA

Commercial products

MEMS-based electric field sensor



UC Berkeley, 2003   MIT,KFH Ltd., AD Inc. etc. 2006   Uni. of Cambridge, U.K. and Uni. of Manitoba, Canada, 2008   AIST, Japan 2008



IECAS, China Jan. 2006   IECAS, China Apr.2006   IECAS, China Oct. 2006   IECAS, China 2010, 2011

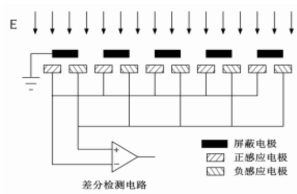
Why MEMS?

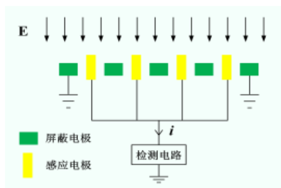
- Advantages
  - Small size, high spatial resolution, low power consumption, low cost;
  - No motor wear parts, good stability, high reliability;
  - Simple to install, easy to maintain
- MEMS Electric Field Sensor
  - Sensing chip size 5×5×1mm^3
  - Batch fabrication

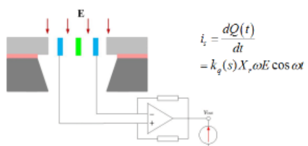
OUTLINE

- Introduction
- Principle, design and fabrication
- Test and applications
- Summary

Working principle



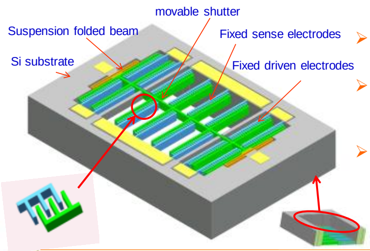




Photograph of the structure

Design of sensing structure

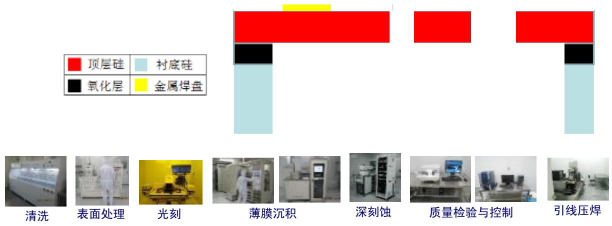
- The coplanar comb-shaped electrodes sensor has the best reported resolution of MEMS electric field sensors.



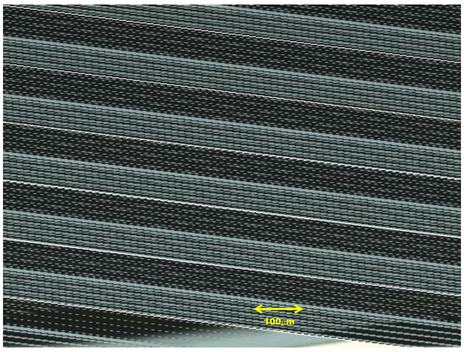
- Coplanar electrodes
  - higher conversion gain
- Comb-shaped electrodes
  - higher sensitivity
- Symmetric structure
  - differential comb drives and sensing electrodes
- Hollow substrate structure
  - improving quality factors, and avoid release stiction

Fabrication Process

- Established a fabrication process, achieve small batch manufacturing in IECAS.

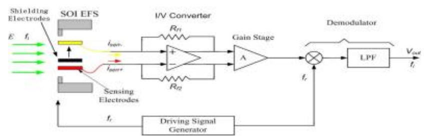


Motion of the coplanar comb-shaped electrodes

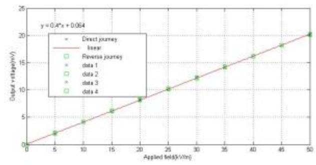


Signal Detection Circuit and Measurement results

- Phase-sensitive demodulation methods
- Design of low noise preprocessing circuit



- Measurement results
- Precision: better than 5%
- Resolution: better than 15V/m



OUTLINE

- Introduction
- Principle, design and fabrication
- Test and applications
- Summary

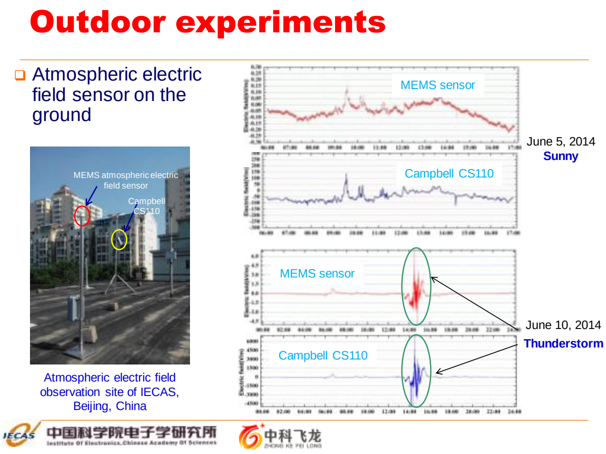
Environmental Adaptability Test

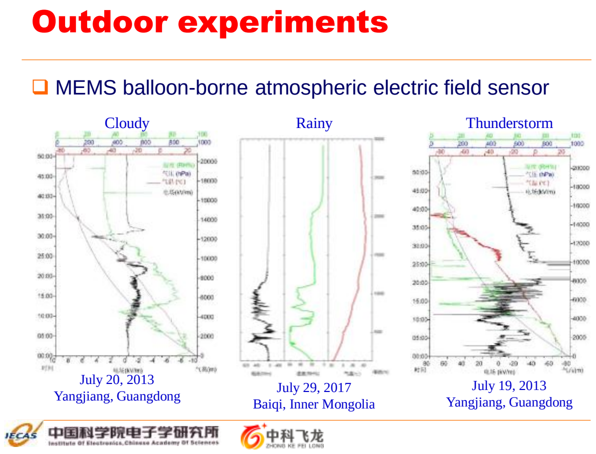
- Environmental Adaptability Test
- Electromagnetic Compatibility Test

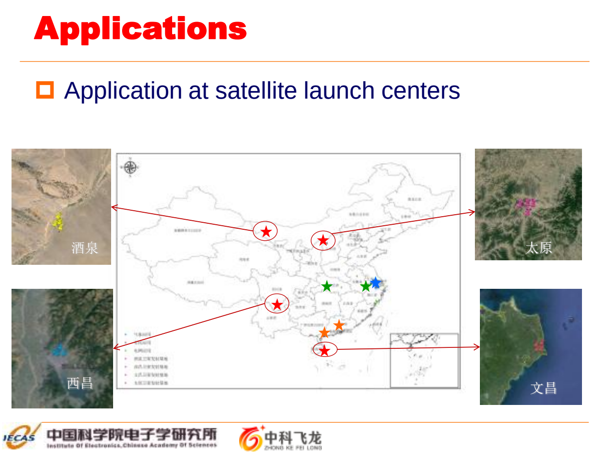
北京第三检测中心

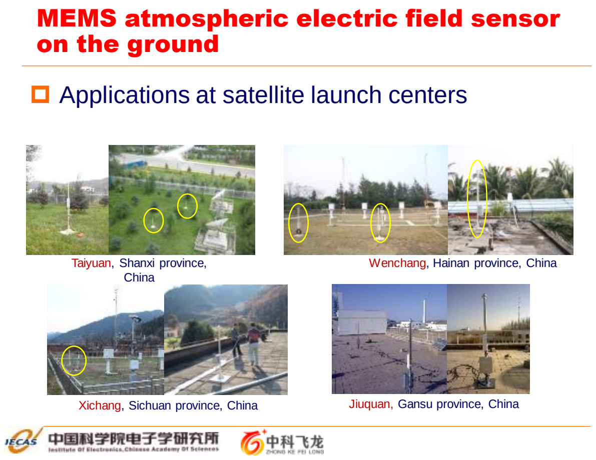
江苏省电子信息产品质量监督检验研究中国赛宝（江苏）实验室(CEPREI)

国家电子计算机质量监督检验中心(NCTC)

