

## EXPANDED-RANGE LOG DETECTOR

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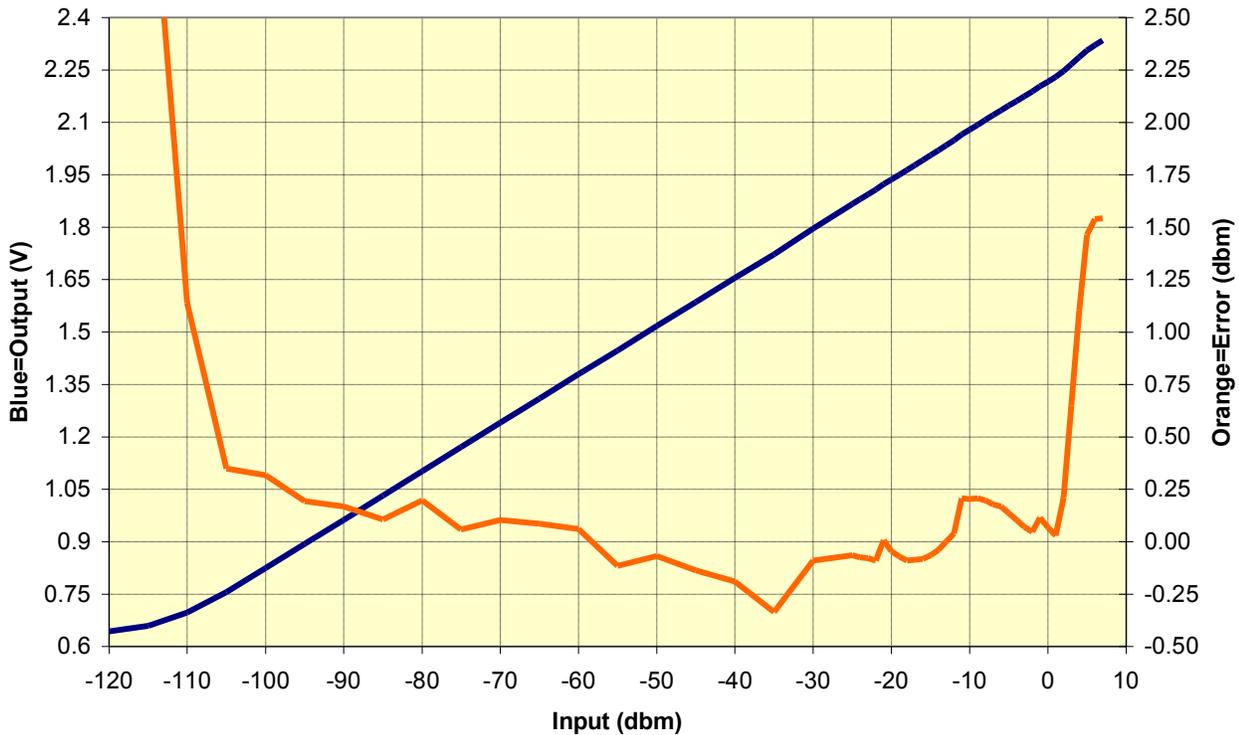
Log detectors take an RF input and produce an output proportional to the RF signal level expressed in dB. Limiting log detectors such as the AD8306 also produce a "limited" RF output which is essentially an amplified and clipped version of the RF input. The AD8306 has a broad range, about 90 dB at 10.7 MHz. This range can be expanded by using a linear-in-dB variable gain amplifier (VGA) as a pre-amplifier for the AD8306, and feeding back a proportion of the AD8306 signal level output as the gain control voltage for the VGA. It is also necessary to put a noise filter between the VGA and the log detector; otherwise the log detector will just be swamped with noise amplified by the VGA.

The underlying math is presented at the end of this paper, but the basic idea is that the combined VGA + log detector acts just like a log detector, an expanded input range. The output range remains the same, but the slope of the output, in mV per dB, is reduced.

