Application Note - Interpoint

Crane Aerospace & Electronics Power Solutions

Transient Suppression: Switching Power Supplies

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Transient Suppression: Switching Power Supplies

APPLICATION NOTE

Although the concepts stated are universal, this application note was written specifically for Interpoint products.

Power line transient requirements are a subject which should be addressed at the beginning of a project, not in the later stages. If let go till later, there may not be enough room left over for a good solution. When the time comes, two very important questions should be asked:

1) What is the transient source impedance? Inquire about both the real & imaginary parts.
2) What is the volt x second product of the transient?

If the answer is a large source impedance and a small volt x second product, the problem will be simple to solve. If the volt x second product is large and the source impedance low, the usual case, the solution will be more difficult.

The following is written around a 28 volt DC aircraft power bus, where positive transients should be contained within the 35 to 50 volt area, where the maximum long term transient rating for most Interpoint power converters is 50 volts. For power converters which have an 80 volt long term transient rating, suppression to within less than say 70 volts should be safe, but the output response of the power supply may require a smaller limit.

The means which are available to suppress voltage transients are listed in the following:

1) Transorbs, MOV's. Brute force approach.
2) Shunt capacitors. Will work for high source Z's.
3) Series inductor to limit DI/DT.
4) Buck regulator for lower voltage longer term transients.
5) Stripper, a series regulator which opens to take the transient and maintain like a 40 V input to the power supplies for the transient duration.
6) Combinations of 1, 2, and 3 above.

Figure 1 shows the functional schematic of a switching power supply with some of the various means of transient suppression shown at its input. The power supply has an incrementally negative input impedance which must be considered before inserting any suppression network in series with its input. The negative input Z is due to the constant power input, at constant load, as a function line voltage. Simply stated, $(V_{in} \times I_{in}) = K$, a constant at constant load, and $I_{in} = (K/V_{in})$. The decreasing input current with an increasing input voltage defines a hyperbola, the slope at the operating point being the negative Z. The input current is largest at minimum line voltage, and the input Z minimum at this point. For stable operation, the impedance looking back into any tran-

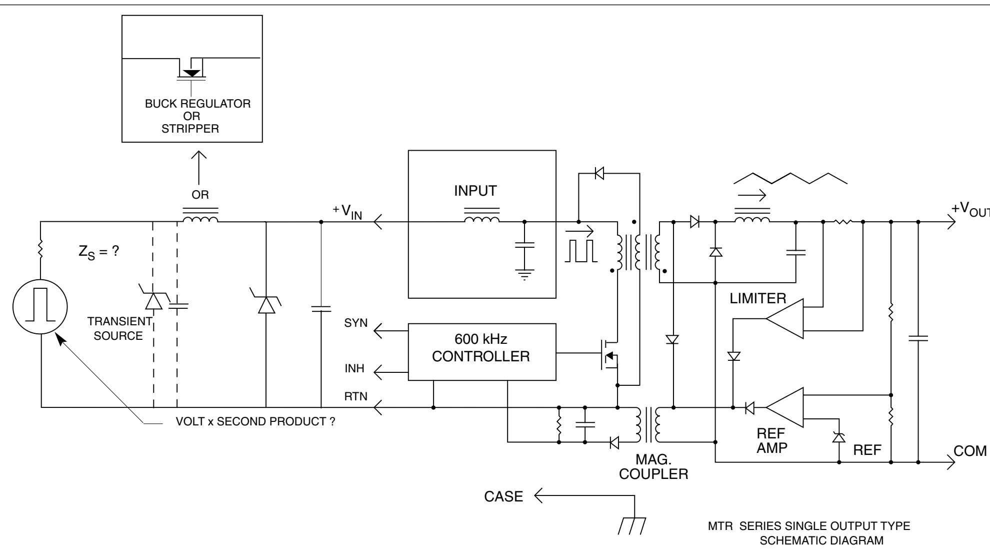

FIGURE 1: TRANSIENT SUPPRESSION FOR A SWITCHING POWER SUPPLY

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sient suppression network must be less than that seen looking into the switching power supply at minimum line voltage, and over the control loop bandwidth. It may be advisable to consult one of the Interpoint applications engineers before finalizing any suppression network design. Also, refer to Figure 2 which has some additional information.

SHORT TERM TRANSIENTS

Figure 3 shows some typical transient waveforms taken from DO-160C and MIL-STD-461C. The top waveform is an approximated damped half sine with a peak of 600 volts and a half period of 10 μs. The 50 ohm source impedance allows it to be suppressed with a shunt capacitor or transorb across the 28 volt line. In either case the peak suppression current will not exceed 12 amps, 600 V/50 ohms. Using a 600 V rectangular pulse for simplicity, a 10 μf low ESR cap placed in shunt with the line will reduce the peak transient response to about 12 volts on top of the 28 volt power line. The time constant of the RC will be 50 x the transient duration, hence the response is 2% of the transient plus the drop across the ESR. Refer to Figure 4. A transorb will also work in place of or with the capacitor. A suitable surface mount device is SMCJ30A from Microsemi Corp. This device should clamp the line at about 40 volts or below and also has a

