# Resistors for High Voltage Applications

Leading specialist resistor manufacturers IRC in the USA and Welwyn in the UK together offer 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.

Both Welwyn and IRC 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 through-hole 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 or SF6 filled assemblies
- MIL-R-49462 approval

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## 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 tradeoff between the time to reach safe discharge and the quiescent power loss.

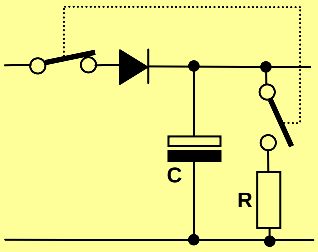



**Figure 1**
**Switched bleed resistor**

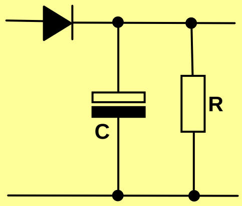



**Figure 2**
**Permanent bleed resistor**

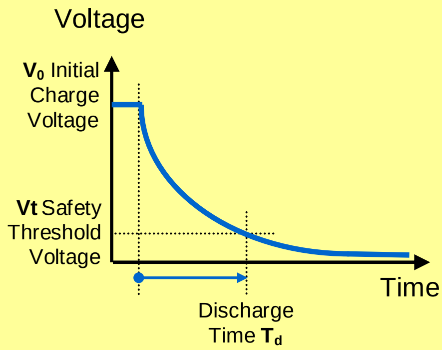



**Figure 3**
**Exponential discharge**

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

$$R_{max} = \frac{-T_d}{C \cdot \ln(V_t / V_o)}$$

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 $R_{max}$ should be used.

For a selected value **R**, the initial power is given by

$$P_o = V_o^2 / R$$

For a switched bleeder this is the peak power. For a permanently connected bleeder it is the continuous dissipation, and the resistor chosen must be rated accordingly.

**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 solution is VRW37-2M2J, 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 [http://www.welwyn-tt.com/CalcTools.asp](http://www.welwyn-tt.com/CalcTools.asp)

In bleeder applications precision is generally unimportant and 5% tolerance can be used. However, 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.

**Example Products**

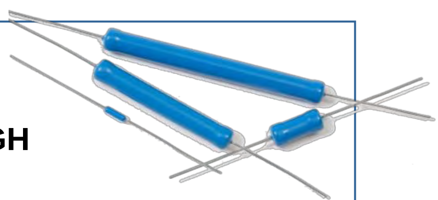
**VRW37**

- **EN60065 Approved**
- **3.5kV rating**
- **10kV pulse rating**

**4500**


- **Ratings to 20kV**
- **Small footprint**
- **Wide range of sizes**

**CGH**



- **Value range to 2kV**
- **Ratings 750V to 20kV**
- **Power to 5W**

## 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.

When building a capacitive reservoir for a high voltage DC bus it is common to use a series combination of two capacitors, each rated at half the bus voltage, as shown in Figure 4. If the capacitors are identical, the bus voltage will be shared equally between them. However, in practice the leakage resistances will differ, leading to uneven sharing and potential voltage overload on the capacitor with the higher leakage resistance. In other words, if **Rl*a*(V*a*) < Rl*b*(V*b*)** then the result will be **V*b* > V*a*** and possible failure of **C*b***.

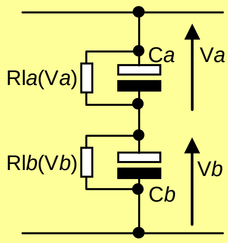



**Figure 4**
**Voltage imbalance**

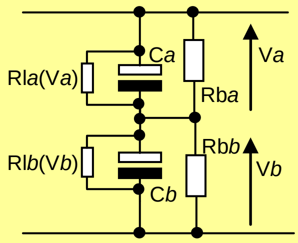



**Figure 5**
**Balancing resistors**

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, **Vr**. That is, **Rb*a* ≤ Rl*a*(Vr)/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* ≈ 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.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**.

