NASA/CR—2002–211839

SEE Design Guide and Requirements for Electrical Deadfacing

J.M. Berki, N.B. Sargent
Analex Corporation, Brook Park, Ohio 44142

Prepared for Marshall Space Flight Center
Under H-Order 34132D
and sponsored by
The Space Environments and Effects Program
managed at the Marshall Space Flight Center

July 2002

The NASA STI Program Office...in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.
- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and mission, often concerned with subjects having substantial public interest.
- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results...even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at (301) 621–0134
- Telephone the NASA Access Help Desk at (301) 621–0390
- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076–1320
  (301)621–0390

NASA/CR—2002–211839

SEE Design Guide and Requirements for Electrical Deadfacing

J.M. Berki, N.B. Sargent
Analex Corporation, Brook Park, Ohio 44142

National Aeronautics and
Space Administration

Marshall Space Flight Center • MSFC, Alabama 35812

July 2002

Available from:

NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076–1320
(301) 621–0390

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487–4650

FORWARD

This report describes work accomplished under contract H-34132D with Analex Corporation. NASA's Space Environments Effects Program funded this work.

Mr. Joe Berki and Mr. Noel Sargent, both of Analex Corporation, performed the contracted support for this report. Questions and comments on this manuscript should be directed to Mr. Joe Ogonek at:

Analex Corporation	Phone:	216-977-0000
1100 Apollo Drive	Fax:	216-977-0200
Brook Park, Ohio 44142	Email:	Joe.Ogonek@analex.com

TABLE OF CONTENTS

LIST OF FIGURES

1.0 PURPOSE

The purpose of this design guide is to present information for understanding and mitigating the potential hazards associated with de-mating and mating powered electrical connectors on space flight vehicles. The process of staging is a necessary function in the launching of space vehicles and in the deployment of satellites, and now in manned assembly of systems in space. During this electrical interconnection process, various environments may be encountered that warrant the restriction of the voltage and current present across the pins of an electrical connector prior to separation, mating, or in a static open non-mated configuration. This process is called deadfacing. These potentially hazardous environments encompass the obvious explosive fuel vapors and human shock hazard, to multiple Electro-Magnetic Interference (EMI) phenomena related to the rapid rate of change in current as well as exposure to Radio Frequency (RF) fields. It is the intent of this design guide to treat each deadface environment separately, and to develop application oriented requirements for the electrical designer to apply as dictated by need. A goal of this design guide is to consolidate safety and EMI considerations for electrically powered staging disconnects and other operations both in flight and pre-flight.

1.1 DEADFACE DESIGN DECISION GUIDE

A Deadface Design Decision Guide, Figure 1.1-1 is included. The designer is provided with a suggested course of action to make decisions regarding deadfacing. Applications that may require deadfacing differ in the means to comply with requirements. The flowchart is intended as a checklist and to reference appropriate section of this guide.

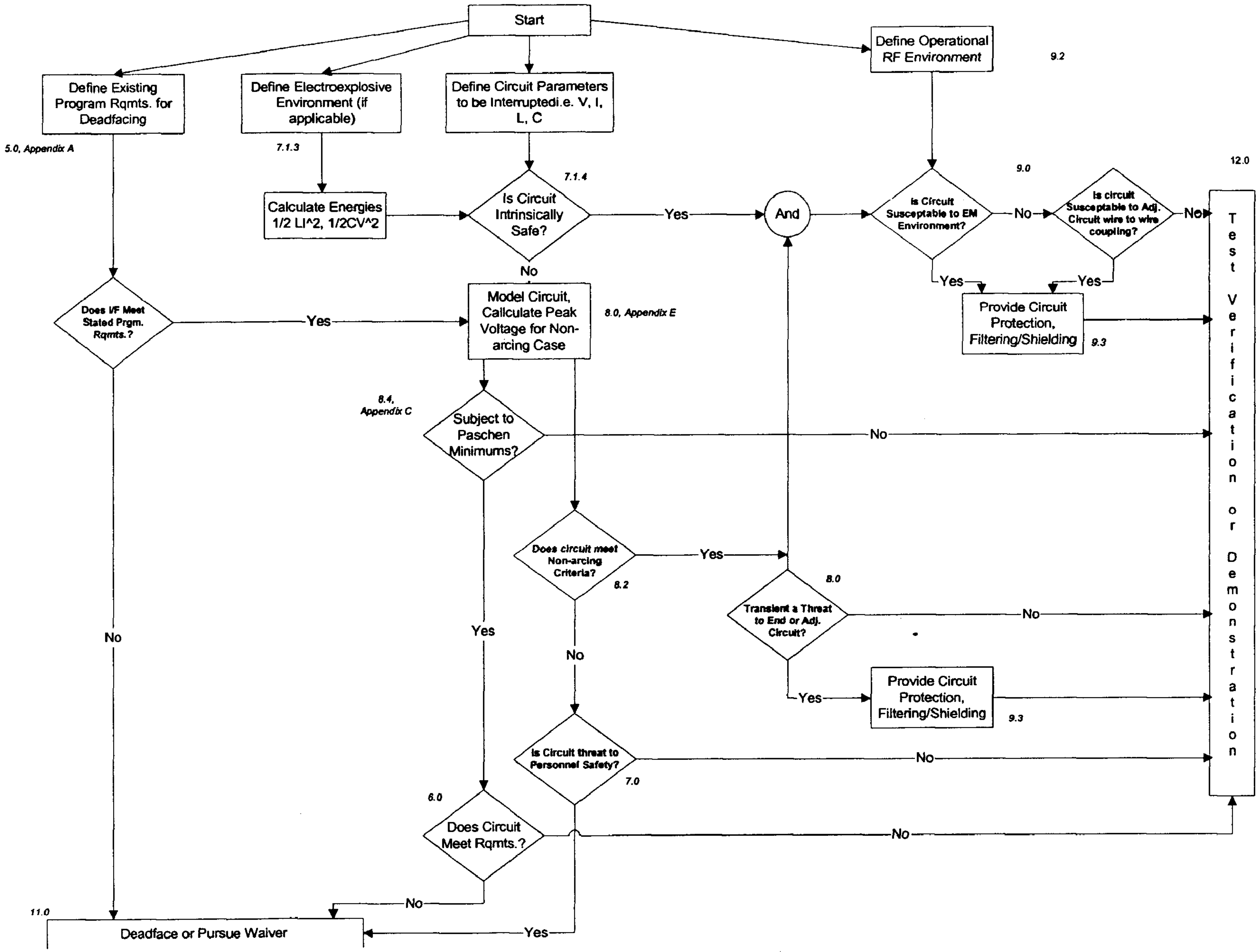

Figure 1.1-1 Deadface Design Decision Guide

2.0 SCOPE

This design guide will treat the following categories of electrical deadfacing:

1. Personnel safety based on the National Electrical Code (NEC) [1] as extended to human activity in space;
2. Explosive environments based on the NEC and other National Fire Prevention Association (NFPA) Codes and Standards;
3. EMI caused by the rate of change of current, dI/dt, and associated coupling into circuits;
4. Contact erosion;
5. Arc enhancement effects due to altitude/plasma; and
6. RF energy coupling into de-mated connectors and associated cabling.

Because of the breadth of information necessary to make this guide complete, the guide will be restricted to application engineering sufficient to determine when a potential hazard exists, then direct the designer to other reference documents for in-depth analysis and theory as required. Recently, a very significant re-evaluation of deadfacing requirements for the International Space Station (ISS) has added new test and analysis data and human safety requirements for manned space flight operations. This guide looks at these existing and historical requirements in an effort to evaluate sufficiency for tomorrow's missions as electrical system power levels increase, and control become more autonomous.

3.0 EXECUTIVE SUMMARY

Electrical deadfacing, or the "removal of power from a circuit prior to de-mating/mating a circuit interface," has been a current and voltage controlled requirement on launch vehicles since the development of the Atlas/Centaur launch vehicle in the 1960s. Although requirements exist for the National Space Transportation System (NSTS), i.e. Shuttle; ISS; and Expendable Launch Vehicle (ELV) programs for reducing current and voltage levels at staging interconnects prior to separation, no design information currently exists that substantiates the origin of these requirements, such that safety margins may be quantified for the environments that deadfacing is expected to protect. This Space Environments and Effects (SEE) Design Guide reviews existing requirements, categorizes the various reasons that deadfacing is required, and provides technical rationale for requirements in each category.

4.0 INTRODUCTION TO ELECTRICAL DEADFACING

The earliest rockets used guillotine-style cable cutters for in-flight staging of electrical cables. To prevent massive electrical short circuits, all power interfaces were interrupted and de-energized by relays prior to this event. As rocket development matured, electrical command and control functions between stages became more numerous, which led to the need for safely separating greater numbers of electrical staging circuits. There was a need to discriminate between circuits that could be safely separated in a powered condition from those that could not, requiring power removal prior to connection separation. There was also concern for the increased arcing that could occur at high altitudes at pressures of less than 0.1 Atmospheres, and for electrical safety near high-energy fuels. This led to requirements being developed for what has been called electrical deadfacing, defined as "the removal of power from a circuit prior to de-mating/mating a circuit interface." Virtually all launch vehicle programs have implemented some sort of deadface requirement based on prudent engineering, but with values differing by more than an order of magnitude. The reasons for this will be borne out by this report.

Early in the history of space flight, difficulties arose attributable to electrical switching transients. One of these transient sources is the result of disconnecting energized circuits by simply pulling umbilical cables and "flying away" from inter-stage electrical connectors. The contributing factors are shorting of circuits caused by arcing as these connector pairs separated, and the electrical transients caused by the inductance of the umbilical wiring and end circuits interacting with this rapid disconnect.

In the case of electrical transients, there are requirements that indirectly limit the current that can be interrupted by specifying maximum transient voltages that may be produced on electrical power wiring (i.e. MIL-STD-461C, [2] CE07). CE07 has now been eliminated in the "E" revision, reopening this deadface issue. Transient voltage rise times for space systems are controlled by MIL-STD-1541A [3].

The history of space flight has indicated a need to eliminate arc sources to ensure safe operation in questionable environments for all phases of flight. It is necessary to determine the parametric circumstances where arcing can occur including current, voltage, atmosphere, and contact design and what effect can be achieved by changing any or all of these parameters.

5.0 A SURVEY OF PRESENT AND HISTORICAL REQUIREMENTS

An extensive search has been undertaken to understand present requirements for deadfacing on the NSTS and ISS manned space flight programs, as well as Atlas, Delta, and Pegasus commercial ELVs. To the extent possible, supporting analysis to these requirements have been included in the bibliography and can be found in Appendix A. The purpose of this design guide is to document how this complex issue has been handled historically, and to unify this vast collection of knowledge and experience into a single reference.

Guidelines were developed during the design phase of these early programs and have become requirements utilized in current space flight programs. What is not clear, and is the subject of this design guide, is what were the design drivers of those early vehicles and whether they remain appropriate today, given the evolution of space flight safety.

Consider the comparison between NSTS and ELVs as an example. Requirements range from 10mA for some specialized interfaces found in ELVs to 500mA for payload separation on NSTS. Why the variance in requirement? This design guide attempts to identify the reasons why deadfacing is required to ensure mission success, and to derive a basis for setting an application-specific value (current/voltage/energy) for each reason.

5.1 NSTS

The NSTS system has a no-arc policy for the vehicle that presents a hazard with a 500mA current limit between ground systems and the orbiter at the T-0 umbilical. This connection is deadfaced prior to launch for currents higher than 500mA. The connections for the Solid Rocket Booster (SRB) and External Tank (ET) are also deadfaced prior to separation. Payload interfaces also have a no-arc requirement and are examined on a case-by-case basis (see Appendix A).

5.2 ISS

Since Space Station requirements are largely derived from the NSTS, requirements for the ISS are consistent with the Shuttle and are characteristic of a "man-rated" program. Because ISS is continuously manned, re-configuration and troubleshooting of electrical equipment and experiment change-out require diligence to prevent accidental disconnection of powered interfaces.

5.3 EXPENDABLE LAUNCH VEHICLES

5.3.1 ATLAS

These deadfacing requirements are usually levied on a connector-by-connector basis. In 1970, the first known (to this author) program requirement came from the Atlas Centaur Program at General Dynamics, San Diego, California, to implement a uniform specification of maximum current and voltage for all staging disconnects. For 28 Volt power, this current was set at 100mA maximum. In discussing with those who worked on the program at that time, the basis of the requirement and any supporting analysis seems lost in antiquity. The engineering manager who signed the letter mandating the requirement quipped, "The number was based on extensive empirical test results of arc thresholds and propagating transient voltage, and that they knew 1 Amp was too much, and 10mA was too little, so 100mA turned out to be right." This also seemed to come at a somewhat convenient breakpoint between lower current data and command/control functions, and that of power distribution circuits.

5.3.2 DELTA II

The Delta program has differing requirements for each class of launch vehicle based on vehicle evolution. Delta II limits the power circuit T-0 disconnect current to 10mA for the stated reason of gold pin erosion on re-usable connectors. Other staging interfaces are generally limited to this value but may increase for one-time use to 100mA. Delta IV has no specific written current requirement but follows this same practice. Waiver requests have been made for spacecraft Ground Support Equipment (GSE) power of 1 Amp, which have been denied. The Delta II second stage also uses a spring-loaded cover plate that is deployed over staging connectors following separation.

5.4 CONCLUSION

There have been several approaches to define what is acceptable and what is unacceptable for current at specified voltages carried by a connector that will experience hot de-mate/mate. It has also been determined that there are environments that have been specified as non-arcing implying that deadface methods are required. The designer needs to understand the requirements for the program that will be part of the design.

6.0 ISSUES RELATED TO DEADFACING

6.1 HOT DE-MATE/MATE

Let us consider the hot separation of a multi-pin staging connector. We will assume reciprocity holds for a hot re-connect in the case of on-orbit assembly/reconfiguration. Let us further assume that this connector contains mixed Electro-Magnetic Susceptibility (EMS) categories (not a good idea) for power, low impedance, high impedance, and RF signals. Prior to separation, each circuit contains a source and a load impedance on either side of the interface. At the onset of separation, those circuits of sufficient energy are subject to arcing until such time that separation distance causes arc quenching. At the open connector halves, end circuits in both directions are open-circuited (high impedance) with connector faces/pins exposed to the environment. This environment may be in a vacuum, at altitude, or on the ground subject to the water deluge of the T-0 event. Some circuits may have a circuit shield, which now may also be open if the connector shell is not bonded (a low impedance connection) to structure. This presents the opportunity for RF coupling to these open circuits for the duration of the mission. The arc event and its effects are essentially not a function of nominal connector separation velocities. The arc produces current instabilities that result in broadband frequencies being conducted into end circuits, exciting their resonance(s), and may efficiently couple into adjacent circuits, with the eventual arc quenching resulting in a large dI/dt event. The arc may erode contact material to produce conducting plasma, which could direct couple conducted energy into adjacent circuits. In the case of the water deluge it presents the opportunity to short all pins together and to ground.

So, no single deadface parameter value will suffice, or should be imposed, as it may unnecessarily constrain design. Good EMI engineering should not constrain design, but should enable the design. Subsequent chapters will focus on a separate effect of the connector staging event, and develop a means to evaluate its threat in sufficient detail to direct the user of this design guide to more thorough material in the bibliography based on the design environment. For example, human safety is amply documented in the NEC [1], for most purposes, and this guide will point the user to appropriate sections. Recommendations will be based on this expert advice tailored for specialized use in space systems.

The designer must consider the ramifications of arcing occurring at or near conductors that are a part of his/her design. Safety margins need to be designed into the system.

6.2 THEORY OF ELECTRICAL CONTACTS

The theory of electrical contacts is very complex and has been studied extensively. One of the most comprehensive references, Holm [4], is the basis for Appendix B. In the case of electrical connectors, the pin/socket arrangement found in most aerospace connectors consists of a solid pin that fits into a tubular socket. The surface finish, material, and loads imposed by the connector mechanical design are contributing factors to potential arcing during hot de-mate. There are other metallurgical processes involved, such as cold welding of contacts mated for long periods of time, so that elimination of arcing does not eliminate contact pitting.

There are many more factors that are discussed in great detail in Holm [4]. In general, low voltage arcs are initialized by local contact heating until ionization occurs in the contact material. High voltage arcs are initialized by direct ionization of the gas and /or contact of material.

Holm is very thorough in his discussion of the subject of Electrical Contacts. The designer should be aware of the various contact characteristics such as contact shape, material, any coatings, environments, and separation velocity.

6.3 CIRCUIT CONFIGURATIONS

The most common configuration for an umbilical interface is shown in Figure 6.3-1. On the powered end of the interface is a connector that is either free in the case of a ground processing umbilical, or attached to the separation structure. In the free umbilical case, the connector shell has lost its local bond to structure, but may still have a connection to structure through a cable shield(s) or metal tether. Modeling of the electric field coupling to these cables and end circuits needs to take this difference into account. Since all functions in the cable are lost after separation, issues of EMI coupling for those end circuits may be for damage only or may still be for upset if the umbilical circuits are "OR-ed" with a similar on-board function, which is sometimes the situation. This also leaves the end circuit vulnerable to RF coupling. There are two models to consider. The first for the free umbilical case looks at cable shields as an open wire above a ground plane, or a dipole. The second considers the cable shield and connector bonded to the structure still intact as a loop just as before the de-mate event.

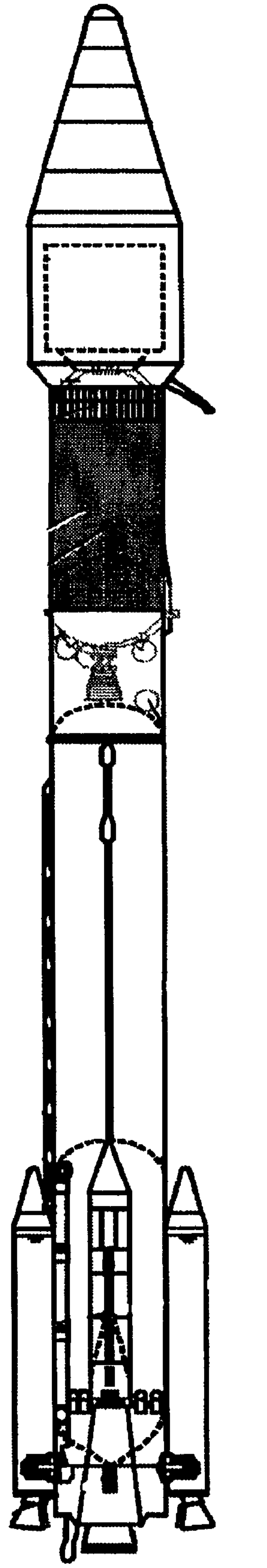

Figure 6.3-1 Typical ELV Umbilical Configuration

7.0 HUMAN FACTORS ENGINEERING

7.1 SAFETY

The NEC governs human safety from electrical shock hazards in the U.S. Because space operations are performed in a weightless and typically cramped working environment, it is prudent to provide additional protection as dictated by ISS requirements. It should be noted however that some of these requirements are for powered operation as well as for open connectors or un-powered equipment.

7.1.1 GROUND FAULT INTERRUPTERS

Ground Fault Interrupters (GFI) are designed to prevent excessive current from flowing from a power circuit's hot or return wire through structure ground, most often from a faulty or degraded piece of equipment. Although this GFI functions to disconnect the circuit, it is not by strict definition deadfacing. This discussion of GFI requirements is included only for completeness.