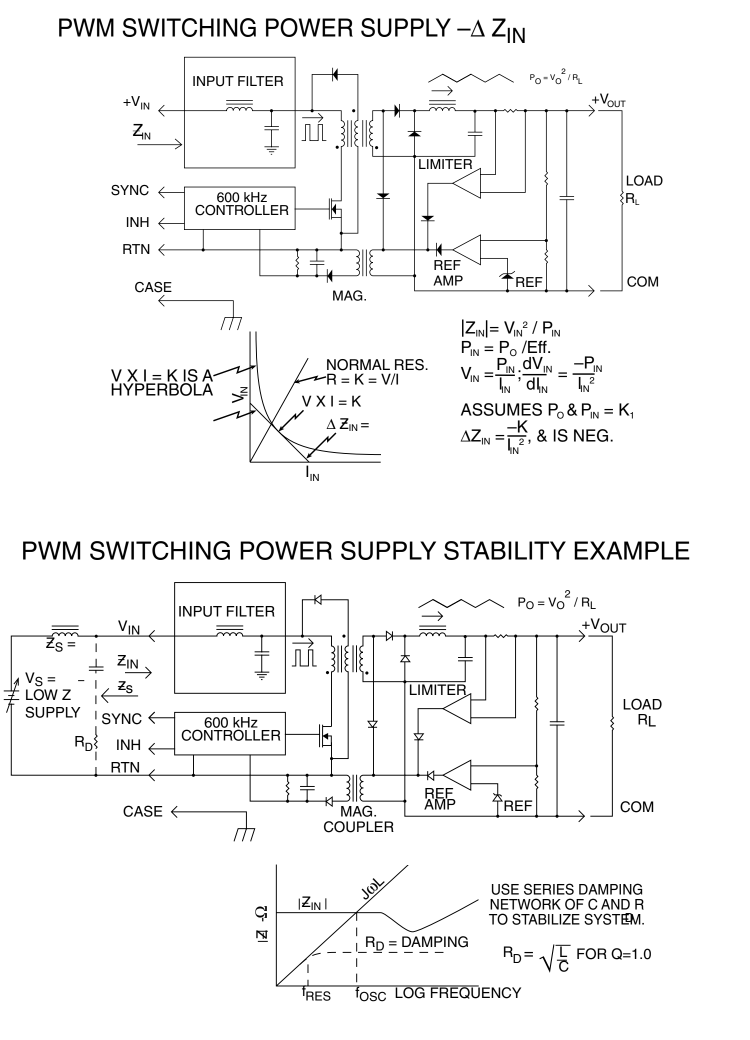

FIGURE 2: NEGATIVE ZIN AND DAMPING FOR STABILITY

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forward rating of 200 Amps for 1/120 of a second which would be useful for suppressing negative transients, if any. Alternately, a forward rectifier in series with the positive line can be used for this purpose.

The MIL-STD-461C transient of Figure 3 has a low source Z and will be harder to suppress than the previous case. Unless defined otherwise, the source Z should be assumed to be zero. A value of 0.5 ohms is often allowed for testing. For the purpose of analysis, a value of 0.1 ohms is used.

The 0.15 *μ*s 200 volt rectangular transient could be suppressed with a low ESR ceramic capacitor, or a transorb. The transient line current, however, would be very large. Adding a small series inductor will reduce the current to a manageable level. Since the transient will substantially appear across the inductor, the rate at

