Resistors for High Voltage Applications

TT Electronics offers one of the most diverse ranges of high voltage resistors. Across the HV range from 1 to 100kV products are available which provide safety in discharge, reliability in balancing and accuracy in measurement. For designers requiring a resistor with parameters outside of this range, bespoke solutions for specific applications may be supplied.

From commercial thick-film & precision high voltage devices to bleeders, dividers and ultra high resistance values (100T or $10^{14} \Omega$), products are supplied to key commercial & military standards. RoHS compliant Pb-free finish and SnPb finish are both available across most product families. Because of its ability to maintain good stability of resistivity in the presence of high voltage stress, the technology normally used for compact high voltage resistors is thick-film.

TT Electronics’ companies have been leaders in thick-film product development since the 1960s and can now offer a full range of component styles including compact SMD chips, conventional axial throughhole and space-saving single-in-line (SIL) radial format.

This Application Note gives data, calculations and typical products for use in high voltage circuits. It should be read in conjunction with the full datasheets for each product referenced.

- EN60065 safety bleeders
- Voltage balancing resistors
- Resistive voltage dividers
- LEVs up to 100kV
- Ohmic values to 100TΩ
- Compatibility with oil of SF₆ filled assemblies
- MIL-R-49462 approval
- X-ray PSU • AED • Electron Microscope • E-beam Welder
- Electrostatic Precipitator • Air Ioniser • Photomultiplier
- Gas Detector • Lightning Ballast • IR Tester • EL Backlight
- PFC • UPS • ESD Protection • Seismic Monitor • Paint Spray

For our full product portfolio, in-house & local design support / distribution partners, visit: www.ttelectronics.com/resistors
Resistors

Application Note

High Voltage Bleeders

Bleed resistors are used to discharge capacitors to safe voltage levels after power is removed. A bleed resistor may be either switched across the capacitor for rapid discharge without quiescent dissipation (Figure 1). or permanently connected for high reliability and low cost (Figure 2). In the latter case there is a trade-off between the time to reach safe discharge and the quiescent power loss.

Selecting a maximum suitable ohmic value is achieved from an exponential discharge calculation (Figure 3):

\[ R_{\text{max}} = \frac{-T_d}{C \ln (V_t/V_o)} \]

where \( T_d \) is discharge time, \( C \) is capacitance value assuming maximum positive tolerance, \( V_t \) is safety threshold voltage and \( V_o \) is the initial voltage. The closest standard value below \( R_{\text{max}} \) should be used.

For a selected value \( R \), the initial power is given by

\[ P_o = V_o^2 / R \]

Example 1

A high voltage rail with a maximum of 1kV has a 1µF±20% reservoir. This needs to be discharged below 50V within 10s of switch-off.

This can just be achieved with a bleed value of 2M7, but to allow for a 5% tolerance, 2M2 is a better choice. With this the maximum time to discharge is 8.3s and the power dissipation at full voltage is 0.45W.

A suitable solutions is VRW37-2M2, rated at 0.5W and 3.5kV.

Capacitor Discharge Calculator is an on-line tool for safety-related bleed resistor selection which is available at:


In bleeder applications precision is generally unimportant and 5% tolerance can be used. Howeve, safety is often critical, and in mains (line) connected applications a suitable safety approval such as EN60065 should be called up. This standard ensures that the component will withstand the lightning or switching induced surges found on power lines.
Voltage Balancing Resistors

All aluminium electrolytic capacitors exhibit a leakage current when a DC voltage is connected across them. This may be modelled by a leakage resistance connected in parallel with the capacitor. This resistance is non-linear, that is, its value is a function of the applied voltage. Furthermore, the value is poorly defined, having a large degree of variation from one capacitor to another.

The solution is to use balancing resistors as shown in Figure 5. These are high value resistors rated at the appropriate voltage and matched in value to within a few percent. The value needs to be as high as possible to minimise power dissipation, but is generally chosen so that it is no more than 10% of the lowest value of leakage resistance at the rated voltage of the capacitor, V. That is, R_{ba} \leq \frac{R_{la}(V_a)}{10}. By this means the effect of the unbalanced internal capacitor leakage resistances is swamped by that of the balancing resistors, and the voltages are approximately equalised, so V_a \approx V_b.