This paper describes experimental results from combining the AD8330 with the AD8306, per the schematics in the Appendix. The AD8330 was chosen as the VGA because it has an extremely flat response of gain vs. control input, and has a fixed gain component that is adjustable by means of the VMag input pin.

To cut to the chase, the test results are shown in Figure 1.

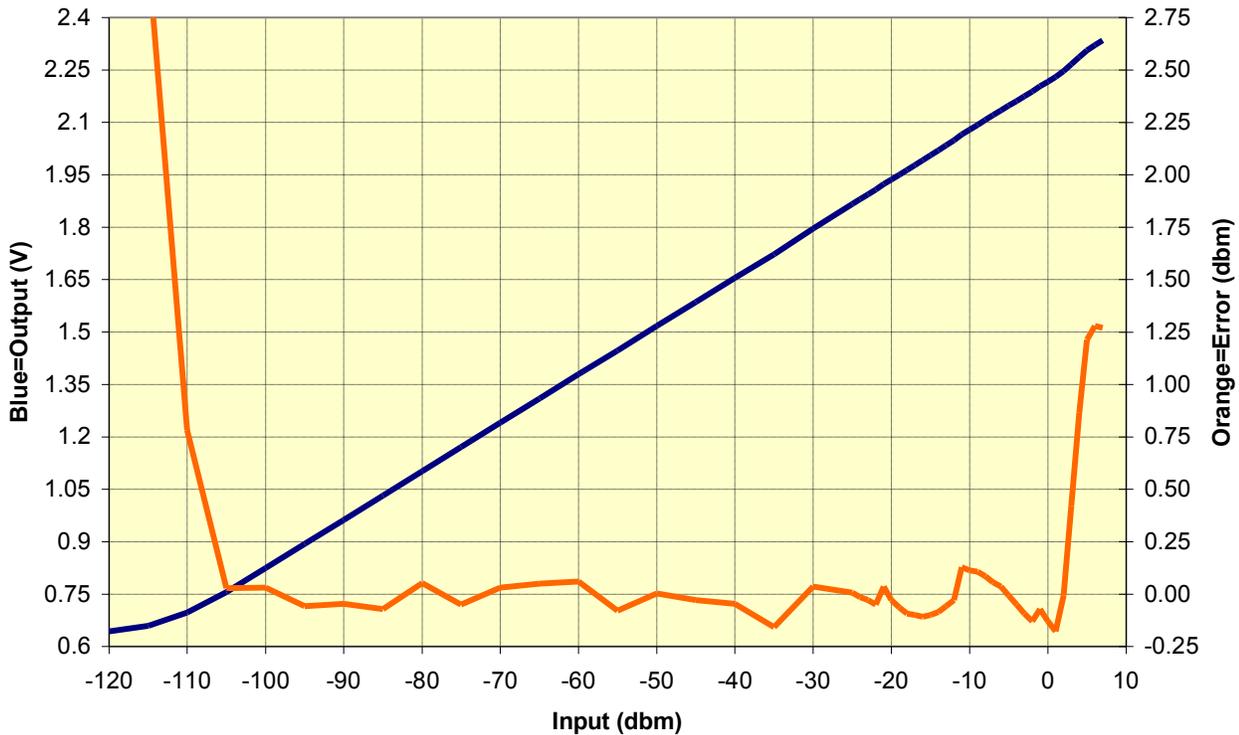
**Test of AD8330+Noise Filter+AD8306 (5/10/08)**  
 "Error" is deviation from single-line fit  
 Measured at 1 dbm intervals down to -25 dbm, then 5 db intervals



**Figure 1**—Output Voltage vs Input Signal Level, shown in blue.  
 Orange line is deviation from a straight line fit.

The accuracy shown in Figure 1 is not bad, about +/-0.25dB, but can easily be improved by a bit of calibration. We would have to calibrate a log detector anyway, to determine its slope. That would require measurement at two points. Notice that the error shown in Figure 1 shows that the circuit response actually follows two separate slopes, changing at -35 dBm. If we fit the data to two separate lines, we get the improvement shown in Figure 2.

