Hardware Demonstration:

Conducted Transients on Spacecraft Primary Power Lines

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Acronym List

CE	Conducted Emissions
CMCE	Common Mode Conducted Emissions
CS	Conducted Susceptibility
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
GEVS	General Environmental Verification Specification
GSFC	Goddard Space Flight Center
LISN	Line Impedance Stabilization/Simulation Network
NASA	National Aeronautics and Space Administration

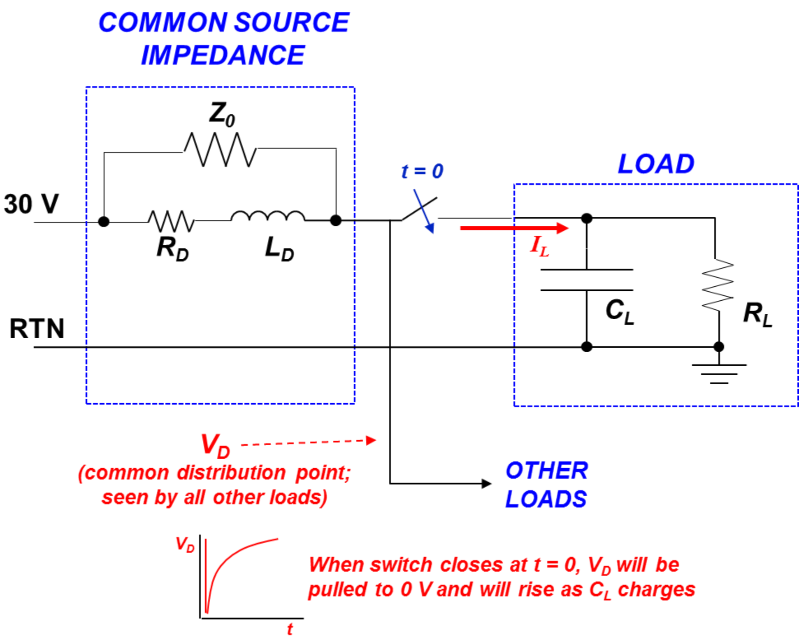
Introduction

- **One of the sources of potential interference on spacecraft primary power lines is that of conducted transients resulting from equipment being switched on and off of the bus**
- **Susceptibility to such transients is addressed by the CS06 requirement of MIL-STD-461/462 prior to 1993**
- **This demonstration provides:**
  - Basis for understanding of the sources of these transients
  - Analysis techniques for determining their worst-case characteristics (e.g. magnitude and duration)
  - Guidelines for minimizing their magnitudes and applying the requirement appropriately

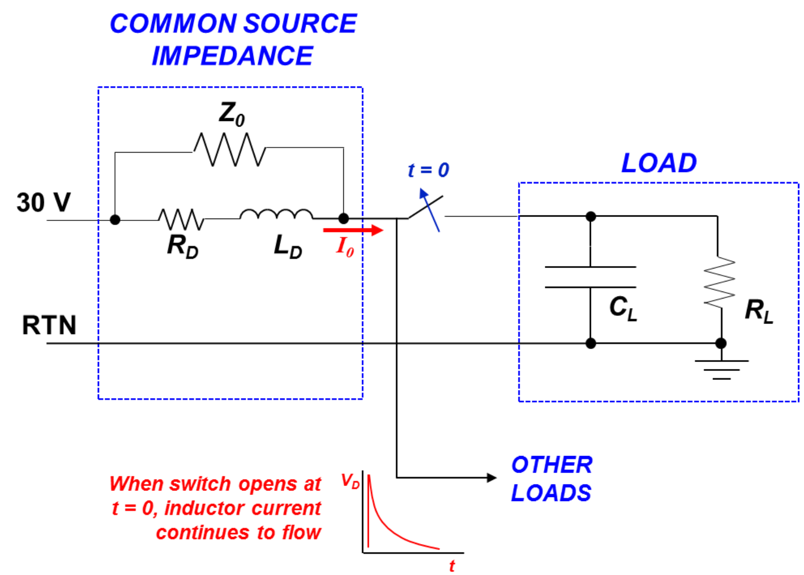
Anatomy of Transients

- **Normal transients on primary power bus result from equipment being switched on/off bus**
  - Turn-on transient: negative going pulse
  - Turn-off transient: positive going pulse
- **Characteristics of transient (magnitude, duration) determined by interaction of common source impedance with load impedance**

TURN-ON TRANSIENT MODEL (negative pulse)



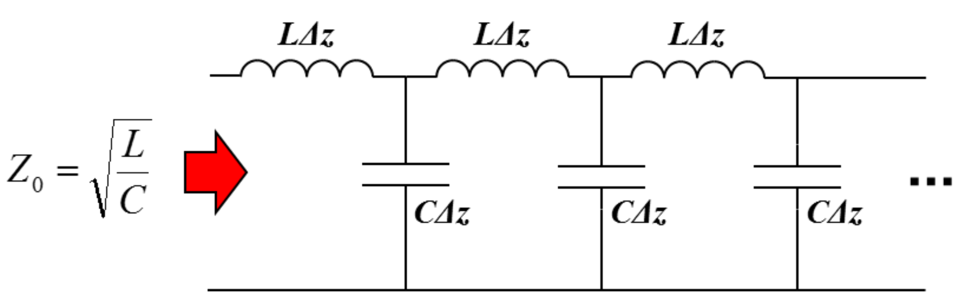
TURN-OFF TRANSIENT MODEL (positive pulse)



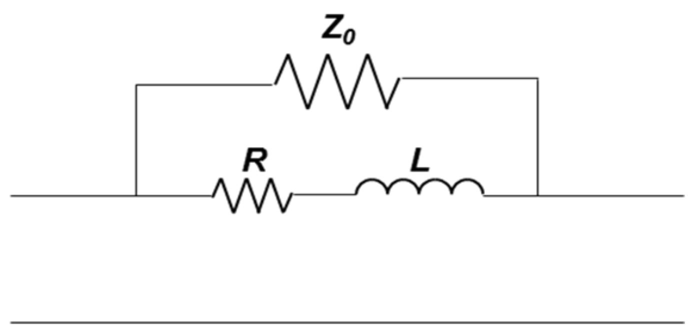
Power Distribution Harness Impedance Model

- **Common distribution impedance generally dominated by distribution wiring**
- **Modeled as 2-wire transmission line**
- **Lumped model sufficient for most applications**
- **Line Impedance Stabilization/Simulation Network (LISN)**
  - Used to represent wiring impedance
  - Based on lumped parameters; schematic usually looks like lumped model
  - Generally identified by inductance, e.g. 5 μH, 10 μH, 50 μH, etc.

DISTRIBUTED MODEL

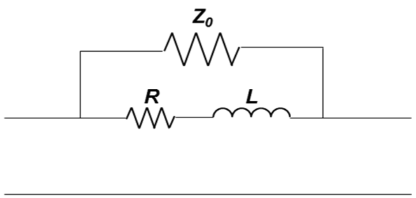


LUMPED MODEL (LISN)

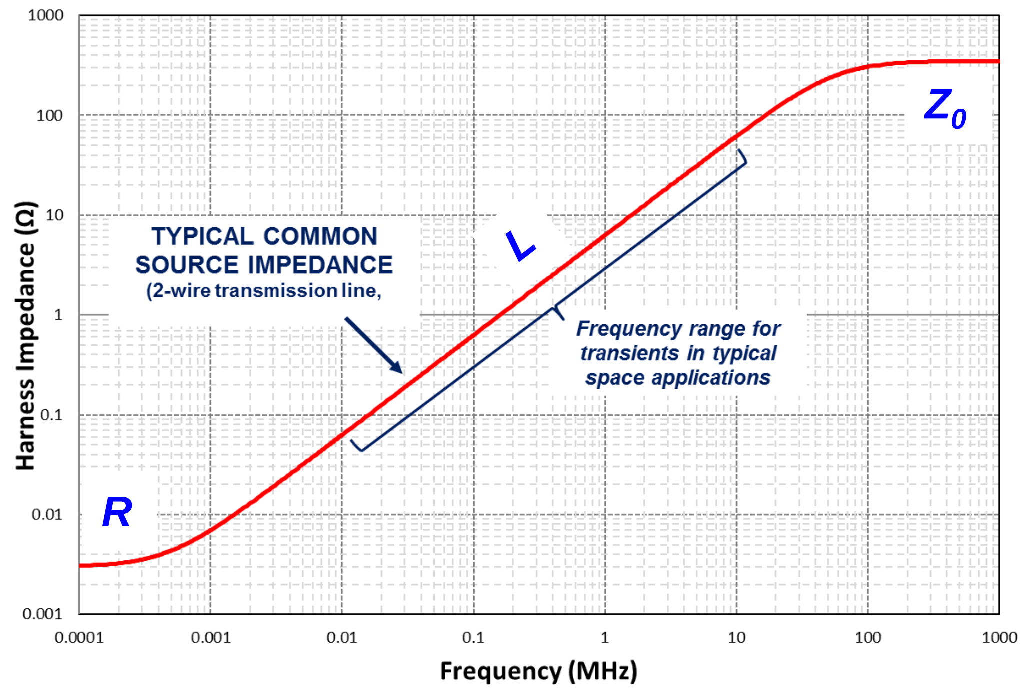


Power Distribution Harness Impedance Model (cont.)