In order to raise the total capacitance value, two or more pairs of capacitors may be connected in parallel. There are two configurations which may be used: either a bank of parallel connected capacitors may be balanced by a single pair of balancing resistors (Figure 6), or each pair of capacitors may be provided with its own pair of balancing resistors (Figure 7). Although clearly offering a lower component count, the first option suffers from a significantly lower reliability. This is because the effect of a short circuit failure of any one capacitor in the bank is that full bus voltage appears across the capacitors in the opposite half of the circuit. The circuit failure rate for n capacitors with a FIT of F is therefore n\cdot F. The second option offers a superior reliability as a capacitor short failure will only cause failure of its twin. Depending on the acceptable level of degradation in smoothing, the FIT rate may therefore be < F.
Voltage Dividers

A common application for high voltage resistors is in voltage dividers for the measurement or control of high voltage rails. Figure 8 shows a typical application in which the output of a high voltage power supply is scaled down and fed back for regulation purposes. Assuming that the input impedance of the buffer is much greater than R1 the loading on the divider is negligible, so the voltage ratio is simply given by:

\[
\frac{V_i}{V_o} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}
\]

It should be noted that the voltage ratio is not the same as the resistance ratio \( R_2 / R_1 \) but is offset by one. Therefore, for example, for a voltage ratio of 1000:1 it is necessary to define a resistance ratio of 999:1. For a discrete resistor design it is preferable to select standard values, and some examples for decade voltage ratios are given in Table 1.

<table>
<thead>
<tr>
<th>Target Voltage Ratio</th>
<th>R2 / R1</th>
<th>R1 (E24/96)</th>
<th>R2 (E12)</th>
<th>Actual Voltage Ratio</th>
<th>Nominal Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:1</td>
<td>9</td>
<td>9K1</td>
<td>82K</td>
<td>10.01</td>
<td>0.1%</td>
</tr>
<tr>
<td>100:1</td>
<td>99</td>
<td>4K75</td>
<td>470K</td>
<td>99.95</td>
<td>-0.05%</td>
</tr>
<tr>
<td>1000:1</td>
<td>999</td>
<td>1K0</td>
<td>1M0</td>
<td>1001</td>
<td>+0.1%</td>
</tr>
<tr>
<td>10000:1</td>
<td>9999</td>
<td>6K81</td>
<td>6M8</td>
<td>9995.5</td>
<td>-0.05%</td>
</tr>
<tr>
<td>100000:1</td>
<td>99999</td>
<td>1K0</td>
<td>10M</td>
<td>10001</td>
<td>+0.01%</td>
</tr>
</tbody>
</table>

Having selected nominal values, the next consideration is the tolerance needed. The tolerance in resistance ratio is simply the sum of the individual resistance tolerances. These are not necessarily the same; often it is most economical to select a tighter tolerance on the low voltage part. For example, high voltage R2 at 1\% and low voltage R1 at 0.1\% gives a resistance ratio tolerance of 1.1\%. The conversion of this to voltage ratio tolerance is shown in Figure 9, but for ratios above 50:1 they are effectively the same. Suitable precision low voltage parts are RC Series (through hole) and PCF Series (SMD chip).

For high precision applications the sources of error to be considered include finite loading of the divider by the buffer amplifier input, voltage coefficient of resistance (VCR) and temperature coefficient of resistance (TCR). The VCR is always negative and approximately linear over a limited voltage range and so may be compensated for to some extent. The effect of TCR, and, indeed, of tolerance, may be reduced by selecting matched sets or integrated dividers with a specified ratio tolerance and TCR tracking.
Resistors