7.1.2 LEAKAGE CURRENT REQUIREMENTS

The ISS requirements for electromagnetic interference, SSP 30237 [5] contains requirement LE01, "AC Power User Leakage Current," which requires that the leakage current from any equipment case not return current through structure ground of more than 5mA. This requirement has nothing to do with deadfacing since it is an operating requirement. Its purpose is to prevent voltage drops from developing in the ground circuit path between equipments in an operating system because of excessive common mode current. These common mode voltages can interfere with analog and digital circuit operational functionality. This requirement has sometimes been interpreted that a 5mA deadfacing requirement exists, but this is not true.

7.1.3 ELECTRO-EXPLOSIVE ENVIRONMENTS

The NEC [1] and the NFPA Codes and Standards govern electrical safety in electro-explosive environments on earth. Requirements documentation that governs safety and handling of payloads for NSTS and ELV programs refer to EWR 127-1 – Launch Vehicle, Payloads, and Ground Support Equipment Documentation, Design and Test Requirements [6] in defining environments and design guidelines that address hazards and practices. Second tier documents called by the EWR 127-1 are:

- NFPA Codes and Standards, Chapter 5 (NFPA 70), Hazardous (Classified) Locations, Classes I, II, and III, Divisions 1 and 2
- NFPA Codes and Standards (NFPA 496) Purged and Pressurized Enclosures for Electrical Equipment
- MIL-HDBK-454A Electrical Connectors [7]
- MIL-STD-810F Explosive Atmosphere [8]

- NEC [1] Article 500 (same as NFPA 70)
- NEC [1] Article 501 (same as NFPA 70)
- NEC [1] Article 504 (same as NFPA 70)

The NFPA Codes and Standards Chapter 5 covers the requirements for electrical and electronic equipment and wiring for all voltages in areas designated by Class and Division. The Classes are broken down into groups that define a specific environment. It is important to define the environment that the circuit or system will operate in and then determine which area in the code that it is governed by. The Code also lists standards for applications and methods for achieving a safe system.

NFPA 496 is a standard that provides the user with information on how to deal with purging and or pressurizing enclosures including, but not limited to rooms and equipment to prevent ignition of a flammable environment. MIL-HDBK-454A [7] contains guidelines for selection of electrical connectors for various applications and functions. MIL-STD-810F [8] defines testing of materials that demonstrate the ability to operate in a fuel-air explosive atmosphere without causing ignition.

The National Fire Prevention Association Codes and Standards, including the NEC [1], and safety requirement documents provide the designer with specific scenarios for making hazardous situations safe. Additional Military Specifications (MIL-HDBK-454A [7] and MIL-STD-810F [8]) and standards provide information on selection and testing components and sub-systems.

7.1.4 INTRINSIC SAFETY

Intrinsic safety as applied to electrical circuits with interfaces are circuits that must be incapable of producing a spark which could ignite any mixture of gases found in the expected environment, present an electrocution hazard to personnel, or damage adjacent systems from the resulting electrical transient.

To design an intrinsically safe circuit, one must take into account the environment and circumstances that are expected during the operation of the circuit. Flammable environments must be considered. Through analysis it is possible to determine the minimum current that would produce an arc in a given environment. Knowledge of materials selected for electrical contacts and flammable properties of different gasses at different pressures present in the operational environment of the circuit are essential in carrying out the analysis. Values for capacitors and inductors should be selected to minimize large energy storage capabilities in the circuit. This should also include examination of transmission lines connected to the circuit. Operation of a circuit in a hazardous environment such as instrumentation can be designed by using guidelines developed by the Safety in Mines Research Establishment (See "Intrinsic Safety, The Safe Use of Electronics in Hazardous Locations," Redding [9]). Several curves were developed for different environment and circuit parameters. Figure 7.1.4-1 depicts at which value of voltage versus current that ignition could occur in a quasi non-inductive circuit for a hydrogen gas environment. Figure 7.1.4-2 shows current versus inductance in an inductive circuit for a hydrogen environment. Areas to the left of the curves should be considered safe while the area to the right of the curve should be considered unsafe. To be intrinsically safe for non-inductive circuits operating at 24 Volts, current should be limited to 100mA. Figure 7.1.4-3, capacitance versus voltage in capacitive circuits in a 22% hydrogen environment, is shown for tin.

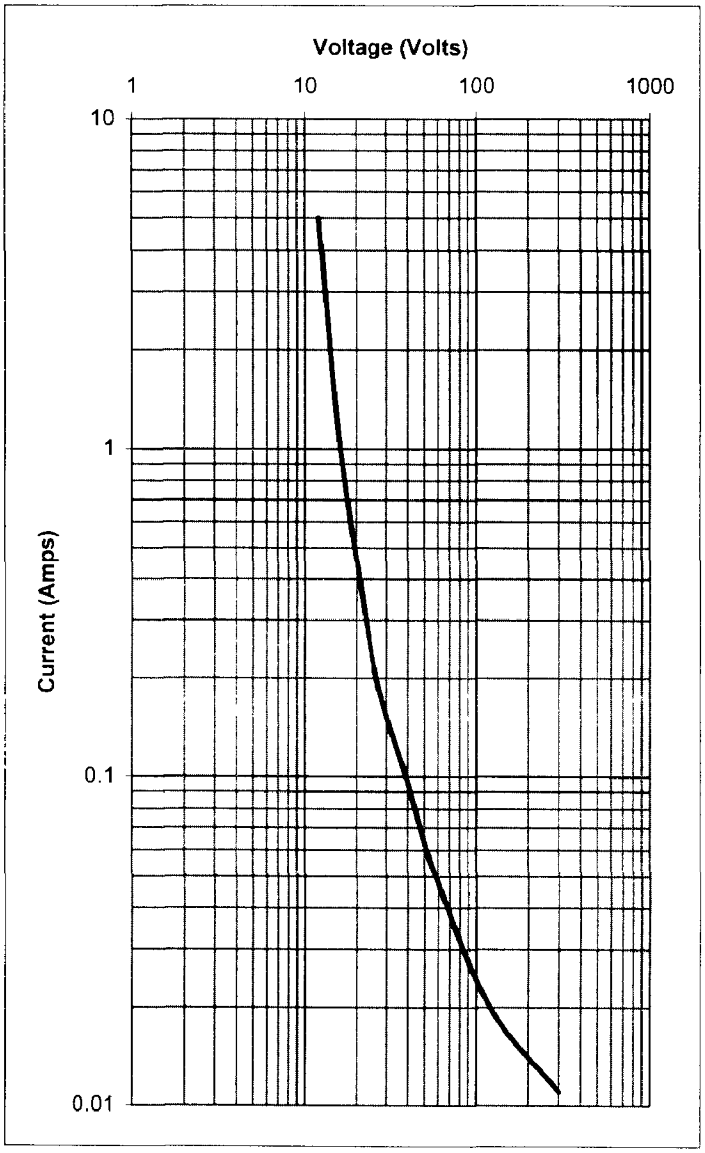

Figure 7.4.1-1 Safe Area for Non-Inductive Circuits

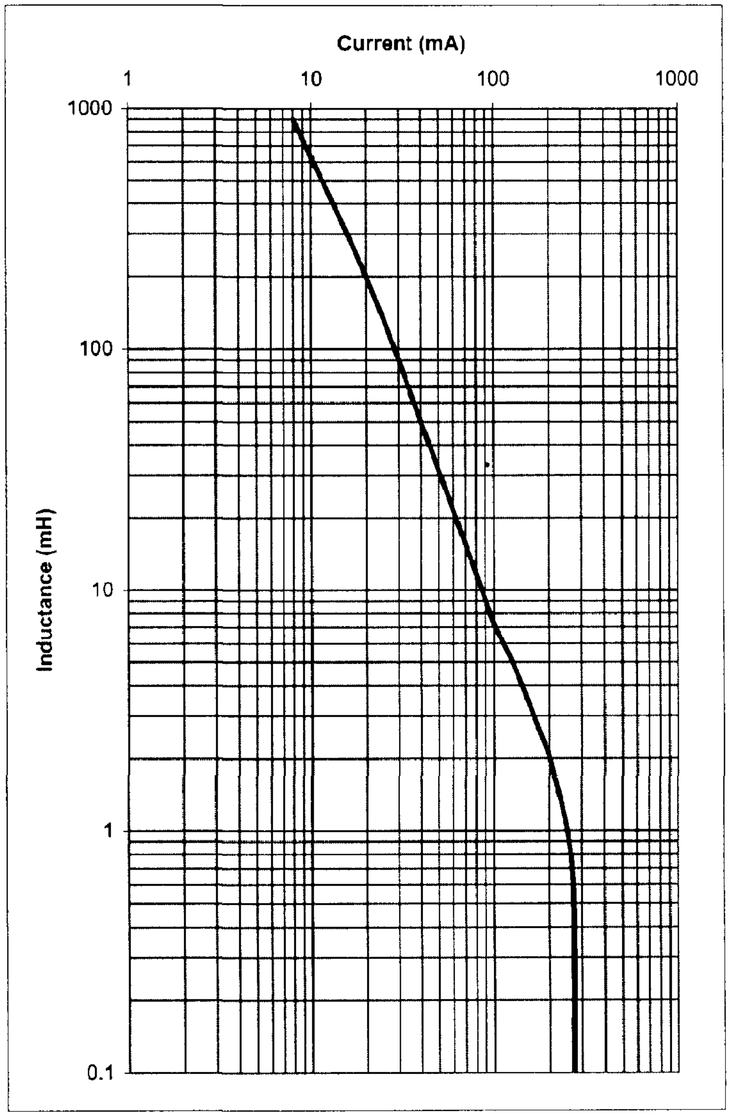

Figure 7.4.1-2 24-Volt Inductive Circuits

For 24-Volt circuits, using a deadface limit of 100mA, inductance must be kept below approximately 7mH to limit $\frac{1}{2}LI^2$.

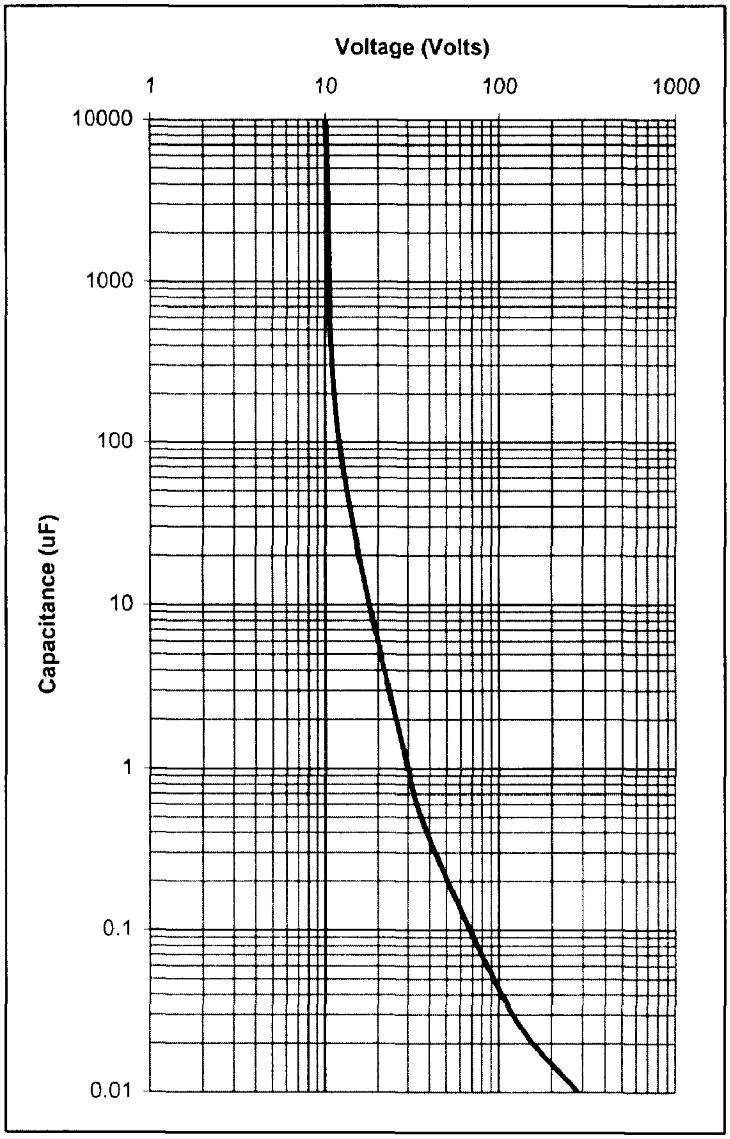

Figure 7.4.1-3 Safe Area for Capacitive Circuits

To limit total energy ½CV^2 for circuits operating at 24 Volts, total circuit capacitance must below 2.0uF. Another consideration for intrinsically safe designs is to minimize components or equipment in the hazardous environment area. Any components, i.e. connector, which is to be hot de-mated, should only occupy the hazardous environment if absolutely necessary like a sensor. If the circuit power supply is self-contained, is the inductance and capacitance low enough? If it is remotely located it will not have to be explosion proof. Are the cable requirements in line with the inductance and capacitive limits to be safe? If changes are made to system configurations how do the changes affect the intrinsic safety? If a cable is added or a component is changed is the circuit still intrinsically safe?

By incorporating the safety requirements in this section into the design of the system the designer can achieve an intrinsically safe design.

8.0 ELECTRICAL TRANSIENTS CAUSED BY RAPID dI/dT

In reality, hot de-mate/mate at a connector is no different than opening a relay contact or flipping a switch. The difference is often one of perception in that designers plan for the suppression of repeated switching transients, but often do not when the current interrupt/inrush is at a connector interface once in its lifetime or infrequently. Transient suppression is most often and best installed at the source of the switching transient, but since this is difficult or impossible at a connector, suppression is frequently overlooked. The switching transient arises from a very fast rate of change of current, dI/dt and by the circuit inductance given by the expression:

$$E = L\,(dI/dt)$$

To the designer, the circuit inductance is somewhat easy to determine, but the magnitude of the term dI/dt is usually very much underestimated. This is the subject of this section.

First the dI/dt event has to be divided into two categories, those separations that do not arc and are rather well behaved, and those that do arc and are not well behaved. In the case where no arcing occurs, the dI/dt event is governed by a changing of resistance as the connector contact's point of disengagement area diminishes. This is contrasted to the case where arcing occurs and current continues to flow across a small gap until the sudden moment of arc extinguishment. This requires a discussion on the onset of arcing, see Appendix B, since it is a function of contact shape, voltage and current, circuit impedance, and the separation time (separation velocity effects result in a decrease of response voltage as separation time is increased). In addition, Holm [4] found that for velocities less than 20 cm/sec little change in the response voltage was noted. See Figure E.1-8 in Appendix E for data obtained in separation testing.

Deadfacing to below the arc threshold level is prudent engineering, however connector arcing can be accommodated in a design if functionally required, and should be considered with other environments.

A generalized observation after reviewing numerous references and data reports is that the peak voltage amplitudes of unsuppressed switching transients tend to group around four times the switched voltage, although 1000 Volt transients have been observed on 28 Volts DC circuits switching high inductance cryogenic solenoid valves. It will be shown that when this transient voltage approaches 300 Volts arcing is inevitable.

8.1 TRANSIENT BEHAVIOR FOR NON-ARCING AND ARCING SCENARIOS

The characterization of what happens during a hot de-mate event can be observed by examining voltages on either side of the connector. In the case where there is no arc, the waveforms depicting the voltages on the load and line sides of the connector can be predicted by linear circuit analysis or modeled as in Section 10.0. In the case where an arc is formed the waveform depicting the condition known as "discontinuous discharge" reveals a transient pulse train that forms on the line side while the voltage recovers rapidly on the load side and goes into relaxation oscillation with the voltage going negative at the natural frequency of the circuit. See Appendix E: Figures E.2-4, E.2-4a, and E.2-4b. This can occur at current levels as low as 5mA to 100mA. The energy resulting in the arc can be as high as 1000 Volts and instantaneous current over 1 Amp. The capacitance and inductance found in the circuit and transmission lines contributes to the performance. If a continuous discharge condition occurs usually at higher initial currents, the voltage on the load side does not go negative as much as the discontinuous discharge condition, and relaxation oscillation occurs much later at a lower level. Transients form on the line side and secondary transients may form with re-strikes. As initial current is increased the duration of the transient increases gradually. Transmission line length contributes to the conditions in that the energy is reflected back from the circuit via the transmission line. In general:

- The rise time of the primary transient is less than 2 nanoseconds
- The duration of the primary transient is dependent on the length of the transmission line on the load side
- The amplitude of the primary transient is half of the break down voltage

Two studies support the three items above and address the complexity of modeling the arcing event in detail as an input to end-circuit effects and wire-to-wire coupling. These are: "Switching Transients in Low Current DC Circuits," J. Shi and R. M. Showers [10], and "Prediction of Crosstalk Due to Showering Arcs at Switch Contacts," S.W. Hall, C.R. Paul, K.B. Hardin, and A.D. Nielsen [11].

8.2 THE NON-ARCING CASE

During hot de-mate the contact area at the connector diminishes to a point. As disconnect occurs, the impedances are such that the creation of an arc does not occur. The load impedance after disconnection does not try to feed energy back to the source causing an arc. The resulting circuit is stable and does not build energy. There is no contact erosion.

Experiments and a PSpice simulation were used to examine the transient voltages produced by connector separation; reference [12] and Appendix E.

The rapid dI/dt, along with the self-inductance of the wiring and the inductance of circuit components, propagates voltage impulses to the opposite ends of the wires and the connected equipment to the equation $E = L\ (dI/dt)$. The PSpice model shows that due to transmission line distributed parameters there is a limit that this voltage transient can achieve and reaches a maximum value at a rise time equal to 1 μsec for t in dI/dt. The importance of accurately defining the current rate of change dI/dt, cannot be understated, and is the key parameter in performing any analysis.

8.3 THE ARCING CASE

We survive daily events of arcing with little consequence. Most notable are Electro-Static Discharge (ESD), which is not treated in this document, and the unplugging of an operating appliance from the wall socket like a vacuum cleaner that has run out of cord. This requires a discussion about the onset-of-arcing physics since it is a function of contact shape, voltage, current, circuit impedance, and, to an extent, separation velocity. The most serious consideration of the hot-disconnect for the EMI engineer is the dI/dt event that comes at the instant of arc extinguishment. At the very beginning of separation, assuming arcing does occur, rapid broadband noise is momentarily superimposed on the current flow until extinguishment occurs.

The stored energy of this inductance is very similar to EMI design issues with the suppression of solenoid switching transients. As wiring becomes long as is the case from GSE through a T-0 disconnect up a launch vehicle to a spacecraft, inductance can be significant. Since the circuit is open at one end, all the stored energy must be dissipated at the load end and the associated wiring.

When arcing does not occur, the dI/dt of the separation event is orders of magnitude slower than when arcing does occur because of the precipitous extinguishment event. Under arcing conditions, the circuit is still drawing current across the ionized path between the connector pins until sufficient pin separation is achieved that the pin-to-pin voltage supports the continued ionization. At the moment of arc quenching, the current is interrupted very rapidly and essentially independent of the actual connector separation velocity. This requires a discussion on the onset of arcing, since it is a function of contact shape, voltage and current, circuit impedance, and separation velocity. Separation velocity effects result in a decrease of response voltage as separation time is increased. In addition, Holm [4] found that for velocities less than 20 cm/sec little change in the response voltage was noted. See Figure E.1-8 in Appendix E for data obtained in separation testing. Figure 8.3-1 shows the dI/dt event for the arcing and non-arcing event given the same circuit voltage but varying the current below and above the point where local heating of the connector pins will sustain arcing at separation. *Eg* is the minimum voltage for glow discharge. *Ea* is the voltage at which an arc can be sustained.