- **Positive (+) and negative (-) bundles can be separated by 10s of cm**
- **Typical distribution wiring length**
  - Unmanned spacecraft: ~1 meter, ~ 1 µH
  - Larger platforms can have higher impedance buses; use LISNs ranging from 5 µH to 50 µH, depending on application

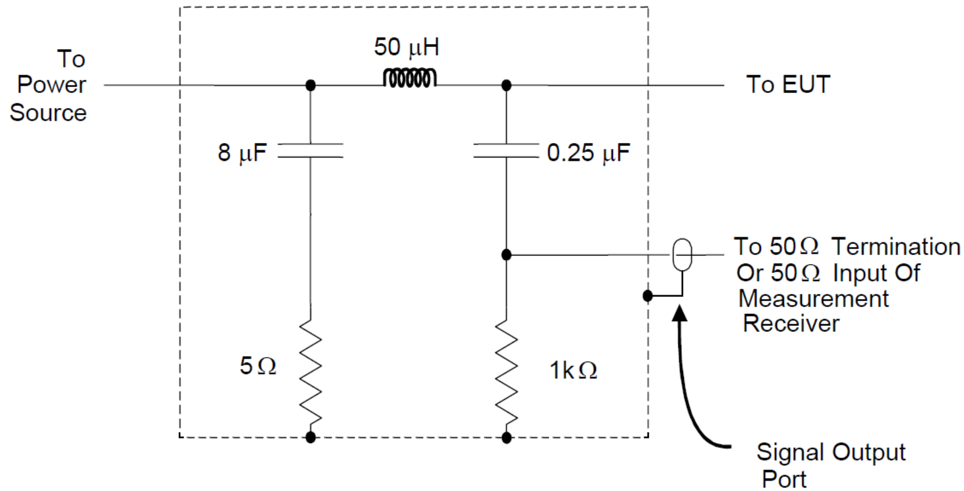


Typical parameters:
$R/l = 3\ m\Omega/m$
$L/l = 1\ \mu H/m$
$C/l = 10\ pF/m$
$Z_0 = 350\ \Omega$

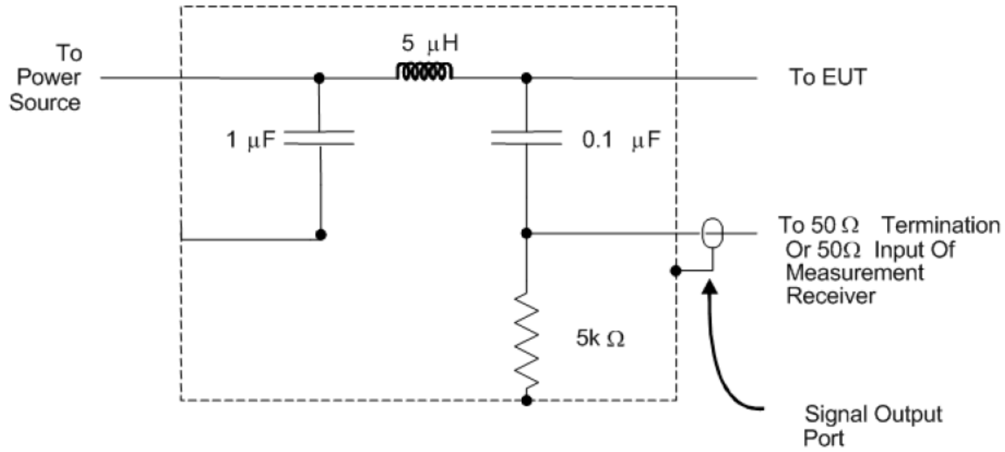


Power Distribution Harness Impedance Model (cont.)

MIL-STD-461 50 µH LISN

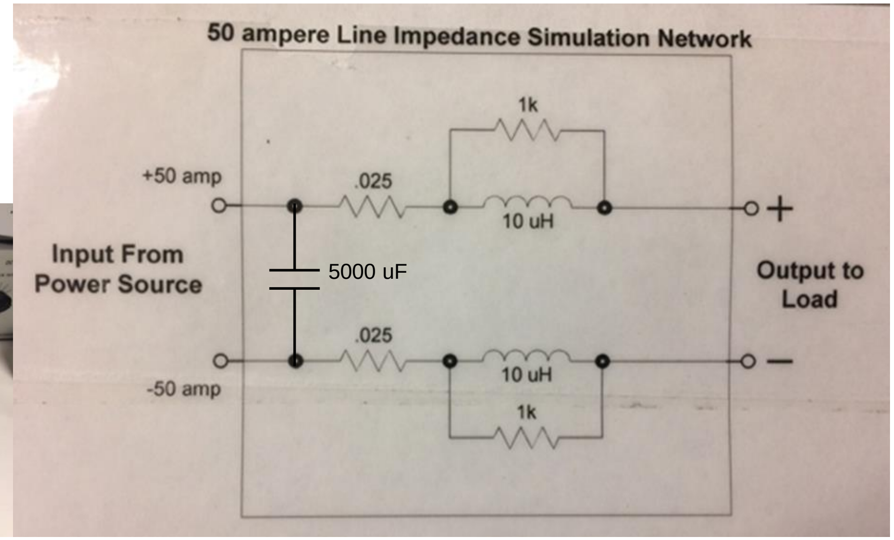


MIL-STD-461 5 µH LISN



Discrete Inductors from LISNs

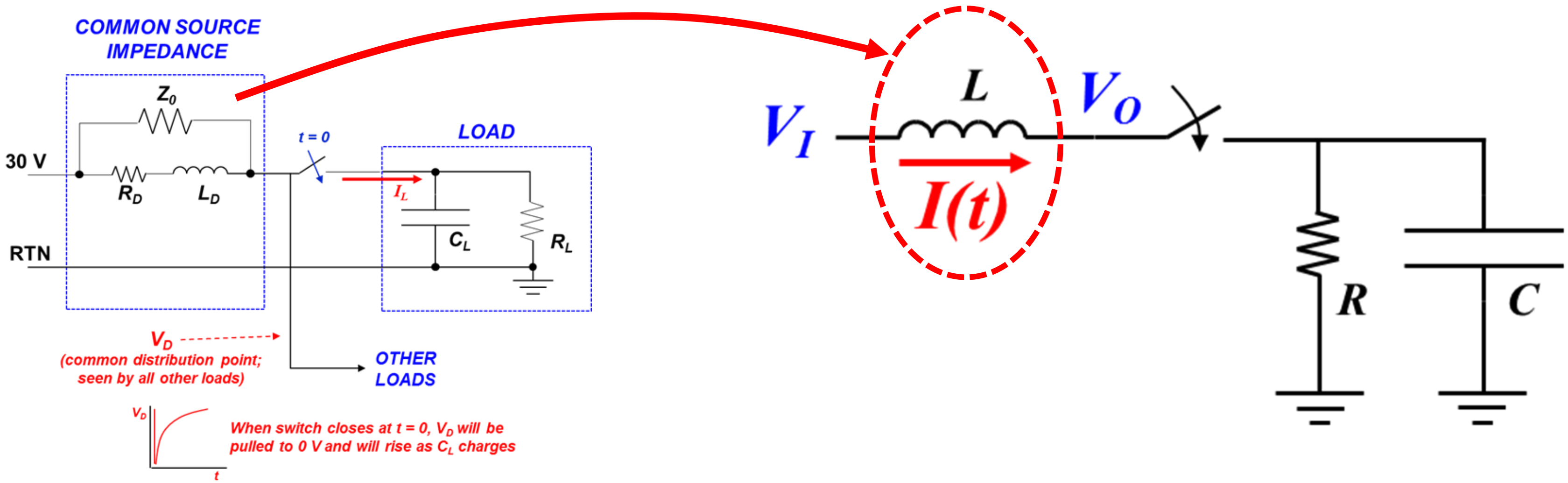
<u>Space Station LISN</u>
Pair of 10 µH inductors
(11 µH as-measured)