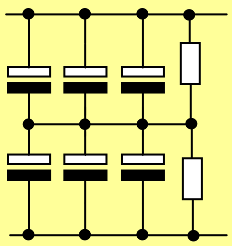


**Figure 6**
**Parallel capacitors**

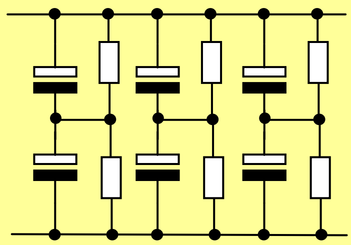
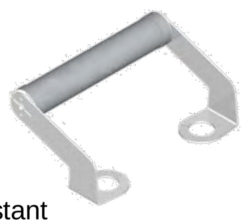


**Figure 7**
**High reliability balancing of parallel capacitors**

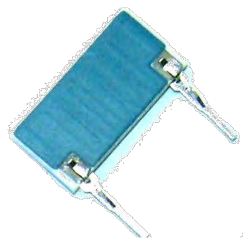
**Example Products**

**WPYP**



- Direct mount
- Vibration resistant
- Rating to 13W
- High overload wirewound

**HVP**



- Ratings to 20kV
- Minimal footprint
- Compact construction
- High value thick-film

## 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 **$R_1$** the loading on the divider is negligible, so the voltage ratio is simply given by:

$$V_i / V_o = \frac{(R_1 + R_2)}{R_1} = 1 + R_2 / R_1$$

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.

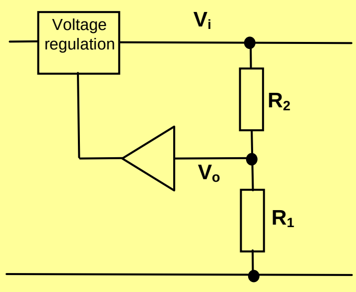
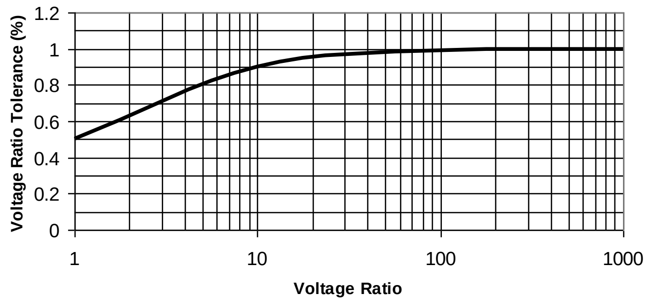



**Figure 8**
**Voltage Divider**

**Table 1** **Decade Voltage Ratios using Standard Values**

| Target Voltage Ratio | $R_2 / R_1$ | $R_1$ (E24/96) | $R_2$ (E12) | Actual Voltage Ratio | Nominal Error |
|---|---|---|---|---|---|
| 10:1 | 9 | 9K1 | 82K | 10.01 | 0.1% |
| 100:1 | 99 | 4K75 | 470K | 99.95 | -0.05% |
| 1000:1 | 999 | 1K0 | 1M0 | 1001 | +0.1% |
| 1000:1 | 999 | 6K81 | 6M8 | 999.5 | -0.05% |
| 10000:1 | 9999 | 1K0 | 10M | 10001 | +0.01% |

**Figure 9** Voltage Ratio Tolerance for 1% Resistance Ratio Tolerance




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 **$R_2$** at 1% and low voltage **$R_1$** 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).

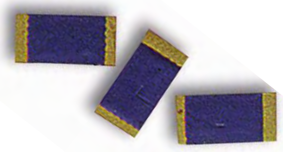
For high precision applications the sources of error to be considered include finite loading of the divider by the buffer amplifier input, voltage coefficient of resistance (VCR) and temperature coefficient of resistance (TCR). The VCR is always negative and approximately linear over a limited voltage 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.

