Revisiting Phantom Power Fault Protection THAT1570, THAT158x & THAT626x

It has been shown that phantom power faults caused by shorting either or both of the XLR inputs to ground will force the preamp's inputs down to -48 V (see Figure 1.) A diode bridge at the inputs is used to clamp any excessive input level swing to the power supply rails (see Figure 2.) During a phantom power fault, the negative rail can momentarily drop well below its nominal value, damaging the preamp (see Figure 3.) The mechanisms and consequences of phantom power faults are well explained in [1] and [2].

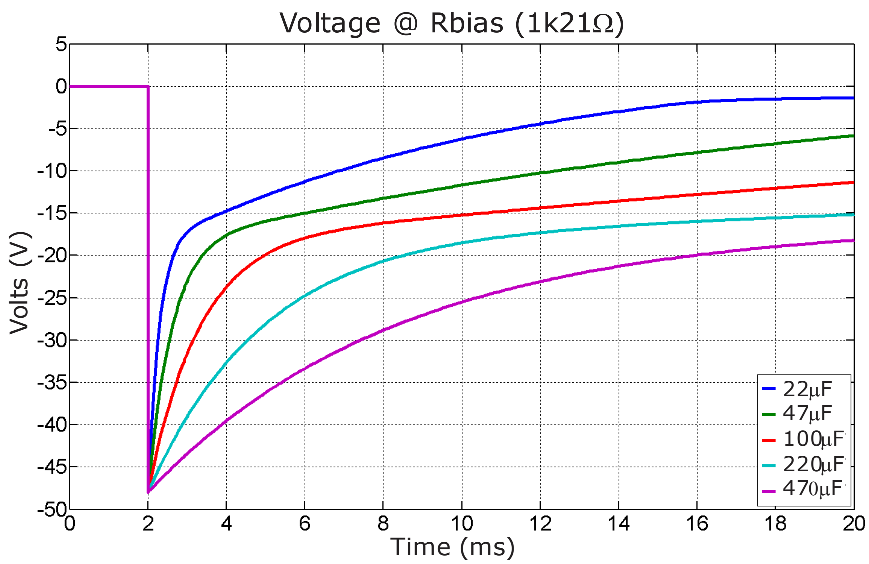

Figure 1. Voltage at Rbias during a phantom power fault for different values of C_C [1] and [2].

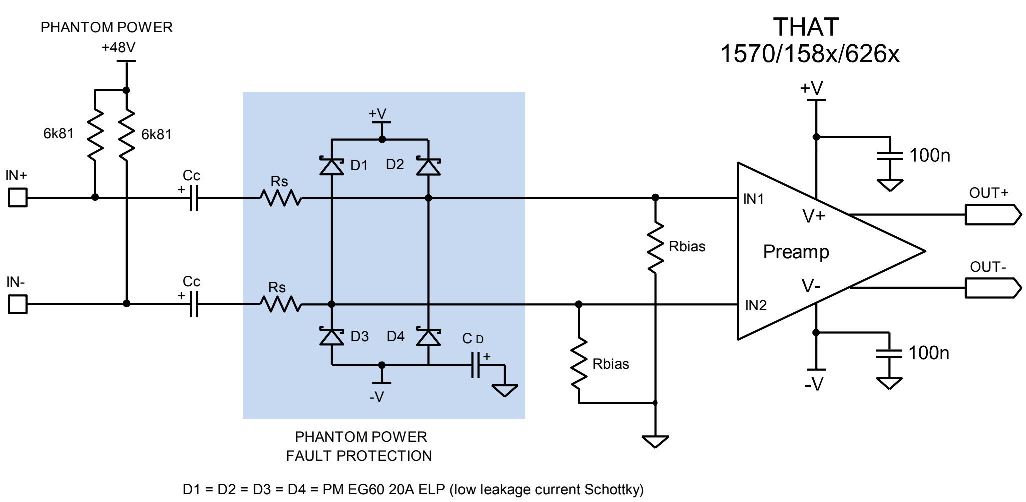

Figure 2. Phantom power fault protection scheme for THAT1570/158x/626x.

