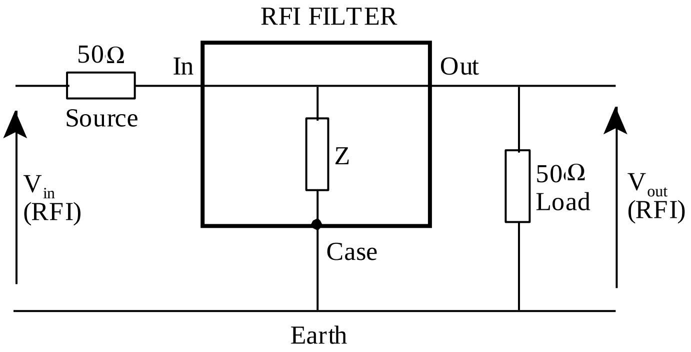
EFFECT OF EARTH RESISTANCE ON FILTER PERFORMANCE

INTRODUCTION

In its simplest form, a filter can be considered to operate by shorting out the radio frequency interference coming down the input line from the noise source. It does this by presenting a very low impedance, Z, to the incoming interference signal which is normally considered to have an impedance of 50Ω.



It can be seen from the above figure that the filter impedance, Z and the 50Ω source impedance form a voltage divider so that if Z is small compared to 50Ω then V_{out} will be smaller than V_{in} by the same ratio.

In fact, provided that Z is small compared to the source and load impedances then the insertion loss provided by the simple filter will approximate to

$$\text{Insertion Loss (dB)} = 20 \log_{10} 25/Z$$

This formula has been found to work quite well in practice for a simple single element filter such as a feedthrough capacitor.

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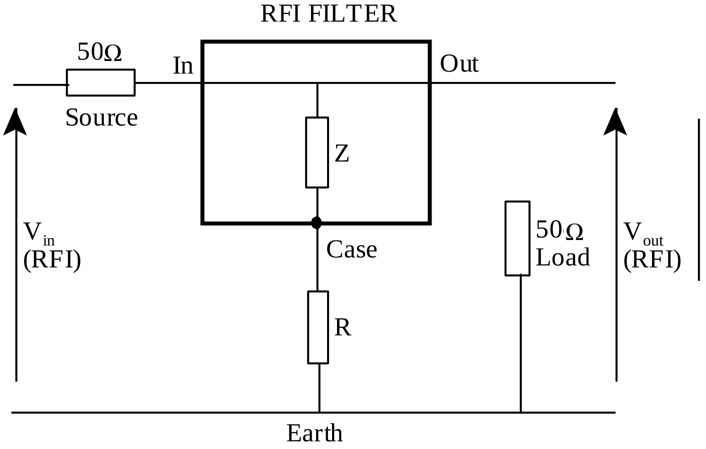
www.mpe.co.uk
sales@mpe.co.uk
+44 151 632 9100

ADDITION OF EARTH RESISTANCE



If a resistance, R is introduced into the earth path of the filter, it is in series with the filter impedance as shown above.
The reduction in RFI noise by the filter is now governed by the ratio of 50Ω to Z+R. If Z is small compared to R, then the insertion loss provided by the installed filter will be determined by R alone, i.e. it is totally independent of the filter. In this case

$$\text{Insertion Loss} = 20 \log_{10} 25/R$$

The above theory is based on a simple single element filter but applies to any filter where Z<<R so the resistance, R becomes the determining factor.
This theory predicts that the achievable insertion loss of any filter in circuit with earth resistance, R will be constant and depend only on the value of R for all frequencies where Z is much smaller than R. As an example, for all very high performance filters, Z is likely to be much smaller than 3Ω from a few kHz upwards.

Insertion loss values predicted using the above formula for different values of resistance are as follows:

Earth Resistance, R (Ω)	Insertion Loss of Installed Filter (50Ω system) in dB
3	18
2	22
1	28
0.1	48
0.01	68
0.001	88
0.0001	108

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Note that for lower values of R, the filter impedance may no longer be much smaller than R, so the filter may then determine the overall insertion loss.

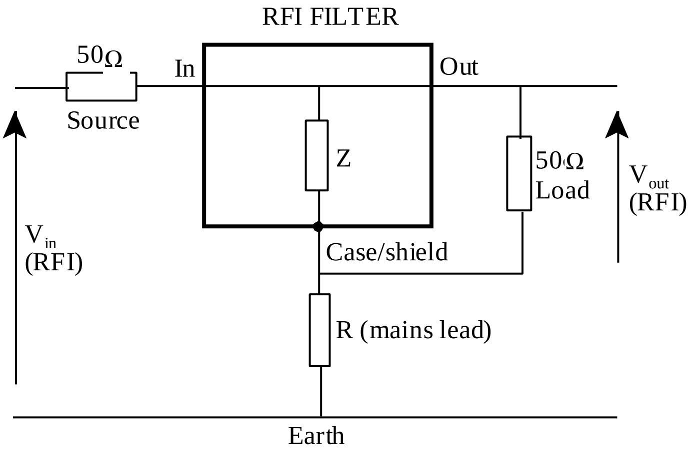
Practical measurements on a high performance filter with 3Ω external earth resistor added confirm that this theory works in practice for R = 3Ω and a flat frequency response of 18dB to greater than 1MHz is obtained. Above this frequency, the insertion loss increases, probably caused by by-passing of the 3Ω resistor due to coupling effects.

FILTERS ON SHIELDED ROOMS

If R is taken as the resistance of the filter case to the shield, then the above theory still applies. This highlights the importance of a good low impedance filter connection to the shield. With normal methods of mounting filters to shields with good filter mounting screws and a good cable entry fitting, this should not be a problem at all.
However, if the shield is dirty, painted, or non-conducting for some reason, then the filter performance will be affected. Even so called "conducting" paints will present a significant resistance and are unlikely to be good enough as a finish for mounting filters on.

In a shielded installation, there may also be a significant resistance to the shield itself from the main earth due to the length of connecting cable. In this case, the situation is a little different provided that the filter has a good earth contact to the shield.

If the noise source is outside the room relative to the true earth, then some of the noise is dropped across R, and V_{out} is relative to the filter case and shield, i.e. the local earth. The filter will give its full performance with respect to noise attenuation even if R is significant.



Likewise if the noise source is inside the shield, the noise source is relative to the filter case and shield so the filter will offer its full performance irrespective of R.

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MAINS FILTERS CONNECTED VIA MAINS LEAD EARTH

This is similar to the screened room situation. The noise let through by the filter, V_{out}, is relative to the filter case (the local earth) so the resistance of the earth cable is not relevant to the filter performance. However, if the filter is poorly mounted to the local equipment earth then there will be a loss in performance. Apart from safety reasons, it is still good practice to keep the lead earth resistance as low as possible to keep the equipment chassis potential as low as possible to minimise re-radiation of RFI from the chassis earth.

CONCLUSIONS

To achieve full filter performance when connected in circuit, it is essential to obtain an earth bond impedance as low as possible from the filter case to the local mounting earth.

For shielded rooms and filters connected via leads, it is desirable to minimise the lead resistance to the main earth but this will not affect the filter performance.

It should be appreciated that in all of the above discussions, it is not the filter itself which has lost performance. It is rather that, because of the high series resistance, only a proportion of the incoming interference voltage is presented to the filter.

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