**Example Products**

**T**

**To 50kV in air or 100kV in oil**
**Power to 10W**
**Matched sets available**
**50ppm/°C available**
**Low VCR**

**HVC**

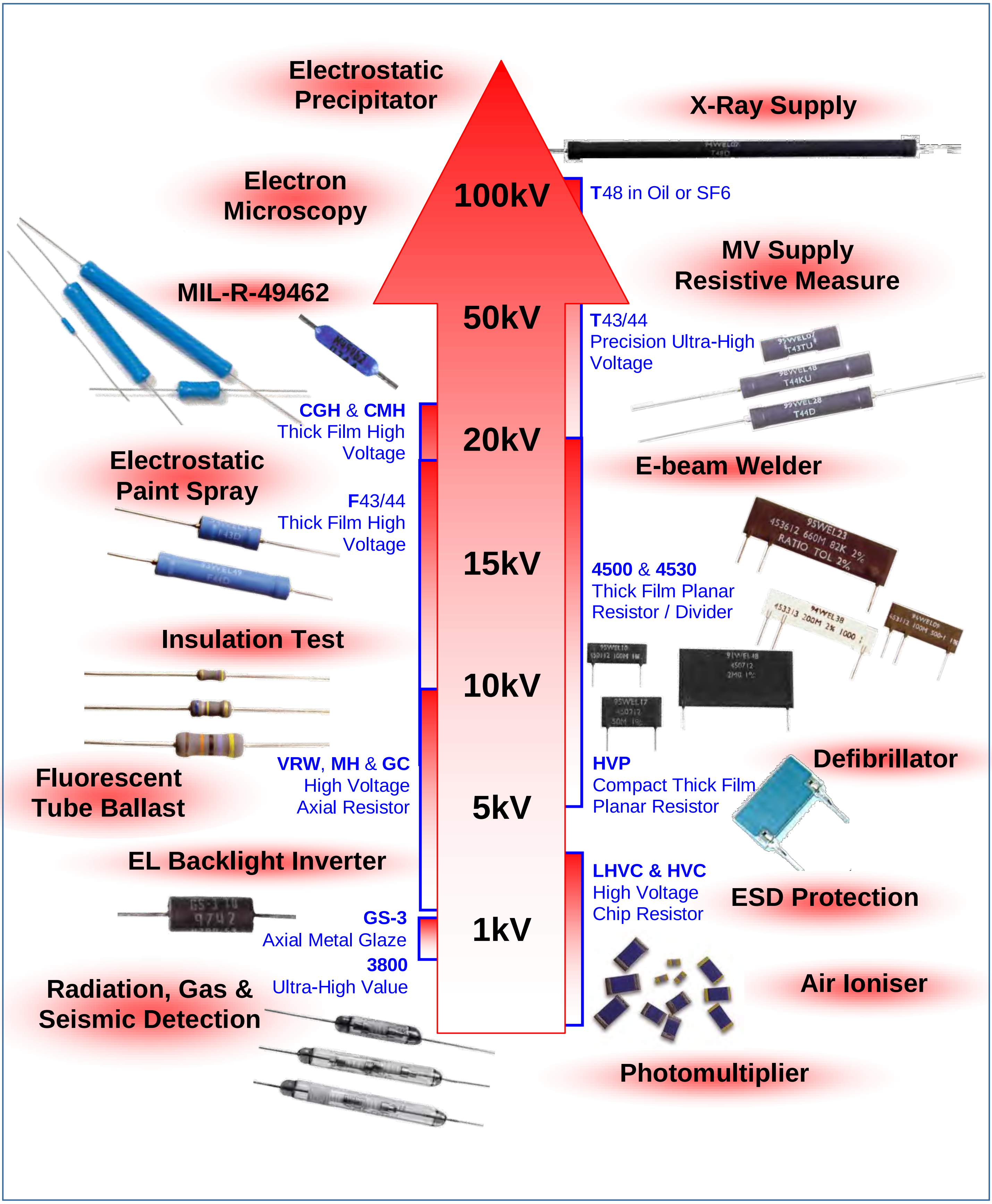


**Compact solution**
**3kV in 2512 size**
**Low assembly cost**

**4530**


**Ratings to 20kV**
**Small footprint**
**Integrated divider**
**Ratio tolerance specified**

## Range of Voltages and Applications

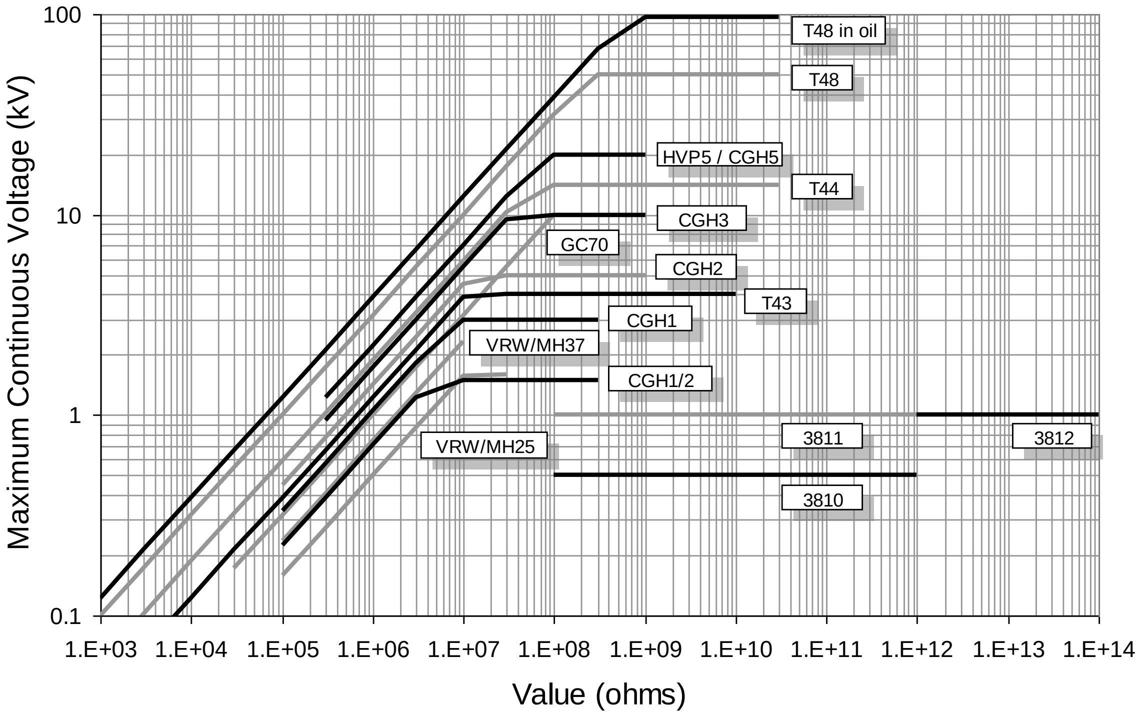


## High Voltage Product Selector

| Voltage Range (kV) | Series | Description | Value Range | Datasheet |
|---|---|---|---|---|
| 0.3 to **0.8** | LHVC | Lower range HV thick-film chip resistors | 50K to 10M | http://www.welwyn-tt.com/pdf/datasheet/LHVC.PDF |
| 0.7 to **0.9** | WPYP | Capacitor-mounted bleed resistors | 1R to 120K | http://www.welwyn-tt.com/pdf/datasheet/WPYP.PDF |
| 0.5 to **1** | 3810 | Glass-sealed ultra high value resistors | 100M to 100T | http://www.welwyn-tt.com/pdf/datasheet/3810.PDF |
| **1** | GS-3 | Axial 2W thick-film resistor | 1R to 3M | http://www.irctt.com/file.aspx?product_id=36&file_type=datasheet |
| 1 to **3** | HVC | HV thick-film SMD chip resistors | 100K to 100M | http://www.welwyn-tt.com/pdf/datasheet/HVC.PDF |
| 1.6 to **3.5** | MH | Axial ¼ and ½ W thin-film resistors | 100K to 10M | http://www.welwyn-tt.com/pdf/datasheet/MH.PDF |