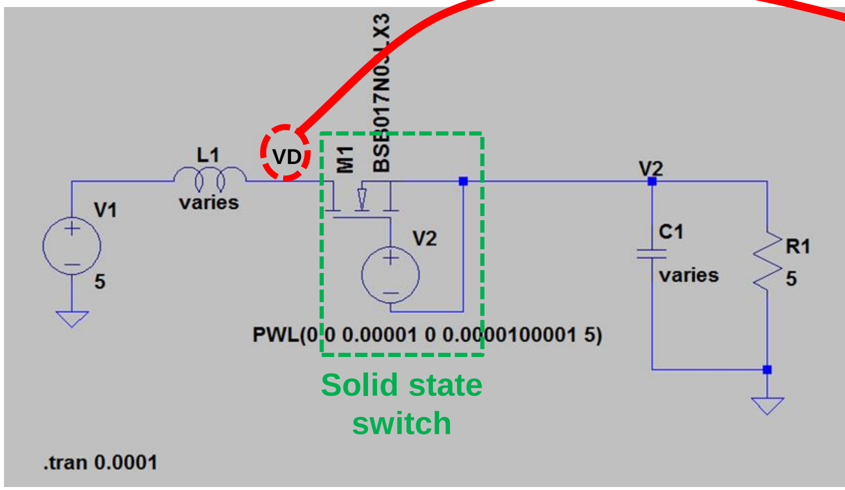
<u>Tegam 95300-50 LISN</u>
50 µH
(51 µH as-measured)

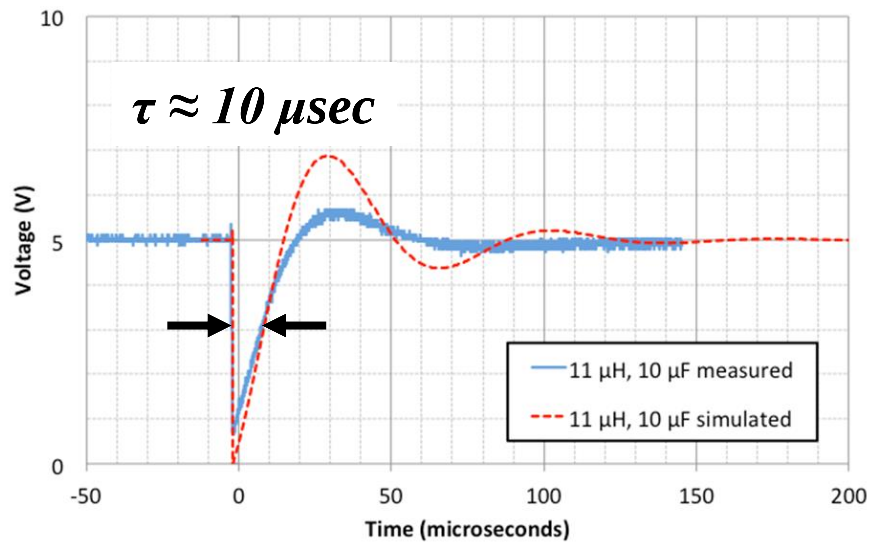
Turn-On Transient Simplified Model

- **For typical turn-on transients, inductance dominates common source impedance**
  - Load capacitance is generally many orders of magnitude higher than the wiring capacitance
  - Wiring capacitance may generally be ignored
  - Common source impedance may be modelled as bulk inductance



Demonstration 1a: Turn-On Transient w/ Discrete Inductor

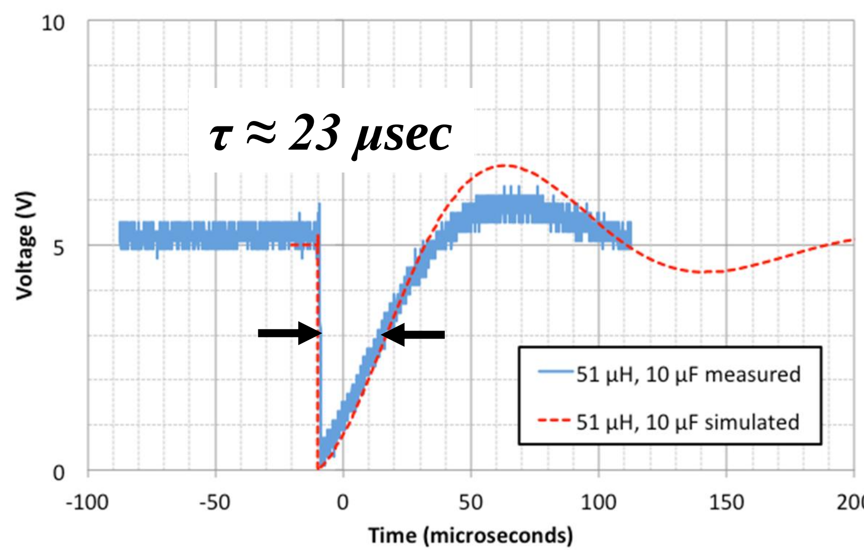




ΔVpeak = bus potential
(pulled to 0 V)