**Test of AD8330+Noise Filter+AD8306 (5/10/08)**  
 "Error" is deviation from two-line fit with slope changed at -35dbm  
 Measured at 1 dbm intervals down to -25 dbm, then 5 db intervals



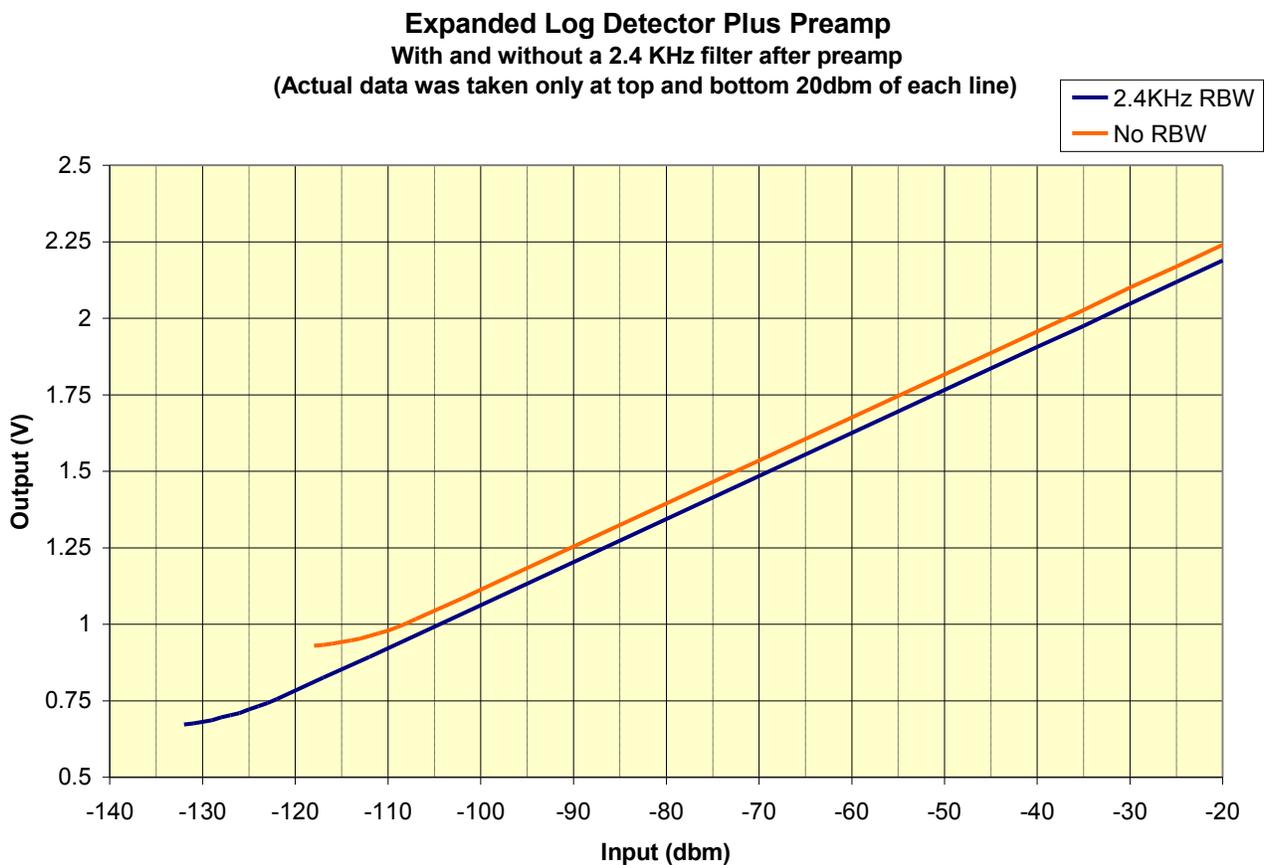
**Figure 2**—Output Voltage vs Input Signal Level, shown in blue. Orange line is deviation from piecewise-linear fit with two separate lines meeting at -35 dBm. Note that some of the remaining ripple may be from errors in the signal source attenuation.