If arcing is allowed to occur the propagated transient and electro-explosive environment must be examined. (This is not to say these can be ignored if no arcing occurs, but the effects are much less.)

It is interesting to note that the circuit source voltage does not appear in the equation $V = L\,(dI/dt)$ and that only the current is responsible for generation of the transient.

In general, for air environment at one atmosphere the transient voltage at connector pins should be kept below 300 Volts to prevent glow discharge. The rate of change for voltage at connector pins should be kept below the value necessary for an arc discharge 1Volt / μsec for this case. See "Noise Reduction Techniques in Electronic Systems," H.W. Ott [13].

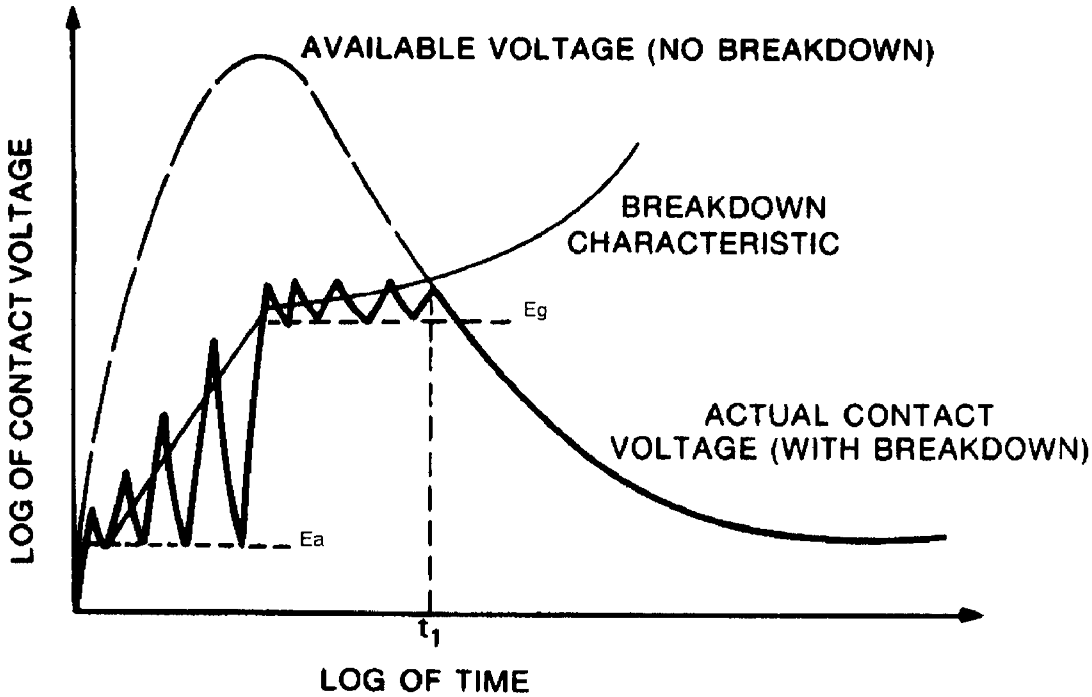

Figure 8.3-1 Voltage Characteristics During Arcing

The plasma generated between the connector halves at the pin has the potential for bridge arcing to adjacent pins as well so that a momentary pin-to-pin shorting analysis is an issue during the separation event.

Because of the requirement for on-orbit contingency operations if spacecraft separation does not occur on command, operations deadfacing of power between the launch vehicle upper stage and the spacecraft would present difficult re-application of power scenarios.

Corona and spacecraft charging is an increased concern at altitude and on orbit. Studies for ISS suggest 60 Volts as a threshold in Low Earth Orbit (LEO) and it is generally agreed that exposed open-circuit voltages less than 32 Volts do not constitute a hazard.

8.4 ARC ENHANCEMENT EFFECTS DUE TO ALTITUDE (PASCHEN'S LAW)

The visualization of a scenario where de-mating of powered connectors occurs, is a launch vehicle during accent. The vehicle experiences atmospheric changes, including pressure, temperature, and composition of the surrounding atmosphere. The surrounding atmosphere may also be affected by the impingement of vented gasses during accent on connectors that de-mate during staging. The analysis of the surrounding environment would determine the breakdown voltage at which an arc would occur when the connector is de-mated. If the design is such that an arc at this point would present a hazard or affect mission success then deadfacing methods should be employed. The formation of an arc starts with a set of contacts that form a conduction path. After contact is broken at t = 0, a gap forms, length *s*, which changes from 0 to some optimum length for arcing and then beyond the affect of the electric field. The effect of speed during separation is negligible for velocities less than 20 cm/sec Holm [4]. See Figure E.1-8 in Appendix E for data obtained in separation testing. A voltage *Vs* appears across the contacts, which is dependant on current and impedance of the resulting circuit. The gap consists of gas or a vacuum [4]. For gas environments ions are formed causing electrons to flow across the gap forming a glow discharge or Townsend effect. The *Vs* must be greater than the cathode fall (for air at one atmosphere V = 300 Volts). The pressure of the gas *p* also affects the result. This is known as Paschen's Law: $V = f\,(pd)$, where p = pressure, d = gap, and f = constant. If there is enough energy left in the circuit to sustain a current an arc will develop. Figure 8.4-1 depicts the relationship between *Vs* and *ps* in an air atmosphere, where *s* is the gap. See Appendix C for an explanation of Paschen's Law.

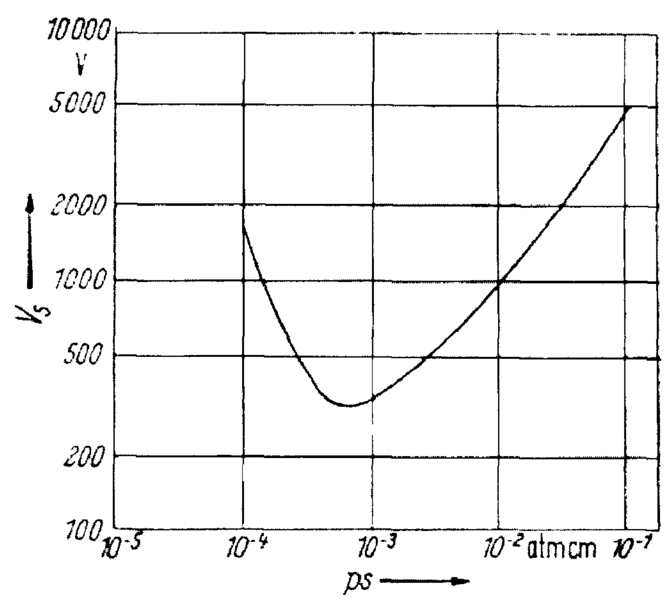

Figure 8.4-1 Breakdown Voltages For Air Gap

8.5 CIRCUIT TO CIRCUIT COUPLING CAUSED BY CONNECTOR TIP-OFF

In the case where the power ground return path separates just prior to the power hot lead separation, significant current may continue to flow momentarily through alternate ground paths, causing CM transient voltages to be developed in those circuits powered by that source.

8.6 CONCLUSION

The designer must deal with how, via unsuspected paths, transients may affect the design by propagating these affects to adjacent systems. Understanding the formation of transients for non-arcing as well as arcing scenarios will assist the designer with design optimization.

9.0 RF ENERGY COUPLING INTO OPEN FACED CONNECTORS AND ASSOCIATED CABLING

The separation event and its resultant changes in the circuit impedance elements at the open connector interface may greatly affect the amount of electric field coupling and hence the RF power delivered to the end-circuit. One might start by asking how much different is the coupling for the open connector case, versus the normally connected case? The issue is whether these changes in configuration make the RF environment's coupling to the end circuits appreciably worse than when the connectors are mated.

Perhaps one of the best treatments of field to transmission line coupling to answer this question is by A.A. Smith in "Coupling of External Electromagnetic Fields to Transmission Lines," [14]. This analysis and supplemental tests show graphically the profound effect of resonance coupling for very resistive terminations (> 10^5 Ohms) with coupling 40 dB greater than when both ends are terminated near the cable's characteristic impedance or lower. This would indicate that induced voltage coupling onto wiring associated with open connectors needs to be seriously considered.

9.1 CHOOSING A FIELD-TO-WIRE COUPLING MODEL

There is no single best choice for a coupling model without knowledge of the configuration. Are wiring circuits small, large, or resonant in terms of wavelength? Are they enclosed in a shield grounded at one or both ends? For this study on deadfacing, it will be assumed that the circuit consists of exposed pins open-circuited at one end and terminated in a well-behaved impedance (the potentially susceptible circuit) at the other end. At higher frequencies, these wires act primarily as a transmission line, and have significant coupling impedance to structure. Figure 9.1-1 (from A.A. Smith [14]) shows the typical response of a transmission line to an electric field. For our purposes, we will always assume the RF source is oriented for maximum coupling. The maximum power is coupled to the transmission line at some multiple of $\lambda/4$ until the transmission line becomes very long (10λ) when the maximum coupling actually decreases. The Air Force Design Handbook DH 1-4 [15] states "...wires can frequently be excited when they are attached to vacant connector pins or open switch contacts. At a quarter wavelength distance, such open wires will be carrying maximum current and can readily couple into other wiring or circuits." Many references on field coupling to transmission lines begin with the extensive work published both by A.A. Smith [14] as mentioned, and by C.R. Paul [16]. Computation of an exact solution for this situation is difficult without the aid of a software tool. SEMCAP [17] is a popular model used by the ELV industry.

What can be accomplished analytically is a culling method to separate circuits having a large Electro-Magnetic Interference Safety Margin (EMISM) greater than 20 dB) from those that may require closer scrutiny. The method found in MIL-STD-1576 [18], Method 4303 is used in the evaluation of pyrotechnic device safety.

Figure 9.1-1 Coupled Voltage Response For Different Impedances

9.2 THE DIPOLE CIRCUIT MODEL

As EMC engineers, with hundreds of circuits to analyze, some sort of culling system must be employed to separate circuits with great EMISM from those that may require more detailed analysis or receive special scrutiny during test. In the case of open circuit wiring, and knowing the shield termination grounding configuration at both ends, first order culling is easiest accomplished with a resonant antenna model, unless a higher fidelity computer model like SEMCAP [17] is deemed worthwhile. Our worst-case choice is to model the open lines as antennas, and to look at the resonance case. If we are okay here, no further analysis should be needed. The maximum power, *P*, received by this resonant matched dipole antenna model is given by the equation:

$$P = 0.13\lambda^2 P_d \quad [19]$$

where *P* is the maximum power received, λ is the wavelength of the transmitted field in meters, and P_d is the power density in watts per meter^2.

See Appendix D, Derivation of E-field coupling to a dipole antenna, for additional information. If the electric field strength is known, then the power density can be computed from:

$$P_d = E^2 / Z_0$$

where *E* is the electric field strength and Z_0 is the wave impedance, or 377 Ohms for the far-field. From the Friis transmission equation, the power density P_d may be computed from:

$$P_d = (P_t\, G_t) / (4\pi r^2)$$

where P_t is the power output of the transmitting source, G_t is the numeric gain of the transmitting antenna, and *r* is the distance from the antenna in meters. Assuming one knows the cable lengths in question, frequencies from λ/4 and its multiples should be compared to the on-orbit Electro-Magnetic Environment (EME) in addition to known on-board sources. An envelope of the on-orbit EME used for the ISS may be found in specification SSP 30237 [5].

DARCOM-P 706-410 [20] states that analog integrated circuits begin to show susceptibility at 10^{-5} Watts at 220 MHz decreasing to 0.1 Watts at 9.1 GHz. Digital circuits are approximately two orders of magnitude less susceptible. Thorough treatment on upset and failure mechanisms is also presented in the Electro-Magnetic Pulse (EMP) Handbook [21]. Updated tabulations of integrated circuit RF susceptibility are given in the references of "Integrated Circuit Electromagnetic Immunity Handbook," NASA CR 2000-210017 [19].

9.3 FILTERING AND SHIELDING OF OPEN CONNECTORS

As a fundamental part of umbilical design, filter pin connectors with shunt capacitance would be an aid to reducing these sharp resonance effects by controlling the pin to connector shell impedance, particularly in the case where the interface connectors remain bonded to structure.

Some designs, Delta second stage for example, minimize the exposed pin issue by having a spring-loaded connector cap that snaps closed over the connector face at separation. This implementation may be mechanically cumbersome in the case where re-connection during an EVA is required. For design information on selection of components based on calculated transient voltages and controlling the effect of this fast transient, the MEDIC Design Handbook [22] has a good discussion in section 3.2.1. Also, "Investigation Into the Effects of Microsecond Power Line Transients on Line-Connected Capacitors," NASA/CR-2000-209906 [22], contains information on overstress of capacitors.

9.4 WIRE-TO-WIRE COUPLING

The resulting transient occurring on the conductor emitting the arc poses a threat to conductors next to it via wire to wire coupling. At the time of de-mate, the impedance of circuits using the de-mated connector changes. Both source and receptor circuits are affected. These "new" impedances must be considered in the analysis. The transient energy being dissipated in the arcing conductor is imposed on conductors next to it through capacitive coupling and inductive coupling. At low circuit impedances and low frequencies inductive coupling is more dominate, while at high circuit impedances and high frequencies capacitive coupling is more dominate. One can see that both capacitive and inductive coupling can inter-react making analysis of the scenario difficult. Based on the equations used to determine voltages for capacitive coupling and inductive coupling the frequency parameter contributes or detracts from the result. If we look at the scenario from a point of view that defines the hot de-mate event as a noise source using classic EMC wire to wire coupling analysis techniques ("System Guidelines for EMC Safety-Critical Circuits: Design, Selection and Margin Demonstration", NASA CR 4759 [23]), we can see how frequency affects the results.

In the case of two parallel conductors, the first being the noise source, i.e. the given circuit interrupted by a hot de-mate event, the second being the victim or receptor circuit (see Figure 9.4-1) the equation for ratio of the voltage coupled into the victim circuit to the voltage in the circuit experiencing the hot de-mate event follows:

$$\frac{E_{2G}}{E_0} = \left[\frac{R_1}{(R_1 + R_0)\,\dfrac{R_2}{X_C}}\right] + \left[\frac{X_M}{(R_1 + R_0)\,\dfrac{R_{2G}}{(R_{2G} + R_{2L})}}\right] = K_G\, f$$

The noise voltage appearing at the load end of the victim circuit is:

$$\frac{E_{2L}}{E_0} = \left[\frac{R_1}{(R_1 + R_0)}\,\frac{R_2}{X_c}\right] - \left[\frac{X_M}{(R_1 + R_0)}\,\frac{R_{2L}}{(R_{2G} + R_{2L})}\right] = K_L\; f$$

where:

E_0 = Noise voltage from hot de-mate

E_{2G} = Noise voltage coupled in the source side of the victim circuit

X_M = Reactance of the inductive coupling

X_C = Reactance of the capacitive coupling

E_{2L} = Noise voltage coupled into the load side of the victim circuit

K_G = Coupling coefficient source side

K_L = Coupling coefficient load side

$$R_2 = R_{2L} \frac{R_{2G}}{(R_{2L} + R_{2G})}$$

f = Frequency of interference

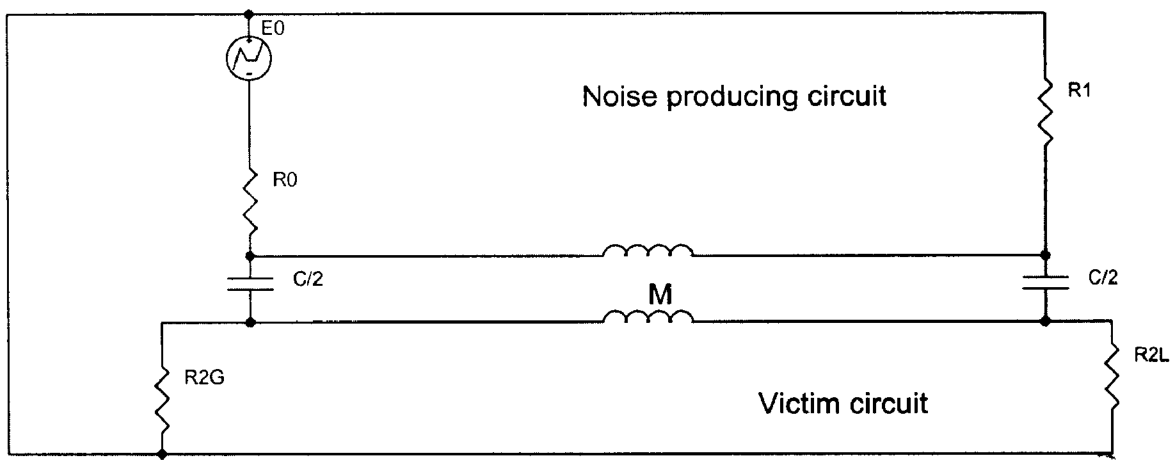

Figure 9.4-1 Wire-to-Wire Coupling Model

If an arc results during a hot de-mate event, there will be a broadband frequency spectrum generated rather than a single frequency. While the preceding equations may be used to analytically solve a time-invariant impedance network, arcing scenarios are best solved by computer modeling [11] as discussed in Section 10.0.

A worst-case scenario should assume the arc energy generates a broad spectrum of frequencies, exciting the circuit's resonance. Because of the complex interaction and difficulty in modeling each scenario the launch vehicle world has adopted techniques and practices for minimizing possible problems. Many subsystem/box level units are tested for susceptibility to extraneous signals appearing on cabling going to the unit. These tests are defined in MIL-STD-461E [24], Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, CS114 Conducted susceptibility, Bulk Cable Injection, 10kHz to 200MHz, CS115, Conducted susceptibility, Bulk Cable Injection, Impulse excitation, and CS116, Conducted susceptibility, Damped sinusoidal transients, cables and power leads, 10kHz to 100MHz. By utilizing these tests for box level testing, the box design can be modeled to tolerate a certain amount of transient impulse that could be the result of an arc from hot de-mate. A document that covers cabling and harnessing practices is MIL-HDBK-83575 General Handbook for Space Vehicle Wiring Harness Design and Testing [25]. This document defines the categories for different cables and harnesses based on content of the signal carried by the conductors. Shielding methods, connector types, as well as testing, is defined. Spacing between cables is specified. By following the guidelines in these two documents one could minimize the detrimental effects from arcs.

9.4.1 THE PROBABILITY OF CIRCUIT UPSET

The characteristics of digital circuits must be evaluated by the designer when the digital devices are part of a system subjected to transients as a result of a hot de-mate event. Characteristics that inter-react with transients are the level of DC voltage required by the device to change state, and the speed of the device. Filtering connected to the device can also contribute/suppress the effect of the transient. Figure 9.4.1-1 shows that for longer times the transient voltage may be lower and closer to the DC value that could trigger a change of state [21].

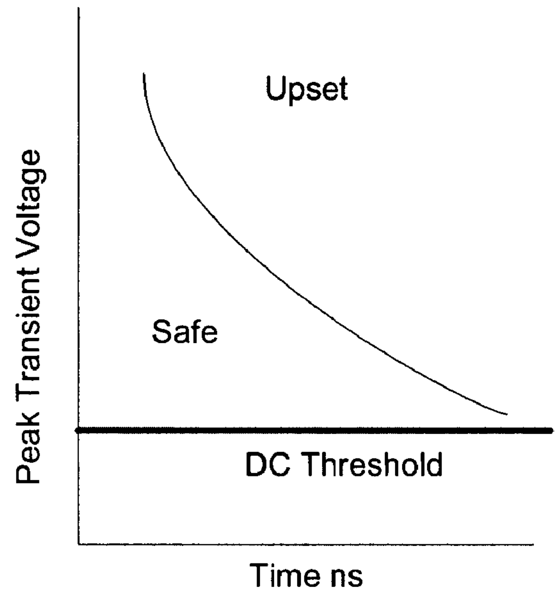

Figure 9.4.1-1 Upset Threshold

The designer must be aware of the effects from transients for arcing and non-arcing scenarios. It is possible for the energy to couple into adjacent circuits/systems. Several references sited define testing and preventative measures that the designer can utilize. Some of these references are from program requirements, of which the designer must be aware.

