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Engineering Note

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Project: Dzero Layer 0 Silicon

Doc. No: A1050923

Subject: Layer 0 power supply filter

Introduction

Noise on power lines limits the performance of the Dzero Layer 0 silicon detector. A broadband filter module has been developed that provides isolation to both differential- and common-mode noise. This filter is small enough that it can be mounted in the “cathedral” area behind or adjacent to the fuse panel for Layer 0. Toroidal magnetic components make the filter inherently resistant to the magnetic fields present in the cathedral.

Filter Design

The filter is designed using two J.W. Miller baluns with a nominal inductance of 10mH in each winding. The first balun is used normally to provide common-mode rejection. A 2.2uF surface-mount capacitor is placed across the outputs of the balun to introduce a low frequency pole. The second balun is used in series anti-resonant (band-reject) mode on the supply line with the return line allowed to pass through unhindered. While one might be tempted to place a capacitor to ground between the two series windings in an attempt to obtain greater rejection, this actually makes the performance *worse* because the current in the two series windings is then unbalanced and the current that flows through the capacitor to ground is then regenerated (due to transformer action) on the second winding.

The prototype used J.W. Miller #8104 baluns. As the printed circuit board was being laid out new information was provided indicating that larger currents may be present in the system, necessitating replacement of the #8104 by the larger #8112. Some filter characterization was made using the #8104s as will be seen below. More careful characterization has been made using the #8112s. The printed circuit board was designed to accommodate the use of either balun using a custom footprint. Capacitors CZ1, CY1 and CX1 are optional additions that will add more filtering. Installation of CX1 is not recommended for Layer 0 because it will create a loop pickup path for the detector.

Filter Schematic

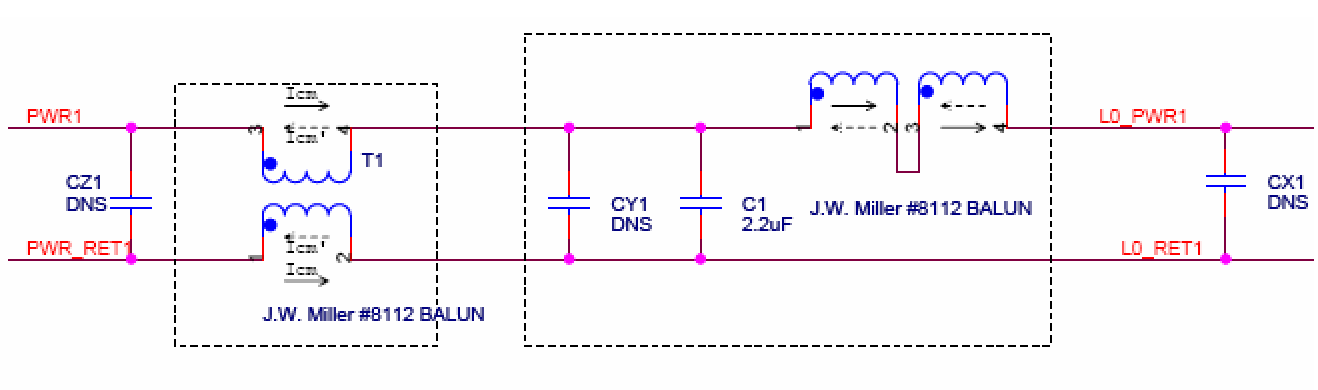

Figure 1

Filter Performance Plots

Figure 2 below shows a performance plot of the prototype filter with the smaller baluns. This is, of course, measured with *no DC current* flowing through the filter, and also with capacitor CZ1 installed (another 2.2uF). Bear in mind that as the current through the filter increases, it would be expected that the primary pole in the response will move *upward* in frequency because the DC current will increase the flux in the toroids, lessening the amount of energy that can be stored in the mutual inductance.