Figure 2 shows extremely good accuracy from -105 dBm to +3 dBm, with the error being almost entirely within a band of +/-0.1 dB. But further calibration can still make improvements. When this log detector circuit is used in Scotty's Modular Spectrum Analyzer, calibration of the analyzer will be done at intervals yet to be determined. It appears that calibration at 10 dB intervals will not do much to improve the accuracy, but calibration at 5 dB intervals would be helpful, and could conceivably reduce the error in much of the range to +/-0.025 dB or better. In the range from -15 dBm to +3 dBm, calibration at 2.5 dB intervals would be helpful, especially since the location of the sharp rise at +3dB is not precisely predictable. At the low end, calibration at 5 dB intervals would substantially account for the effects of noise down to -110 or -115 dBm.

Note that because the ripple in the response comes primarily from the AD8306 log detector, a secondary benefit of combining the log detector with the AD8330 VGA is that ripple is horizontally stretched a bit. This allows calibration at larger intervals than would otherwise be needed.

The combined circuit still has considerable range left to cover signals below -115 dBm, but a narrower noise filter would be needed to utilize that range. Unfortunately, the input to the noise filter is about +18 dBm, which makes a crystal filter out of the question. The solution is to put a low-noise preamplifier in front of the resolution bandwidth (RBW) filters. With a 20dB amplifier, the RBW filters will then have the opportunity to eliminate 20dB of noise which is outside their bandwidth but falls within the bandwidth of the actual "noise filter". By this mechanism, the RBW filters themselves become to some extent noise filters.

Figure 3 shows the test results of using a 21.5 dB amplifier with and without a crystal filter. The amplifier uses an AD8099 op amp to achieve low distortion and minimize IMD products.



**Figure 3**—Output voltage vs. Input level using a preamplifier with and without an intervening filter. That filter simulates a resolution bandwidth filter. It is clear that the RBW filter will expand the low-end range of the expanded log detector.

Note that if the preamplifier is placed before the RBW filters, there will be losses from Mixer 1 (7dB), the cavity filter (6dB) and Mixer 2 (7dB), or about 20dB of losses preceding the preamp. This means that a spectrum analyzer input range of -110 dB to 0 dB would become -130 dB to -20 dB at the preamp input, where it would be handled nicely with

the 2.4KHz filter in place. This gives a total range of 110 dB for the spectrum analyzer. (Of course, 0 dB at the SA input can be handled, but the results coming out of Mixer 1 may be full of IMD products, so the top end of this range is best avoided when possible.)

### **Integrating the Expanded Log Detector into the MSA**

The design used here was experimental and has been modified somewhat to optimize it for use in the MSA. The updated schematic and layout are available at [www.wetterlin.org/sam](http://www.wetterlin.org/sam). The current design requires no modification to the standard log detector module, but the log detector output is fed back to the VGA, which contains an extra connector to pass that signal on the ADC module. R6 of the log detector may also be changed to 100 ohms to increase the output level. With the expanded log amp, the log detector never reaches maximum gain, so the increased output does not create instability. The Noise Filter is a fixed 500 kHz ceramic filter, which will allow for RBW filters up to about 330 MHz. The RBW filters must all have pass bands contained within that of the Noise Filter.

The signal path runs from the IF2 filter, through the RBW Filter Switch Board, to the VGA, then the Noise Filter, then the Log Detector. The Log Detector RF output runs to the PDM as usual. The Log Detector "DC" output, which formerly ran to the ADC, runs back to the VGA, and is fed from there to the ADC.