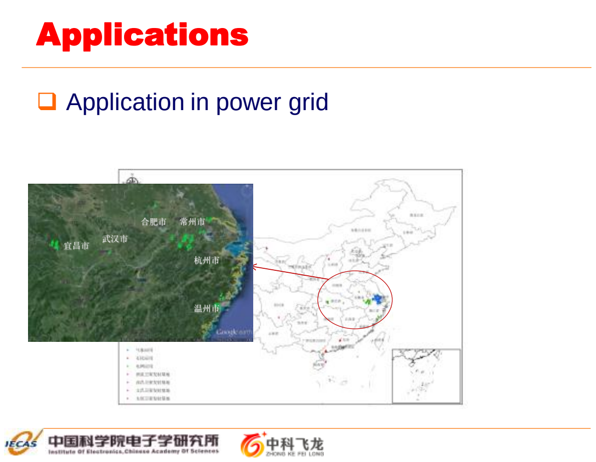

Outdoor experiments
Atmospheric electric field sensor on the ground
MEMS atmospheric electric field sensor
Campbell CS110
Atmospheric electric field observation site of IECAS, Beijing, China
MEMS sensor
Campbell CS110
June 5, 2014
Sunny
MEMS sensor
Campbell CS110
June 10, 2014
Thunderstorm
中国科学院电子学研究所
中科飞龙


Outdoor experiments
MEMS balloon-borne atmospheric electric field sensor
Cloudy
Rainy
Thunderstorm
July 20, 2013
Yangjiang, Guangdong
July 29, 2017
Baiqi, Inner Mongolia
July 19, 2013
Yangjiang, Guangdong
中国科学院电子学研究所
中科飞龙


Applications
Application at satellite launch centers
酒泉
太原
西昌
文昌
中国科学院电子学研究所
中科飞龙


MEMS atmospheric electric field sensor on the ground
Applications at satellite launch centers
Taiyuan, Shanxi province, China
Wenchang, Hainan province, China
Xichang, Sichuan province, China
Jiuquan, Gansu province, China
中国科学院电子学研究所
中科飞龙


MEMS balloon-borne atmospheric electric field sensor
Atmospheric electric field sounding at satellite launch centers
Sensor
Xichang, Sichuan Province
Jiuquan, Gansu Province
Taiyuan, Shanxi Province
Wenchang, Hainan Province
中国科学院电子学研究所
中科飞龙


Applications
Application in power grid
合肥市
常州市
武汉市
宜昌市
杭州市
温州市
中国科学院电子学研究所
中科飞龙

MEMS atmospheric electric field sensor on the ground

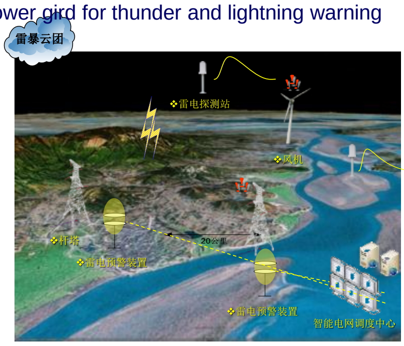
- Applications in power gird for thunder and lightning warning

Power grid important transmission channel, Anhui province, China

Power grid important transmission channel, Zhejiang province, China

Power grid important transmission channel, Jiangsu province, China

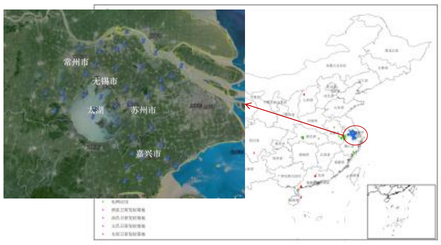
Near the Yangtze Gorges important transmission channel, Hubei province, China



IECAS 中国科学院电子学研究所 中科飞龙

Applications

- Applications in meteorological observation



MEMS atmospheric electric field sensor on the ground

- Applications for meteorological observation

Yangtze River flood control department, Zhangjiagang, Suzhou, China

Kunshang meteorological bureau, Suzhou, China

Shengze bureau, Wuzhong meteorological bureau, Suzhou, China

Mashanlongtouzhu scenic spot, Wuxi meteorological bureau, Wuxi, China

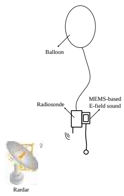
Jiangyin meteorological bureau , Wuxi, China

MEMS balloon-borne atmospheric electric field sensor

- Applications for meteorological observation

July 20, 2013, cloudy

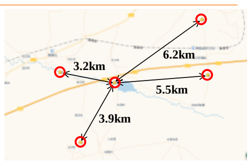
Yangjiang, Guangdong Province



Beijing National Basic Meteorological Observing Cite

MEMS balloon-borne atmospheric electric field sensor

- Distributed three-dimensional atmospheric electric field detection system



Zhengxiangbaiqi, Inner Mongolia

Applications

- Applications at petrochemical works

Applications at petrochemical works

- China Petroleum & Chemical Corporation, Guangzhou Branch


广石化聚丙烯（二）


广石化生产调度指挥中心

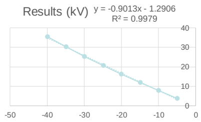

广石化化工区01


广石化化工区02

Applications at petrochemical works

- Electrostatic measurements

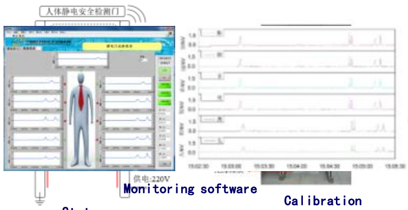
Non-contact electrostatic meter
- Advantages:
  - ✓ No exposed wear parts
  - ✓ High precision: better than 1%
  - ✓ Batch manufactory, low cost
  - ✓ Long measurement distance



Applications at petrochemical works

- Electrostatic measurements
- ➢Electrostatic measurement gate
- ➢Measuring head, shoulder, arm, hands, legs, feet, etc.


Strture

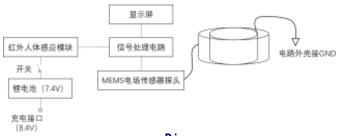


Monitoring software

Calibration

Applications at petrochemical works

- Electrostatic measurements
- ➢Electrostatic measurement&discharge ball
- ➢Non-contact electrostatic charge measurement



Diagram

MEMS balloon-borne atmospheric electric field sensor

- Airborne atmospheric electric field sounding for weather modification application


Yulin, Shanxi Province

MEMS electric field sensor on UAV


Xi'an, Shanxi Province

MEMS electric field sensor on manned aircraft (Y12)

OUTLINE

- Introduction
- Principle, design and fabrication
- Test and applications
- Summary

Summary

- The innovative MEMS based electric field sensors have been successfully developed;
- The sensors have demonstrated good performances;
- Applications in several areas have proven to be successful;
- New products will be developed for more applications and for future market.

中国科学院电子学研究所 中科飞龙

ESD-S 第六届静电防护与标准化国际研讨会

6th Electrostatic Protection and Standardization International Conference

Thank you for your attention

中国科学院电子学研究所 中科飞龙

万发雨

万发雨博士是南京信息工程大学电子与信息工程学院教授/博士生导师，2011 年博士毕业于法国鲁昂大学，从事集成电路的电磁兼容仿真模型与测试方法研究，之后在美国密苏里大学罗拉分校电磁兼容试验室从事博士后工作，研究方向为静电放电的环境效应、电磁危害效应以及二次放电机理。万博士在电磁兼容领域主流期刊发表了 20 多篇 SCI/EI 论文，包括 IEEE TEMC, IEEE TED,IEEE MWCL, IET EL,IET SMT, ASHRAE Transactions, AIP Advance,获得 APEMC2010 最佳学生论文，是电磁兼容领域 10 多个期刊的审稿人，是 IEEE EMC 协会 EMI control 的技术委员。万博士主持了包括 2 项国家自然科学基金,军方预研项目,江苏省自然科学基金等项目 10 余项。

Wan Fayu

Dr. Fayu Wan is now a Professor of School of Electronics and Information Engineering, Nanjing University of Information Science and Technology, Nanjing, China. He received Ph.D. degree in Department of Electrical Engineering, University of Rouen, France, in 2011. After that he worked as a Post doctor at University of Missouri-Rolla，EMC lab from 2011 to 2013. His current research interests include IC EMC/EMI design and measurement, ESD and Secondary ESD. Dr. Wan has published papers in journals including IEEE TEMC, IEEE TED,IEEE MWCL, IET EL,IET SMT, ASHRAE Transactions, AIP Advance and leading conferences including IEEE EMC,APEMC, EMC Europe and EMC Compo. He received the Best Student Paper Award of APEMC in 2010. He is a reviewer for more than ten key journals and conferences in the fields of EMC, ESD and IC EMC. Dr. Wan is a member of IEEE and a Technical Committee member of IEEE EMC Society in EMI control . Dr.Wan is a leader of ten projects including two National Natural Science Fundations of China, one Defense Research Foundation and one Natural Science Foundation of Jiangsu.