10.0 MODELING FOR DEADFACE APPLICATIONS

Limited applications of modeling type software have been utilized to determine the nature of transients occurring during the hot de-mate/mate process. The current version of PSpice that works in conjunction with OrCAD™ was used with limited success. Initially, a simple circuit with a source, load (with capacitance, inductance and resistive elements) and a transmission line was modeled, Figure 10-1. A method to disconnect the circuit was found in the voltage controlled switch element in PSpice. The device (S1) can open or close with a programmable voltage on two terminals with an adjustable resistance for on and off states on two additional terminals. The piece-wise linear source (V3) was used to actuate the switch, permitting adjustable on off rise times. The transmission line (T2) is 20 feet of 22 AWG twisted pair. In this case, the nature of the energy that is stored in the capacitor and inductor is realized when S1 is opened. Figure 10-2 depicts the energy stored in the capacitor and inductor V_C 1:2 and is compared to the voltage at the other end of the transmission line V_S 1:4. The voltage probes on either end of the transmission line illustrate the effect of the transmission line.

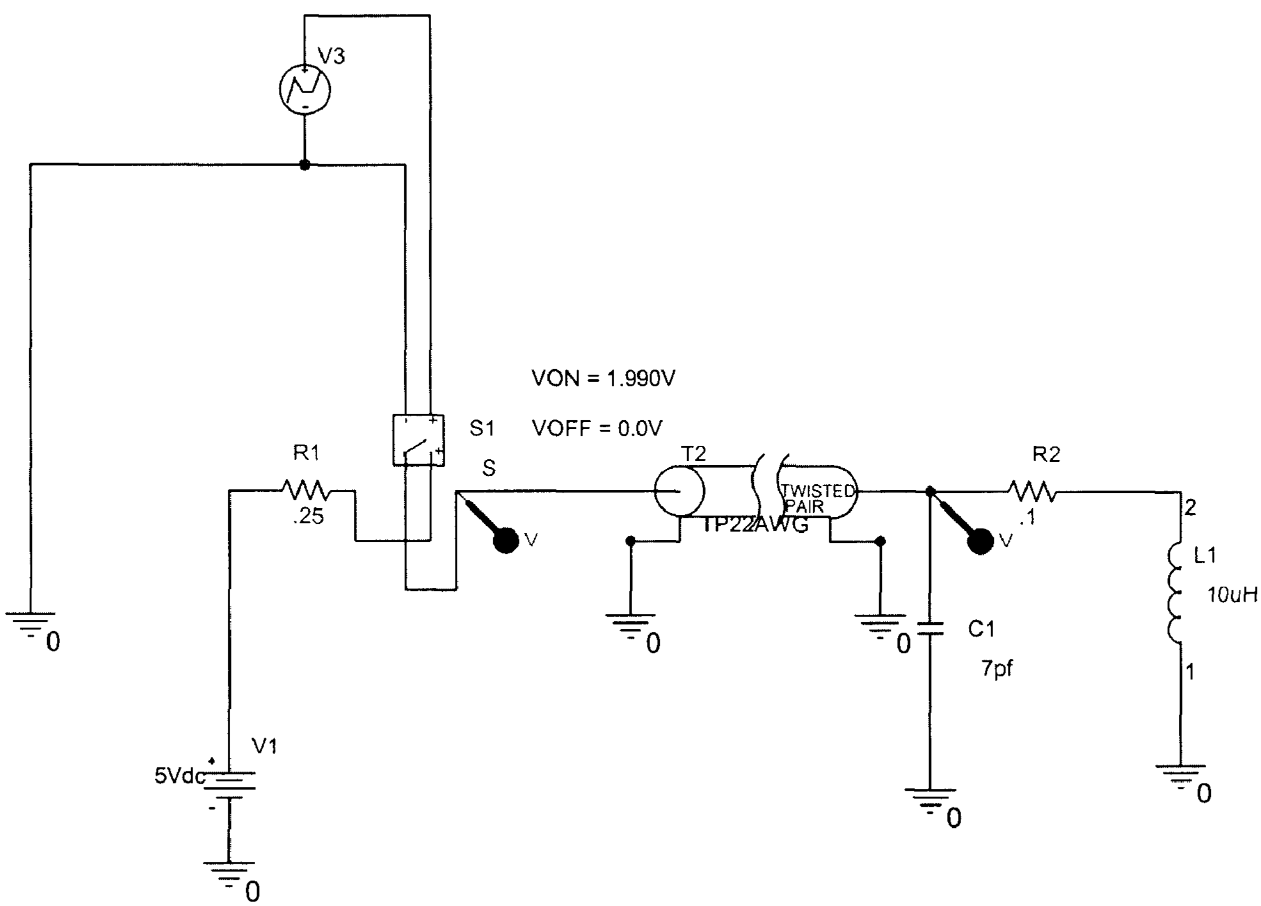

Figure 10-1 Non-Arcing Model

If the transmission line is removed and S1 is connected to the load, the frequency of the damping energy is the resonant frequency of the capacitor and inductor, $f = 1 / (2\pi\sqrt{LC})$. In the circuit above, the pulse resulting from the disconnect event, is 40 Volts peak-to-peak from the 5 Volt source. This is a non-arcing model. If arcing were to occur, additional energy would be dumped into the load side resulting in higher transient voltages.

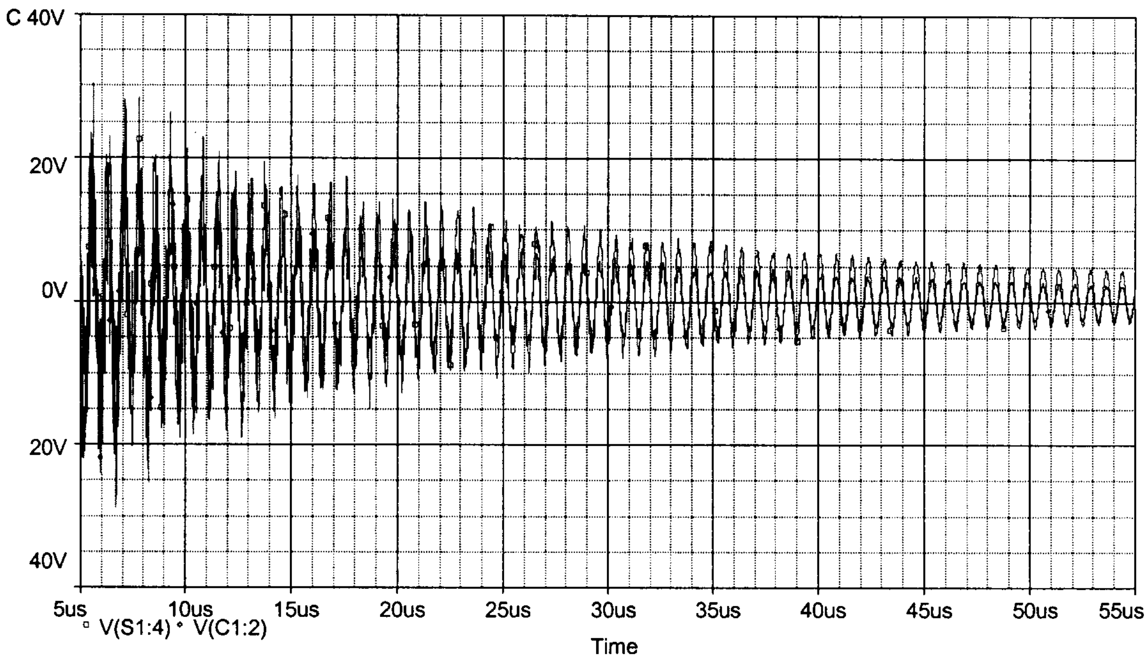

Figure 10-2 Response On Either Side Of Transmission Line

By utilizing computer modeling it is possible to predict transient behavior and how it affects the designer's circuits during a hot-de-mate event.

11.0 AUTONOMOUS DEADFACE CONTROL

The traditional autonomous method for providing the deadface function is through an inhibit in the form of a switch closure, or multiple switch closures if redundancy is required. While this method adequately provides the function, it must be commanded at some set time, or tied to some other set function. In the case of anomalous operation, the deadface function could be in jeopardy. In addition, the deadface function is most often not reversible should an anomaly occur after removal of power, leaving the circuit un-powered until the anomaly is resolved. This has been a dilemma for spacecraft having time-critical keep-alive power or trickle charge requirements in dealing with aborted launch sequences or failure-to-respond scenarios on orbit. Other methods of providing the deadface function that are reversible, and occur autonomously, just prior to guaranteed connector separation would be to great advantage in some cases.

There are two methods that can accomplish the autonomous deadface event. The first is through the use of "short pins" or a mechanical finger integral to the connector that separates first before any other circuits in the connector. Because of separation velocities, this may not by itself allow sufficient time to discharge storage/filter capacitors so that arcing or transients may occur anyway. A second, and most attractive method is receiving much attention today. That is the contact-less power transfer device, essentially comprised of two pot-core halves mated at the separation interface. The disadvantage of this system is that power conversion electronics are required at either end of the device since the power transfer is done at AC frequencies typically hundreds of kilohertz. Many designs require power conditioning on either side of the interface at the load and so this extra burden is not necessarily prohibitive, given the advantage of contact-less power transfer with no exposure of voltage at the interface. Today these devices are not off the shelf but are in use to charge electric vehicles and to provide power to underwater welding offshore oil platforms. The space community will make increased use of such devices and is being considered for certain attached payloads and tethered satellites. Further research in this area of power electronics is needed to accelerate this technology for space applications.

Methods of deadfacing are discussed. It is important to be aware of devices that potentially eliminate possible arcing and transients during de-mate. However, the timing of the deadface event, and its criticality during anomalous operation scenarios must be considered.

12.0 TEST AND VERIFICATION

What is the appropriate test method and test level that would ensure that a hot de-mate will not cause a susceptibility to adjacent circuits? Two cases exist: the first is flight-like hardware with hi-fidelity interfaces and cable lengths that are connected to a simulated satellite/payload via an adapter separation interface for the purpose of test and verification of the satellite/payload system interfaces; and the second is a T-0 interface with GSE of lower fidelity or fidelity that would be updated when the spacecraft/vehicle mate at the launch facility, which is far to late to find that a problem exists. In the flight-like case, it is recommended that at least 10 hot de-mate events be performed (using connector savers, and perhaps one without connector savers) to establish a worst case transient as measured with bulk current probes on all cables to include all sources of cross coupling both external cable to cable and internal circuit to circuit. This measurement is made in the time domain. Care must be taken to include the correct probe calibration factors based on the input impedance of the measuring device (50 Ohm or 1 mega-Ohm). It is recommended that a wide-band current probe be used (1 GHz) to capture the peaks. To simulate the wide band nature of the event, MIL-STD-461E CS115-CS116 type injection tests should be performed at some selected margin over current values observed in the emission tests, based on worst-case peak test results. In the case where long umbilical wiring is involved, a specially designed Line Impedance Stabilization Network (LISN) may be employed to account for the wiring transmission line characteristics. The test measurement and stimulus should always be applied very close to the Equipment Under Test (EUT), not at the point of cable disconnect. Detailed procedures for bulk current injection testing are given in MIL-STD-461E [24].

13.0 ABBREVIATIONS AND ACRONYMS

AC	Alternating Current
ATVC	Ascent Thrust Vector Control
AWG	American Wire Gage
CM	Common Mode
CDR	Critical Design Review
DC	Direct Current
DM	Differential Mode
DSO	Digital Storage Oscilloscope
ELV	Expendable Launch Vehicle
EMC	Electro-Magnetic Compatibility
EME	Electro-Magnetic Environment
EMI	Electro-Magnetic Interference
EMISM	Electro-Magnetic Interference Safety Margin
EMP	Electro-Magnetic Pulse
EMS	Electro-Magnetic Susceptibility
EMU	Environmental Manned Unit
ESD	Electrostatic Discharge
ET	External Tank
EUT	Electrical unit Under Test
EVA	External Vehicular Activity
EWR	Eastern/Western Range
GFI	Ground Fault Interrupter
GRC	Glenn Research Center
GSE	Ground Support Equipment
ISS	International Space Station
IVA	Internal Vehicular Activity
JSC	Johnson Space flight Center
LEO	Low Earth Orbit
LeRC	Lewis Research Center
LISN	Line Impedance Stabilization Network
MEDIC	MSFC Electromagnetic Compatibility Design and Interference Control
MS/s	Mega-Samples per second
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration

NEC	National Electrical Code
NFPA	National Fire Prevention Association
NSTS	National Space Transportation System
PSRP	Payload Safety Review Panel
RF	Radio Frequency
RMS	Root Mean Square
SEE	Space Environments and Effects
SEMCAP	Specification and Electromagnetic Compatibility Analysis Program
SRB	Solid Rocket Booster
TSM	Tail Service Mast
VDC	Volts Direct Current

14.0 BIBLIOGRAPHY

1. National Electrical Code, National Fire Prevention Association
2. MIL-STD-461C – Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
3. MIL-STD-1541A – Electromagnetic Compatibility Requirements for Space Systems, 12/30/87
4. "Electric Contacts Theory and Application," R. Holm, New York, 1967
5. SSP 30237 – Space Station Requirements for Electromagnetic Emission and Susceptibility Requirements, 9/1/94
6. EWR 127-1 – Launch Vehicle, Payload, and Ground Support Equipment Documentation, Design, and Test Requirements, 3/31/95
7. MIL-HDBK-454 – A General Guidelines for Electronic Equipment, 3-11-00
8. MIL-STD-810F – Environmental Engineering Considerations and Laboratory Tests, 1/1/00
9. "Intrinsic Safety The Safe Use of Electronics in Hazardous Locations," R.J. Redding, London, 1971
10. "Mechanism of the Switching Transients In Low Current DC Circuits", J. Shi, R. M. Showers, IEEE, 1984
11. "Prediction of Crosstalk Due to Showering Arcs at Switch Contacts," S.W. Hall, C.R. Paul, K.B. Hardin, A.D. Nielsen, IEEE, 1991
12. Titan IV – Cassini Hardware CDR Action Item #10 closeout 9/7/95
13. "Noise Reduction Techniques in Electronic Systems" H.W. Ott, Wiley, New York, 1988
14. "Coupling of External Electromagnetic Fields to Transmission Lines," A.A. Smith, Wiley, 1977
15. Air Force Design Handbook DH 1-4, Electromagnetic Compatibility, Fourth Edition, 3/2/84
16. "Introduction to Electromagnetic Compatibility", C.R. Paul, Wiley, New York, 1992
17. SEMCAP – Specification and Electromagnetic Compatibility Analysis Program, Proprietary FORTRAN computer program developed and maintained by the Electromagnetic Compatibility Department of the Space Systems Division Of TRW Systems.
18. MIL-STD-1576 – Electro-explosive Subsystem Safety Requirements and Test Methods for Space Systems, 7/31/84
19. "Integrated Circuit Electromagnetic Immunity Handbook, J.G. Sketoe, NASA/CR-2000-210017, August 2000
20. DARCOM-P 706-410 – Army EMC Design Handbook, March 1977

21. Electromagnetic Pulse Handbook for Missiles and Aircraft in Flight, Air Force Weapons Lab (document access is limited)

22. Marshall Space Flight Center Electromagnetic Compatibility Design and Interference Control (MEDIC) Handbook, June 1995

23. "System Guidelines for EMC Safety-Critical Circuits: Design, Selection, and Margin Demonstration," NASA CR 4759

24. MIL-STD-461E – Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, 8/20/99

25. MIL-HDBK-83575 – General Handbook for Space Vehicle Wiring Harness Design and Testing, 6/4/98

26. ICD-2-19001 – Shuttle Orbiter/Cargo Standard Interface Requirements Document

27. JSCM 8080, Standard 69

28. JPG 8080.5, E9

29. NSTS 1700.7b – Safety Policy and Requirements for Payloads Using the Space Transportation System

30. Discussion of NSTS and ISS payload requirements with the Office of Payload Safety at JSC (Christine Stewart)

31. Pegasus User's Guide, Release 5.0, August 2000

32. Report from Noel B. Sargent regarding LMSS Report EMC 96092, 9/13/95 (see [12])

APPENDIX A PRESENT AND HISTORIC REQUIREMENTS FOR DEADFACING

The NSTS interfaces with a variety of systems and subsystems that are either a part of the vehicle or a payload. The following was the result of searching documentation that defines interfaces for a payload:

The NSTS requirement comes from ICD-2-19001 7K-2 [26], which references JSCM-8080, Standard 69 [27], which has been updated by JPG 8080.5, E9 [28].

The ICD states:

"Electrical deadfacing of interfacing connectors when mating or de-mating shall comply with JSCM-8080, Standard 69" [27], (JPG 8080.5, E9 [28]) "except that connectors that mechanically de-mate in flight will not require electrical de-energizing of signals prior to de-mating under the following conditions:

a. The de-mating connector is in the Orbiter cargo bay.

b. At the time of connector de-mate, the Orbiter shall be in the "on-orbit" flight phase with the cargo bay doors open.

c. At the time of connector de-mate, the current on any single circuit halls not exceed 500mA.

d. The de-mated connector retained on the Orbiter side shall be mechanically retained.

e. Either the de-mated connector retained on the Orbiter side shall be the socket (female) side of the connector, or all power shall be removed from the de-mated connector in the Orbiter bay before the entry phase of the flight."

JPG 8080.5, E9 [28] states:

> "Spacecraft electrical systems shall be designed so that all necessary mating and de-mating of connectors can be accomplished without producing electrical arcs that will damage connector pins or ignite surrounding materials or vapors.
>
> Unless connectors are specifically designed and approved for mating or de-mating in the existing environment under loads being carried, they shall not be mated or de-mated until voltages have been removed from the powered side(s) of the connector.
>
> If the circuit breakers and switches normally provided in the power distribution system of the spacecraft do not provide a satisfactory means of complying with the intent of this standard in all planned flight and ground test operations, additional circuit interruption capability shall be provided, as required."

There are two types of interfaces found in the shuttle. The first interface type relates to the vehicle, for example: umbilicals, solid booster to vehicle interface, and main tank to orbiter interface. The second interface type is payload interfaces, which are controlled by the Payload Safety Office and will vary due to the nature of different payload types and the hardware used for an interface carrier. The following conditions are considered hazardous and are applicable to the evaluation of de-mating mating hot connectors:

"The PSRP's assessment of the hazards associated with mating/de-mating defined three concerns:

1. Generation of molten metal
2. Electric shock (only applies to IVA; the extravehicular mobility unit (EMU) provides electrical isolation)
3. Damage to safety-critical circuits (protected by the requirement to maintain separation per NSTS 1700.7B [29], paragraph 207)"

Each payload is evaluated on a case-by-case basis. The current philosophy is to not allow arcing to occur and set the limit to deadface at 500mA. This is based on past experience. The case-by-case basis would permit a situation where hot mate/de-mate can occur. The servicing of the Hubble space telescope was recently evaluated for hot de-mate events. This payload was not designed for servicing and NASA has decided to upgrade the avionics in order to obtain more science. Risks were evaluated and procedures created to minimize risks [30]. The mating and de-mating of low-power connectors (IVA or EVA) is permissible without upstream inhibits or special connector design features. Low-power connections are defined as those with design features that have power supply capacity or upstream circuit protection that limit maximum continuous current to 3 Amps or less with an open circuit voltage no greater than 32 Volts RMS or DC.