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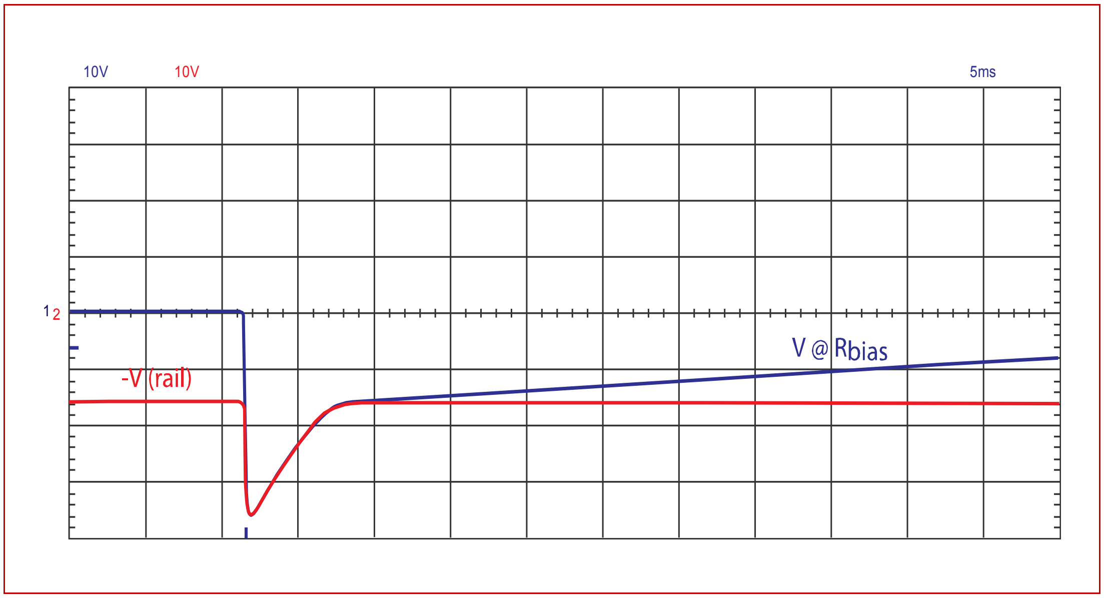

Figure 3. Impact on –V (red trace) during a phantom power fault [1] and [2].

In order to absorb that momentary surge caused by a phantom power fault (Figure 3,) the minimum value for the decoupling capacitor C_D on the negative power supply rail is calculated as follows:

$$C_D = N \times C_C \times \frac{2 \times \left(-V_{ph} - V_{inmin}\right)}{V_{inmin} - V_{sup} + V_D} \quad (1)$$

Where:

- N is the total number of channels; see note below on how to choose N;
- C_C is the coupling capacitor between the phantom power supply and preamp input;
- V_{ph} is the phantom power supply, typically 48 V (±10 %);
- V_{inmin} is the minimum allowed voltage at the preamp inputs (differs by part number);
- V_{sup} is the negative power supply voltage;
- V_D is the forward voltage drop on the protection diode at the rated current during phantom fault.

V_D voltage should be carefully checked in the diode specification. It's based on the peak current possible during a phantom power fault. The peak current is a function of the resistor value connected between the dc blocking capacitor C_C and preamp input (R_S,) and the coupling capacitor' ESR.

The maximum peak current in the diode can be calculated as follows:

$$I_{Dpeak} \cong \frac{V_{ph} + V_{sup}}{R_S + ESR_{C_C} + 2 \times\ ESR_{C_D}} \quad (2)$$

Where:

- R_S is the series protection resistor;
- $ESR_{C_{C,D}}$ are the internal series resistors from the capacitors models.

The parameter V_{inmin} is the lowest allowable voltage that can be applied on the preamp inputs without causing it to fail:

Device	V_{inmin}
THAT1570 & THAT1583	-31 V
THAT1580	-21.5 V
THAT626x	-12.5 V

Considering the component values shown on the respective data sheets [3] and $ESR_{C_{C,D}}$ about 1 Ω, we can calculate for THAT1570/158x:

$$I_{Dpeak} \cong \frac{48V + (-15V)}{10 + 1 + 2 \times 1} = 2.54\ A \tag{3}$$

And for THAT626x:

$$I_{Dpeak} \cong \frac{48V + (-5V)}{20 + 1 + 2 \times 1} = 1.87A \tag{4}$$

Looking up the forward voltage drop at 1.87 A and 2.54 A peaks in the Schottky diode datasheet [4], we find $V_D \cong 0.65\ V$ (average, since there is a small variation.)

$$C_{D_{THAT1580}} = 1 \times 47\mu F \times \frac{2 \times [-48 - (-21.5)]}{-21.5 - (-15) + 0.65} = 47\mu F \times 9.06 \cong 426\ \mu F \tag{5}$$

$$C_{D_{THAT1570/1583}} = 1 \times 47\mu F \times \frac{2 \times [-48 - (-31)]}{-31 - (-15) + 0.65} = 47\mu F \times 2.22 \cong 104\ \mu F \tag{6}$$

$$C_{D_{THAT626x}} = 1 \times 22\ \mu F \times \frac{2 \times [-48 - (-12.5)]}{-12.5 - (-5) + 0.65} = 22\ \mu F \times 10.36 \cong 228\ \mu F \tag{7}$$

Note that when using ±18 V rails, the maximum allowable supply voltage for THAT1570/158x, the calculated values for the capacitors are $C_{D_{THAT1580}} \cong 874\ \mu F$ and $C_{D_{THAT1570/1583}} \cong 129\ \mu F$.