第六届静电防护与标准化国际研讨会

静电放电与二次放电湿度效应研究

汇报人：万发雨

贵州●贵阳

南京信息工程大学

2017. 11. 10

主要内容

第一部分 空气放电湿度效应机理研究

第二部分 毫米级间隙二次放电现象和机理研究

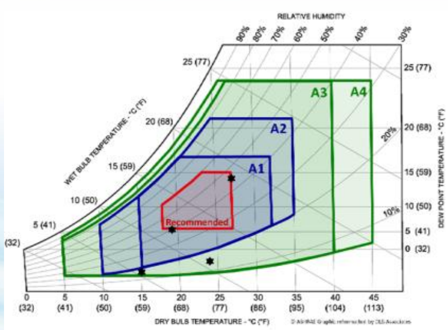
2

研究意义

- 静电放电不仅在民用领域更在军用领域造成电子设备可靠性问题。 低湿度增加静电放电造成电子设备发生故障概率的风险，而高湿度帮助控制静电放电事件，但是会增加能耗。因此由于静电放电造成电子设备发生故障的风险和湿度水平之间的相互关系是值得研究的。
- 三方面内容：
- 研究意义
- 测试方法
- 分析方法

3

ASHRAE 给数据中心推荐的温湿度环境参数



4

研究目的

确定由静电放电造成的电子设备故障风险和湿度之间的相互关系。

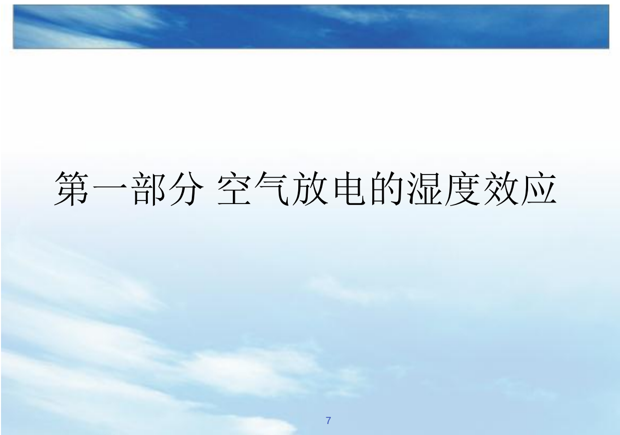
- 评估湿度在空气放电中的作用效应
- 研究二次放电机理和二次放电对电子设备的影响
- 湿度在二次放电的放电时延中的效应

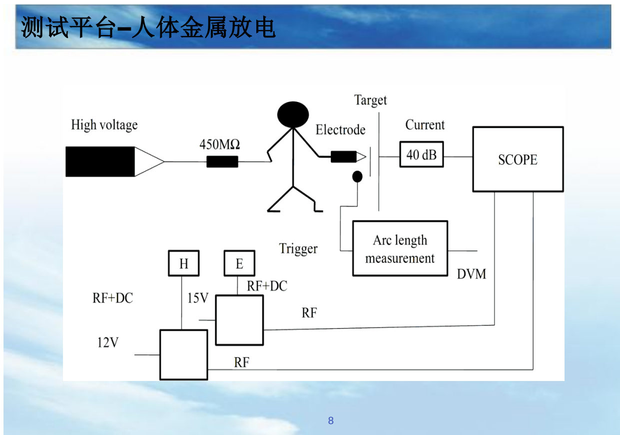
5

情景 – 站立和走动条件下静电放电事件

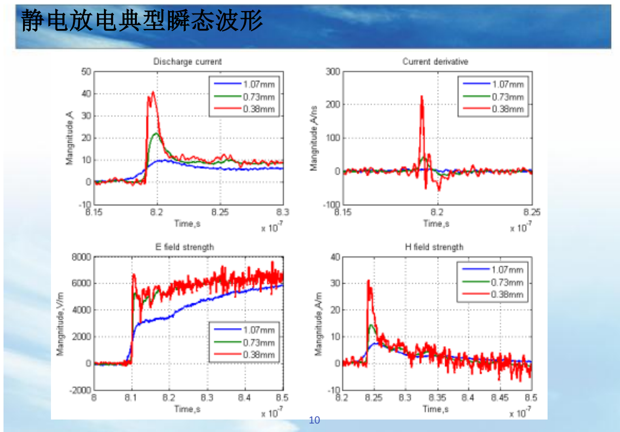
- 考虑一个操作工人对设备进行维护。如果事先的保护措施没有做好，例如，接触电子设备之前人体接地没有做，操作工人可能会由于摩擦生电带较高电压（一般3-5kV）。如果操作工用金属工具如螺丝刀对设备进行维护，当螺丝刀趋近于设备时，很可能会发生静电放电事件。
- 即使没有维护设备，工作人员仍可能触发静电放电事件。考虑一个人通过一个有敏感设备的区域，擦拭或者倚靠在设备上也会触发ESD事件。这些事件应被视为直接放电，因为它们涉及到人体与设备的直接接触。

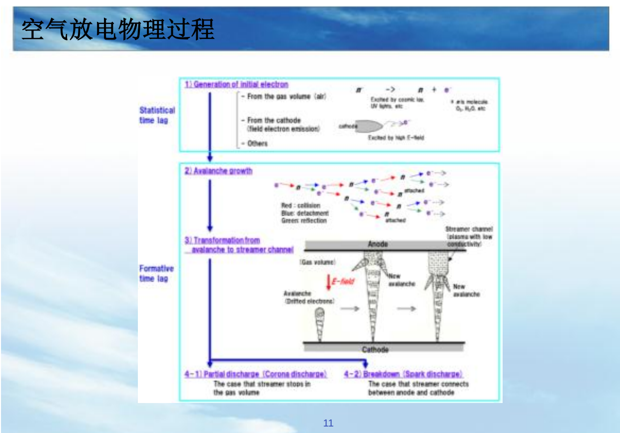
6

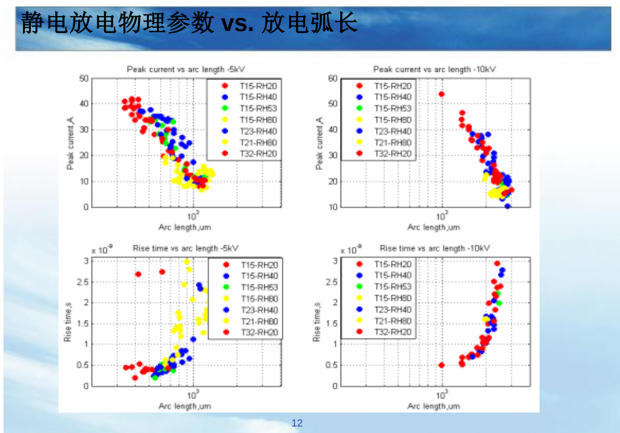

第一部分 空气放电的湿度效应
7


测试平台–人体金属放电
High voltage
450MΩ
Target
Electrode
Current
40 dB
SCOPE
Trigger
Arc length
measurement
DVM
H
E
RF+DC
15V
RF+DC
RF
12V
RF
8

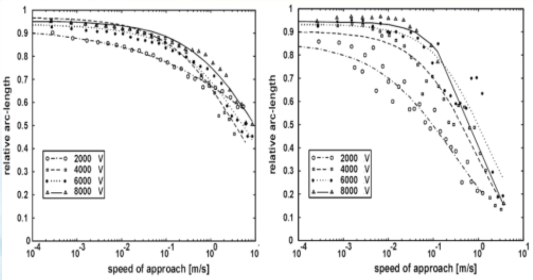

人体金属测试平台
High voltage supply
450 Mohm resistors
Cabinet
E field sensor
H field sensor
Trigger of
arc length
Electrode
人体金属放电的测试设备放在法拉第笼内，一位同事通过高压源充电后手持电极对放电靶进行放电。
9