Application Note

Electrostatic Precipitator

100kV

50kV

20kV

15kV

10kV

5kV

1kV

MIL-R-49462

Insulation Test

Electrostatic Paint Spray

Fluorescent Tube Ballast

EL Backlight Inverter

Radiation, Gas & Seismic Detection

X-Ray Supply

HVD & RHVD

SIL & DIL Thick Film Divider

E-beam Welder

MV Supply Resistive Measure

T48 in Oil or SF6

HVP

Compact Thick Film Planar Resistor

Defibrillator

ESD Protection

Air Ioniser

Photomultiplier

3800

Ultra-High Value

CGH & CMH

Thick Film High Voltage

F43/44

Thick Film High Voltage

VRW, MH & GC

High Voltage Axial Resistor

LVVC & HVC

High Voltage Chip Resistor

3900

Ultra-High Value

BI Technologies IRC Welwyn

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## Resistors

### Application Note

## High Voltage Product Selector

<table>
<thead>
<tr>
<th>Voltage Range (kV)</th>
<th>Series</th>
<th>Description</th>
<th>Value Range</th>
<th>Datasheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7 to 0.9</td>
<td>WPYP</td>
<td>Capacitor-mounted bleed resistors</td>
<td>1R to 120K</td>
<td><a href="http://www.ttelectronics.com/sites/default/files/resistors-datasheets/WPYP.pdf">http://www.ttelectronics.com/sites/default/files/resistors-datasheets/WPYP.pdf</a></td>
</tr>
<tr>
<td>0.5 to 1</td>
<td>3810</td>
<td>Glass-sealed ultra-high value resistors</td>
<td>100M to 100T</td>
<td><a href="http://www.ttelectronics.com/sites/default/files/resistors-datasheets/3810.pdf">http://www.ttelectronics.com/sites/default/files/resistors-datasheets/3810.pdf</a></td>
</tr>
<tr>
<td>0.2 to 2</td>
<td>LHVC</td>
<td>Lower range HV thick-film chip resistors</td>
<td>50K to 10M</td>
<td><a href="http://www.ttelectronics.com/sites/default/files/resistors-datasheets/LHVC.pdf">http://www.ttelectronics.com/sites/default/files/resistors-datasheets/LHVC.pdf</a></td>
</tr>
<tr>
<td>1 to 3</td>
<td>HVC</td>
<td>HV thick-film SMD chip resistors</td>
<td>10K to 1G0</td>
<td><a href="http://www.ttelectronics.com/sites/default/files/resistors-datasheets/HVC.pdf">http://www.ttelectronics.com/sites/default/files/resistors-datasheets/HVC.pdf</a></td>
</tr>
<tr>
<td>1.6 to 3.5</td>
<td>MH</td>
<td>Axial ½ and ½ W thin-film resistors</td>
<td>100K to 10M</td>
<td><a href="http://www.ttelectronics.com/sites/default/files/resistors-datasheets/MH.pdf">http://www.ttelectronics.com/sites/default/files/resistors-datasheets/MH.pdf</a></td>
</tr>
<tr>
<td>1.6 to 10</td>
<td>VRW</td>
<td>Axial ¼, ½ 1W thick-film resistors</td>
<td>100K to 68M</td>
<td><a href="http://www.ttelectronics.com/sites/default/files/resistors-datasheets/VRW.pdf">http://www.ttelectronics.com/sites/default/files/resistors-datasheets/VRW.pdf</a></td>
</tr>
<tr>
<td>1.7 to 10</td>
<td>GC</td>
<td>Axial ¼ and ½ and 1W thick-film resistors</td>
<td>47K to 1G</td>
<td><a href="http://www.ttelectronics.com/sites/default/files/resistors-datasheets/GC.pdf">http://www.ttelectronics.com/sites/default/files/resistors-datasheets/GC.pdf</a></td>
</tr>
<tr>
<td>7.5 to 30</td>
<td>HVD</td>
<td>Thick-film high voltage SIL resistive divider</td>
<td>7K5 to 5G0</td>
<td><a href="http://www.ttelectronics.com/sites/default/files/resistors-datasheets/HVD.pdf">http://www.ttelectronics.com/sites/default/files/resistors-datasheets/HVD.pdf</a></td>
</tr>
<tr>
<td>0.75 to 20</td>
<td>CGH†</td>
<td>High voltage precision axial resistor</td>
<td>100K to 2G</td>
<td><a href="http://www.ttelectronics.com/sites/default/files/resistors-datasheets/CGH.pdf">http://www.ttelectronics.com/sites/default/files/resistors-datasheets/CGH.pdf</a></td>
</tr>
<tr>
<td>2 to 20</td>
<td>HVP</td>
<td>Thick-film compact high voltage SIL</td>
<td>1K to 1G5</td>
<td><a href="http://www.ttelectronics.com/sites/default/files/resistors-datasheets/HVP.pdf">http://www.ttelectronics.com/sites/default/files/resistors-datasheets/HVP.pdf</a></td>
</tr>
<tr>
<td>4 to 28</td>
<td>F</td>
<td>High voltage axial resistor</td>
<td>2M to 150G</td>
<td><a href="http://www.ttelectronics.com/sites/default/files/resistors-datasheets/F.pdf">http://www.ttelectronics.com/sites/default/files/resistors-datasheets/F.pdf</a></td>
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<tr>
<td>4 to 100</td>
<td>T</td>
<td>Ultra-high voltage precision axial resistor</td>
<td>1K to 5G</td>
<td><a href="http://www.ttelectronics.com/sites/default/files/resistors-datasheets/T40.pdf">http://www.ttelectronics.com/sites/default/files/resistors-datasheets/T40.pdf</a></td>
</tr>
</tbody>
</table>

1. MIL-R-49462 approved version available as CMH

### Maximum Voltage Plots for Selected Products

[Graph showing maximum voltage plots for selected products]