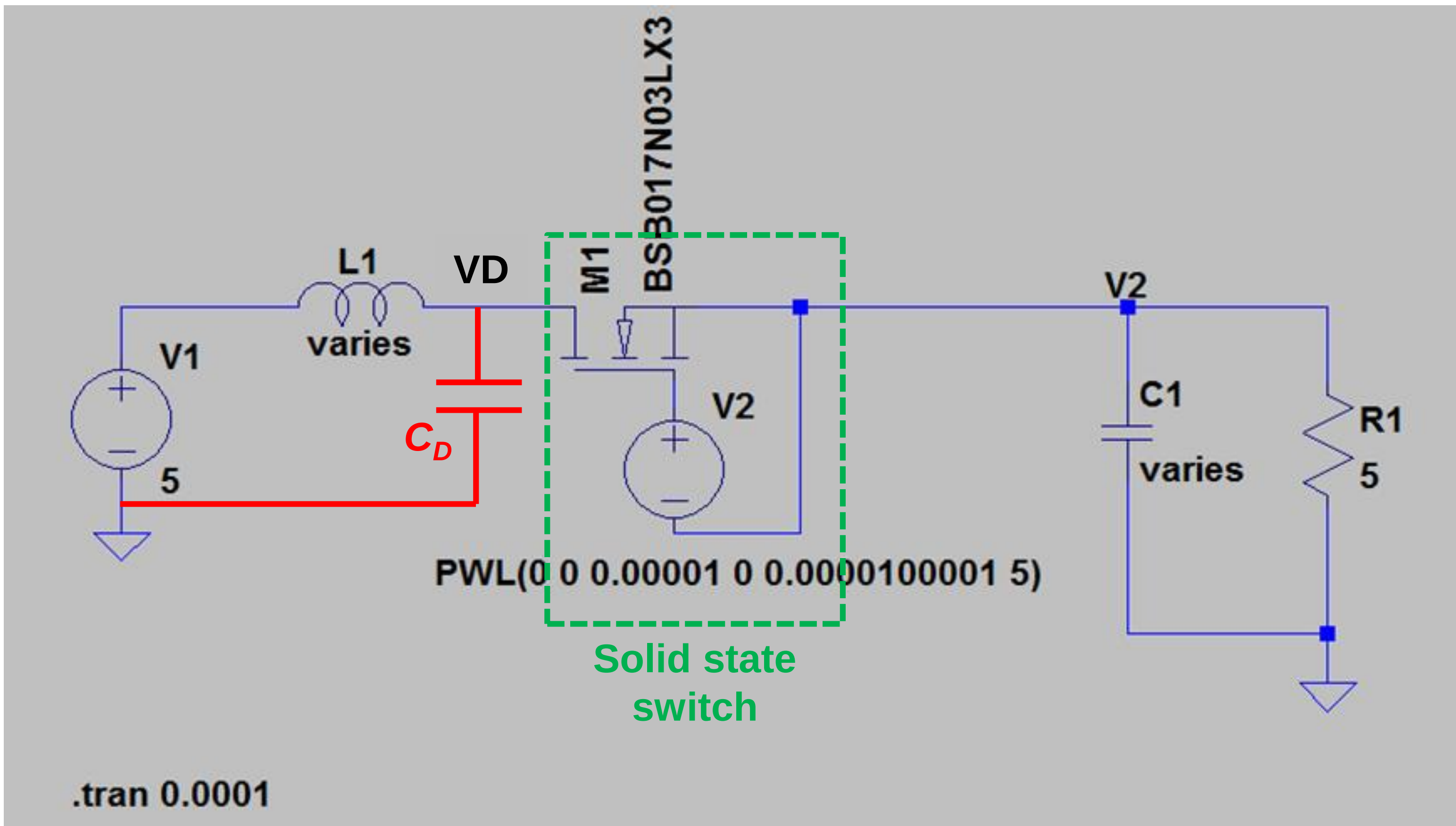
$$\tau = \sqrt{LC}$$

Good agreement betwixt measurements and simulations for discrete inductors



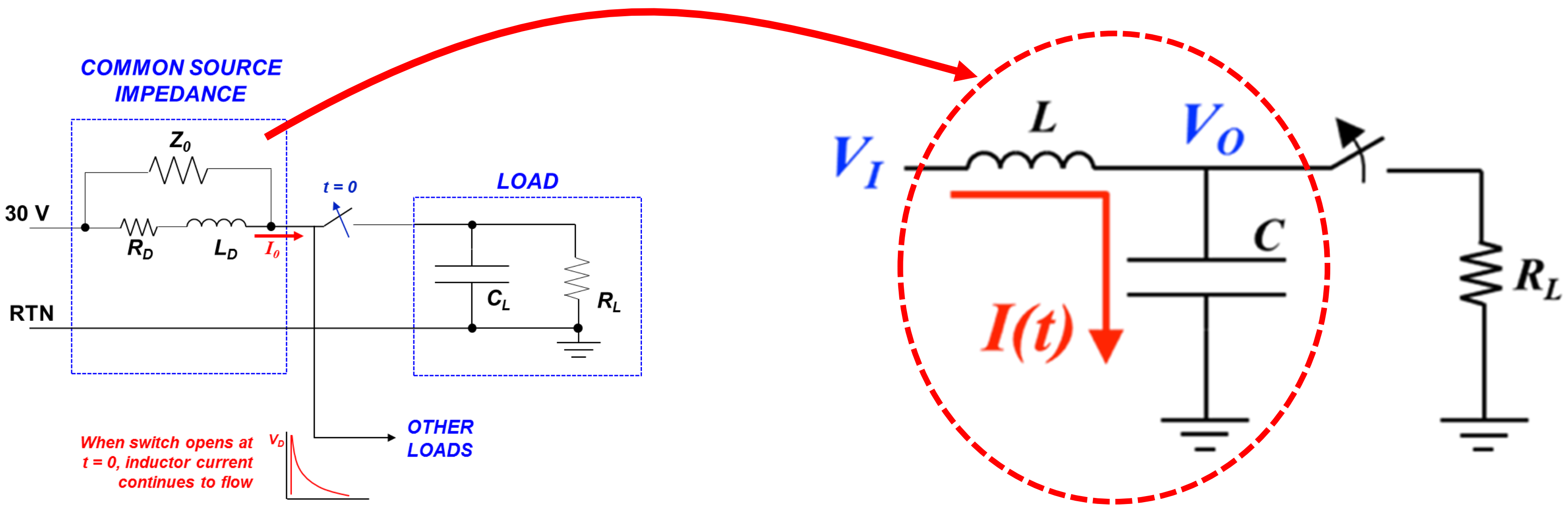
Demonstration 1b: Turn-On Transient with Added Capacitance at Distribution Point

- **What happens when we add capacitance C_D at distribution point that is greater than load capacitance *C1*…?**

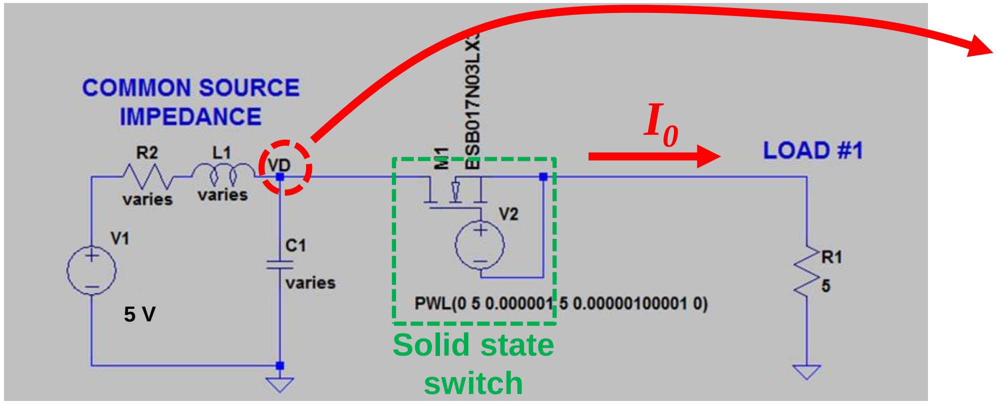


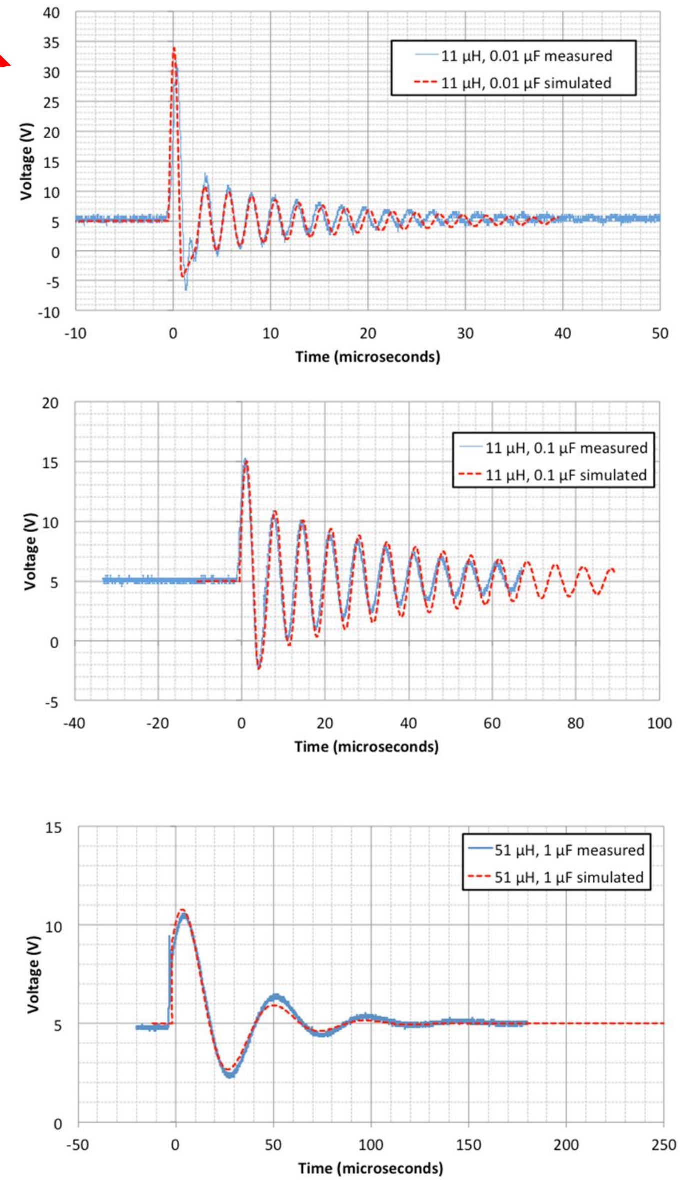
Turn-Off Transient Simplified Model

- **For typical turn-off transients, common source impedance may be modeled by bulk series inductance and bulk shunt capacitance**
  - Javor in [1] and [2] emphasized use of LISN in order to define a repeatable test method
  - This study addresses the physical parameters of the harness, i.e. inductance and capacitance, in order to properly bound the properties of typical transients observed on GSFC platforms in order to assess the applicability of the CS06 positive transient