静电放电典型瞬态波形
Discharge current
Current derivative
E field strength
H field strength
1.07mm
0.73mm
0.38mm
Time,s
10


空气放电物理过程
Statistical time lag
Formative time lag
1) Generation of initial electron
2) Avalanche growth
3) Transformation from avalanche to streamer channel
4-1) Partial discharge (Corona discharge)
4-2) Breakdown (Spark discharge)
Anode
Cathode
11


静电放电物理参数 vs. 放电弧长
Peak current vs arc length -5kV
Peak current vs arc length -10kV
Rise time vs arc length -5kV
Rise time vs arc length -10kV
T15-RH20
T15-RH40
T15-RH53
T15-RH80
T23-RH40
T21-RH80
T32-RH20
Arc length,um
12

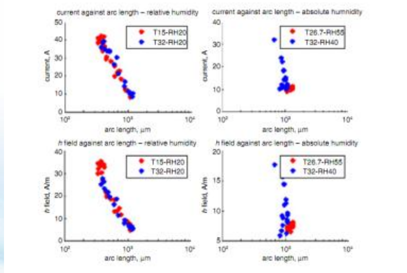
趋近速度与放电弧长的关系



- 阈值趋近速度是湿度、电极表面粗糙度和电压等参数的函数 (左图是粗糙电极, 右图是光滑电极)

13

相对湿度vs. 绝度湿度



- 5kV放电电压下，放电电流与弧长之间的关系。左图是相对湿度案例，右图是绝对湿度案例
- 在相同趋近速度和绝对湿度环境下， 32℃ 40%RH 的放电电流有较大的变化范围，而26.7℃ 55%RH 的放电电流都非常小，变化范围也较小。所以在相同绝对湿度条件下，不同的相对湿度会造成放电电流有较大差异。
- 如右图所示，在相同的趋近速度和相对湿度条件下，即使绝对湿度不一致，放电电流大小的和变化范围是一致的。

14

第二部分 二次放电现象和机理研究

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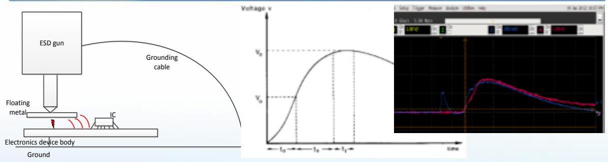
二次放电图示



- 二次放电是接触放电的寄生放电。
- 电子设备的按钮，螺丝，开关，指示灯，显示屏等会与电子设备的本身产生亚毫米的间隙，如果这些部分在平时的使用中能够被接触到，通常会使用接触放电模式进行试验。
- 如果放电电压大于一定的阈值电压，将会在亚毫米间隙中产生二次放电，二次放电的上升时间较快，幅值较大。

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案例分析

(a) (b)

●如图所示，对螺丝和镜头的缝隙进行4kV的接触放电，有敏感现象出现，手机屏幕出现花屏，有未知错误信号出现

●但是这个放电现象重复性较差，10次放电中只有2次出现该现象。

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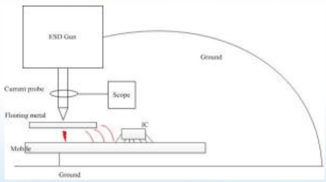
测试平台-二次放电



Setup of secondary discharge

●悬浮金属和电子设备主体形成电容，初级放电电流将对该电容充电。

●亚毫米间隙电容的充电时间常数由其电容值和静电放电源的阻抗决定

●实验装置如图所示，Noiken 的ESD枪对手机的悬浮金属进行放电，间距大约为0.5mm。

●一个电流探头用来测量放电电流，它通过一个40dB的衰减器连接到安捷伦示波器，示波器放置在法拉第笼里。

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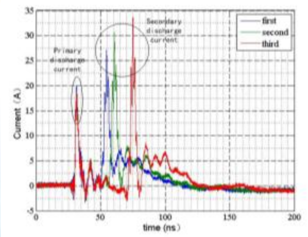
测试结果1 放电电流



6kV放电电压下，三个放电电流时域波形

- 三个放电电流波形的一次放电波形重合，幅值大约为20A，遵循IEC 61000-4-2标准。
- 二次放电电流从27A变化到33A，远大于1次放电电流。
- 二次放电电流峰值随着放电时延的增加而增加。

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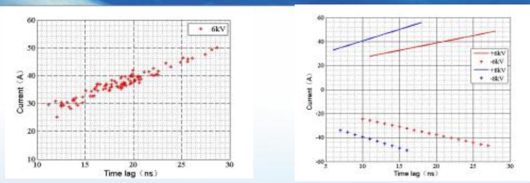
测量结果2 放电电流 vs 放电时延



(a) (b)

6kV电压下，二次放电电流峰值vs 放电时延(a), 不同电压幅度和电压极性下 放电电流vs放电时延(b)

- 如图a所示，在6kV的放电电压下，随着放电时延从10ns上升到30ns，二次放电电流的峰值从25A上升到50A，二次放电电流峰值随放电时延增加而线性增加。
- 如图b所示，在正负6kV和8kV电压下，放电电流成对称波形(正负)。高电压放电电流峰值与放电时延的斜率 比 低电压要大。

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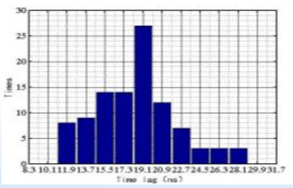
测量结果3 放电时延分布



- 所有放电时延大小都取决于种子电子的有效性。这些种子电子可以通过场发射、氧分子和水分子的分离来提供。通过多次测量，发现放电时延分布满足概率统计特性。
- 放电时延分布结果表明，虽然放电时延变化较大，但四分之一落入中部，两端下降较少，密度分布对称，服从正态分布。

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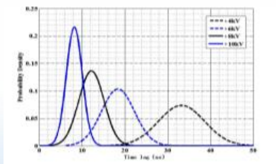
测试结果3- 放电时延分布



- 不同电压下放电时延概率分布如图所示，都服从正态分布。
- 随着电压的上升，放电时延平均值和方差都下降，但不是线性关系。
- 超过放电阈值电压越多，就有更多的种子电子来引发击穿，放电时延也就更小。
- 但是随着放电电压达到一个非常大的电压时， 放电时延不再变小，趋近常数，该常数称之为形成时延。
- 形成时延是击穿开始直到间隙被低电阻电弧连接为止。对于亚毫米间隙来说，形成时延小于几纳秒。

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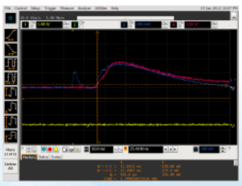
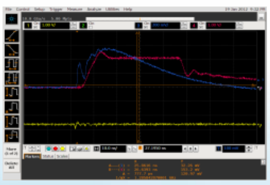
纳秒级小放电时延图示





- 小于10纳秒的放电时延是更值得研究的，但是如图所示，由于一次放电电流和二次放电电流重合，很难分辨出10纳米以下的放电时延。
- 由于放电时延具有统计特性，且受湿度，场致发射，金属表面情况等参数影响，在不同参数下，放电时延变化较大。

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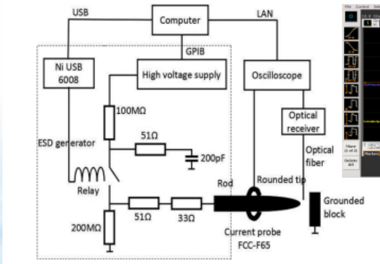
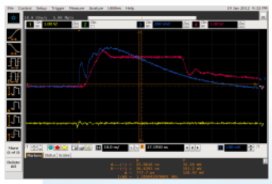
测试平台-放电时延