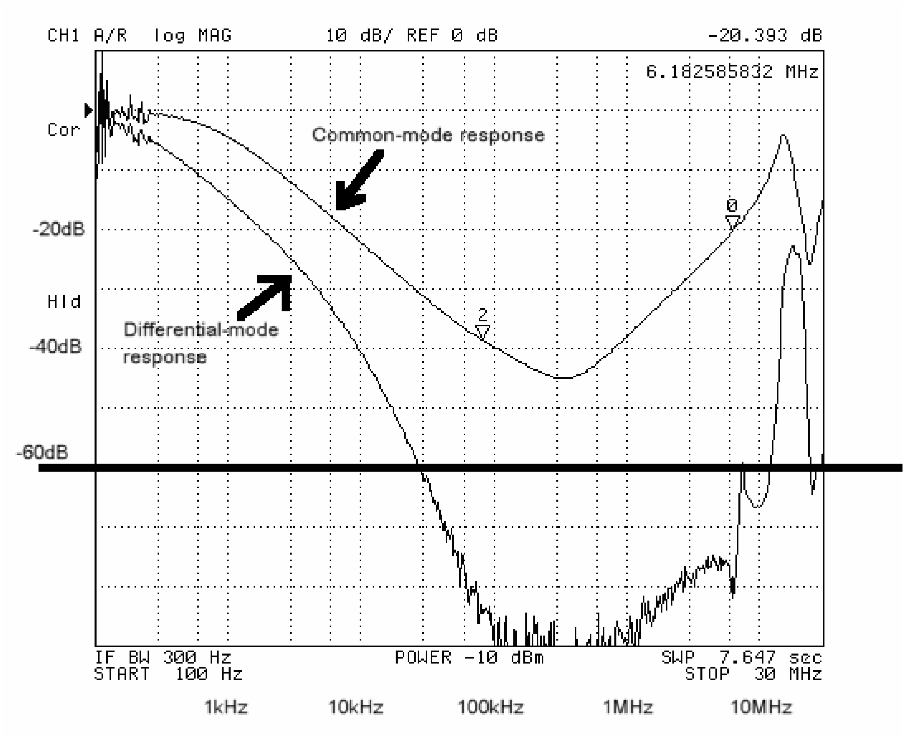

Figure 2

The differential-mode response curve is obtained by connecting all four network analyzer wires to the filter. In this way the current driven by the RF generator of the network analyzer runs through the 'supply' leg of the filter, through the input impedance of the analyzer and back through the 'return' leg of the filter. To obtain the common-mode response the two input side pins of the filter are shorted together and the two output side pins of the filter are also shorted to each other. The 'supply' leads of the network analyzer are connected to the filter and the 'return' leads of the network analyzer are shorted together external to the filter. The current in this common-mode case then runs through both sides of the filter in the same direction. As expected, the construction provides filtering to both types of current.

The loss of filtration at higher frequencies is also expected and normal. At sufficiently high frequencies the series inductance of the capacitors will begin to dominate and raise their impedance. Additionally, inter-winding capacitance in the coils will begin to short the coils out, lessening their impedance. Both effects reduce the filtration. However, the filter performance is still excellent up to the SVX4 sampling rate of Layer 0 and so these high-frequency effects will not cause trouble.

Performance of PCB filter with larger coils

Printed circuit boards with the larger #8112 baluns were manufactured in October, 2005. The larger coils can handle more current but don't have the same inductance as the smaller ones, so some degredation in performance is expected. Figure 3 shows the base (no DC current in filter) response. The curves shown use the base design, with neither CX1, CY1 nor CZ1 installed. This will allow the low-frequency effects of the coils themselves to be more apparent. All pictures shown are differential-mode unless stated otherwise. The test setup contains a power supply and a 50 ohm load resistor. The effect of the load resistor is not calibrated out. Since it is a 50 ohm load resistor in parallel with the 50 ohm input impedance of the analyzer, the expectation is that this will simply shift the baseline down 3dB across the entire measurement; thus, to obtain the filter performance, add 3dB to what you see on the graph.