Current NASA requirements for the orbiter itself:

1. Each request for a new or increased load across connectors during connect or disconnect operations shall be evaluated on a case by case basis, however, the current across the Orbiter Tail Service Masts (TSM) Takeoff (T-0) umbilical shall not exceed 500mA. Any power loads across this interface shall be diode isolated or deadfaced before lift-off.
2. The separation subsystem(s) shall provide for Shuttle element separation without damage to or re-contact of the elements during or after nominal mode separation. Damage to the SRB/ET connectors on the aft upper struts at the SRB/ET interface during SRB separation after Ascent Thrust Vector Control (ATVC) power is deadfaced is acceptable.
3. NSTS 08080, Standard 69, Electrical Circuits - De-energizing Requirement
4. Spacecraft electrical systems shall be designed so that all necessary mating and de-mating of connectors can be accomplished without producing electrical arcs that will damage connector pins or ignite surrounding materials or vapors. Unless connectors are specifically designed and approved for mating or de-mating in the existing environment under the loads being carried, they shall not be mated or de-mated until voltages have been removed from the powered side(s) of the connector.

A.1 ISS

The requirements for deadfacing for the ISS have evolved from the NSTS requirements. The extensive range of different payload/experiments as well as ISS system maintenance will require analysis of many hot de-mate scenarios. The current philosophy is to not allow arcing to occur and set the limit to deadface at 500mA. The Payload Safety Office will evaluate each scenario on a case-by-case basis.

A.2 Expendable Launch Vehicles (ELV)

A.2.1 Atlas

The present commercial Atlas program is proprietary in nature. Mission peculiar deadface requirements are negotiated after the payload is manifested as part of the Interface Control Document (ICD) process, but generally limited to 100mA.

A.2.2 Delta

The present commercial Delta program is proprietary in nature. Mission peculiar deadface requirements are negotiated after the payload is manifested as part of the ICD process.

A.2.3 Pegasus

Orbital Science Corporation takes a conservative approach to deadfacing. The Pegasus User's Guide [31] states: "Prior to T-0, all space vehicle system electrical ground support equipment electrical interfaces at the umbilical shall be deadfaced to ensure that there shall be no current flow greater than 10mA across the umbilical interface. Prior to drop, all aircraft power shall be isolated from the launch vehicle and the payload. Pre-separation electrical constraints prior to initiation of separation event, all payload and launch vehicle electrical interface circuits shall be constrained to ensure that there shall be no current flow greater than 10mA DC across the separation plane during the separation event."

APPENDIX B THE ONSET AND EXTINGUISHMENT OF ARCING

The electrical breakdown of the gas in a gap between electrodes, similar to a pin and socket found in most electrical connectors, results in an electron avalanche. When a potential is applied across this gap, the cathode electrons are liberated due to cosmic radiation or light. The electrons move to the anode and leave positive ions. These ions enhance the field strength of the cathode as additional electrons are liberated causing additional avalanches. The cathode fall is established by these ions. This forms a glow discharge or Townsend Effect, which then develops into an arc if sufficient current is available. The following conditions must be met for this process to occur:

1. The potential across the gap (breakdown voltage) must be greater than the cathode fall of the gas in the gap.
2. The gas in the gap must contain enough gas to feed the avalanches. This is known as Paschen's law (see Appendix C). The breakdown voltage is a function of the gas and the product of the density of the gas and the width of the gap. Other parameters contribute to this process including contact shape, material, temperature, humidity, number of prior disconnects, and to an extent separation velocity. If voltages on either side of the gap are monitored one could observe that the transient behavior characterizes the arc type (See Appendix E.2, Transient Behavior). Discontinuous discharge, continuous discharge, and non-arcing scenarios are distinct and are affected by circuit elements and the layout of associated transmission lines. Arc extinguishment is a result of the decrease in the current to feed the arc. Relaxation oscillation appears on the load side after arc extinguishment and no re-strikes appear. The three steps in development of an arc are:
   a. Gaseous breakdown
   b. Transition from discontinuous discharge to continuous discharge
   c. Relaxation oscillation

APPENDIX C PASCHEN'S LAW

Paschen's Law must be considered when evaluating arcing potential for a specific scenario. Several parameters contribute to arcing such as contact distance or spacing, minimum arcing current, minimum arcing voltage and contact separation velocity. The affect of pressure changing as a launch vehicle ascends and is staged is an example. Another is hot mate/de-mate in a gas environment. Paschen's Law (C.R. Paul [16]) simply stated:

$$V_{Bgas} = \frac{K_1(pd)}{K_2 + \ln(pd)}$$

where V_{Bgas} is the voltage at which break down occurs in a gas at a pressure p and where the contacts are at a distance d. K_1 and K_2 are constants that are determined by the electron behavior of different gas molecules. Other secondary parameters that affect breakdown are temperature and humidity.

APPENDIX D DERIVATION OF E FIELD COUPLING FOR A DIPOLE ANTENNA

The dipole antenna has been chosen as the worst-case model for coupling of electric fields on to wiring as a means of culling circuits for more detailed analysis. The boundary condition for a $\lambda/2$ dipole requires that the current at the ends are zero, and a maximum current at its center feed point. It is assumed that this current is induced in the $\lambda/2$ wire or cable being modeled. The RF current induced by the electric field in volts per meter can be expressed by:

$$E = \frac{I Z_o}{2\pi r} \qquad (1)$$

where Z_o = 377 Ohms, the impedance of free space. This current then produces maximum power in the resonant condition. To compute the power in watts received requires capturing this electric field by the antenna's effective aperture, A_e, given in meters squared such that the power received:

$$P_r = A_e P_d \qquad (2)$$

where P_d is expressed in watts/meter^2. The power density and electric field are related by the free space impedance such that:

$$P_d = \frac{E^2}{Z_o} \qquad (3)$$

For maximum power to be received by the dipole, it must be matched to its characteristic impedance, which is 73 Ohms. Noting that

$$A_e = \frac{\lambda^2 G}{4\pi} \qquad (4)$$

implies that the maximum received power is related to wavelength $\lambda/2$ where the directivity gain G of the dipole antenna is 1.64 or 2.15 dB. When substituting A_e (equation 4) into equation 2 the max power received becomes:

$$P_r = \frac{P_d \lambda^2 (1.64)}{4\pi}, \text{ or } P_r = 0.13\, P_d \lambda^2 \quad (5)$$

For a more rigorous derivation see C.R. Paul [16].

APPENDIX E TRANSIENT BEHAVIOR FOR NON-ARCING AND ARCING SCENARIOS

E.1 Cassini Spacecraft

In 1995, flight electrical separation interface connections to the Cassini Spacecraft aboard a Centaur upper stage were modeled in PSpice as described in an internal Lockheed Martin [32] Cassini report. The PSpice results of transient voltage produced versus dI/dt are shown in Figure E.1-1. These results raised a question as to actual voltages that the connectors could see. A series of investigative tests were performed to resolve the dI/dt issue for the Cassini Spacecraft that resulted in a 5 Volt GSE interface being deadfaced to protect circuitry OR-ed at the spacecraft from over-voltage. These empirical tests were the result of many repeated trials. The experimental results were corroborated using a PSpice model, once the proper dI/dt was determined.

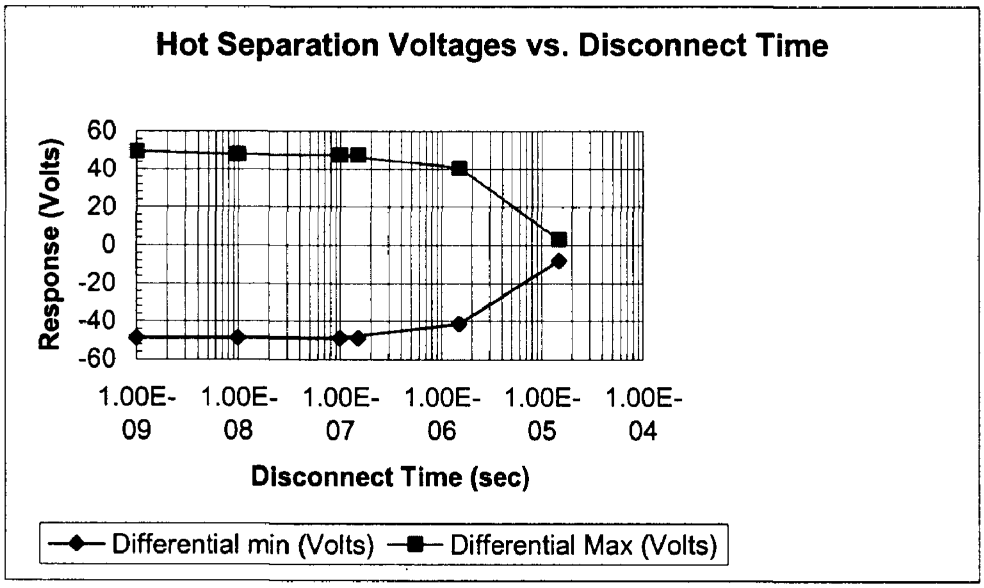

Figure E.1-1 Results of PSpice Modeling for Cassini Spacecraft

Three cases were run with approximately twenty trials each. The test circuit is depicted in Figure E.1-2. The cases were:

1) 5 Volts, 22 Ohm load - Figures E.1-3, E.1-4, and E.1-5
2) 5 Volts, 50 Ohm load, Figures E.1-6 and E.1-7
3) 28 Volts, 280 Ohm load, Figure E.1-8

The latter two, at 100mA were to investigate circuit voltage dependence. Data presented are "worst case in family," meaning there were repeatable results of similar greatest magnitude. Results vary to lower magnitudes for trials related to connector disconnect/reconnects (pin chattering). Clean disconnects produce the highest magnitude transients. Transients do not seem related to connector disconnect velocity unless separated very slowly where disconnect/re-connects occur resulting in several lower magnitude events. Figure E.1-3, 5 Volt / 22 Ohm, shows approximately 30 Volt peak-to-peak DM + CM transients (note: V_1 and V_2 at 10 Volts/division and M1 = $V_1 - V_2$ at 25 Volts/division). Sweep time was 400 nanoseconds/division. Figure E.1-4 shows a lower 22 Volt peak-to-peak transient with a reconnect. Figure E.1-5 shows a much slower sweep with multiple reconnects. Peaks are not recorded because of the slower DSO acquisition time. Figure E.1-6, 5 Volt / 50 Ohm, shows approximately 18 Volt peak-to-peak transients, scaling with current from the case in Figure E.1-3. Figure E.1-7 records a rapid reconnect case evidenced by ringing prior to the transient. Figure E.1-8, 28 Volt / 280 Ohm shows a similar result as the 5 Volt / 100mA case indicating the transient peak is a function of current, not applied voltage. Experience with ignition measurements and a range of arc production/quenching phenomena indicates that quenching rise times are proportional to energy or total stored charge and gap distance, and for this case is probably tens of nanoseconds at most.