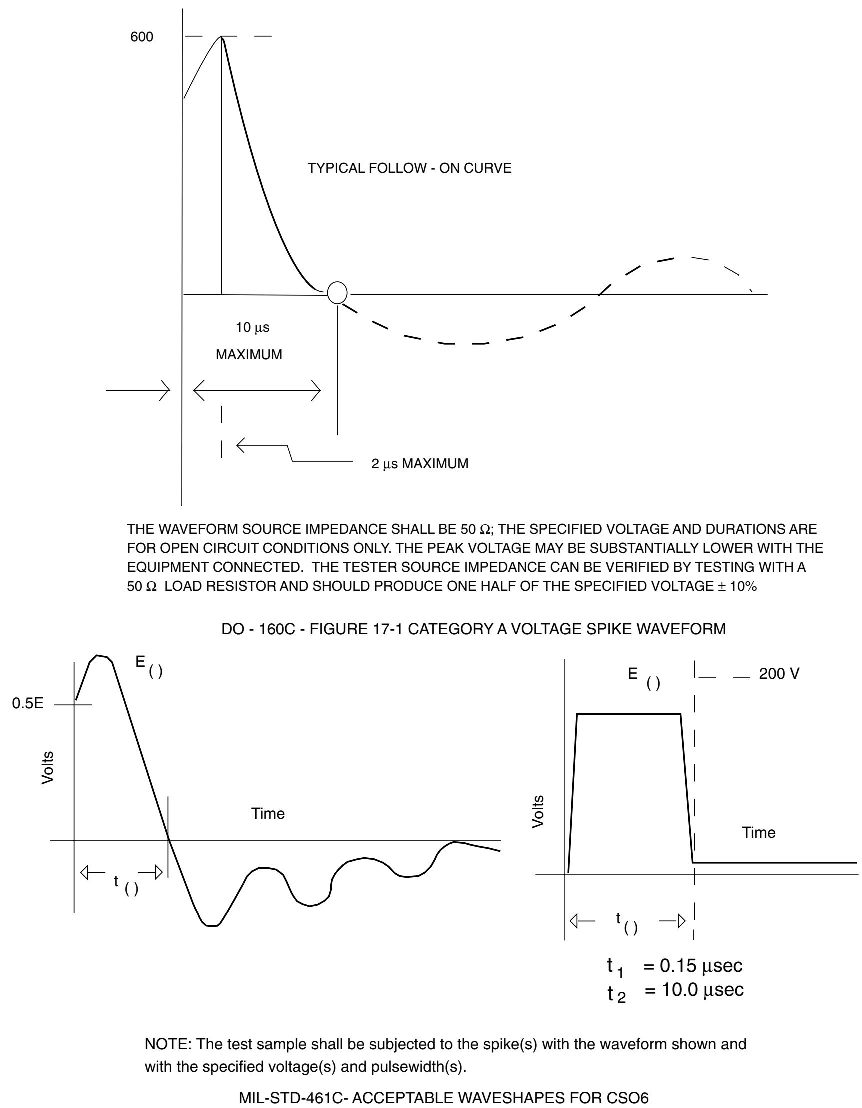

FIGURE 3: TYPICAL TRANSIENTS – DO-160C AND MIL-STD-461C

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which the current rises will be V/L, where V is the transient peak voltage L is the inductance in henries, and the rate is in Amps/second. If we limit the peak current to 10 Amps, the inductance = (V)(t)/(10) or greater, where t is the pulse duration of 0.15 μs. The calculated inductance is then 3 μhenries. Either a shunt capacitor or transorb can be used for the small value inductor to work against. In this case we will use a 10 μfd capacitor forming a resonant circuit with the inductor. Based on a Q = 1, the total damping resistance in series with the L and C should be $= \sqrt{(L/C)}$ = 0.55 ohms to minimize the driving point impedance. A 0.5 ohm resistor is added in series with the 10 μf capacitor, and includes its ESR. The circuit models and results are shown on Figures 5 and 6. Note that the output response to the 200 volt transient rises to only about 34 volts.

The inductor has to carry not only the transient current, but also the normal load current. A sample design on a 0.4” diameter Kool Mu toroid will carry 20 amps at a flux density of about 80% of saturation. The inductor has 7 turns of #22 AWG wire with a DC resistance of about 0.006 ohms at 23* C. The part number of the Mag. Inc. core is 77040-A7. The formulas for inductance and flux density are given below for those who want to try it themselves.

$L = \frac{4\pi\mu AN2 \times 10^{-7}}{\ell}$, where

A = the cross sectional area in square meters,
ℓ = the magnetic path length in meters,
u = permeability,
N = number of turns
I = Maximum inductor current - Amps,
$B = 4\pi\mu NI \times 10^{-3}$
The units of inductance are Henries, and hose of Flux Density are Gauss.

The 10 μs 200 volt transient will require a much larger inductor if the same method of suppression is used. If we want to limit the transient current to 20 amps for example, then the inductor value will be 100 μhenries minimum. Here, we will use a transorb to clamp the line voltage and select a 47 μf capacitor

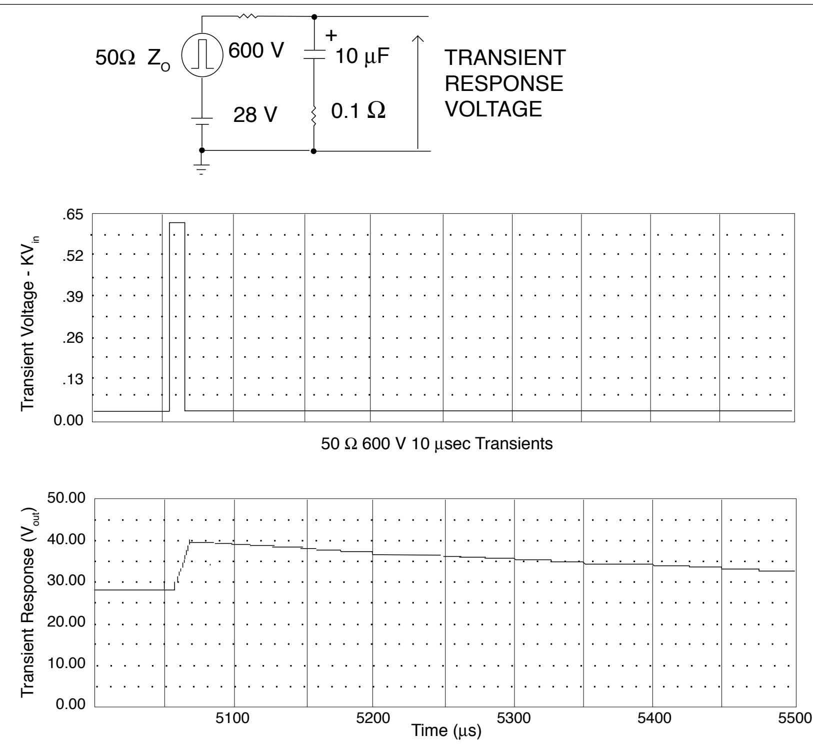

FIGURE 4: TRANSIENT RESPONSE

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to set the driving point impedance to less than two ohms. The damping resistor is 1.4 ohms as calculated from $\sqrt{(L/C)}$. The transient response and driving point Z graphs are on Figures 7 and 8. The transorb breaks over at 39 volts and has a 0.5 ohm dynamic resistance. A similar surface mount part is SMLJ30A. If the driving point Z needs to be lower, make the shunt capacitor larger and recalculate the damping resistor. For example if the capacitor is increased to 470 μf, the driving point Z can be lowered to below 0.5 ohms, and the transorb can be eliminated.