The regular IF2 amp can be used, but it provides more gain (nominally 40 dB) than is necessary, and may overdrive the RBW filters. It may work to use just one of the two amps on that board, or an attenuator could be put at the output using both halves. I used an op amp (AD8099 or OPA847) with 28 dB gain.

With this arrangement, and 3 dB of attenuation built into the input of Mixer 1, I have achieved a range at the MSA input of -115 dBm to +7 dBm. At the high end, there is a lot of mixer distortion, but signal levels can be measured accurately. At the low end, it required a strong video filter to suppress the noise, but the -115 dBm signal stood out clearly, as shown in Figure 4.

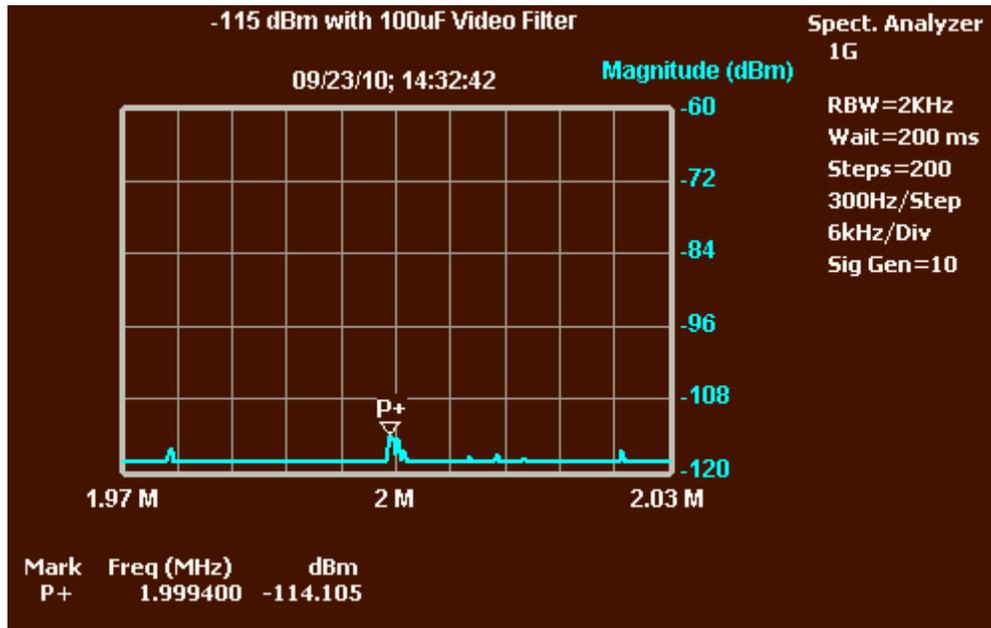


Figure 4—MSA display of -115 dBm signal with strong video filter

Over several scans, the little noise blips come and go; the 2 MHz peak changes shape but always remains. Note that the P+ marker attaches to the peak, which is likely to be a place where noise increases the signal level. Therefore, it tends to read high for low level signals. Figure 4 was generated with a 2 kHz resolution bandwidth filter. An 8 kHz filter could display a signal a few dB higher. A 1 kHz filter might be able to display signals a tiny bit lower.

### Mathematics for Those Interested

For completeness, I will present a summary of the mathematics of the VGA-log detector combination, but this section can be skipped by the uninterested. Assume as follows:

1. The VGA gain equation is  $Gain = K_1 - A_1 * V_{ctrl}$ , where  $K_1$  and  $A_1$  are constants and  $V_{ctrl}$  is the VGA control voltage.
2. The filter has loss of  $L$ , a positive number in dB.
3. The log detector output, in dB, is  $V_{DET} = A_2 * (S - I)$ , where  $A_2$  and  $I$  are the slope and X-intercept, respectively, as provided in the data sheet, and  $S$  is the signal level at the log detector input, in dBm.
4.  $P$  is the proportion of the log detector output fed back to the VGA as  $V_{ctrl}$ .  $P$  is a positive value between 0 and 1. Thus,  $V_{ctrl} = P * V_{DET}$ .