Demonstration 2: Turn-Off Transient w/Discrete Inductors





I_0 normalized to 1 A for all measurements and simulations

$$\Delta V_{peak} = I_0 \sqrt{\frac{L}{C}}$$

$$\tau = \sqrt{LC}$$

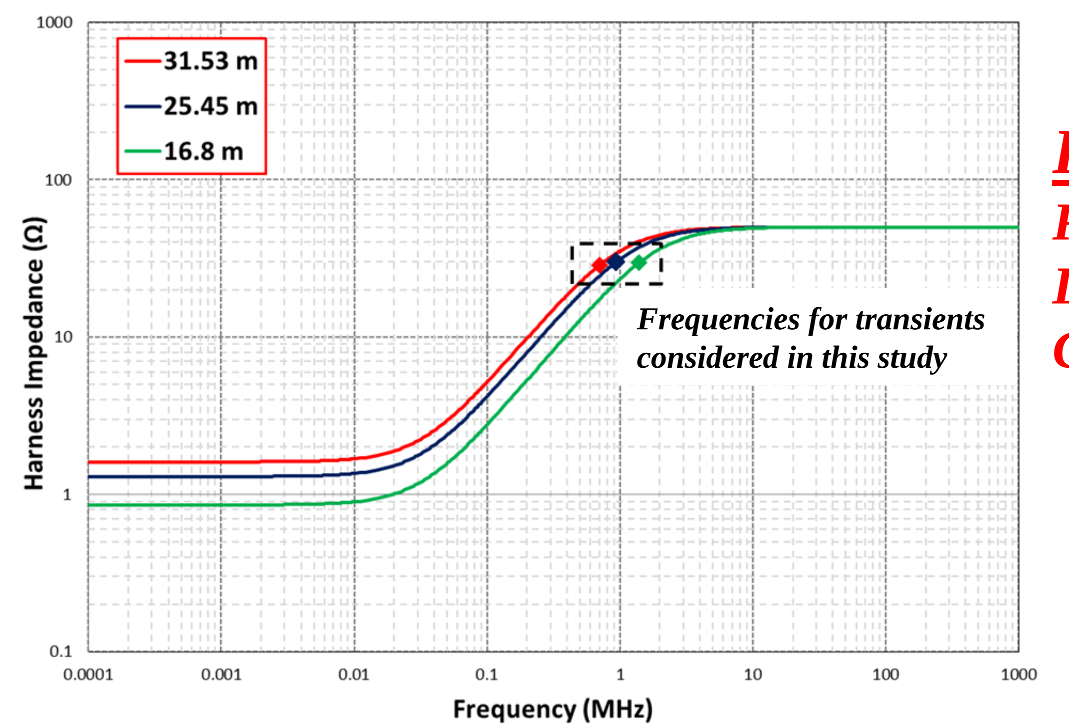
τ = duration of impulsive spike due to opening switch

Ringing occurs with period

$$T = 2\pi\tau$$

How about a real cable?

- **Previous simulations and measurements were performed using discrete components**
- **We wanted to see if the lumped model accurately predicted the transients on actual cable**
- **RG58 used as case study**
  - Coax never used for power wiring
  - Used because of well-defined and well-controlled impedance characteristics
- **Used lengths of 16.8 m, 25.4 m, and 31.5 m**



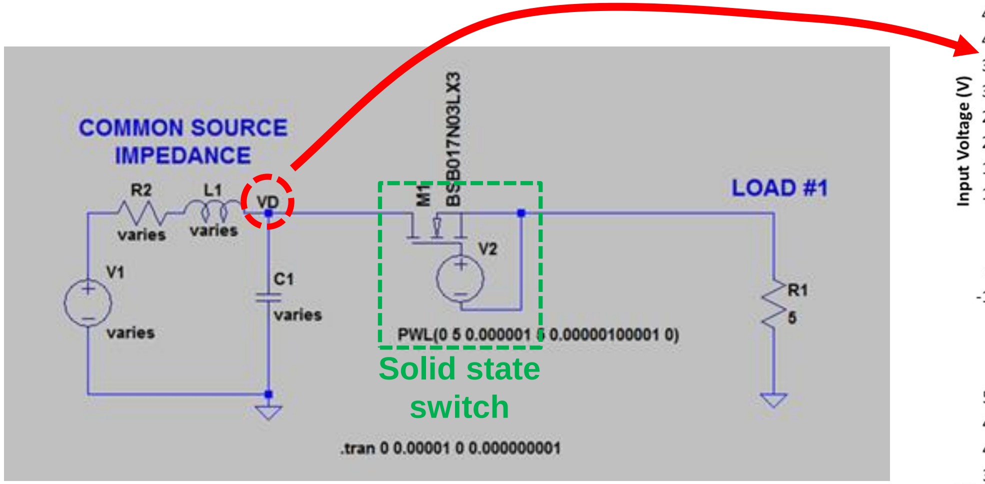
RG58 parameters:

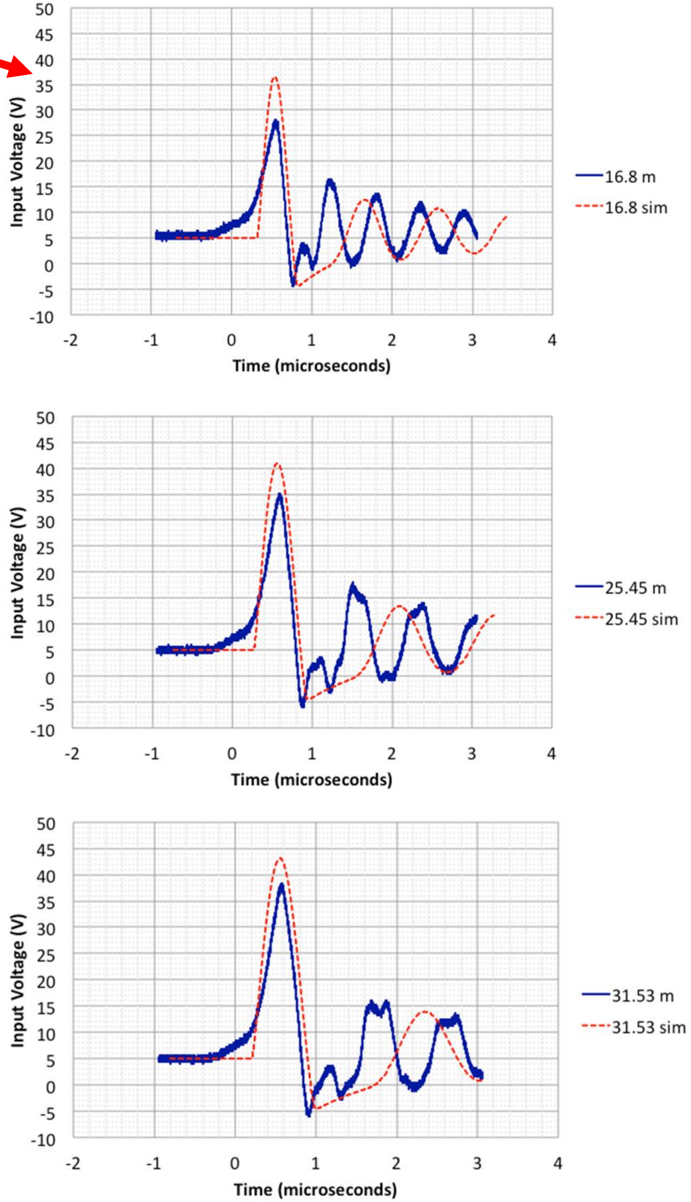
R/l = 51 mΩ/m

L/l = 0.25 µH/m

C/l = 100 pF/m

Demonstration 3: Turn-Off Transient w/RG58 Coax





$Z_0 = \sqrt{(L/C)} = 50\ \Omega$

ΔV_{peak} independent of pulse width

$\tau = \sqrt{(LC)} = 5$ nsec/m

Period = $2\pi\sqrt{(LC)}$

= 31 nsec/m

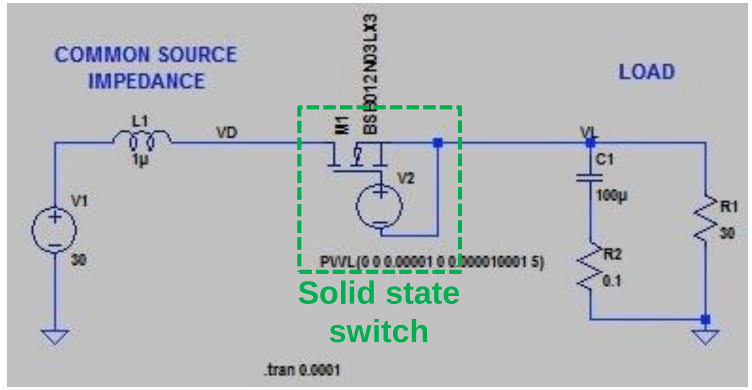
Bulk parameter model provides good agreement with measured results