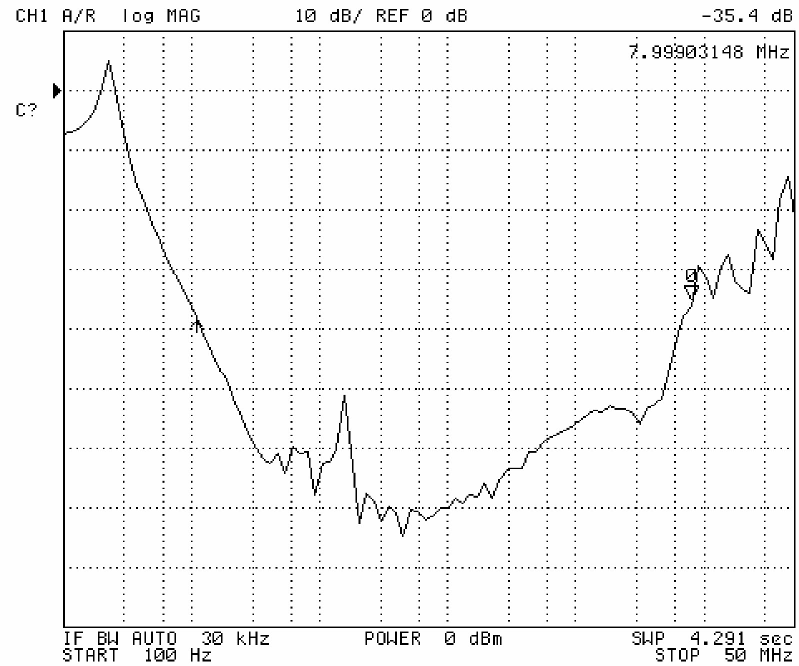

Figure 3 – differential-mode response of PCB filter with #8112 coils with no DC current

For comparison, the power supply is set to drive a current of 1.5A through the filter to the load resistor. To perform this measurement, the four network analyzer leads are protected from the DC current by using a 50uF series capacitor on each leg. The network analyzer is recalibrated using just the four capacitors prior to making the measurement so that the effects of the capacitors are subtracted out by the analyzer.

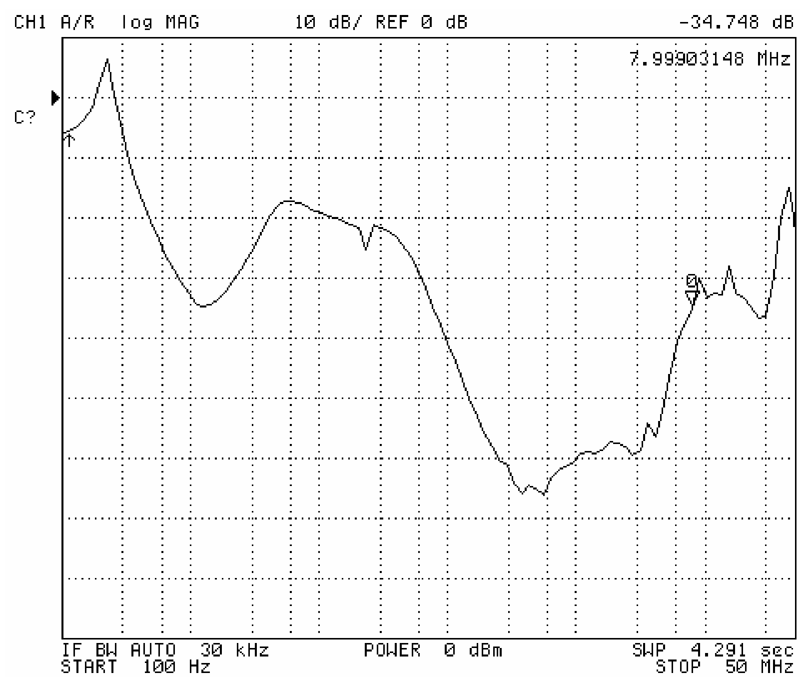

Figure 4 - differential-mode response of PCB filter with 1.5A DC current

As expected, the current in the filter degrades the performance but the filtration in the 100kHz – 10MHz range is relatively unaffected.

Effects of adjacent circuits

The filter PCB design has three filter circuits on the same PC board. The toroidal design of the magnetics should insure that current in one filter will not have deleterious effects upon other filters on the same board. Tests with currents of up to 1.5A in the adjacent filters show that the response of the filter under test are completely unaffected by current in the adjacent board sections.

Effects of external magnetic fields

One filter board with three filter sections was placed into a test magnet at Dzero. The center section of the filter was excited by a 1 Amp DC current flowing into a 50 ohm load. As before, the network analyzer was AC coupled to the input and output ports of the filter to measure the transfer function. Because of the toroidal construction of the filter coils, the board needs to be tested in three orientations relative to the axis of the test magnet. In addition, since a DC current is flowing in the filter during the test, the board must also be flipped over to insure that effects due to the direction of the current flow with respect to the direction of the external field are investigated.