Combining these equations, the resulting log detector output is as follows:

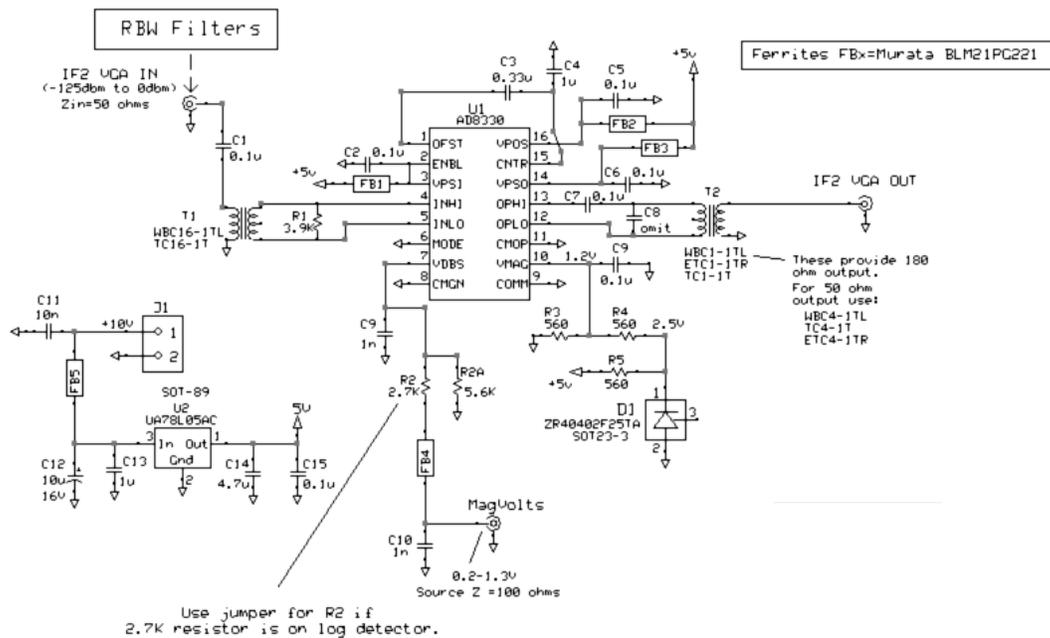
$$V_{DET} = C * S + C * (K_1 - L - I), \text{ where } C = A_2 / (1 + A_1 * A_2 * P)$$

The most important thing to notice about this equation is that the detector output is still a linear function of  $S$ , with a new slope of  $C$ , and a Y-intercept of  $C*(K_1-L-I)$ . That means the combined circuit is still acting as a log detector. Applying this to the AD8330/Filter/AD8306 combination described below, we find:

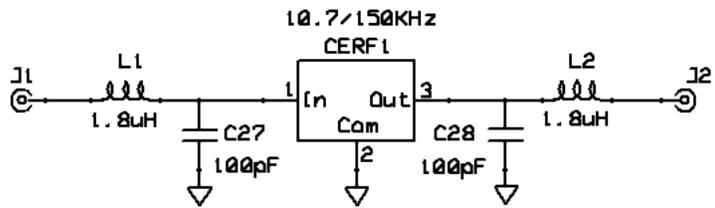
1. The AD8330 has  $A_1=33$  and a basic  $K_1=50$ , but  $K_1$  is adjustable and in our case is about 65, due to the voltage setting at the VMag pin and the transformer step-up of voltage at the input.
2. Our ceramic filter has  $L=5$  dB.
3. The AD8306 has slope= $A_2=0.020$  V/dB and intercept  $I=-95$  dBm.
4. The feedback proportion  $P=0.67$ . This number was selected to account for the fact that the AD8306 output can range to about 2.3V, whereas the AD8330 control voltage must be below about 1.5V. It was adjusted to get the AD8306 output for input of 0 dBm near 2.2V.