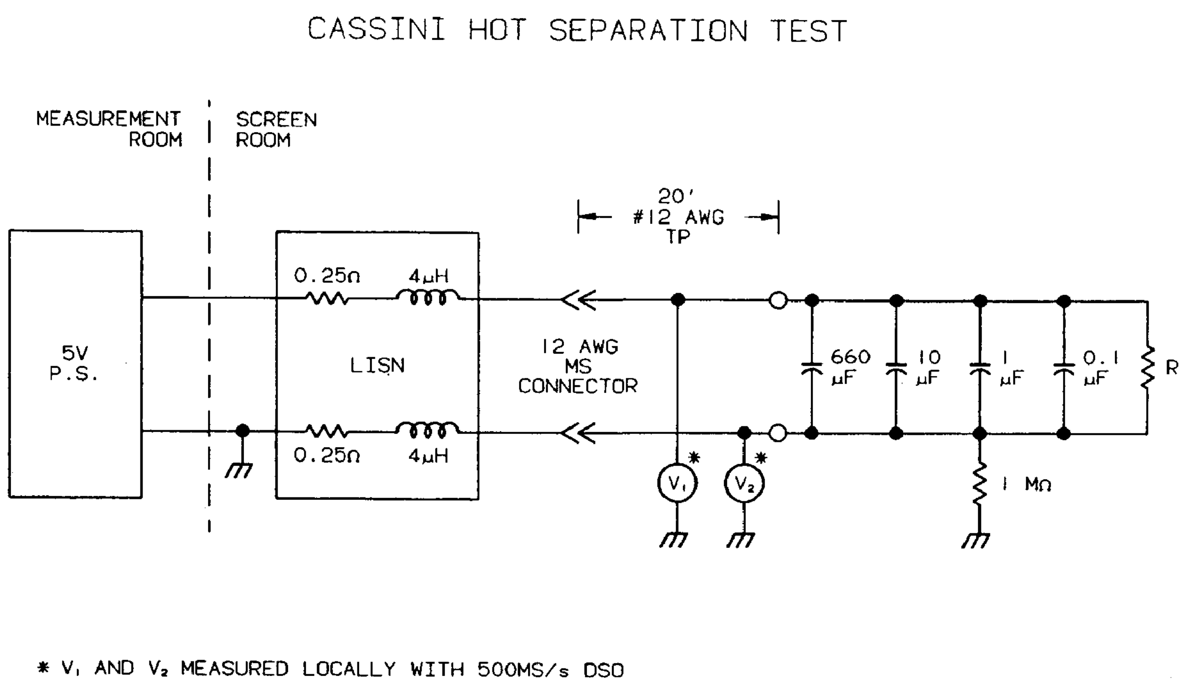

Figure E.1-2 Cassini Hot Separation Test Circuit

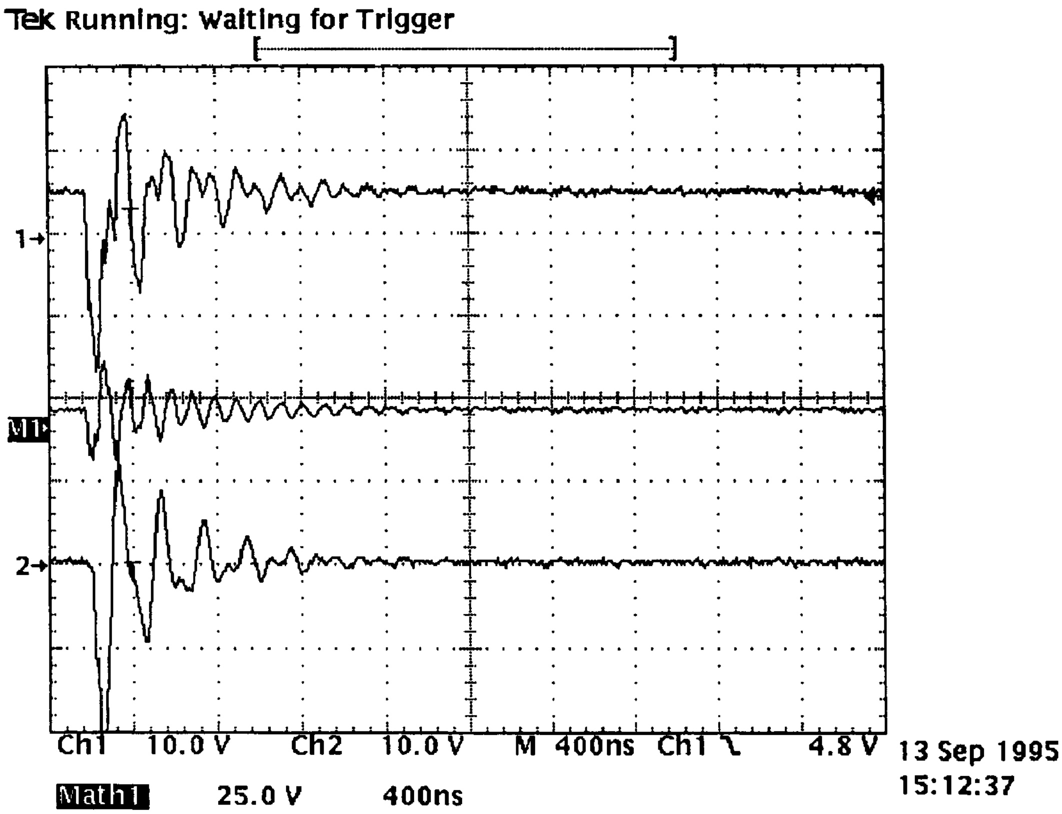

Figure E.1- 3 5 Volt / 22 Ohm

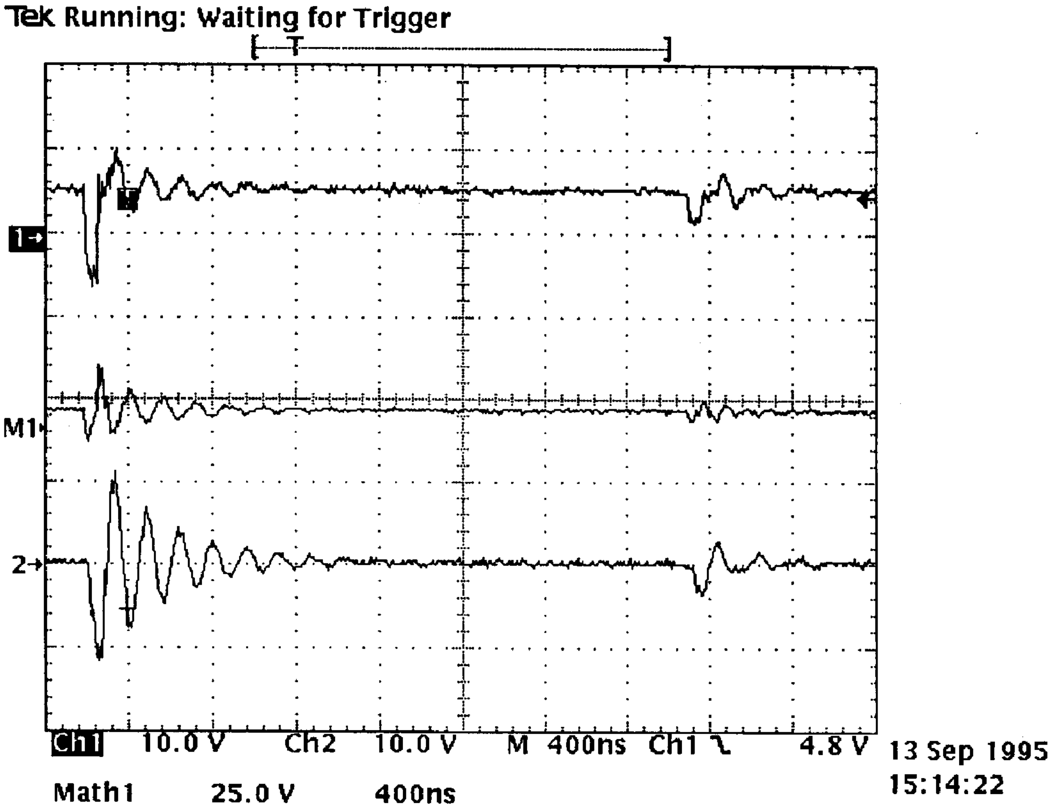

Figure E.1-4 5 Volt / 22 Ohm

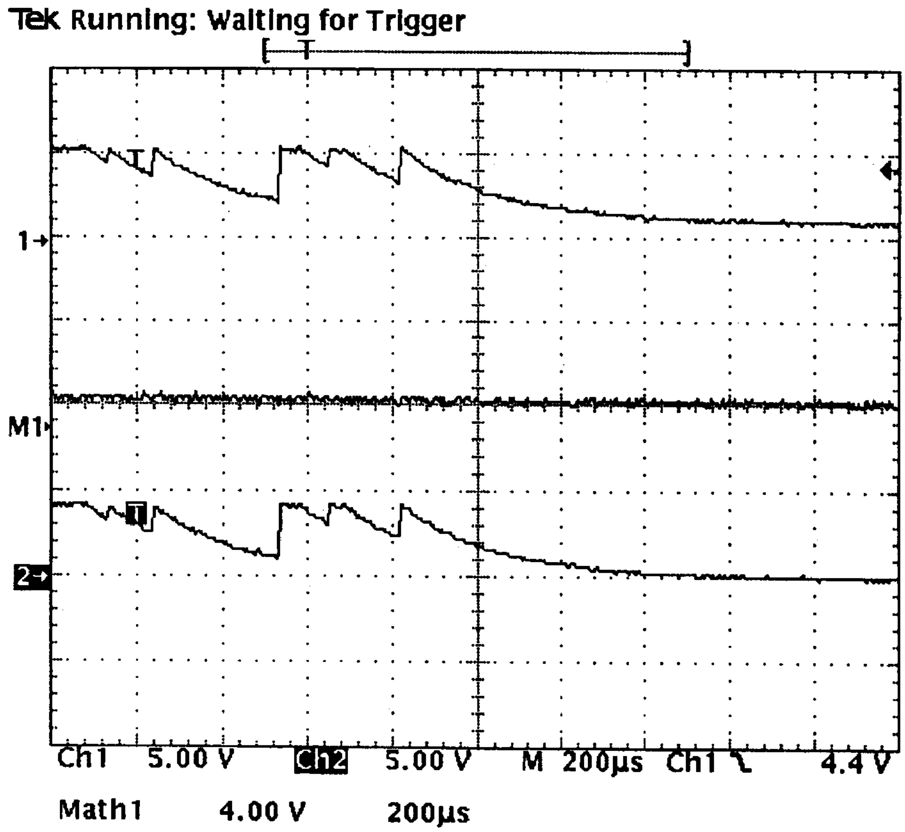

Figure E.1-5 5 Volt / 22 Ohm

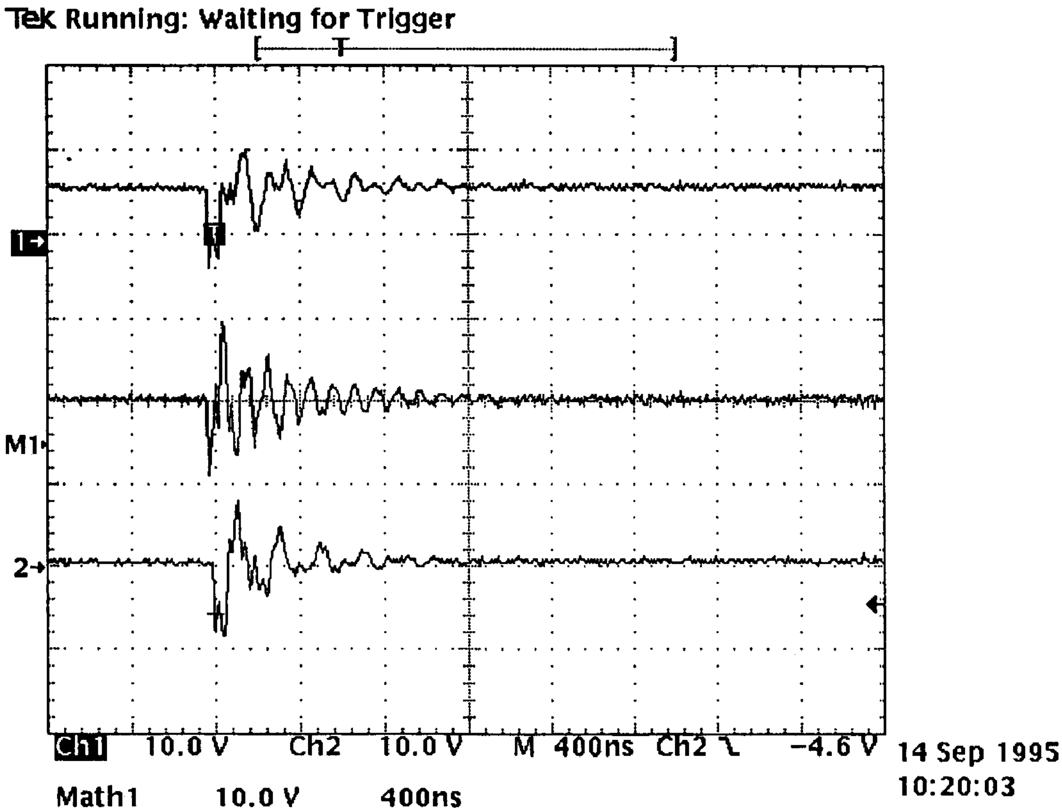

Figure E.1-6 5 Volt / 50 Ohm

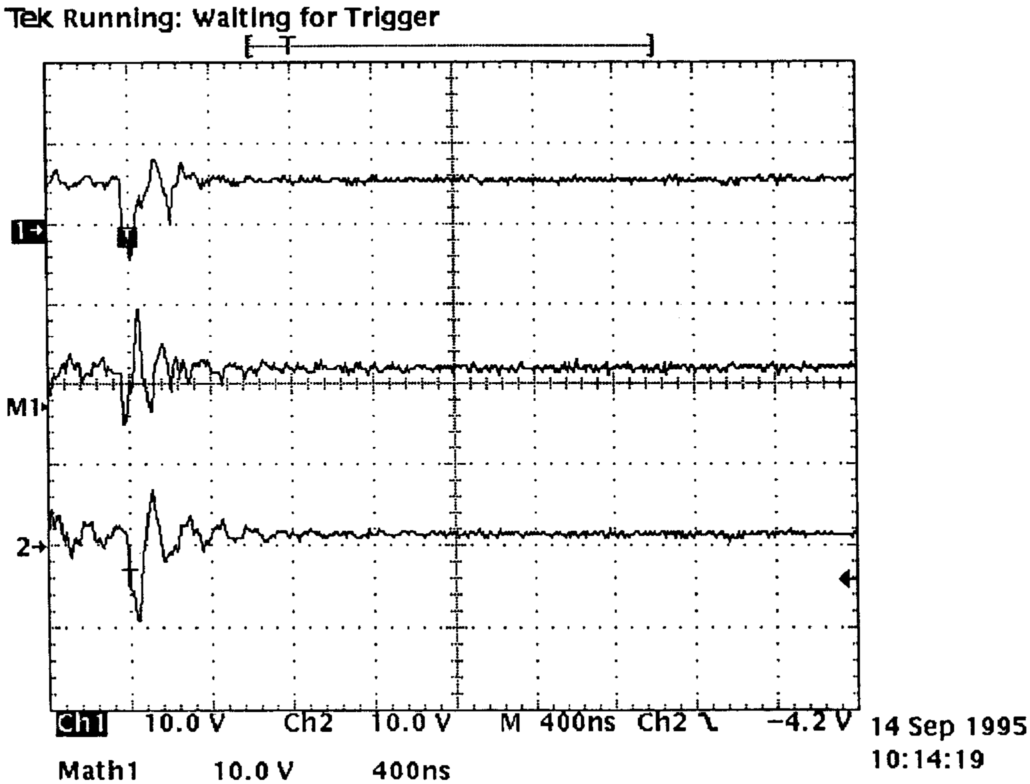

Figure E.1-7 5 Volt / 50 Ohm

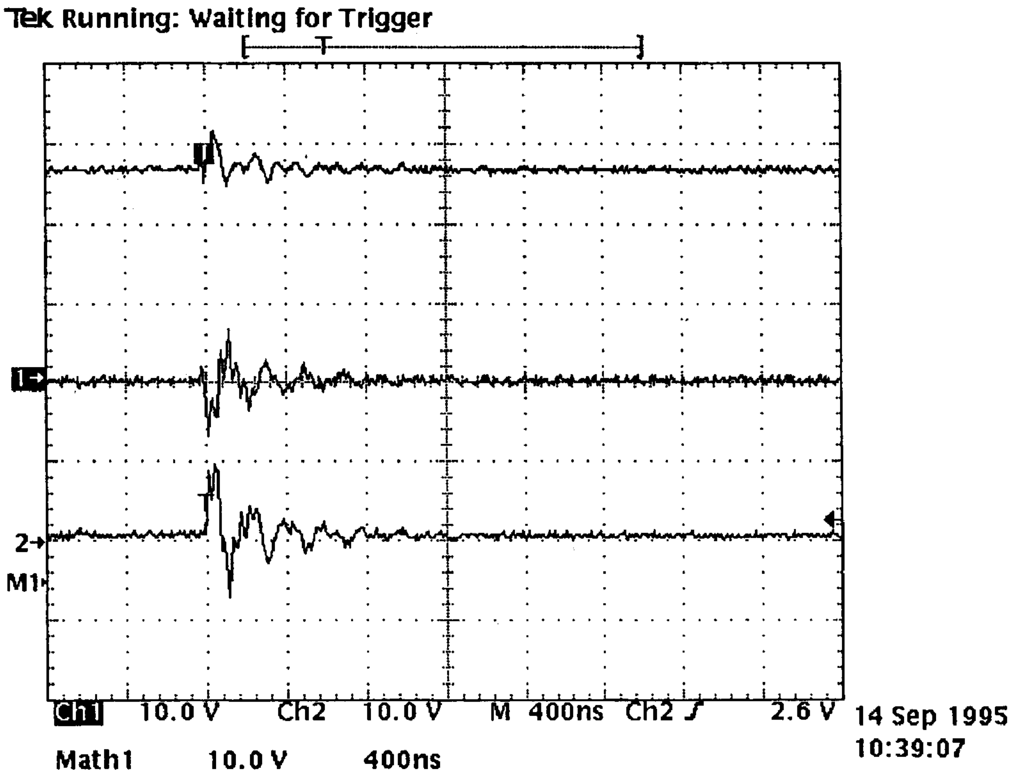

Figure E.1-8 28 Volt / 280 Ohm

E.2 Transient Behavior

Transient behavior for de-mating/mating powered connectors can be compared to the findings of J. Shi and R.M. Showers in "Mechanism of the Switching Transient in a Low Voltage DC System [10]. The schematic below depicts the subject circuit in the Shi and Showers paper. A connector either umbilical or staging disconnect could replace the switch function.

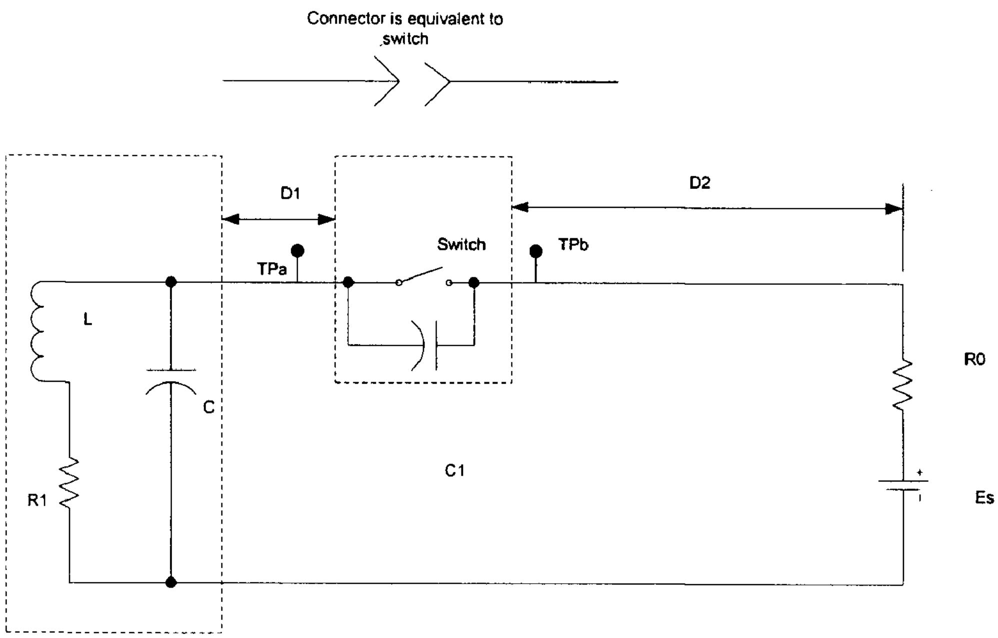

Figure E.2-1 Typical Circuit Experiencing Hot De-mate

In Figure E.2-1 [10], *D1* and *D2* represent transmission line length. The paper contains explanations what occurs for non-arcing and arcing cases. Energy stored in the system will require time for dissipation as the state is changed (switch opened or de-mate of connector). If conditions are such that no arcing occurs then the waveform of the resulting transient can be predicted by linear circuit analysis. Elements to the right of the switch/connector shall be referred to as the line side (TPb) while elements to the left of the switch/connector shall be referred to as the load side (TPa). Measurements at TPa and TPb voltages shall be Ea and Eb. Figure E.2-2a [10] depicts an ideal switch or de-mate function with no apparent effects. Figure E.2-2b [10] shows the current for this event. Figure E.2-3a [10] illustrates what happens in a non-arcing scenario. Ea the load side has a damped oscillation with a natural frequency. On the line side Ea recovers to Es with an exponential rise. Both of these waveforms develop independently. Figure E.2-3b [10] shows the current for the corresponding voltage waveforms in Figure E.2-3a. By increasing the initial current, the negative peak voltage on the load side increases. When the voltage across the switch gap or connector de-mate exceeds a critical value known as Ebk, breakdown occurs and an arc develops.

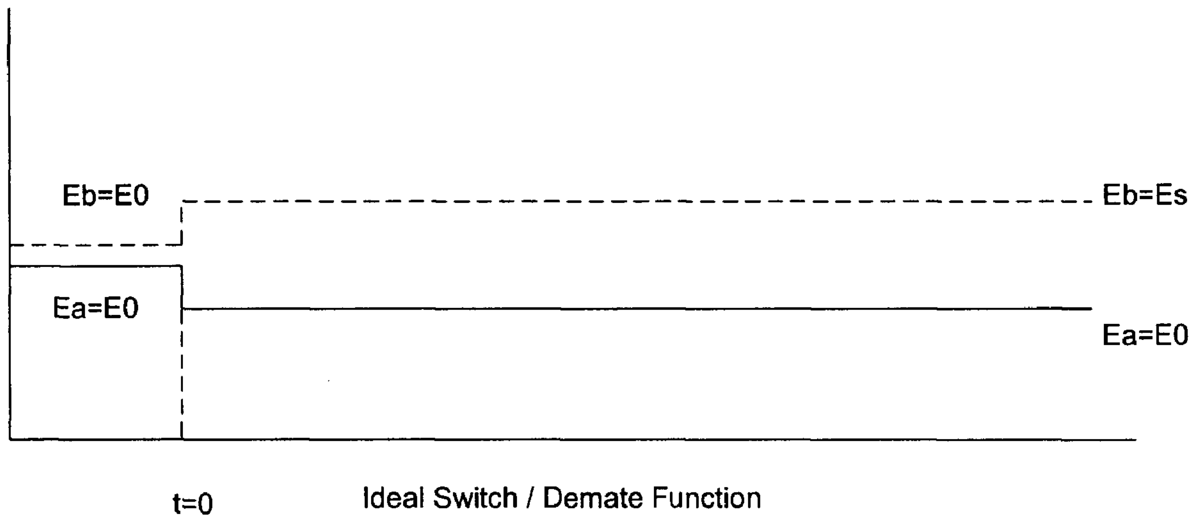

Figure E.2-2a Ideal Switch/De-mate Function

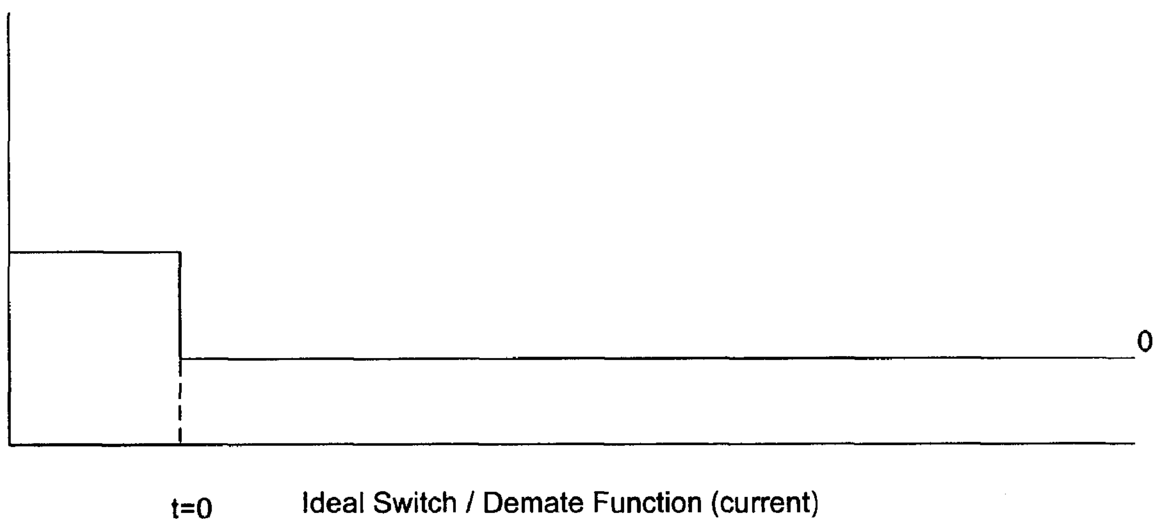

Figure E.2-2b Ideal Switch/De-mate Function (Current)