放电电流和火花放电两路测量平台

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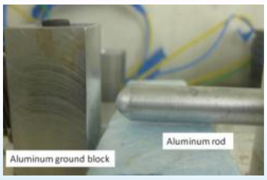
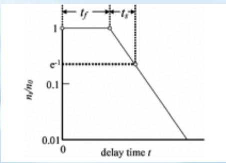
不同放电电极





$$\frac{n_t}{n_0} = \exp\left(-\frac{t-t_f}{t_s}\right)$$

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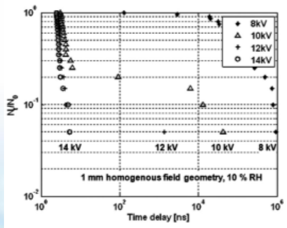
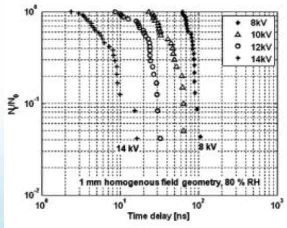
测试结果1- 不同放电电压下的放电时延



10%RH，1mm 间隙，圆形铝材质电极的放电时延Laue plot图



80% RH 1mm 间隙，圆形铝材质电极的放电时延Laue plot图

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测试结果1- 不同电压下放电时延

TABLE I
MEAN VALUE OF THE TIME LAG FOR DIFFERENT APPLIED VOLTAGES, GAP LENGTHS, AND RH LEVELS FOR A ROD TO GROUND BLOCK DISCHARGE GEOMETRY, MATERIAL

Voltage [kV]	5	6	7	8	9	10	11	12	13	14	15
0.55 mm 10% RH	x	x	x	5.1 µs	340 ns	120 ns	73 ns	9.1 ns	7.8 ns	1.7 ns	1.3ns
1 mm 10% RH	x	x	x	0.22 ms	94 µs	3.1 µs	1.5 µs	71 ns	17 ns	3 ns	2.6 ns
0.55 mm 65% RH	330 ns	190 ns	86 ns	46 ns	13 ns	9.4 ns	5.1 ns	3.4 ns	2.9 ns	1.7 ns	1.5 ns
1 mm 65% RH	590 ns	170 ns	0.1µs	84 ns	76 ns	56 ns	39 ns	28 ns	17 ns	11 ns	7.3 ns

x: Time lag too long to be measured >1 ms.

- 放电电压对放电时延的影响非常强，在干燥的空气中，10%RH，8kV条件下0.22ms，但是12kV下减小到71ns。
- 在湿空气下，放电电压对放电时延的影响较弱，因为强场可以提供种子电子，缩短放电时延，而在湿空气下，水分子已经提供了足够的种子电子，放电时延已经较小了，增加放电电压也不会减小放电时延太多。

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测试结果2- 间隙对放电时延的影响

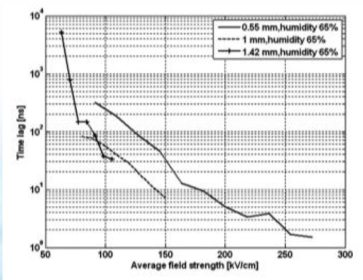

Fig. 7. Time lag against the field strength with the same humidity and at different gap lengths.

- 平均电场=电压/间隙距离
- 较大的间隙，空间较大，能够提供更多的种子电子，导致较小的放电时延。

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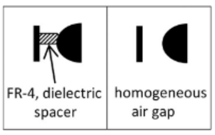
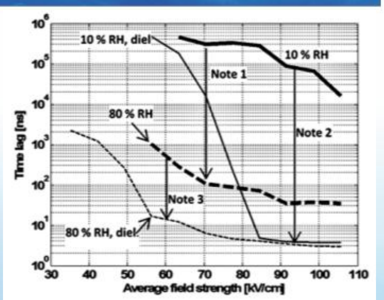
测试结果3-介质空气表面对放电时延的影响





- Note 1 描述了没有介质条件下，湿度对放电时延的影响。
- Note 2 描述了在干燥空气条件下，介质对放电时延的影响。
- Note 3 描述了在湿润空气条件下，介质对放电时延的影响。

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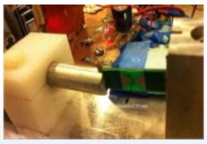
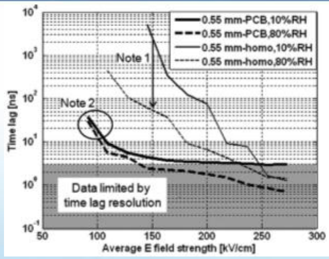
测试结果4 基于PCB间隙的放电时延





- 由于PCB板上金属层较薄（35um），尖端半径较小（30um），电场是强非均匀场
- Note 1 描述了均匀场和非均匀场放电时延的对比关系，均匀场的放电时延较大。
- Note 2 描述了对于100kV/cm的场强下，放电时延已经接近10ns。更高的场强对减小放电时延没有太大帮助。

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炭电极对放电时延的影响

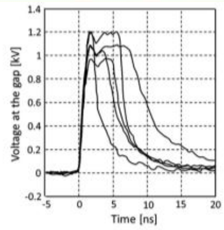

Fig. 12. Gap voltage for an approximately 0.1 mm graphite coated spark gap for multiple discharges having a static breakdown voltage of about 860 V, showing less than 8 ns time lag for voltages between 1 and 1.2 kV.

- 炭电极薄膜层加强了电场，极大的减小了放电时延
- 由于放电时延极大的减小了，高于1.2kV的击穿电压的放电放电时延维持在7ns左右

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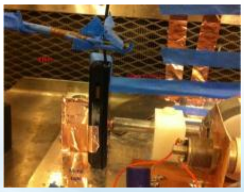
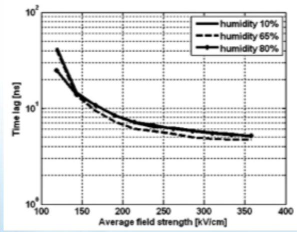
手机中的二次放电





- 由于间隙形状是非均匀的，有尖角，击穿电压在2.5至3kV之间。即使在非常低的湿度下，放电时延也较小，在数十纳秒。
- 这些发现指明了很多有效的种子电子不是从水分子分离出来。
- 相反，大部分时候是间隙结构的尖角，或者表面特性引发了击穿。

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结论(1)

- 放电弧长与放电参数相关，如短弧长导致快速的上升时间和较大的峰值电流。
- 电极快速接近增加了放电的严重性。
- 与绝对湿度相比，相对湿度对于表征放电过程是更为重要。
- 相同放电电压下，较大的放电时延导致较大的二次放电电流。
- 小间隙情况下二次放电电流可能是造成电子设备损坏的主要原因，也是接触放电重复性较差的原因。

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结论(2)

- 有效的初始电子是决定放电时延的主要因素。
- 对光滑，干净的金属表面，湿度能够极大的减小平均放电时延。
- 由于较锐利的边缘造成场强的增强，会导致电子发射，表面的污染或者介质层也会分离出初始电子，引发放电时延的减小。

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Thank you for your attention！

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The 6th Electrostatic Protection and Standardization International Conference

The effect of humidity on electrostatic discharge and secondary discharge

Dr Fayu Wan
Nanjing University of Information Science and Technology

2017.11.10

Main Contents

Part I The effect of humidity on air discharge process

Part II Secondary discharge of MM gap length

2

Motivation

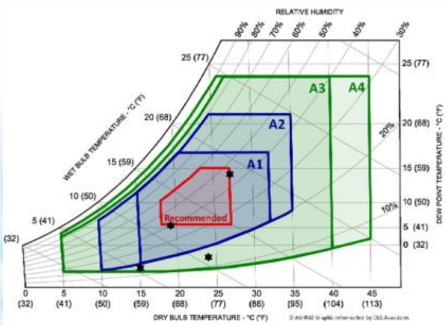
- ESD causes may cause reliability issues in civilian area but also in military area. Low humidity increases the risk of ESD induced equipment failures, high humidity helps to control the ESD events but increases cost of energy consumption. The correlation between the risk of equipment failure from ESD and humidity level need to be studied.

This presentation shows:

- Motivation
- Test methods
- Analysis methods

3

ASHRAE recommend environment condition for data center



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Objective

Determine the correlation between the risk of equipment failure from ESD and humidity levels.