There is, of course, some variability in the numbers for each device. Plugging these values into our equation gives  $V_{DET} = 0.014*S + 2.17$  volts, very close to the actual results.

# APPENDIX

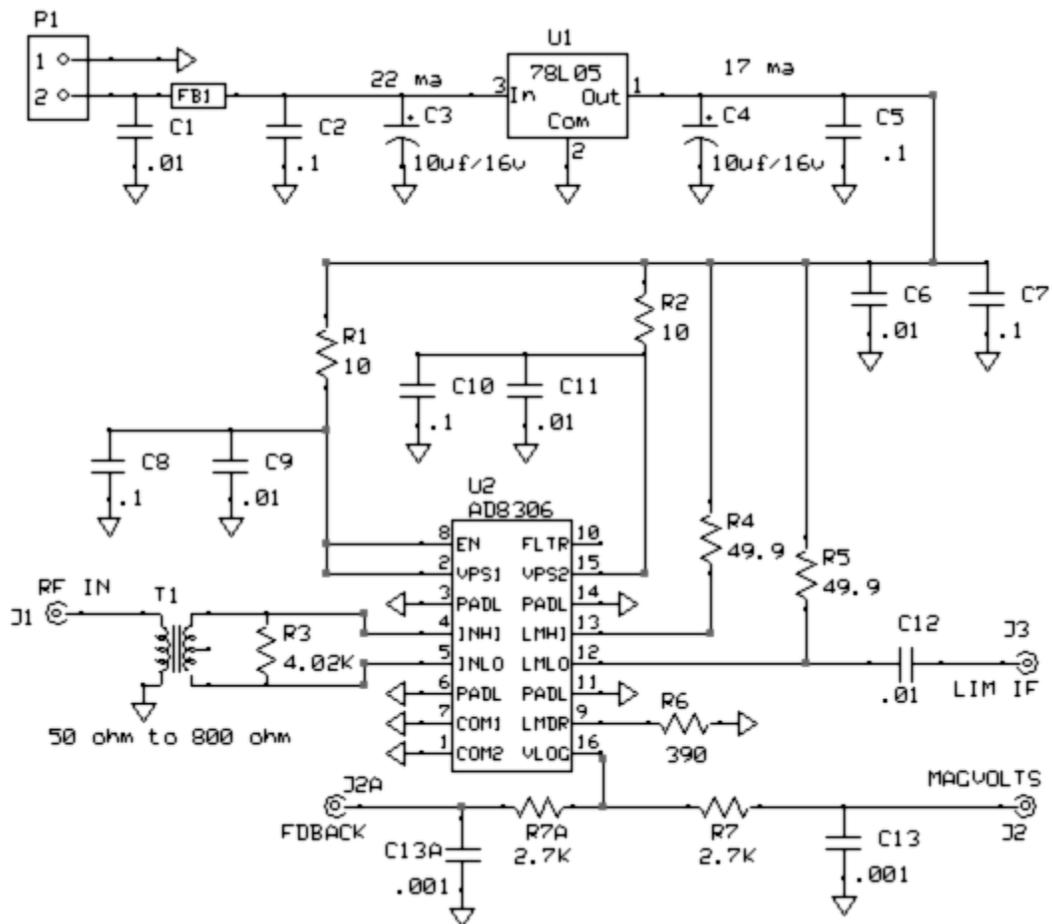


VGA Schematic—R2 was replaced with a jumper



50 ohm to 330 ohm matching network shown.  
 This filter has a center frequency of 10.7 MHz, and a 150 kHz bandwidth.

Noise Filter Schematic



Log Detector schematic—This is Scotty's SLIM design, with the addition of R7A, C13A and J2A, which provide the feedback to the VGA.