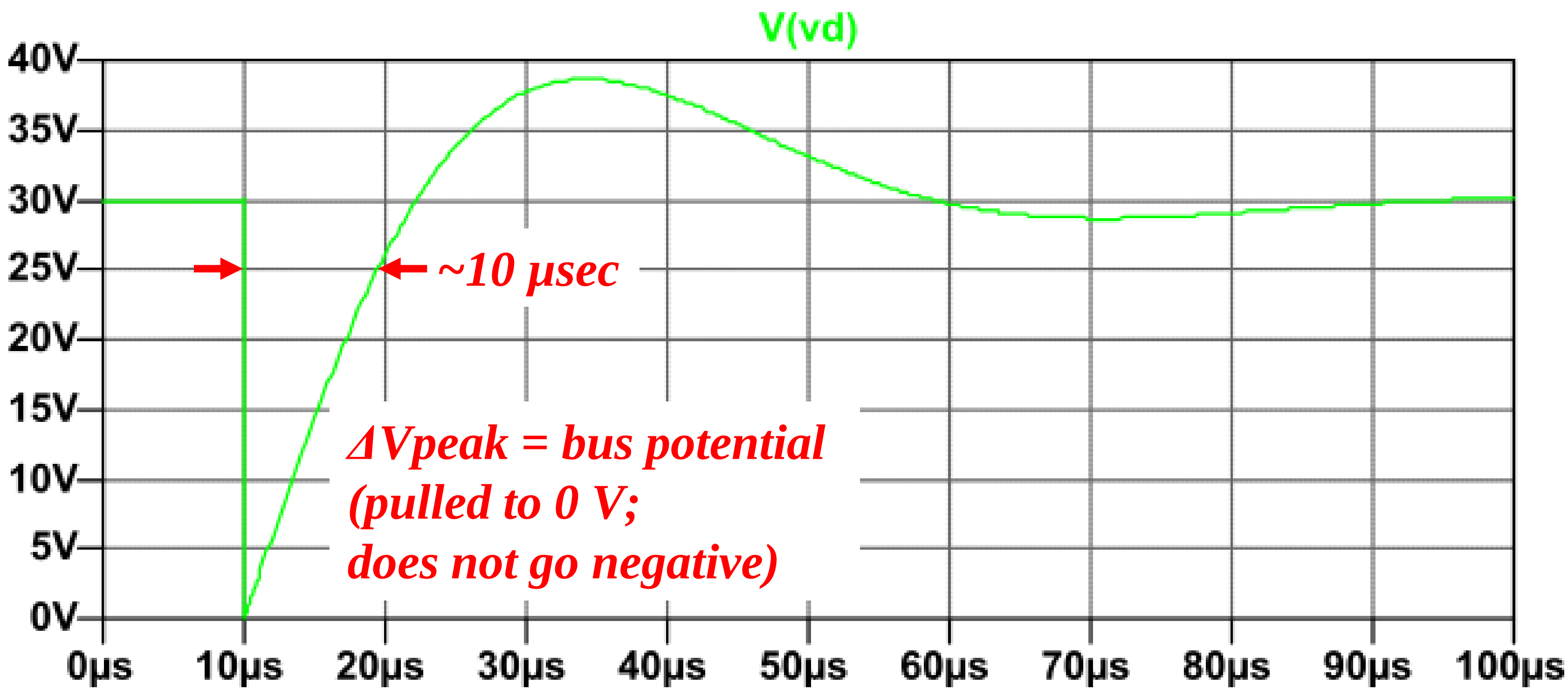
Typical Transients on Spacecraft

- **Now that we have established confidence in our models, we can extrapolate them to predict typical transients on spacecraft**
- **Recall typical power wiring characteristics**
  - (+) and (-) bundles separated by 10s of cm
  - ~1 meter from battery to distribution point
  - Parameters
    - $R = 3\ m\Omega$
    - $L = 1\ \mu H$
    - $C = 10\ pF$
    - $Z_0 = 350\ \Omega$
- ***We can plug these values into our models...***

Turn-On Transient: Typical

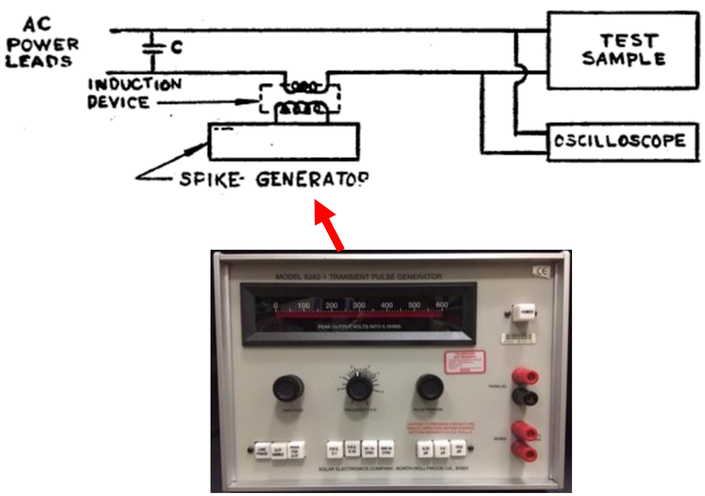
Representative Turn-On Transient Circuit Model

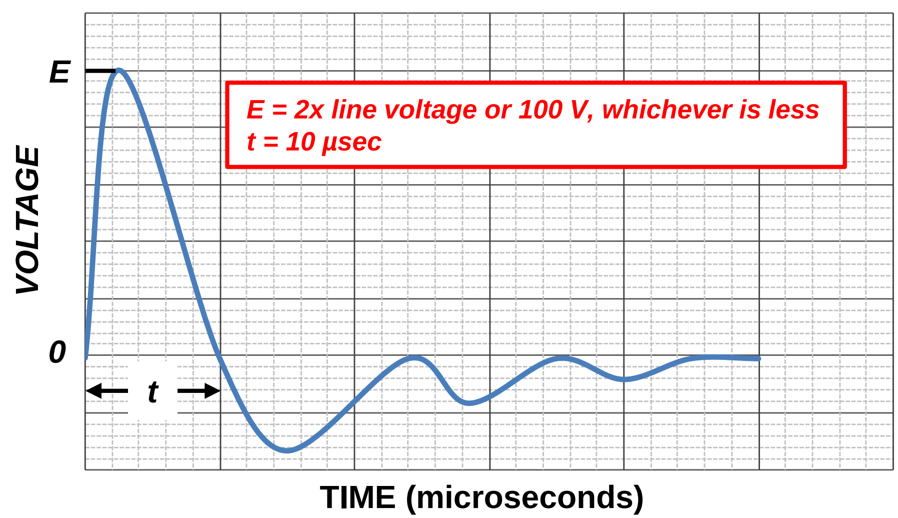




CS06 Negative (-) Pulse

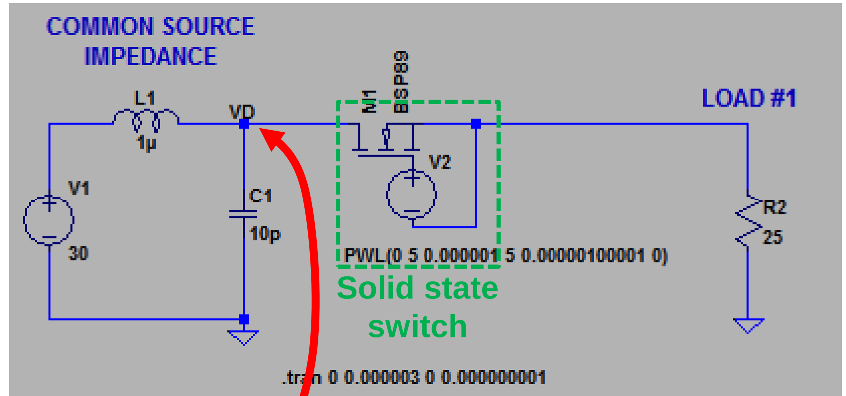
- **Tailored CS06 (-) pulse good representation for turn-off transient**
  - 10 µsec pulse width
  - Magnitude
    - Tailor to equal line potential to pull bus to 0 V (no lower)
    - MIL-STD-461A default is lesser of 2x line voltage or 100 V
    - WILL pull the bus negative; not desired