The cathedral area of the Dzero detector is expected to present an external field of up to 500 Gauss. The test magnet calibration curve shows that the maximum field that can be achieve is between 200 and 250 Gauss. The tests performed show that marked change in filter operation occurs between 0 and 100 Gauss but that no further changes are observed at 200 or 250 Gauss. The figures presented herein are at a current of 100 Amperes in the test magnet, corresponding to an expected field of 100 Gauss.

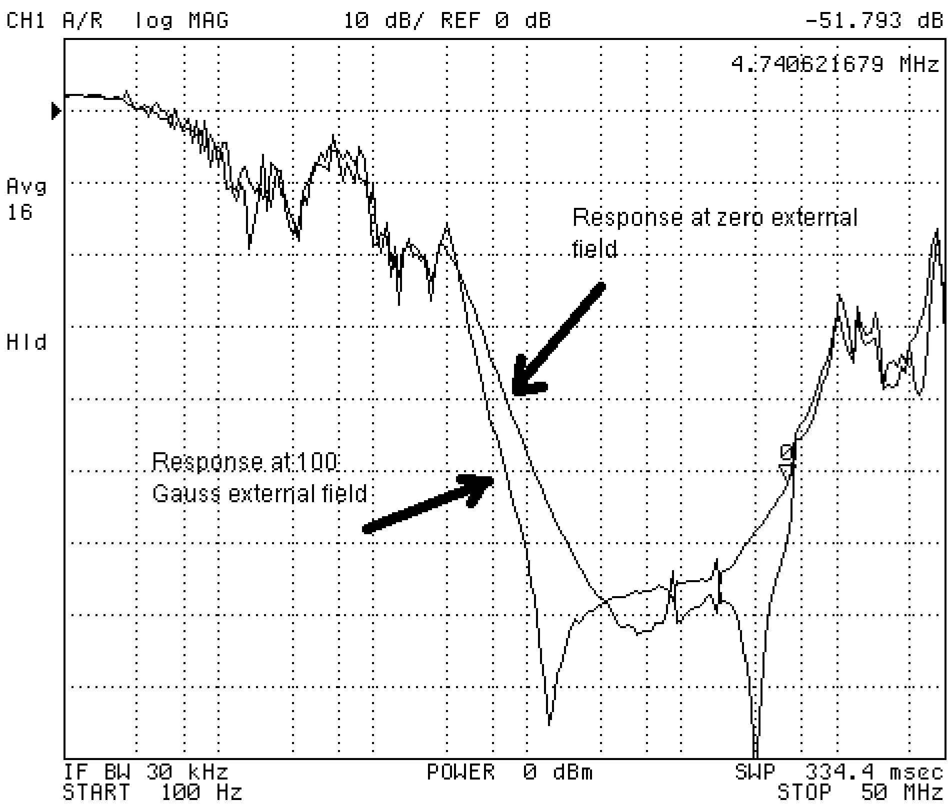

Figure 5 - Operation with field lines along axis of toroids

Figure 5 shows the filter response in the expected orientation. It's not obvious here, but the response at zero field is a smooth "U" shape and there is a double negative peak that shows up when the magnet is turned on. For comparison, Figure 6 shows the operation of the filter under the same conditions but flipped 180 degrees such that the vector of magnetic field is still upon the axis of the toroids, but pointing the other way.