The inductor of this example will carry 30 amps, 10 for normal operation and the additional twenty for transient suppression. The inductor is wound on a Kool Mu toroid with 19 turns of #11 AWG with a resistance of about 0.005 ohms at 23˚ C. The core is Mag. Inc, part number 77438-A7 with an O.D. of 1.85˝ and a thickness of 0.71˝. This inductor would be suited to a 150 watt system where the max operating current at 28 volts is 5+ amps, and 10 Amps at low line.

For a smaller system where the normal operating current is less than say 1.5 amps at 28 VDC, the inductor can be somewhat smaller. If the transient current is restricted to less than 5 amps, then the series inductance becomes 400 uh or greater. If we keep the 47 μf capacitor, the optimum damping resistor becomes 2.8 ohms. The transient response is much the same as Figure 7 except the amplitudes are smaller. The driving point impedance is about 4 ohms at the resonant peak, and 2.8 ohms thereafter. The 400 uh series inductor has 51 turns of #22 AWG wire with a

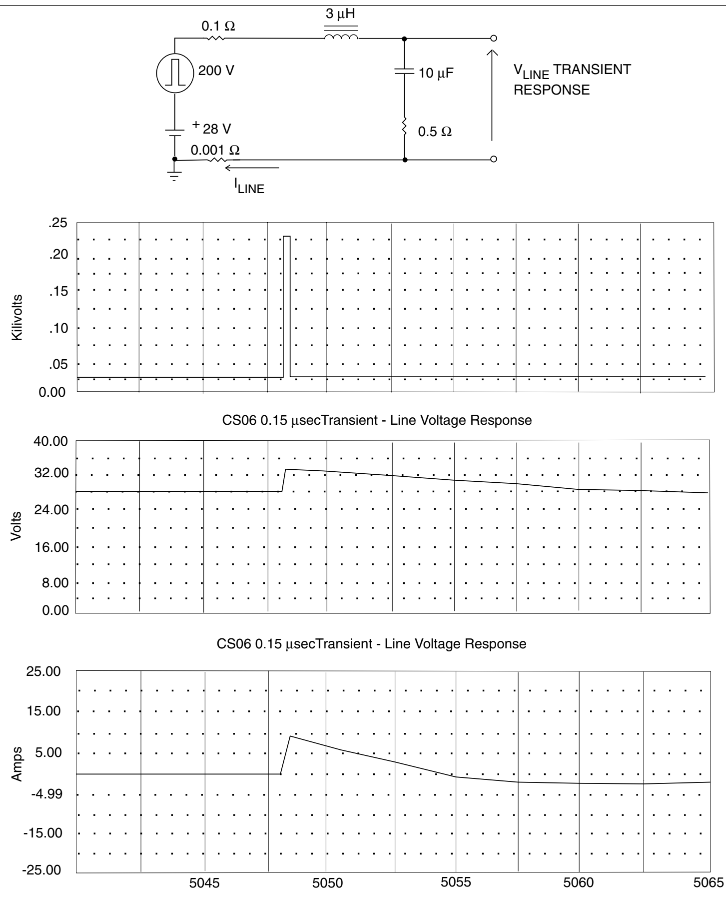

FIGURE 5: TRANSIENT RESPONSE

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resistance of 0.102 ohms at 23° C. The toroidal core is Kool Mu 77930-A7 with an O.D. of 1.06" and a thickness of 0.44". This is smaller than the previous example, but possibly larger than what is desirable. A stripper might be considered as an alternate solution. This is covered in later paragraphs.

LIMITED ENERGY TRANSIENTS

MIL-STD-1275A has a transient with an energy limit of 0.015 Joules, or 0.015 watt seconds. The transient is shown on Figure 9, and occurs over a time period of 1 millisecond. The total power then won't exceed (.015)\(.001) = 15 watts, which can be clamped with a small transorb at 40 volts or so. A shunt capacitor could also be used for suppression, and the minimum value can be calculated from energy storage equations as shown in the following.

$$C_{min} = (2 \text{ x Energy})/(V_{max}^2 - V_{line}^2)$$

$$= (0.03)/(40^2 - 28^2) = 37\ \mu F$$

DROPOUT TRANSIENTS

During dropout transients, the power line can be held up with a battery or pre-charged capacitor connected to the power line through a reverse rectifier. Interpoint has holdup modules which charge up an external capacitor to about 40 volts, and then connect it to the internal power line through a FET switch when dropout occurs. These devices are HUM-40 and HUM-70. The "HUMMER" (HUM-40 and HUM-70) datasheet has a wealth of technical information on the subject and when the parts are used in an application, a significant reduction in the volume of capacitance needed will result. Where a capacitor is to be used