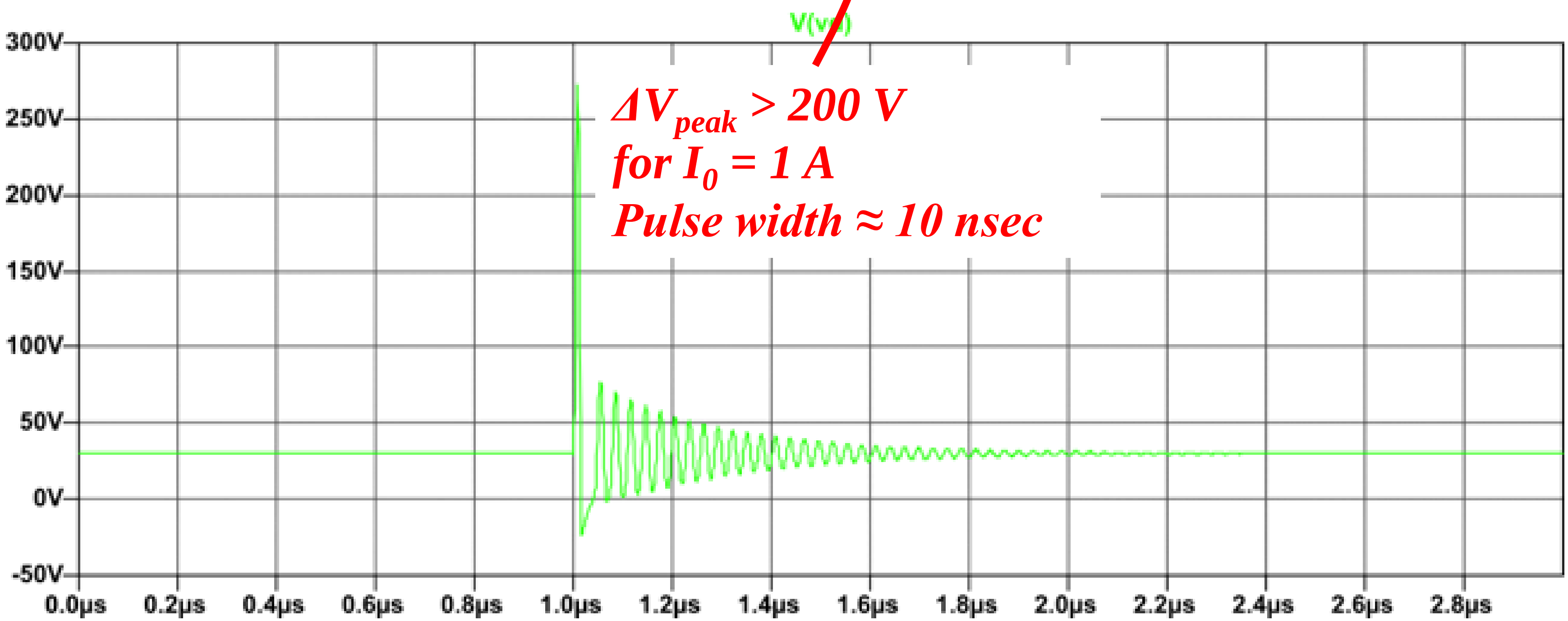




Turn-Off Transient: Typical (open circuit)

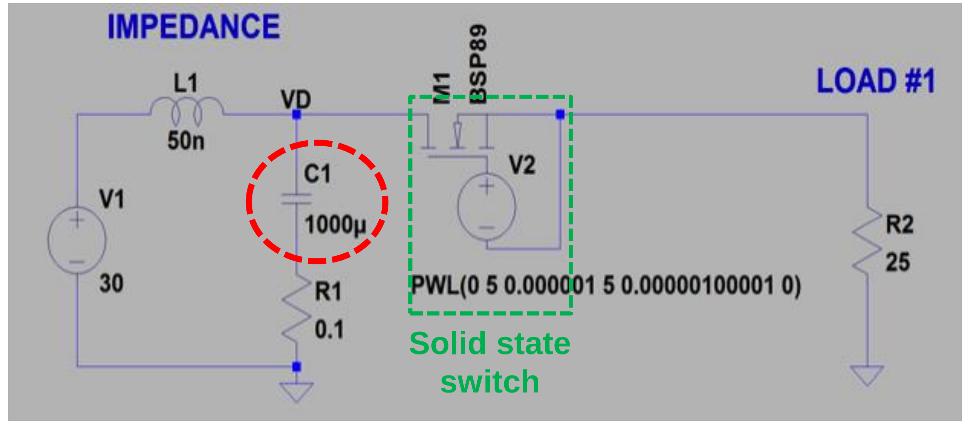
Representative Turn-Off Transient Circuit Model

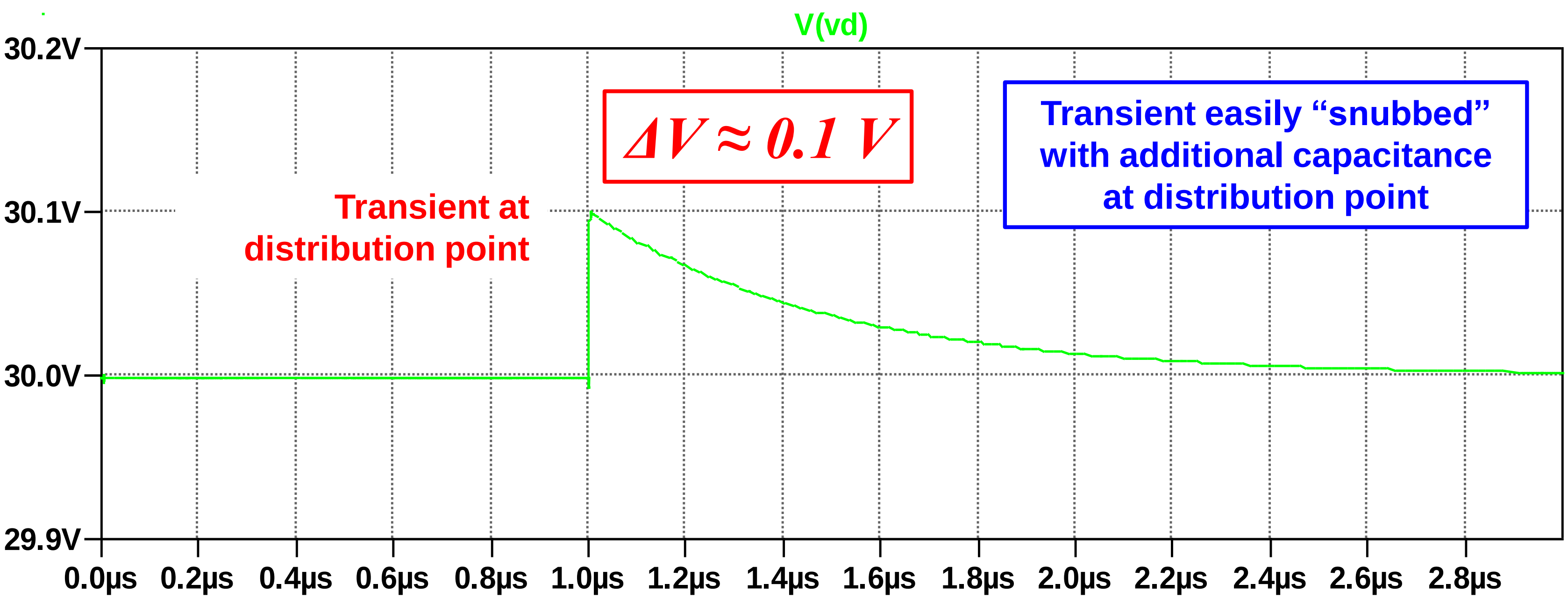




Turn-Off Transient With Filter at Distribution Point

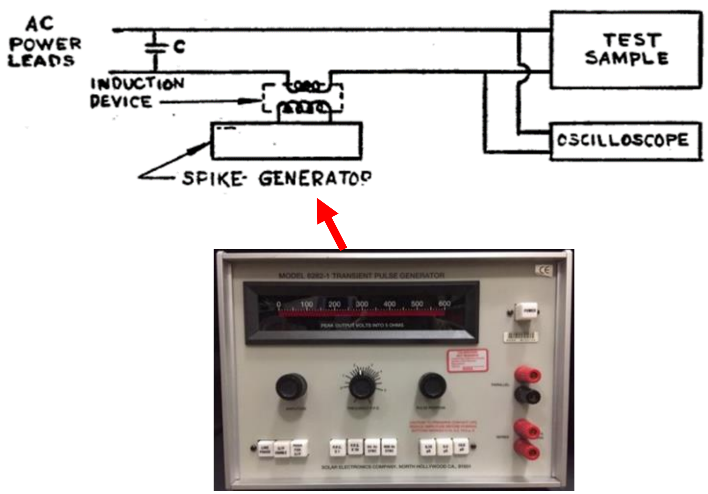
Representative Turn-Off Transient Model With Filter in Power Distribution Unit (PDU) or equivalent