- To evaluate the effect of humidity in discharge severity
- To investigate the secondary discharge mechanism and the effect of humidity on the time lag of secondary discharge

5

Scenarios – Standing and Walking Discharge Event

- Consider an operator performing maintenance on equipment. If appropriate safety precautions such as personnel grounding are not taken before interacting with equipment, the operator could be charged up to a significant voltage. If the operator then uses a metal tool such as a screwdriver to interact with the equipment, there is likely to be an ESD event as the tool approaches the equipment.
- When not operating on equipment, personnel could still trigger ESD events. Consider an individual walking through an area with sensitive equipment and brushing or leaning against said equipment. This could trigger an ESD event. These events should be considered as direct discharges since they involve direct human contact to the conducting equipment.

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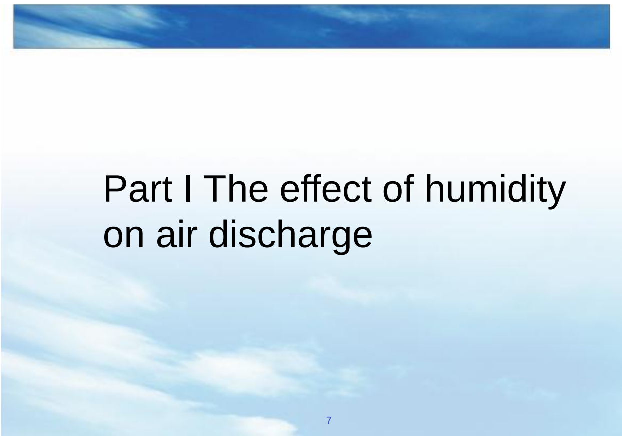
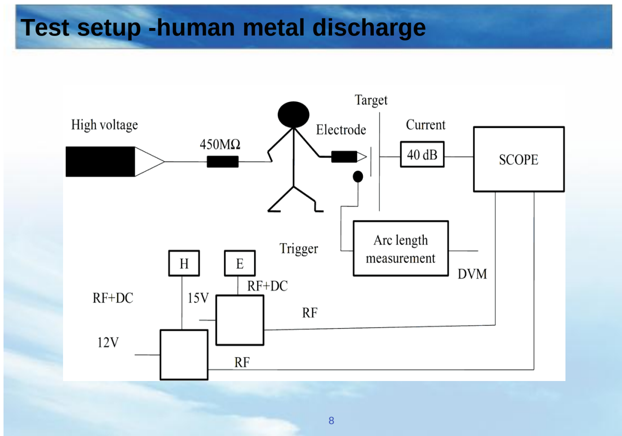
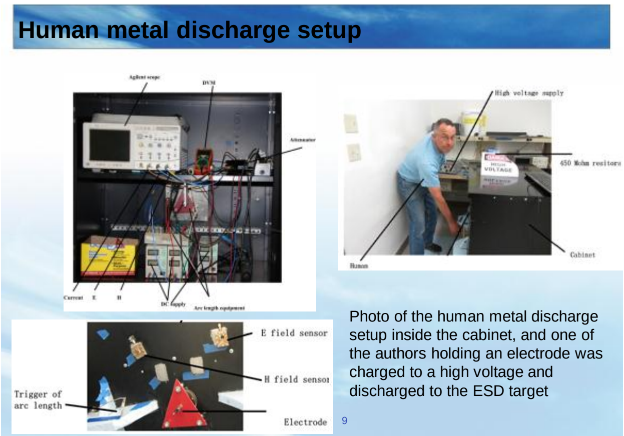
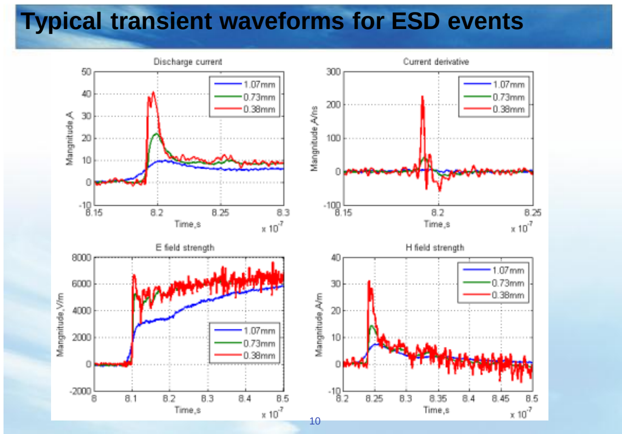
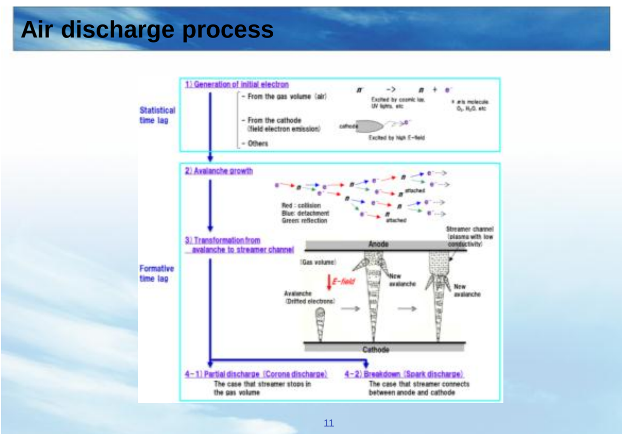

Part I The effect of humidity on air discharge
7


Test setup -human metal discharge
Target
High voltage
Electrode
Current
450MΩ
40 dB
SCOPE
Trigger
Arc length measurement
H
E
DVM
RF+DC
RF+DC
15V
RF
12V
RF
8


Human metal discharge setup
E field sensor
H field sensor
Trigger of arc length
Electrode
Photo of the human metal discharge setup inside the cabinet, and one of the authors holding an electrode was charged to a high voltage and discharged to the ESD target
9


Typical transient waveforms for ESD events
Discharge current
Current derivative
E field strength
H field strength
1.07mm
0.73mm
0.38mm
Time,s
10


Air discharge process
Statistical time lag
1) Generation of initial electron
2) Avalanche growth
3) Transformation from avalanche to streamer channel
Formative time lag
Anode
Cathode
4-1) Partial discharge (Corona discharge)
4-2) Breakdown (Spark discharge)
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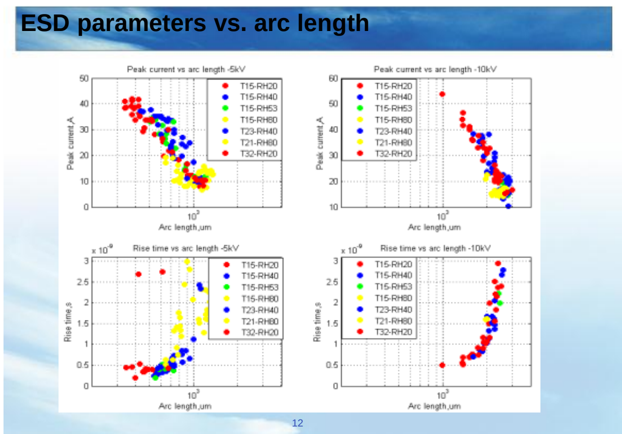
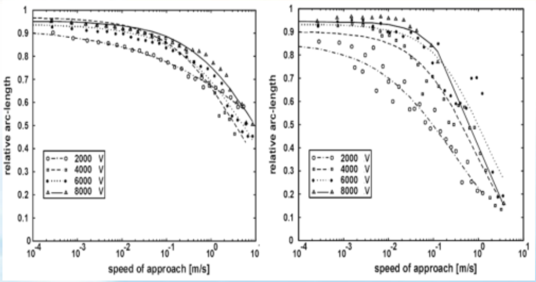

ESD parameters vs. arc length
Peak current vs arc length -5kV
Peak current vs arc length -10kV
Rise time vs arc length -5kV
Rise time vs arc length -10kV
Arc length,um
12

Approach speed



- This threshold approach speed is a function of humidity, surface conditions and voltage. (Rough cathode shown on left, Smooth cathode shown on right)
- Critical approach speed is much higher for a rough contact.