| 1.6 to **3.5** | VRW | Axial ¼ and ½ W thick-film resistors | 100K to 30M | http://www.welwyn-tt.com/pdf/datasheet/VRW.PDF |
| 1.7 to **10** | GC | Axial ¼ and ½ and 1W thick-film resistors | 47K to 1G | http://www.welwyn-tt.com/pdf/datasheet/GC.PDF |
| 6.5 to **15** | 4530 | Thick-film high voltage SIL resistive divider | 20K to 1G4 | http://www.welwyn-tt.com/pdf/datasheet/4530.PDF |
| 0.75 to **20** | CGH* | High voltage precision axial resistor | 100K to 2G | http://www.welwyn-tt.com/pdf/datasheet/CGH.PDF |
| 2 to **20** | HVP | Thick-film compact high voltage SIL | 1K to 1G5 | http://www.welwyn-tt.com/pdf/datasheet/HVP.PDF |
| 10 to **20** | 4500 | Thick-film high voltage SIL resistor | 20K to 1G5 | http://www.welwyn-tt.com/pdf/datasheet/4500.PDF |
| 4 to **28** | F | High voltage axial resistor | 2M to 150G | http://www.welwyn-tt.com/pdf/datasheet/F.PDF |
| 4 to **100** | T | Ultra-high voltage precision axial resistor | 1K to 50G | http://www.welwyn-tt.com/pdf/datasheet/T.PDF |

* MIL-R-49462 approved version available as CMH

**Figure 10** **Maximum Voltage Plots for Selected Products**




**Welwyn Components Ltd and IRC have over 70 years experience in designing and manufacturing resistive components.**

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