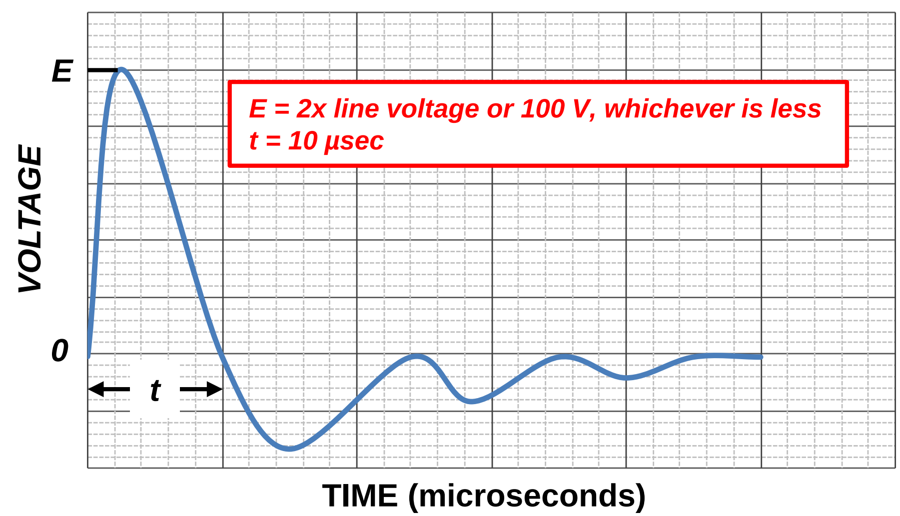




CS06 Positive (+) Pulse

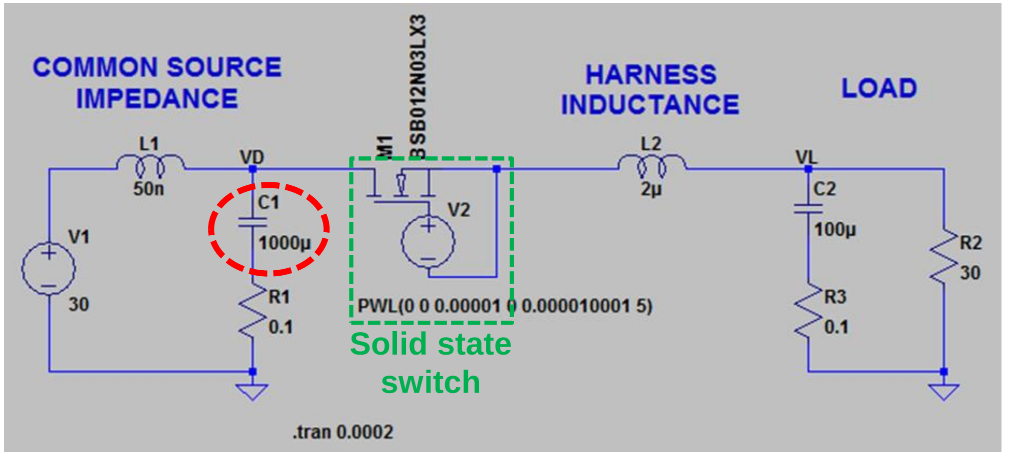
- **CS06 (+) pulse NOT good representation for turn-on transient**
  - Magnitude: tailorable; not really an issue
  - 10 µsec pulse width much longer than that of typical transients
  - Source impedance < 1 ohm; much lower than that of typical transients (not as easily “snubbed”)

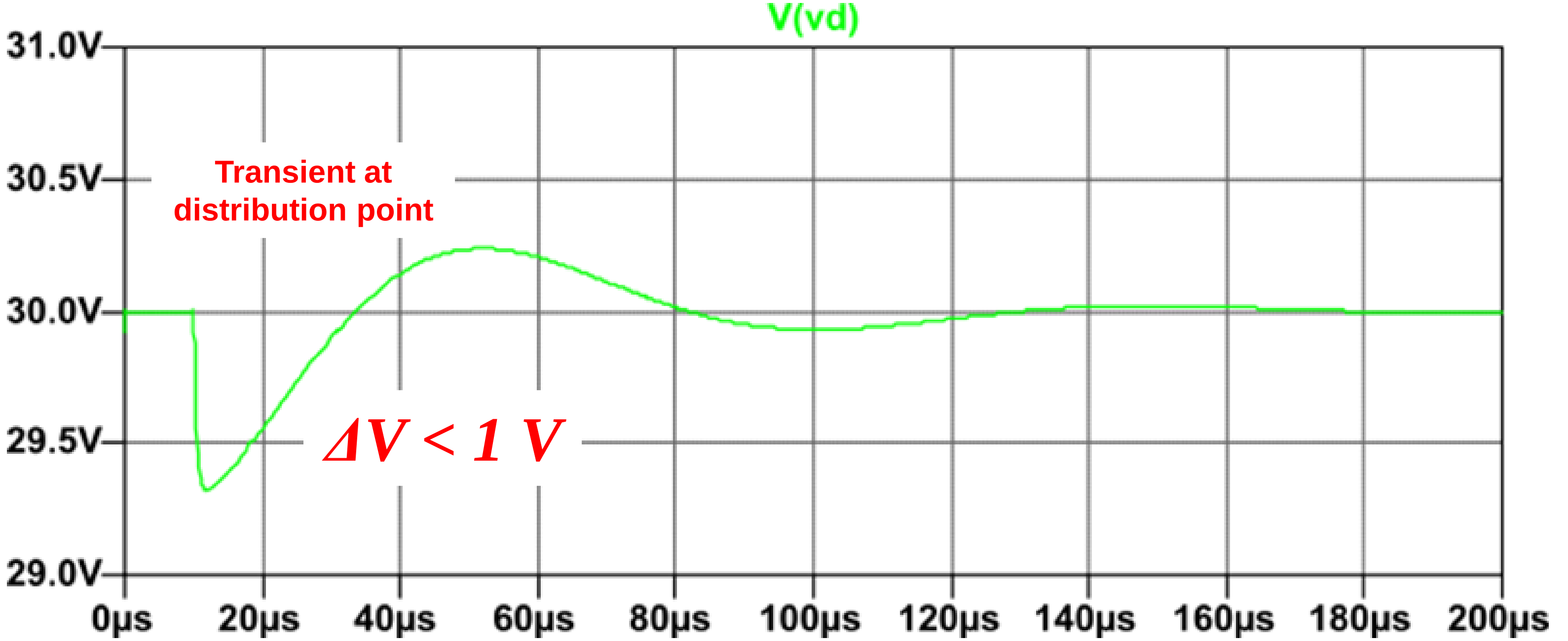




Let's Return to Our Turn-On Transient Model…

Representative Turn-On Transient Model With Filter in Power Distribution Unit (PDU) or equivalent





Summary

- **Turn-off transients do not pose significant problem on most spacecraft**
  - Open-circuit potential can be high, but very short duration
  - Easily "snubbed" with modest amount of capacitance on load input filters or at distribution point
  - Eliminated with large filter capacitor at distribution point (if used)
  - CS06 positive-going pulse need not be applied
  - Even if open-circuit large magnitude, short duration turn-off transient were considered real, Javor showed in [3] that it poses no threat to input filter components
- **On any spacecraft platform, an analysis of the power subsystem should be performed as early as possible in order to determine the worst-case magnitudes of turn-on and turn-off transients that may be observed at the point of distribution**
- **If these magnitudes are determined to be sufficiently benign, i.e. on the order of 3 V or less, then CS06 negative-going pulse need not be applied either**
- **Any concerns sufficiently covered by GEVS tailoring of CS101 and CS114 as below:**
  - CS101, 1 Vrms (2.8 V peak-to-peak) from 30 Hz to 150 kHz
  - CS114, effective limit of 1 Vrms (20 mA into 50 Ω) from 150 kHz to 50 MHz

References

[1] K. Javor, “Specifying Control of Immunity to Power Line Switching Transients,” 1994 IEEE EMC Symposium, Chicago

[2] K. Javor, “Specification, Measurement, and Control of Electrical Switching Transients,” NASA/CR-1999-209574, NASA Marshall Space Flight Center, AL 35812, September 1999

[3] K. Javor “Investigation Into the Effects of Microsecond Power Line Transients on Line-Connected Capacitors” NASA/CR-2000-209906, NASA Marshall Space Flight Center, AL 35812, February 2000

THANK YOU!

Backup

A Proper Switch

- **Proper testing of transients requires:**
  - Bounce-less, arc-less switch
  - Repeatable rise times that are fast (short) compared to circuit response