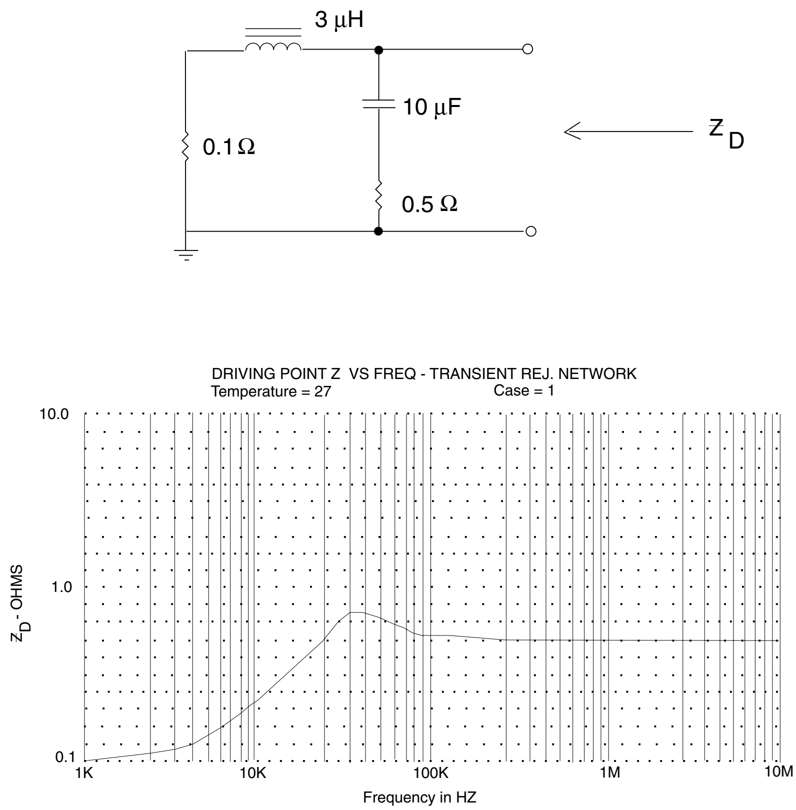

FIGURE 6: TRANSIENT RESPONSE

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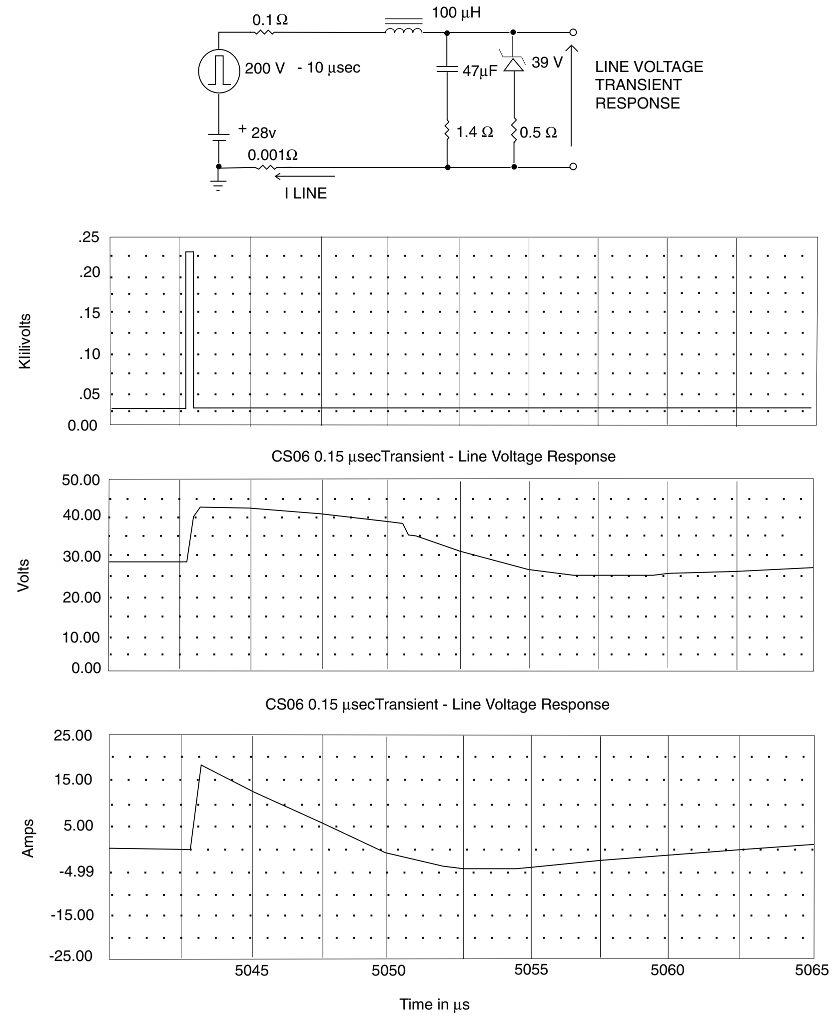

FIGURE 7: TRANSIENT RESPONSE

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for holdup, the minimum value of capacitance required can be calculated from:

$C = 2P\Delta T/(V_{CH}^2 - V_{LL}^2)$, where,

- P = input power in watts,
- ΔT = dropout time in seconds,
- V_{CH} = holdup capacitor voltage at dropout,
- V_{LL} = low line voltage where power supply, loses regulation, usually 12 to 16 V.

LONG TERM TRANSIENTS

Long term transients, as defined here, are those which have a duration of 50 to 100 milliseconds, and then return to the normal 28 volt line voltage in 50 milliseconds to a second or more. Examples are the 80 volt transient of MIL-STD-704A, and the 100 volt transient of MIL-STD-1275A. The latter has a defined source impedance of 0.5 ohms. The 704A transient does not have a defined source Z, and the value could range from a few millohms to a half ohm for individual systems. Refer to Figure 10 for examples.