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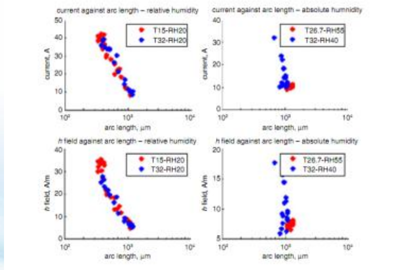
Relative humidity vs. absolute humidity



- Current as a function of arc length with 5kV discharge charge voltage, Constant absolute humidity on left and constant relative humidity on right
- For constant approach speed and absolute humidity, the discharge current has a much larger range for a 89.6F (32℃),40%RH environment than for a 80.06F (26.7℃), 55%RH environment.
- For constant approach speed and relative humidity, the discharge current ranges are similar.

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Part II

Secondary discharge

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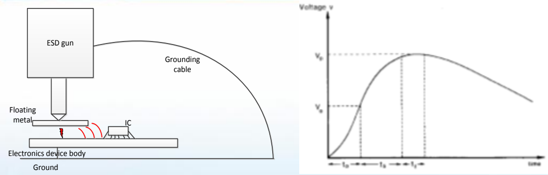
Secondary discharge illustration



- Secondary discharge is a parasitic discharge in contact discharge method.
- Sub millimeter gaps are formed between buttons, screws, switches, indicators ,screens and electronics body. If these floating metals could be touched in its normal use, contact discharge will be chosen.
- If the applied voltages is higher than a threshold voltage, it will cause a secondary discharge in the sub millimeter gap, this leads to a very rapid current rise.
- Due to the combined effect of the very rapid voltage collapse and the availability of charges in close proximity, a very high peak current is reached within 10s of picoseconds in the secondary ESD.

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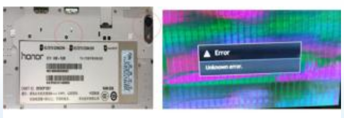
Problems explanation



(a) (b)

- Figure shows the 4 kV contact discharge to screws and the lens of a mobile phone, the sensitive phenomenon happens, the screen is crash and unknown error information appears.
- The repeatability is bad, during ten discharges test, the failure appears two times.

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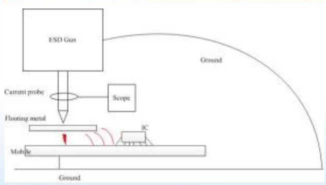
Test setup-Secondary discharge



Setup of secondary discharge

- The floating metal and the electronics device body will form a capacitor, the primary discharge charges the capacitor.
- The charging time constant of the sub millimeter gap is determined both by its capacitance value and by the impedance of the ESD source.

- The experiment setup is shown in Figure, the Noiseken ESD gun(ESS-S3011) is used to discharge to a floating metal of a mobile phone, the gap is set to be 0.5mm.
- A current probe (Solar 9119-1N, frequency range, 1MHz to 1.2GHz) is used to measure the discharge current, it is connected to the Agilent oscilloscope (DSO9404A, bandwidth 4GHz，sampling rate 20G Sa/s) through an 40 dB attenuator which is used to protect the oscilloscope and the oscilloscope is set in the Faraday cage.

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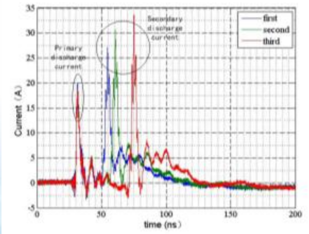
Measurement results 1 discharge current



Three discharge current waveforms at 6kV voltage

●The primary discharge current of the three discharge tests are overlapped, the amplitude is about 20A which follows the rule 3.75 A/kV of the IEC 61000-4-2 standard.
●The amplitude of the secondary discharge current varies from 27A to 33A which is much more larger than the primary discharge current.
●The peak secondary discharge current increases with time lag.

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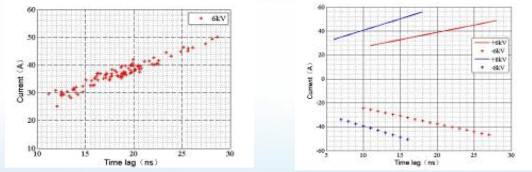
Measurement results 2 Current vs time lag



(a) (b)

Peak secondary discharge current vs time lag at 6kV(a), at different negative and positive voltages(b)

●The peak of secondary discharge current as a function of time lag is shown in Figure (a). The peak of secondary discharge current varies from 25A to 50A, and the time lag varies from 10ns to 30ns. The peak secondary discharge current increases linearly with the time lag.
●To evaluate the peak of secondary discharge current as a function of time lag at different voltages, at each applied voltage(±6kV, ±8kV), one hundred times discharge tests are conducted, the results are shown in Figure (b). The positive voltage and negative voltage results are symmetrical. The rate of peak of discharge current to time lag in higher voltage is larger than that at lower voltage.

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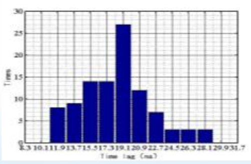
Measurement results 3 Time lag distribution



● Principal: All time lags are determined by the availability of seed electrons. These can be provided by field emission, detachment from Oxygen and water molecules. From many times measurements, the time lag distribution is found to satisfy probability and statistics characteristic.
● Time lag distribution: The shortest and longest time lag at 6kV voltage are calculated, then the time difference is divided equally into ten sections, the frequency of time lag in each section is calculated, the result is shown in Figure. From the result, though the time lag varies largely, a quarter times fall into the middle section, less fall in the two ends section, the intensity distributing is symmetrical and it follows normal distribution.

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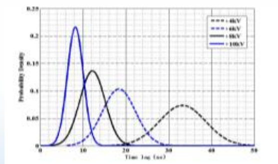
Measurement results 3- Time lag distribution



●The time lag probability density at different applied voltage is shown in Figure. They all follow normal distribution.
●As the applied voltage increases, the mean and the variance decreases, but it is not decreased linearly.
●The more the applied voltage exceeds the DC breakdown voltage, the more electrons will be able to initiate a breakdown, then the time lag is shorter.
●But as the applied voltage increases to a even higher value, the time lag decreases to a constant value which is formative time lag.
●The formative time lag is the time from the initiation of the avalanche until the gap is bridged by a low impedance arc. For millimeter length gaps, the formative time lag is typically less than a few nanoseconds.

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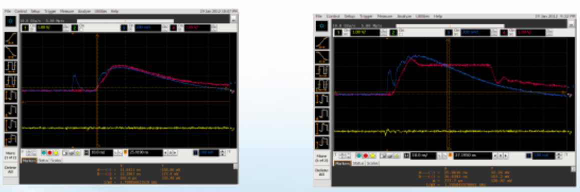
Small time lag illustration



●Less than 10ns time lag is more interesting, but from the current waveform, the overlap between the secondary discharge and primary discharge stop identifying the time lag.
●As the time lag has statistic characteristic and influenced by humidity, field emission, metal surface condition. The secondary discharge current varies largely at different conditions.

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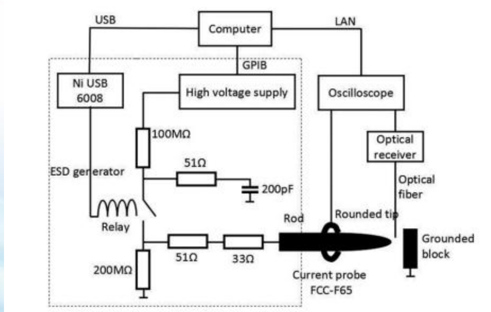
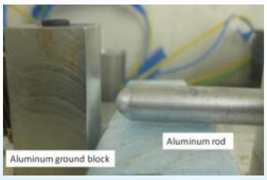
Measurement setup-small time lag

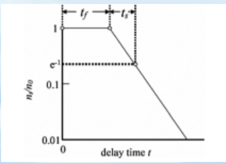


Current and spark two paths measurement setup

Patents: Micro gap length time lag measurement

Different electrodes comparison





$$\frac{n_t}{n_0} = \exp(-\frac{t-t_f}{t_s})$$

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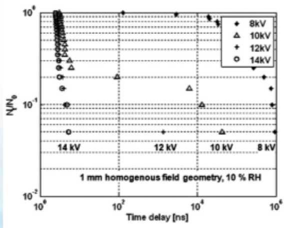
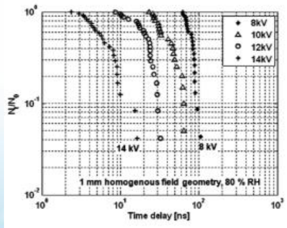
Measurement results 1- Time lag in different voltage



Laue plot for the discharge of a rounded aluminum rod to a plate, 1mm gap distance, 10% RH.