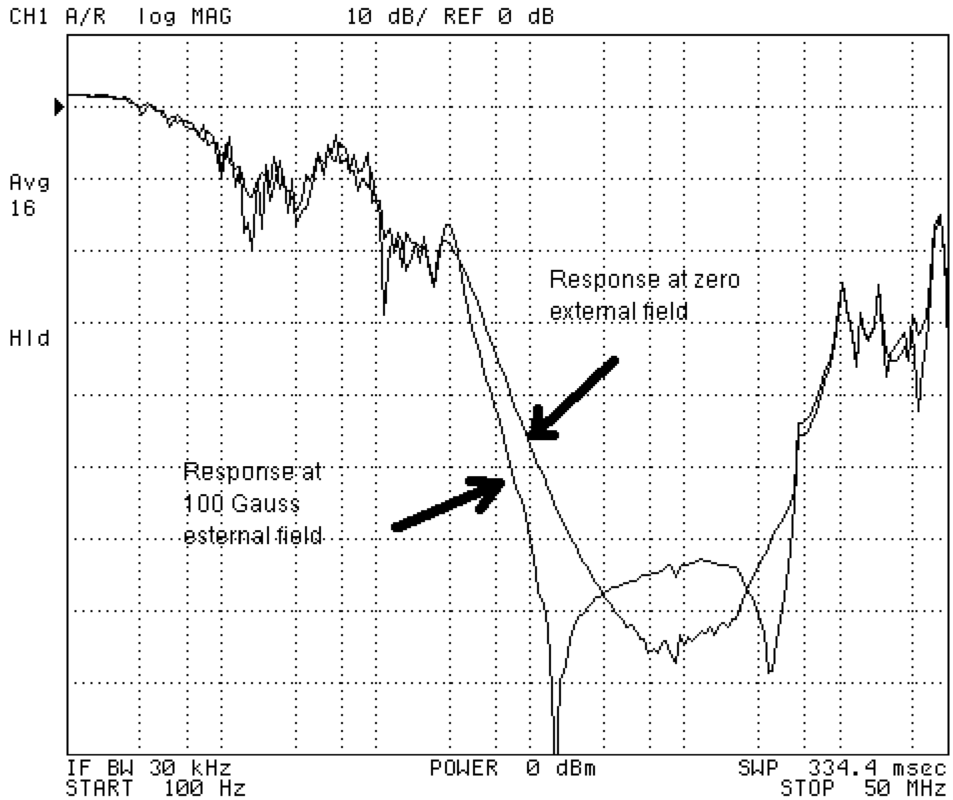

Figure 6 - operation with magnetic field aligned with axis of toroids in other direction

To be complete, measurements were also taken with the filter coils at ninety degrees (both ways) with respect to the magnet coil. Figures 7 & 8 show the response. Yes, those really are two unique data sets. Pretty hard to tell them apart.

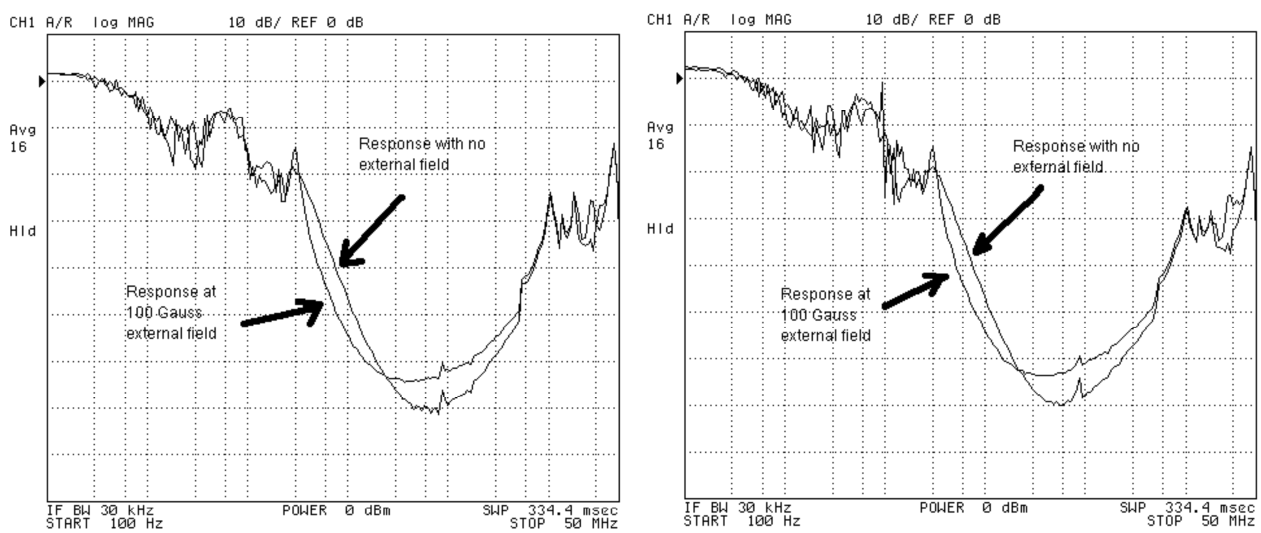

Figure 7/8 : operation with external field cutting across toroids

Consistency of operation between filters

Six filter boards were given to the Layer 0 group to test using the actual detector. It is expected that there will be variations in filtering on the order of ±10%, but that all filters will be sufficient for the needs at hand. Verbal feedback received on November 18th, 2005 indicates that performance of the filters at the Layer 0 detector is acceptable.