Transients like these have too large a volt second product to be suppressed by conventional energy storage means as in the previous examples. The L and C components would be much to large. This would also be generally true for transients having

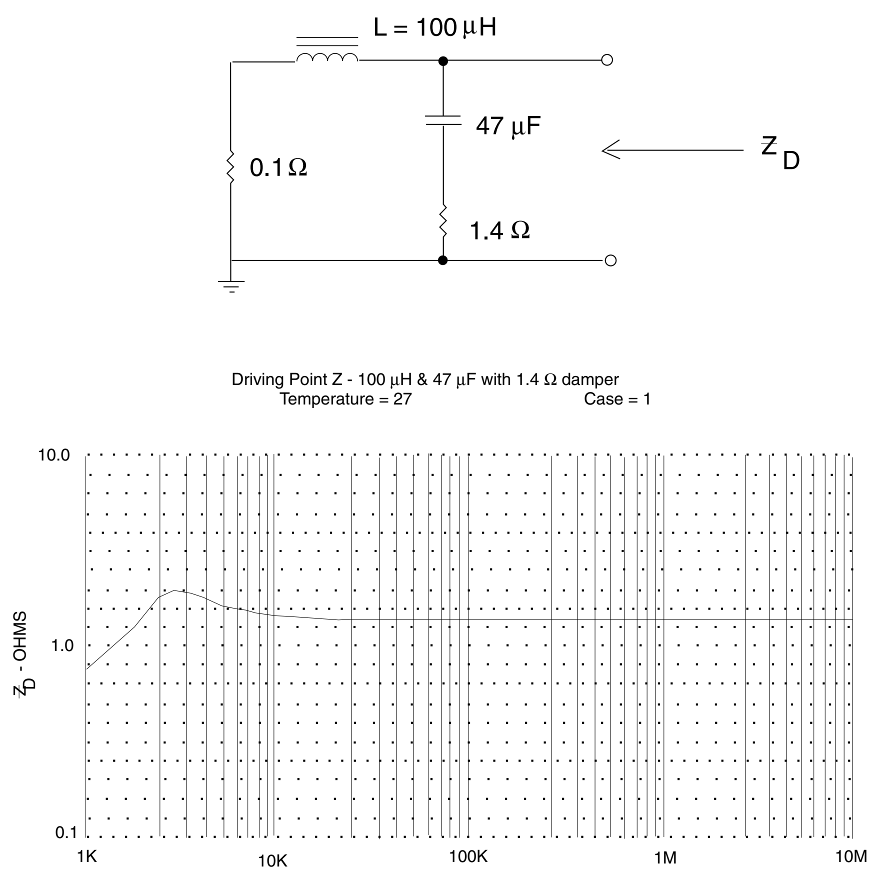

FIGURE 8: TRANSIENT RESPONSE

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a low source Z and durations in excess of a few tens of μs. Transorbs can be used for these as well as the longer duration transients, but they may be large, and safe energy as well as peak current ratings need to be observed.

A buck switching regulator is the most efficient means of rejecting the long term transients, but it generates its own noise and requires a finite time to get up and running, typically about a millisecond. For fast turn on transients, this would not work well. The stripper is the best overall solution. The Interpoint FM-704A combines a stripper and conducted interference EMI filter. The stripper uses a pair of high line N channel power FETS, and a charge pump to obtain gate enhancement above the +28 volt line. Refer to the data sheet for the functional schematic and other useful information. Two additional examples are shown on Figure 11. One of these uses an N channel FET in the return line, and the other uses P channel FETS in the +28 volt high line.

The stripper is a fast voltage regulator, where in normal operation the FET is in full enhancement with its Rds in series with the power line. When the transient comes along, the stripper regulates its output in the 40 to 50 volt area, with the balance of the transient appearing across the series FET. The FET current during the transient is the load current at the regulated output voltage. In the case of a switching power converter load, where the regulated output is 45 volts, the current will be about 60% of its value at 28 volts. The power dissipated across the FET as well as the total energy absorbed during the transient need to be considered in the design of a stripper.

INDUCED CURRENT TRANSIENTS

Induced current transients caused by EMP or high level signals in adjacent wiring can be common mode, differential mode, or a combination of the two in nature. The example of Figure 12 is from MIL-STD-461C, method CS11, and is common mode in nature. This transient can be suppressed with good quality