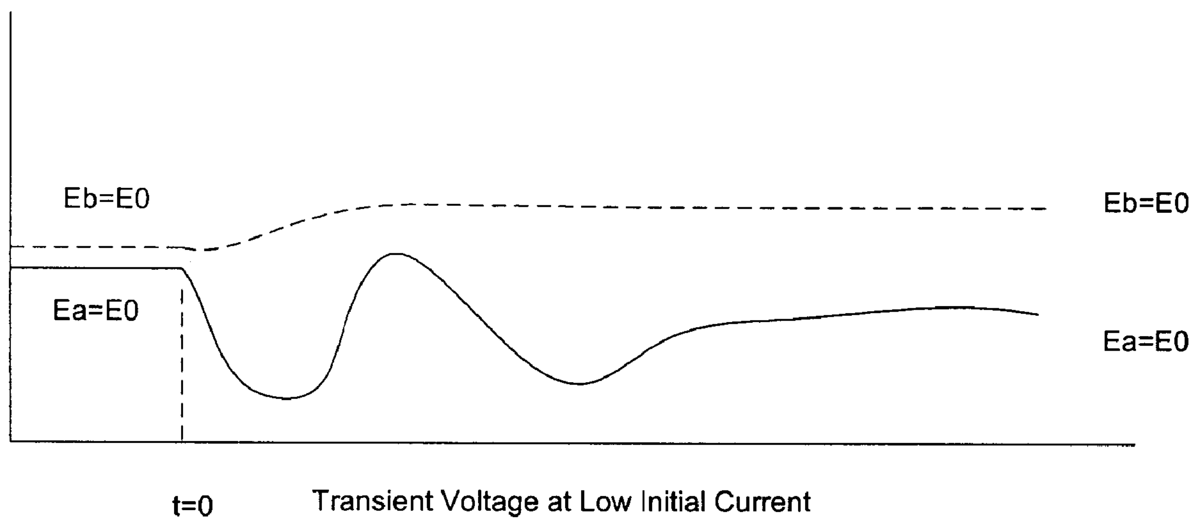

Figure E.2-3a Transient Voltage Low Initial At Current

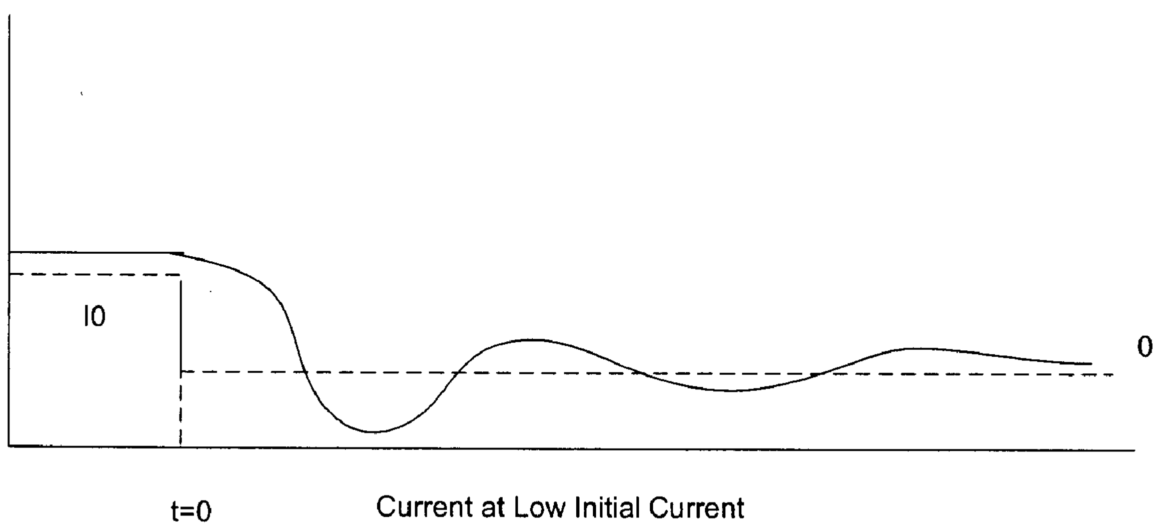

Figure E.2-3b Current At Low Initial Current

Figure E.2-4a [10] depicts what occurs at the moment of breakdown. The voltage on the load side recovers rapidly to its level, while on the line side Figure E.2-4b [10], transients appear that correspond to those in Figure E.2-4a. The corresponding current for this event is shown in Figure E.2-4c [10]. This current pulse can range as high as 1 ampere and the voltage Ebk can be as high as 1000 Volts. The energy path for these large currents is distributed through the capacitance on both sides of the switch/connector. At arc extinguishment, the voltage on the load side starts to increase negatively again and the process is repeated. Shi and Showers describe this as "discontinuous discharge."

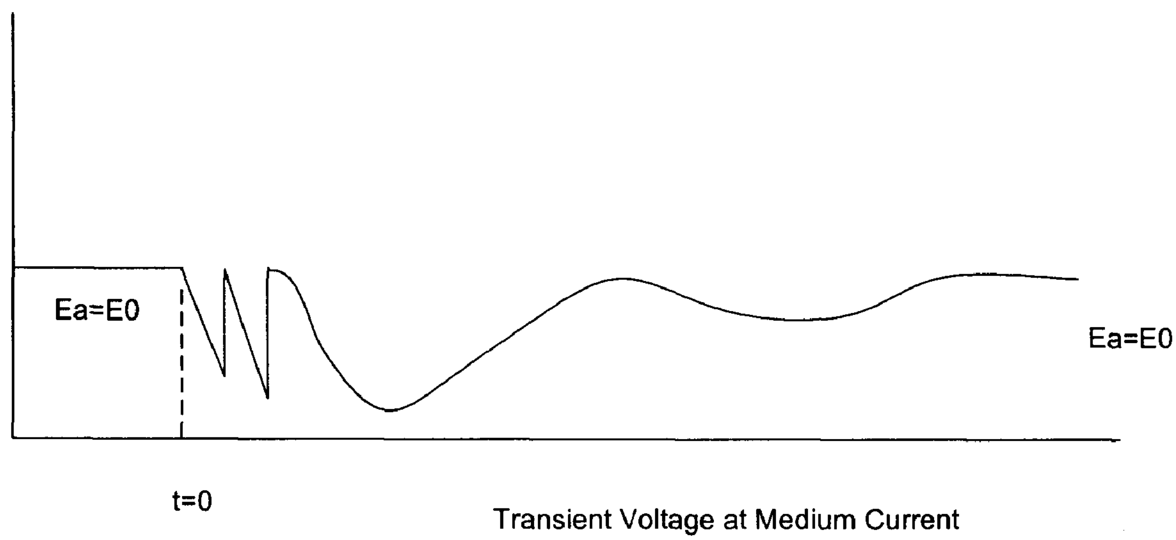

Figure E.2-4a Transient Voltage At Medium Current

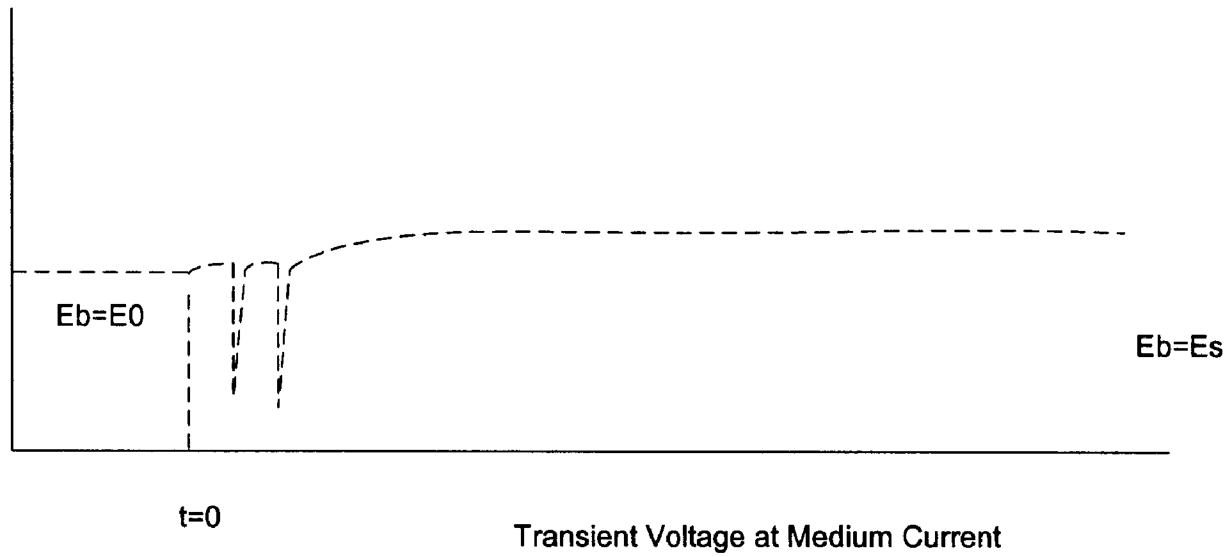

Figure E.2-4b Transient Voltage At Medium Current

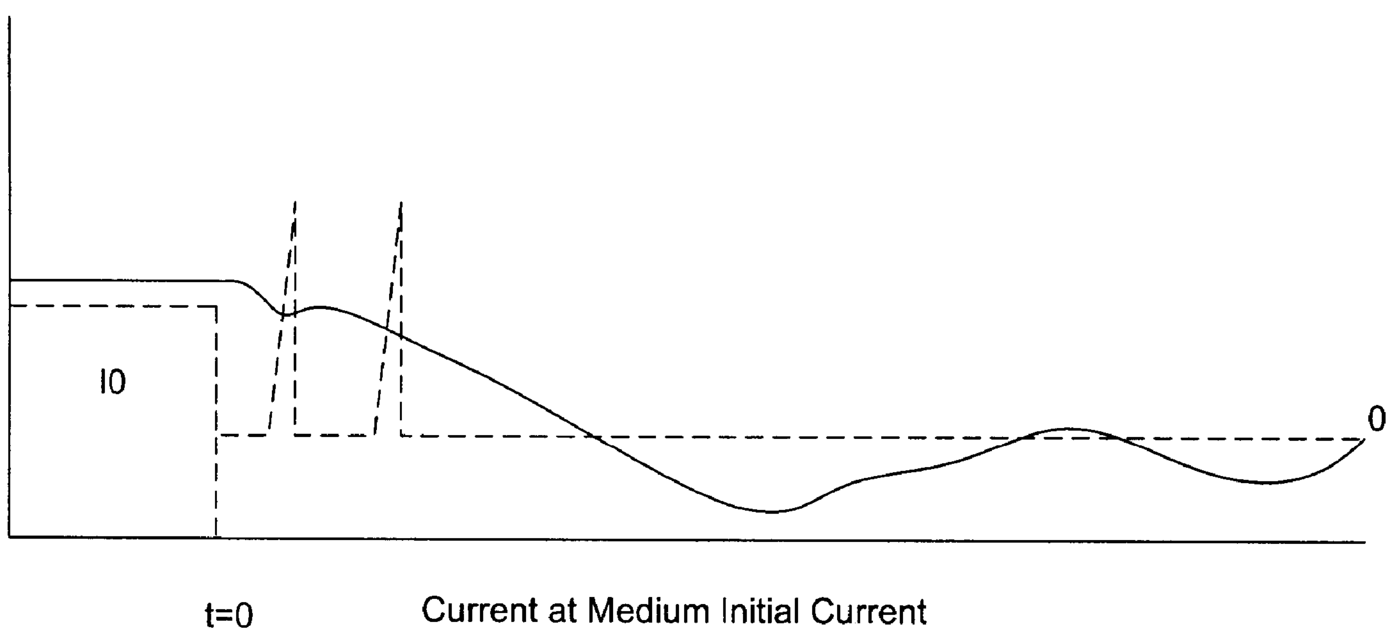

Figure E.2-4c Current At Medium Initial Current

At higher initial currents it is possible to develop a condition known as "continuous discharge." It always follows one or more breakdowns or re-strikings. In the case of de-mating connectors, a tip off of the connector pins could provide favorable conditions for continuous discharge. The voltage on the load side no longer increases negatively at the natural frequency of the load side current, but decreases gradually Figure E.2-5a [10]. As the current decreases, the discharge dies out and the damped oscillation returns on the loads side when the arc is extinguished. During the event, relaxation oscillation may occur and a secondary pulse train will be generated on the line side Figure E.2-5b [10]. Shi and Showers found that if the initial current increases further, no change of the basic patterns were observed, except that the overall duration of the transient increased gradually. Their upper current limit was 100mA. Figure E.2-5c [10] depicts current at high initial current application.

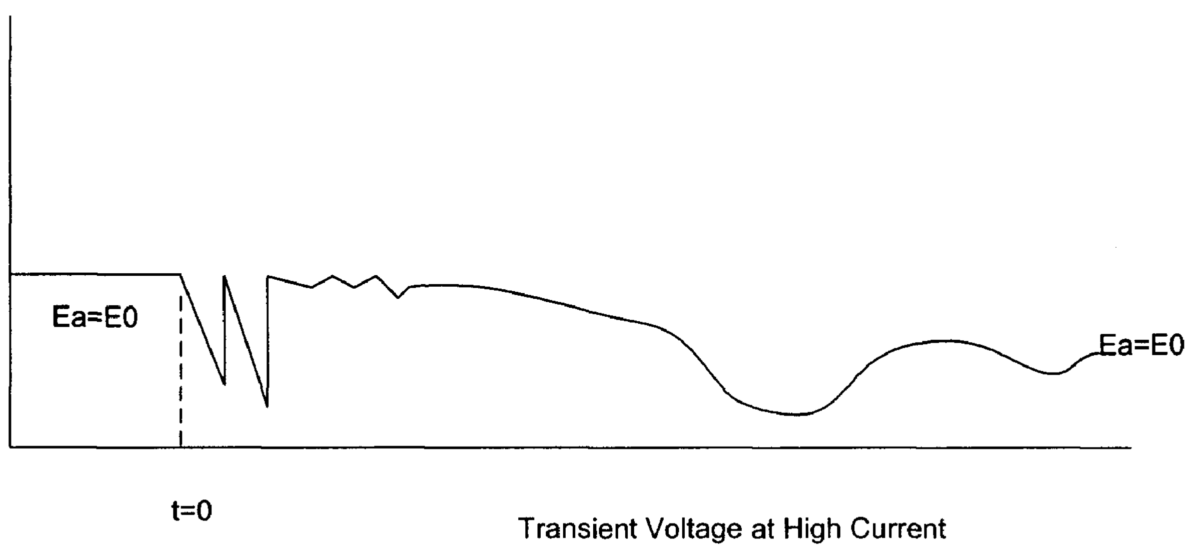

Figure E.2-5a Transient Voltage At High Current

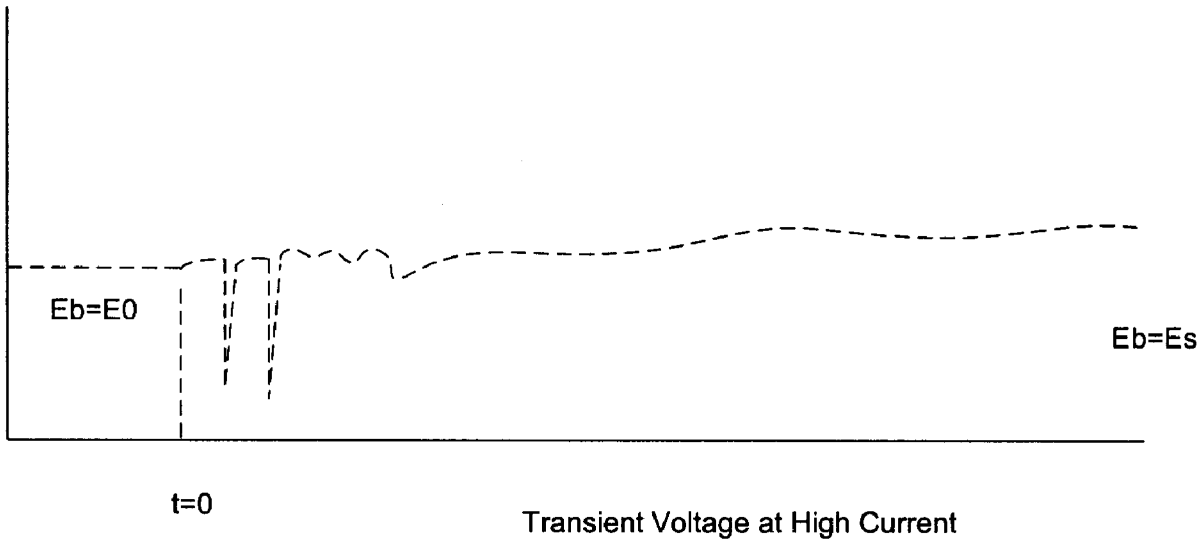

Figure E.2-5b Transient Voltage At High Current

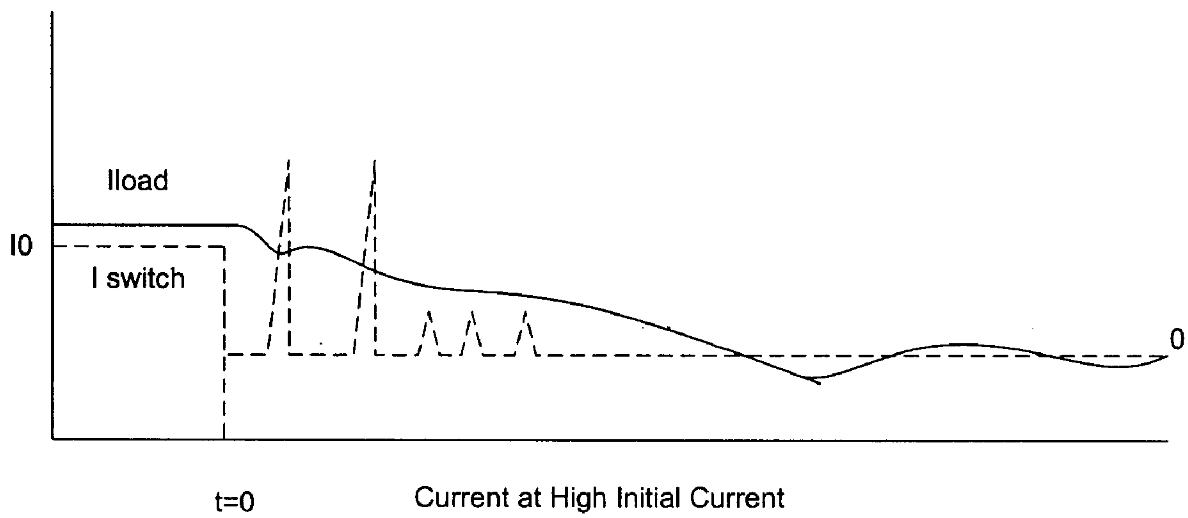

Figure E.2-5c Current At High Initial Current

From Figure E.2-6 [10], and the waveforms that follow the effects of transmission line lengths are discussed.

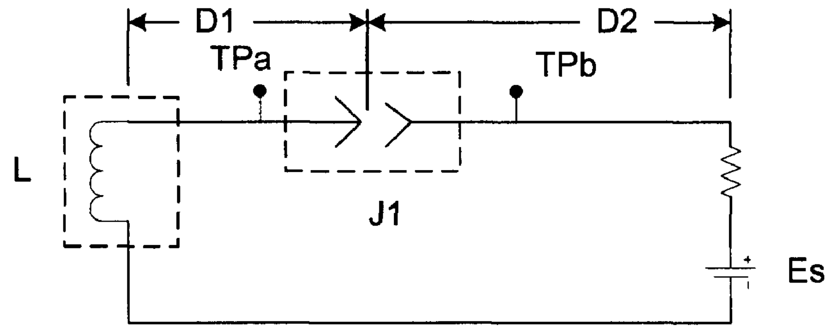

Figure E.2-6 Circuit Modeling Transmission Line Length

Before breakdown occurs, the cable, depicted by *D1*, is charged to a negative value by the inductive load. The cable *D2* rises to the supply voltage. As the voltage drop rises during disconnect Ebk is exceeded and discharge occurs. The voltage on the load side rises rapidly and the voltage on the line side drops rapidly. A positive step occurs on the load side while a negative step occurs on the line side (Figure E.2-7a [10]). The rise time between these steps is less than 2 nanoseconds. If *D1* and *D2* are equal and have the same characteristic impedances, the amplitude of the energy traveling in both directions is the same Ebk/2 (Figure E.2-7b [10]).