Effects of capacitors Cx, Cy and Cz

Reserved for future investigation.

Photograph of finished unit

A photo of the first assembled circuit board using the larger (J.W. Miller #8112) coils is shown in figure 8. The large capacitors shown at either end are not part of the circuit. They were used in testing to AC couple the network analyzer when DC current was being run through the filter as described earilier in this paper.

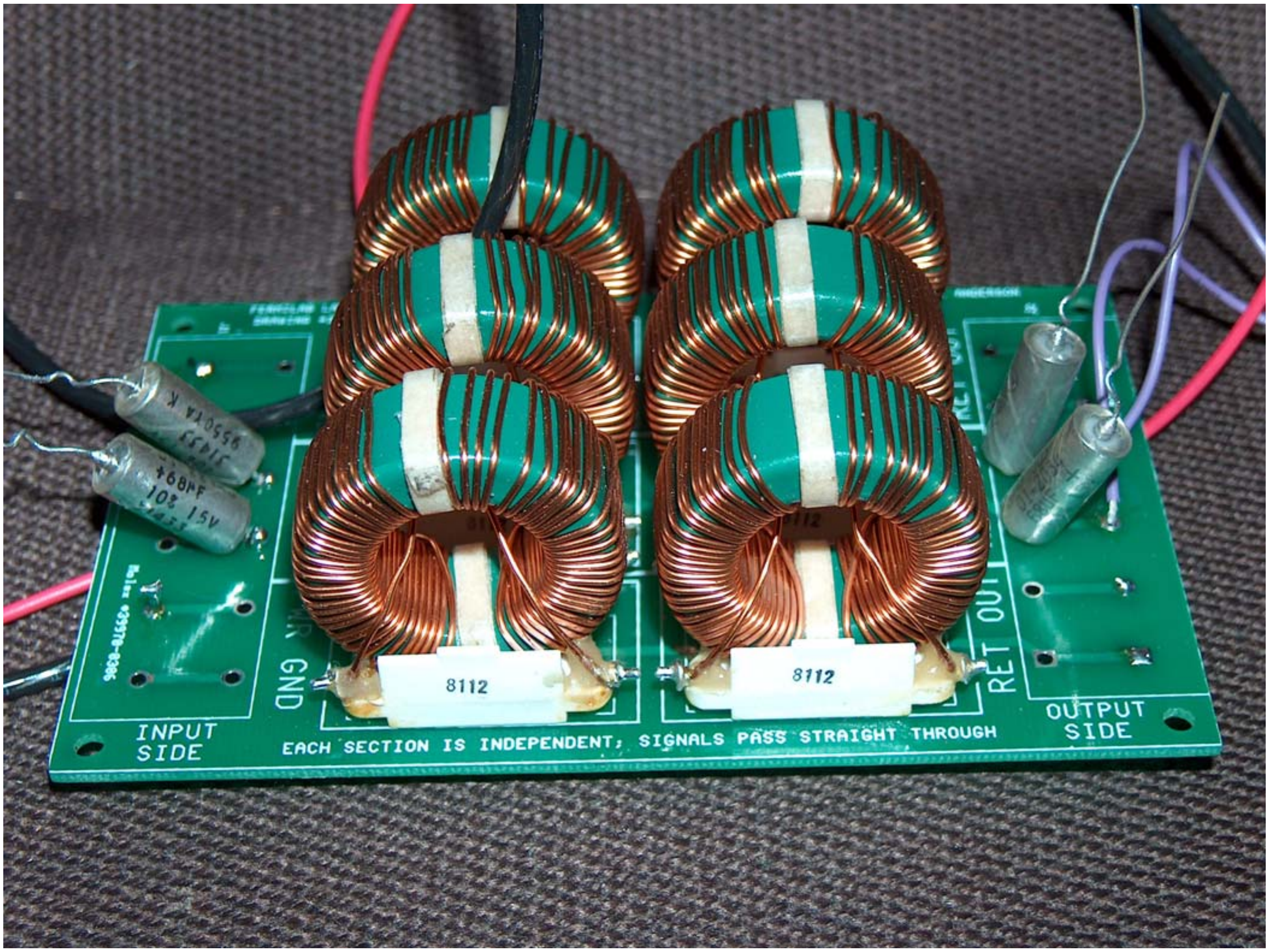

Figure 8 – prototype used in testing