The calculated value for C_D is the minimum value required for absorbing the phantom power fault and larger values will provide even more protection. Ideally, C_D should be placed as close as possible to the diode bridge, but our experiments have shown that it can be at the device's power supply and/or split and distributed along the PCB, assuming the power traces/planes provide low impedance for the momentary fault surge.

A note about the number of channels, N: it's unlikely that all channels will get shorted with phantom power on at the same time. We believe that it's safe to assume that only one channel will be at fault at one time but it is up to the designer to decide the number of channels to be considered. One exception could be during production test if the manufacturer has a setup when all the channels are shorted to GND at the same time with phantom power on.

Protecting with TVS

Experiments have shown that TVS can effectively be used on protecting the circuit against phantom power faults [2]. A TVS has three specified voltages: a) the working voltage, or the maximum safe voltage to indefinitely operate, b) the break down voltage range, the voltage window in which the part will start to conduct, and finally c) the clamping voltage which is rated at the maximum current, typically a current which's very high and in 10-20 A range and outside our interest range.

There are two possible locations for a TVS: on the power supply, to clamp the power rail (Figure 4,) and on the input lines to clamp the input swing (Figure 5.) In the first case, during the phantom power fault, the current flows from the coupling capacitor, through the typical 10 Ω protection resistor, protection diode to negative power supply, TVS and ground. The voltage at the input pin is the TVS's breakdown minus a protection diode drop. For instance, if the TVS breakdown range is 19 V to 21 V, we can expect –20 V to –23 V at the input. Therefore, the power supply voltage, protection diode and TVS specifications have to combine for a successful implementation [5]. This can be a challenge when using high voltage power supplies.

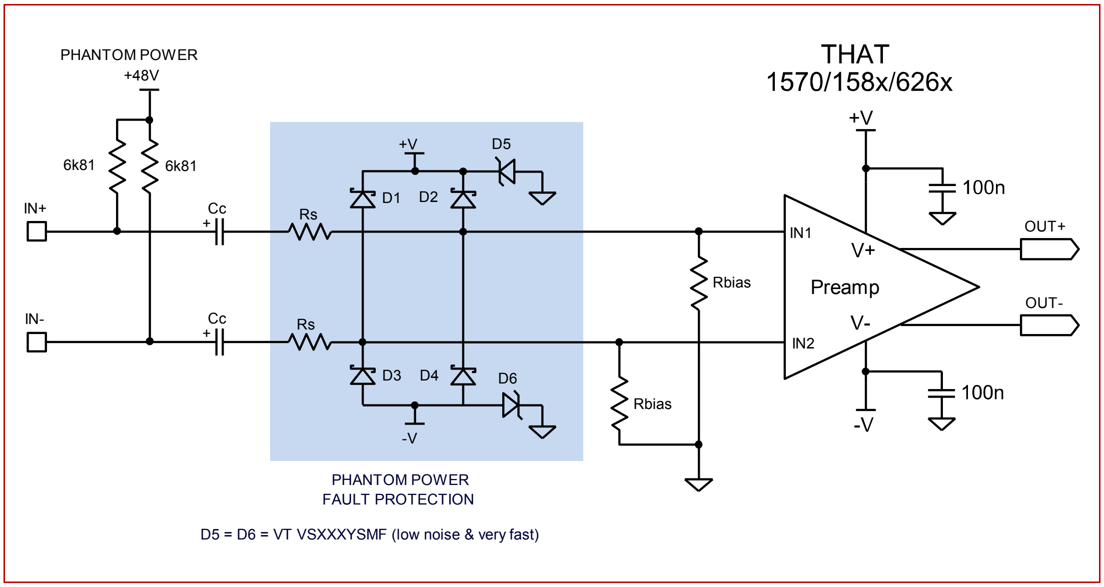

Figure. 4. TVS on the negative rail [2].