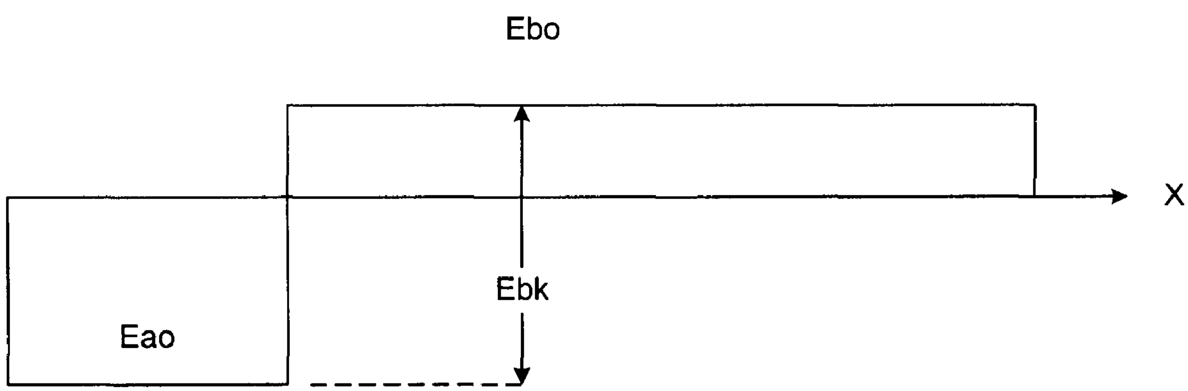

Figure E.2-7a Voltage When Z On Both Sides Is Equal

Let us say that τ represents the time lag from breaking the connection to breakdown. A time:

$$\tau_1 = \frac{D1}{S}$$

(where S = the speed of the energy wave in the transmission line and $D1$ is the distance between the load and the connector) the positive step voltage arrives at the load and a reflected wave with double voltage travels back toward the connector (Figure E.2-7c [10]).

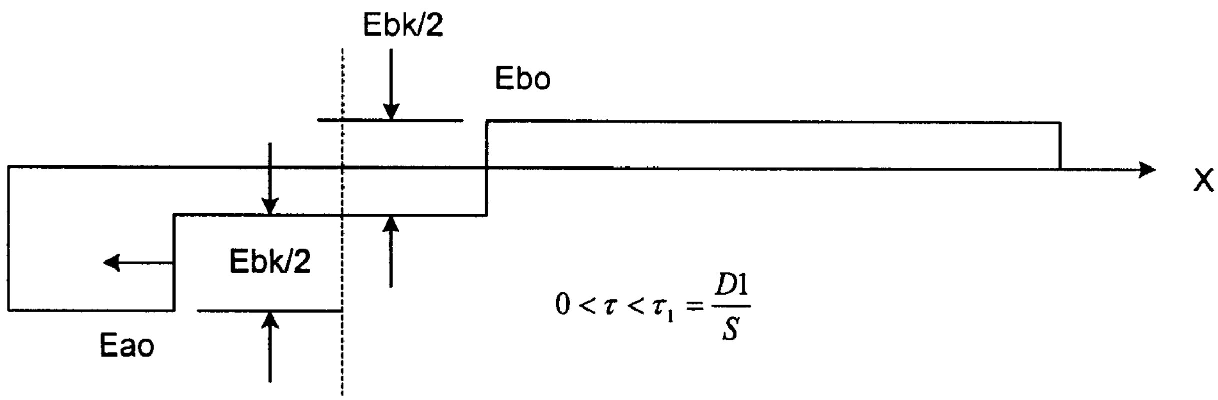

Figure E.2-7b Lag Time When Z On Both Sides Is Equal

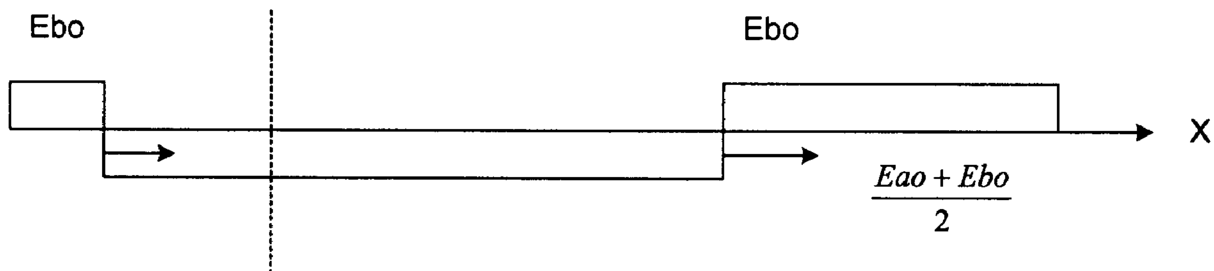

Figure E.2-7c Reflected Energy (Load Side) When Z On Both Sides Is Equal

At time:

$$\tau_2 = 2\frac{D1}{S}$$

the reflective wave arrives at the connector and rises to Ebo (Figure E.2-7d [10]).

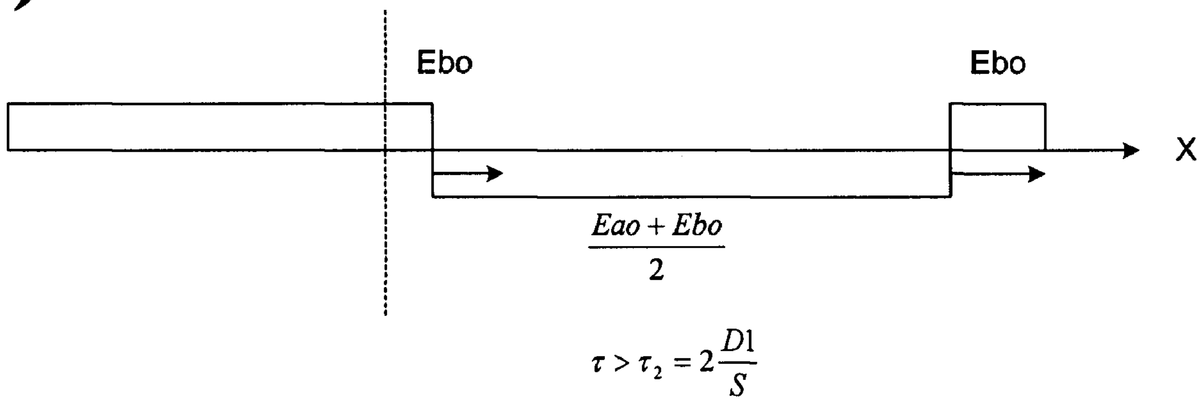

Figure E.2-7d Reflected Energy Arrives At Connector

Looking at the voltages on load side TPa (Figure E.2-7e [10]) we see how the voltage is related to the timelines above.

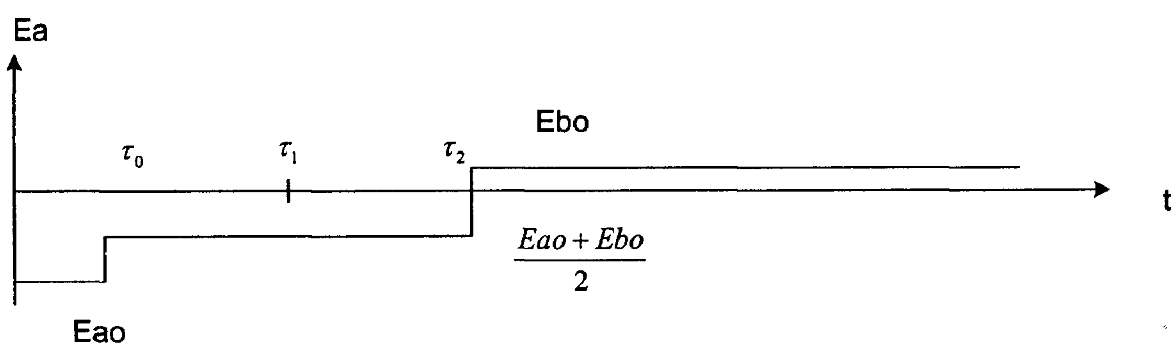

Figure E.2-7e Reflected Energy On Line Side

Looking at the voltage on the line side TPb (Figure E.2-7f [10]) we can see how the voltage is related to the timelines above.

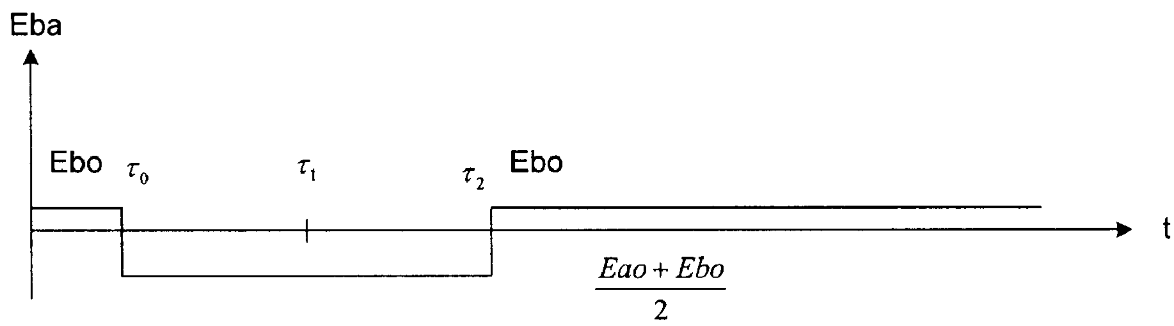

Figure E.2-7f Duration Of Primary Transient

At this time the direction of the current is reversed and the arc is extinguished. This is how the "Primary Transient" is generated and its duration is:

$$\tau_2 - \tau_0 = 2\frac{D1}{S}$$

APPENDIX F SOFTWARE MODEL

The circuit used for evaluation of transient responses was created using OrCAD™ Capture. The Cadence Corporation offers this and PSpice together. Previously PSpice was a stand-alone package. The assumption that the reader is familiar with OrCAD™ and PSpice is necessary in developing and running simulations. Below is the netlist for the circuit. This is generated by PSpice and lists the component and the node (N followed by a number). The component value follows the node numbers. The schematic depicted in Figure F-1 contains the parts and their values. T1 is a transmission line 20 feet of 22 AWG twisted pair. S1 is an ideal switch with programmable characteristics. It is initially listed and at the end of the netlist. A sub-circuit paragraph lists the parameters. These parameters are entered when the circuit is designed in Capture. During design one must select the analog or mixed A/D as an option. This will enable PSpice to run as it will appear on the menu. V3 is a piecewise linear programmable source. The series of numbers that follow are time, for example 10e-7, which is 1 microsecond. The next number is the value, for example 0.0 Volts. This source is programmed to turn on at 1.5microseconds to 2 Volts, and turn off at 2.5 microseconds. In this manner it is possible to program the rise/fall times.

ARCNOT Source

```
X_S1    N31625 0 N31570 N31119 SCHEMATIC1_S1
X_T1    N31119 0 N31181 0 TP22AWG_SLL  PARAMS: FRQ=5k  LEN=20
R_R1    N31089 N31570  .25
V_V1    N31089 0 5Vdc
R_R2    N31181 N31212  .1
V_V3    N31625 0
+PWL .1e-6 0 10e-7 0 15e-7 2 20e-7 2 25e-7 0 30e-7 0 35e-7 2 40e-7 2
C_C1    0 N31181  7pf
L_L1    0 N31212  10uH
.subckt SCHEMATIC1_S1 1 2 3 4
S_S1    3 4 1 2 _S1
RS_S1   1 2 1G
.MODEL   _S1 VSWITCH Roff=1e6 Ron=.10 Voff=0.0V Von=1.0V
.ends SCHEMATIC1_S1
```

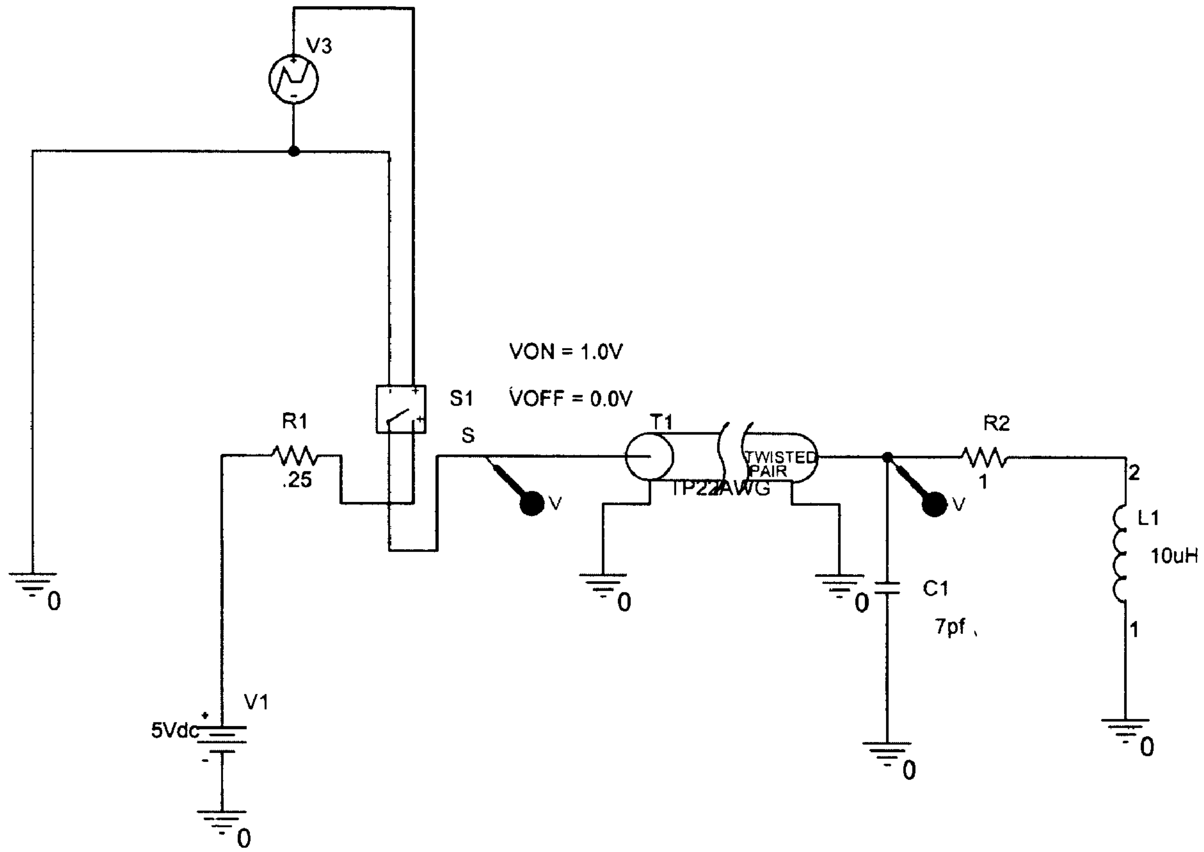

Figure F-1 Modeled Circuit With Transmission Line

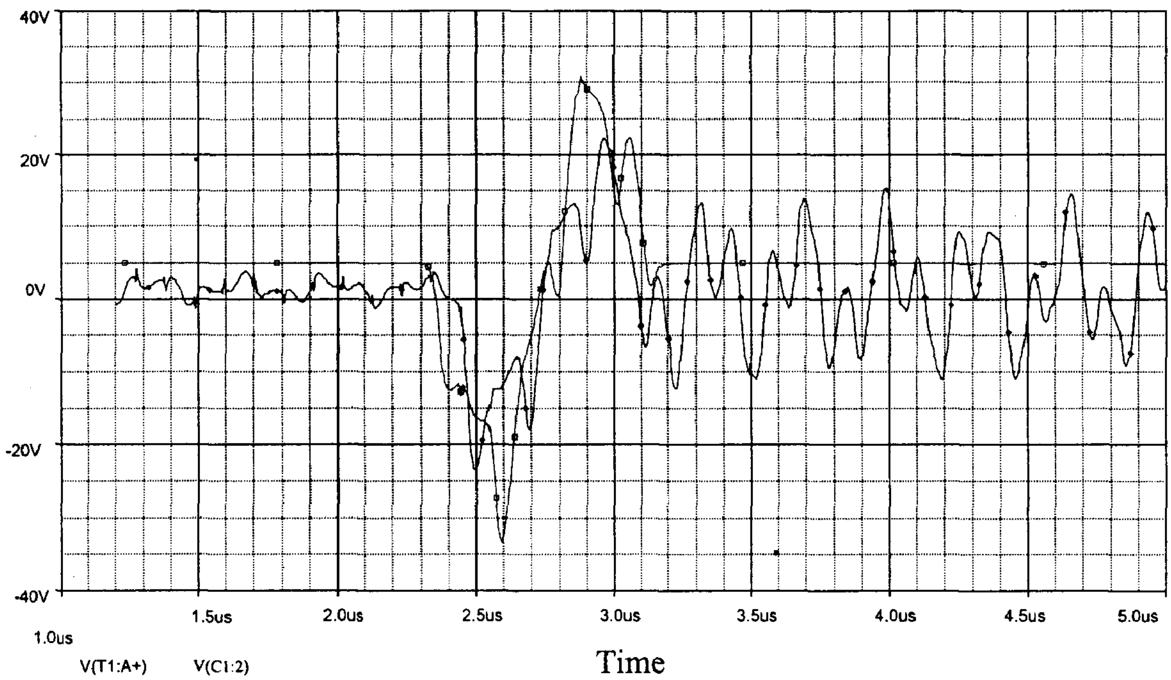

Figure F-2 Response On Either Side Of The Transmission Line

The two traces depicted in Figure F-2 show the voltages on either side of the transmission line. The effects of the transmission line can be seen.

The files needed for this circuit are contained in arcnot.zip. The key file is arcnot.ojp. This file should open from OrCAD™ Capture CIS. From the circuit schematic, values can be changed and different simulations can be run.

Filename:	SEE Deadfacing Guide (Final).doc
Directory:	E:
Template:	D:\Documents and Settings\yungsp\Application Data\Microsoft\Templates\Normal.dot
Title:	SEE Design Guide and Requirements for Electrical Deadfacing
Subject:	Electrical Deadfacing
Author:	J.M. Berki and N.B. Sargent
Keywords:	
Comments:	
Creation Date:	6/4/2002 3:54 PM
Change Number:	3
Last Saved On:	6/4/2002 3:56 PM
Last Saved By:	ogonekj
Total Editing Time:	4 Minutes
Last Printed On:	6/18/2002 9:21 AM
As of Last Complete Printing	
Number of Pages:	69
Number of Words:	13,438 (approx.)
Number of Characters:	76,601 (approx.)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 2002	Contractor Report (Final)

4. TITLE AND SUBTITLE

SEE Design Guide and Requirements for Electrical Deadfacing

5. FUNDING NUMBERS

H-34132D

6. AUTHORS

J.M. Berki and N.B. Sargent

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)

Analex Corporation
1100 Apollo Drive
Brook Park, Ohio 44142

8. PERFORMING ORGANIZATION REPORT NUMBER

M–1053

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA/CR—2002–211839

11. SUPPLEMENTARY NOTES

Prepared for NASA's Space Environments and Effects (SEE) Program
Technical Monitor: W. Kauffman

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified-Unlimited
Subject Category 33
Standard Distribution
Availability: NASA CASI (301) 621-0390

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The purpose of this design guide is to present information for understanding and mitigating the potential hazards associated with de-mating and mating powered electrical connectors on space flight vehicles. The process of staging is a necessary function in the launching of space vehicles and in the deployment of satellites, and now in manned assembly of systems in space. During this electrical interconnection process, various environments may be encountered that warrant the restriction of the voltage and current present across the pins of an electrical connector prior to separation, mating, or in a static open non-mated configuration. This process is called deadfacing. These potentially hazardous environments encompass the obvious explosive fuel vapors and human shock hazard, to multiple Electro-Magnetic Interference (EMI) phenomena related to the rapid rate of change in current as well as exposure to Radio Frequency (RF) fields.

14. SUBJECT TERMS

de-mating, mating powered electrical connectors, deadfacing, electro-magnetic interference, radio frequency

15. NUMBER OF PAGES

72

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

National Aeronautics and
Space Administration
AD33
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama
35812