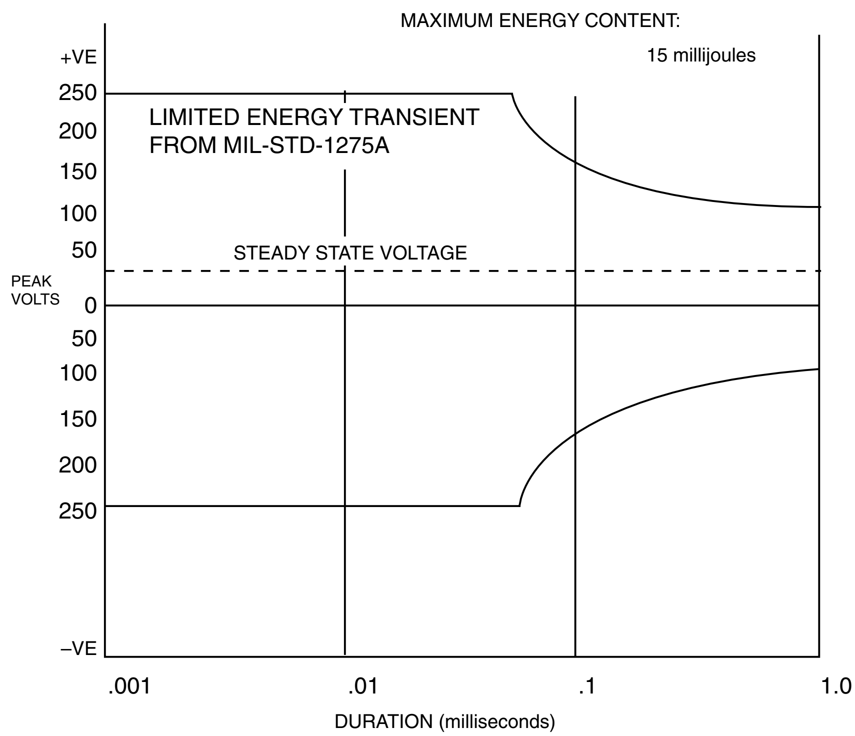

FIGURE 9: MIL-STD-1275A LIMITED ENERGY TRANSIENT

ceramic capacitors from both the +28 volt and the return line to the power converter case. In case of unbalance, a capacitor can be placed across the lines also. The minimum capacitor value is easily calculated once a maximum acceptable voltage deviation is defined. If we assume a maximum voltage deviation of 1.0 volt is allowable, the minimum capacitance is 2.7 μf. Refer to Figure 12 for the details. The capacitors can also be paralleled with which may be effective in suppressing lightning induced transients.