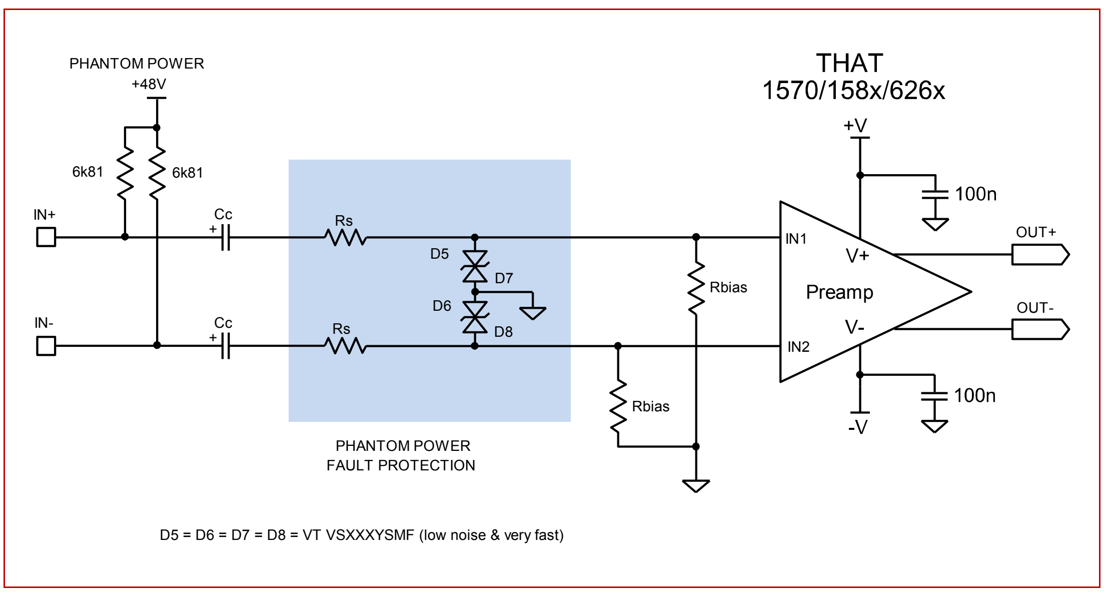

Figure. 5. TVS on back-to-back configuration from the inputs to ground.

For the case of ±17 V supplies, the correct TVS is VTVS19ASMF which has working voltage of 18.7 V. However, the breakdown range is 20.9 V to 23.2 V. Adding the forward diode drop of the protection diode the input voltage will be lower than the -21.5 V minimum required (1580 only). The next TVS on the list has a working voltage of 16.9 V which would not work in this case.

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So, going backwards from the input to the power supply, if we need to limit the negative swing to -21.5 V we need a TVS with a breakdown range no more than ~20 V to be on the safe side. The closest one is VTVS15ASMF, which has a working voltage of 15.1 V. It barely works for ±15 V power supplies.

For high voltage power supplies, moving the TVS's to the input lines makes more sense (Figure 5.) The stray capacitance is the first concern that comes to mind for THD degradation. However, we've tried this approach and the THD was not affected at all*. The phantom power fault current has a shorter path now, coupling capacitor, the 10 Ω resistor and TVS to GND. The negative power supply doesn't move at all in this case because the current doesn't go that way. Another limitation is the maximum allowable input swing. Fortunately, we can accommodate the TVS and large input swings because the minimum input voltage swing is -V + 3.7 V (THAT1580,) otherwise the input will clip. For ±17 V power supplies it means that the minimum negative swing is -13.3 V. Going back to the TVS datasheet we can use VTVS14ASMF which has a working voltage of 13.8 V and a breakdown range of 15.4 V to 17 V. This part is more than adequate to protect the inputs at high power supply voltages.

To conclude, to protect with TVS's we have two options depending on the power supply range:

a) Above ±15 V the TVS's need to be connected on the input lines;
b) Below ±15 V they can be moved on the power supply rails.

Using TVS's on the power supply rails:

Pros:
1) Only two TVS's required for all channels;
2) The filter capacitor on the negative rail can be smaller, for instance 22 µF;
3) Protection while power is down via the protection diodes.

Cons:
1) There is no adequate TVS (that we could find) for higher power supply applications;
2) Negative power supply will be dragged down a few volts depending on the TVS's breakdown range;
3) Protection diodes to the rails are still required.

Using TVS's on the input lines:

Pros:
1) Phantom power fault protection at any power supply;
2) The large phantom power current is confined to a smaller loop;
3) Potentially, protection diodes are not required anymore (see cons below for comments);
4) The negative rail is not affected at all;
5) The filter capacitor on the negative rail can be smaller.

Cons:
1) Cost. Each preamp input requires four TVS's;
2) Protection during power down is not available unless protection diodes are used in conjunction with TVS's. For some cases this may not be an issue, so it depends on the application.

* IMPORTANT: the THD was measured with a specific TVS, the Vishay VTVS14ASMF. Other TVS's may perform differently, so the user must check the THD for any TVS used in this configuration (Figure 5.)

References

[1] Gary K. Hebert and Frank Thomas, 110th AES Convention, Paper 5335, May, 2001.
http://thatcorp.com/datashts/AES5335_48V_Phantom_Menace.pdf
[2] Rosalfonso Bortoni and Wayne Kirkwood, 127th AES Convention, Paper 7909, October, 2009.
http://thatcorp.com/datashts/AES7909_48V_Phantom_Menace_Returns.pdf
[3] http://thatcorp.com/Datasheets.shtml
[4] https://assets.nexperia.com/documents/data-sheet/PMEG6020AELP.pdf (July 2018)
[5] http://www.vishay.com/docs/85891/vtvs3v3asmf.pdf (July 2018)

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