Laue plot for the discharge of a rounded aluminum rod to a plate, 1mm gap distance, 80% RH.

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Measurement results 1- Time lag in different voltage

TABLE I
MEAN VALUE OF THE TIME LAG FOR DIFFERENT APPLIED VOLTAGES, GAP LENGTHS, AND RH LEVELS FOR A ROD TO GROUND BLOCK DISCHARGE GEOMETRY, MATERIAL

Voltage [kV]	5	6	7	8	9	10	11	12	13	14	15
0.55 mm 10% RH	x	x	x	5.1 μs	340 ns	120 ns	73 ns	9.1 ns	7.8 ns	1.7 ns	1.3ns
1 mm 10% RH	x	x	x	0.22 ms	94 μs	3.1 μs	1.5 μs	71 ns	17 ns	3 ns	2.6 ns
0.55 mm 65% RH	330 ns	190 ns	86 ns	46 ns	13 ns	9.4 ns	5.1 ns	3.4 ns	2.9 ns	1.7 ns	1.5 ns
1 mm 65% RH	590 ns	170 ns	0.1μs	84 ns	76 ns	56 ns	39 ns	28 ns	17 ns	11 ns	7.3 ns

x: Time lag too long to be measured >1 ms.

- The strong influence of the applied voltage is visible, For dry air (1 mm, 10% RH) the time lag was 0.22 ms at 8 kV. But it reduced to 71 ns at 12 kV.
- The effect is less severe in humid air. Simply because the time lag is already much lower due to the detachment of seed electrons from water molecules

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Measurement results 2- Time lag gap size

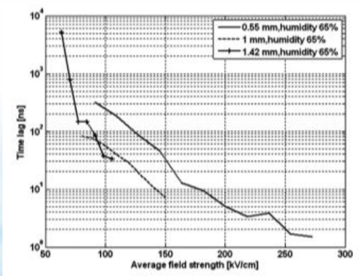

Fig. 7. Time lag against the field strength with the same humidity and at different gap lengths.

- Average E field=Gap voltage/gap length
- Large gap size provides more seed electrons, induces short the time lag

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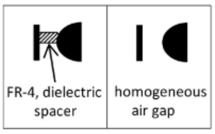
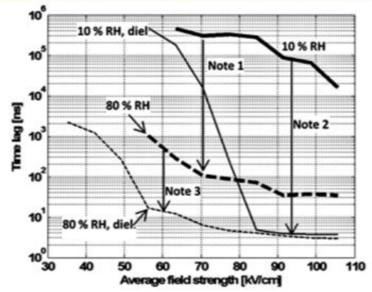
Measurement results 3-Dielectric–air interface





- Note 1 illustrates the effect of humidity on the time lag without the dielectric.
- Note 2 emphasizes the effect of the dielectric on the time lag for dry air.
- Note 3 emphasizes the effect of the dielectric interface for a higher humidity.

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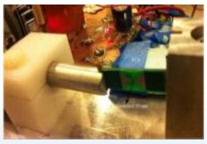
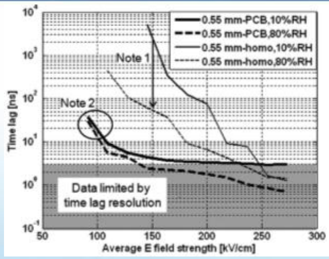
Measurement results 4 PCB-based spark gap





- The electric field is strongly non uniform due to the thin metal layer (35 μm) on the PCB and the tip radius of about 30 μm
- Note 1 shows much longer time lags for the homogeneous field geometry
- Note 2 shows the time lag is already close to 10 ns for 100 kV/cm

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Effect of Coating the Electrodes With Graphite

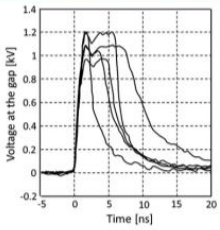

Fig. 12. Gap voltage for an approximately 0.1 mm graphite coated spark gap for multiple discharges having a static breakdown voltage of about 860 V, showing less than 8 ns time lag for voltages between 1 and 1.2 kV.

- The edges of the carbon layers enhance the field emission strongly, reducing the time delay
- Due to the strongly reduced time lag, the breakdown occurred at voltages above 1200 V always within 7 ns

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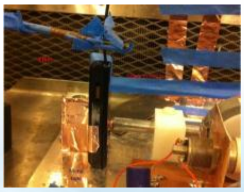
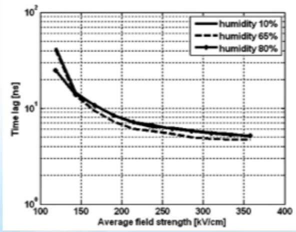
Secondary Breakdown in a Mobile Device





- The spark gaps had sharp corners and a static breakdown voltage between 2.5 and 3 kV. Even at low humidity, the time lag was short .
- This finding indicates that there were many available seed electrons that are not provided by the detachment from water molecules.
- Instead, either the sharp corners or the surface properties of the metals initiated the breakdown.

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Conclusion(1)

- Arc length is correlated to the discharge parameters, short arc length induce fast rise time and large peak current
- Fast electrode approach speed increases the severity of ESD
- Compared with absolute humidity, relative humidity is more important.
- With same applied voltage, the large time lag induces larger secondary discharge current.
- Due to the combined effect of the very rapid voltage collapse and the availability of charges in close proximity, a very high peak current is reached within 10s of picoseconds in the secondary ESD
- The secondary discharge current might be the main reason causing the failure on equipments with small gap

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Conclusion(2)

- The availability of seed electrons determines the statistical time lag;
- For smooth, clean surfaces, humidity greatly reduces the average time lag;
- Enhanced electron emissions due to field enhancement at sharp edges, detachment of electrons from surface contaminations or at dielectric layers can contribute to the reduced time lag.

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- Fayu Wan, Xiangwei Wang, Binhong Li, The effect of secondary discharge on the repeatability of contact discharge method, IET Electron. Lett., xx(xx): xx-xx, 2017. DOI:

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Thank you for your attention！

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45	贵州航天计量测试技术研究所	潘积文	副所长	
46	贵州航天计量测试技术研究所	黄贤武		
47	贵州航天计量测试技术研究所	陆定红		
48	贵州航天计量测试技术研究所	张荣荣		Email:237912549@qq.com
49	宁楚(上海)智能科技有限公司	谈平	经理	Email:sales188@neacho.com
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Seq. No.	Organization 单位名称	Name 姓名	Title 职务	Contact 联络方式
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52	遵义市产品质量检验检测院	冯发辉		
53	贵州省机械电子产品质量监督检验院	章俊华	副院长	Email:359492676@qq.com
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56	黄山佳美奇科技有限公司	程学锋	总经理	Email:18955960101@qq.com
57	上海晨隆静电科技有限公司	黄建华	董事长	Email:webmaster@esd-world.com
58	上海创纪科技发展有限公司（上海协会代表）	毕戈雄	总经理	
59	上海航天电子有限公司（上海协会代表）	张明	总工	Email:1711173909@qq.com
60	深圳市宇浩静电科技有限公司（上海协会代表）	王兴义		
61	深圳市宇浩静电科技有限公司（上海协会代表）	周宏刚		

Seq. No.	Organization 单位名称	Name 姓名	Title 职务	Contact 联络方式
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65	航天五院西安分院	蔡阿宁	部长	
66	航天五院西安分院	王栋	主管	
67	北京空间机电研究所	张翠	主管	Email:zzhang-cui@163.com
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77	中国电子科技集团公司第四十三研究所	童洋	质量管理	Email:adam_tong@163.com
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82	振华集团云科电子有限公司	周瑞山	总工	
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