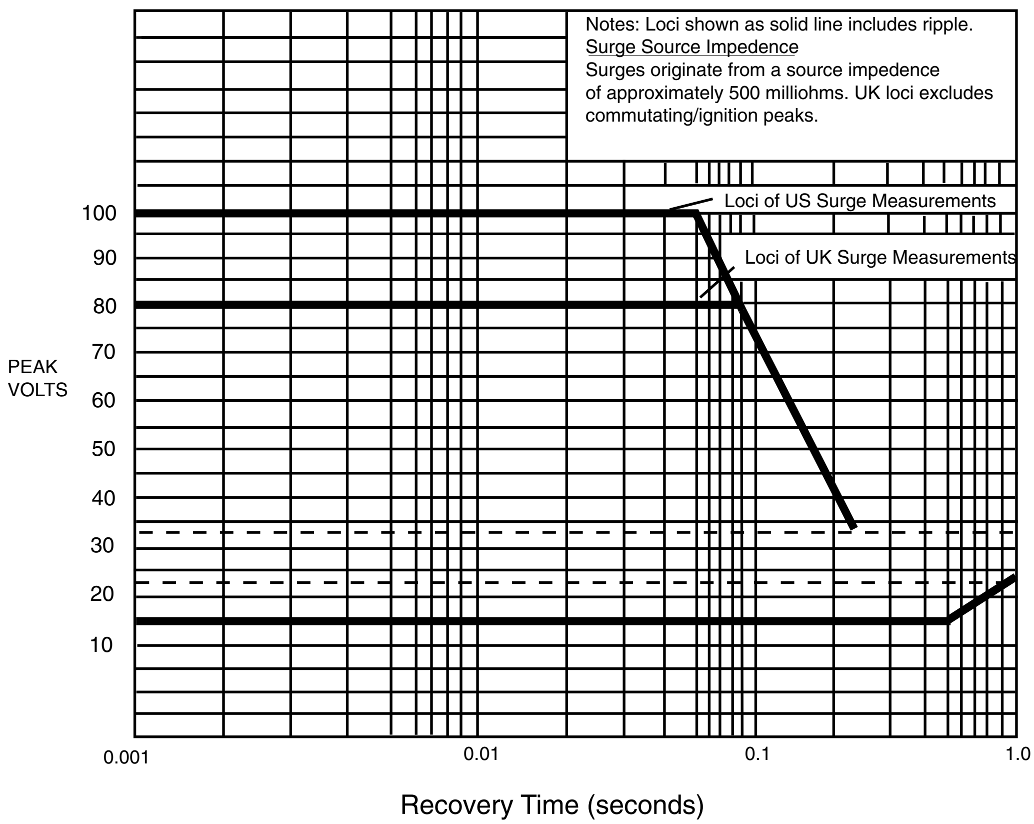

FIGURE 10: MIL-STD-1275A LOW IMPEDANCE TRANSIENTS

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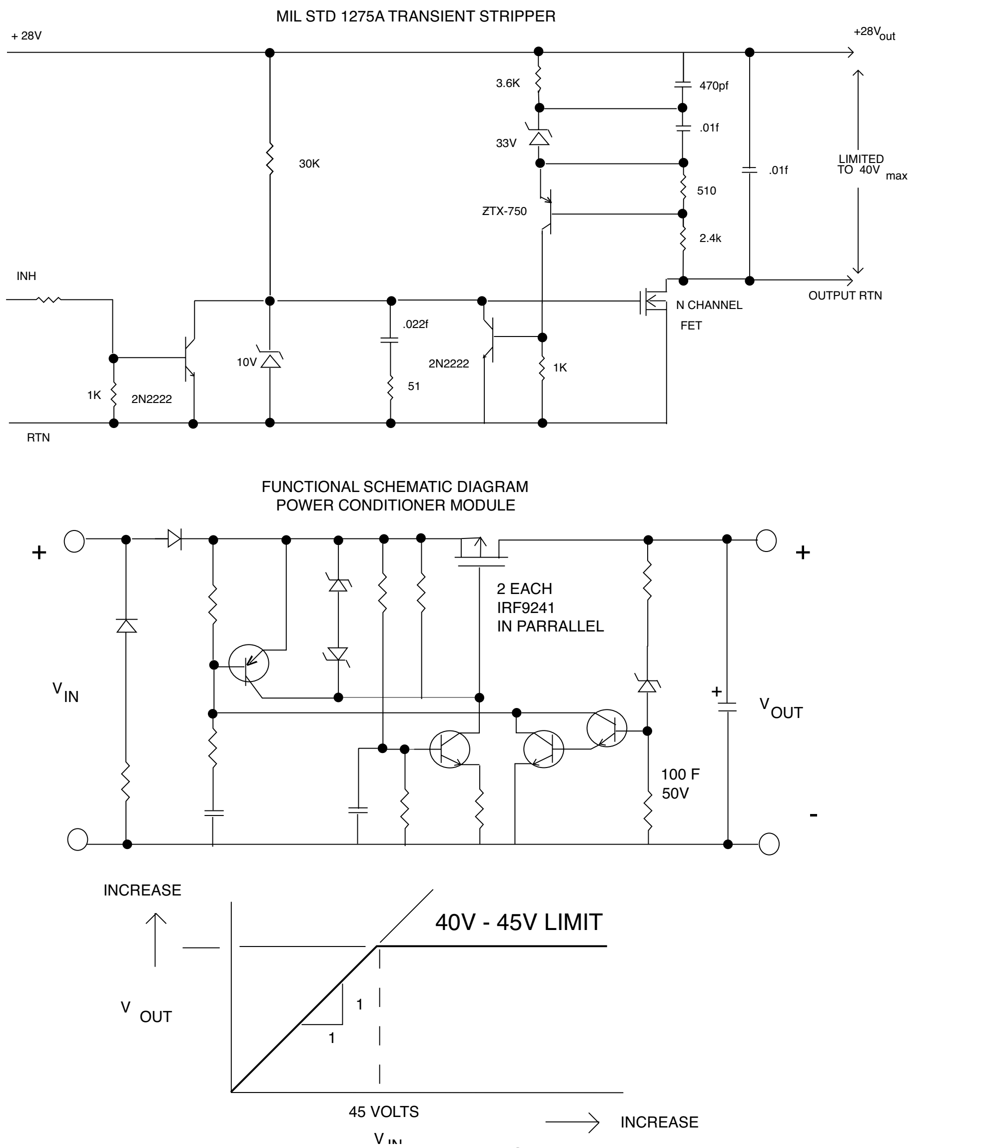

FIGURE 11: TRANSIENT STRIPPER

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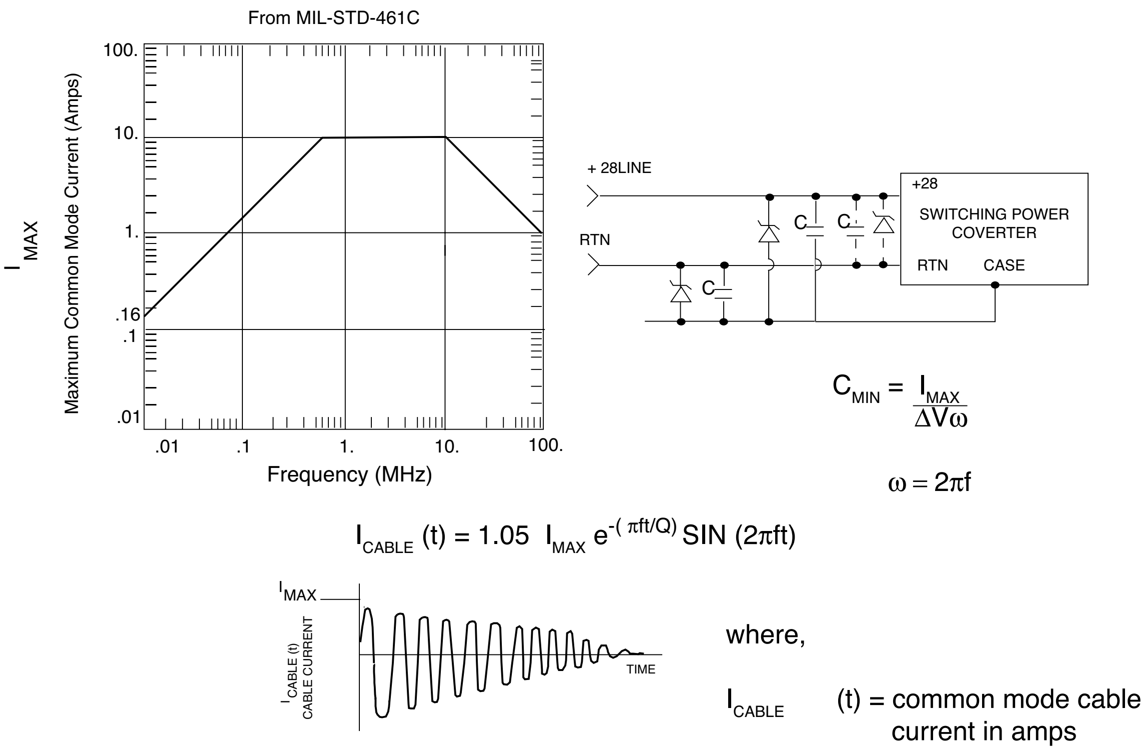

$$C_{MIN} = \frac{I_{MAX}}{\Delta V \omega}$$

$$\omega = 2\pi f$$

$$I_{CABLE}(t) = 1.05 \ I_{MAX} \ e^{-(\pi f t / Q)} \ SIN(2\pi f t)$$

where,

I_{CABLE} (t) = common mode cable current in amps
f = frequency, hertz
t = time, seconds
Q = decay factor

FIGURE 12: INDUCED CURRENT TRANSIENT – MIL-STD-461C, METHOD CS11

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