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The Noble Art of Signal Detection

The device described here is intended as a RF detector. It works fine to above 700MHz, but it actually works very well for DC and audio signals as well! In this article we will basically consider it a RF detector. If nothing else, I must try to restore my sliding reputation after only having written about DC and HF devices lately...

1. Background

This device saw the light of day because I got a few samples of the AD8307 in the wrong package! I assumed they were going to be on the Small Outline format, SO-8 package, for surface mount. Instead they came in the standard, 8 pin, DIL package!

A bit down the road, as I was working with rechargeable Lithium batteries for another project, I became impressed by the capacity of these batteries. Not only quite a few mAh in a small package, they hold 4 to 3V during the discharge cycle, remaining around 3.6 for a good while, and rechargeable as well! The higher voltage alone doubles, almost triples, the capacity as compared to Alkaline and NiCd cells.

The thoughts went on: could the AD8307, a “5V device”, possibly work on these voltages? A look in the data sheet reveals: “Min 2.7V”! This got all four grey cells engaged, and here is what they came up with!

2. Construction

I got the idea to put it all in an Altoid box, and to use a rechargeable 900mAh Lithium-ion battery (Unitrode UBC543483-C or B14FT00200) and a little edge meter that fitted very nicely (Fig 1).

The output from the AD8307 is only approximately 2µA per dB, about 200µA for full range. The output voltage on pin 4 is created by putting this current through an on-chip 12.5kΩ resistor. In my application I want to drive a meter. The one I found, of suitable size, had been waiting for a project like this in my Noble Junk Box! It was a 1mA meter. Well, an NPN transistor in between provided the needed boost! The first one, in the box of various NPN transistors, was a 2N2222. This is way more than needed, it can handle 1A, but will do. An added advantage of using a transistor here is that the AD8307 has a constant approximately 0.9V output with no signal. The V_{BE} of the transistor then takes

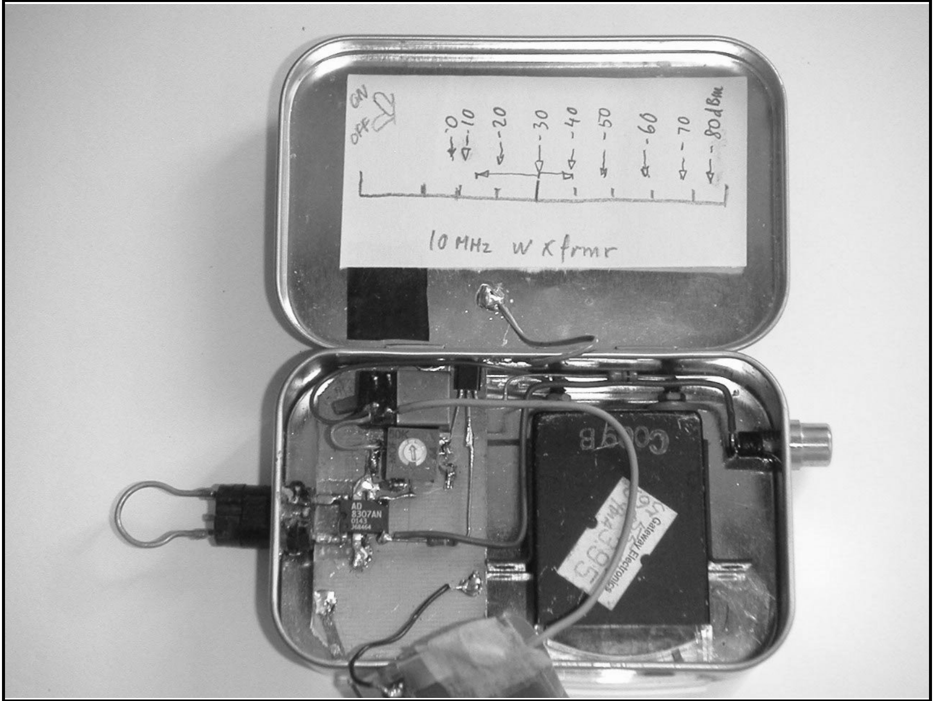

Fig 1: Picture of the Signal Detector in it's Altoid box.

care of some 2/3rd of this voltage. I calculated the resistors and it came close enough. Fig 2 show the circuit diagram of the signal detector.

For my particular 1mA meter the resistor in series would have to limit the battery current (at a little more than 3V) to 1mA when the transistor turns on fully; so 3kΩ in series with the meter. It is a fair assumption that a small transistor has a current gain of 100 in this range. The full output voltage (from a 12.5kΩ source) is approximately 200µA x 12.5kΩ ~ 2.5V. Say 3V and the base needs 10µA for IC=1mA. Say 300kΩ. It should really be more like 220kΩ. It worked well, but later I changed the resistors to 3k9 and 240k.

Naturally, for different meters and transistors, different values would be proper. If your meter is sensitive enough, FS=100µA or less, you may not need the transistor, but a diode, or two Schottky diodes, in the forward direction, in series with the meter will absorb most of the constant 0.9V on the output. Although, see under "Conclusions" for more about this issue!

This detector circuit is insensitive to the supply voltage range, as it can vary with Li battery, but for the meter part where a low voltage will limit maximum deflection. For small deflections, due to small signals, (one division on my meter) B+ can drop to 2.8V before the meter drops. At about 8 divisions (out of 10) the meter begins to drop at 3.8V. So it is quite well adapted to life with a Lithium battery.

Using AD8307 in the SO-8 package is of course perfectly fine too. It will likely increase the upper frequency limit somewhat, in comparison to the performance of the N-8 package.

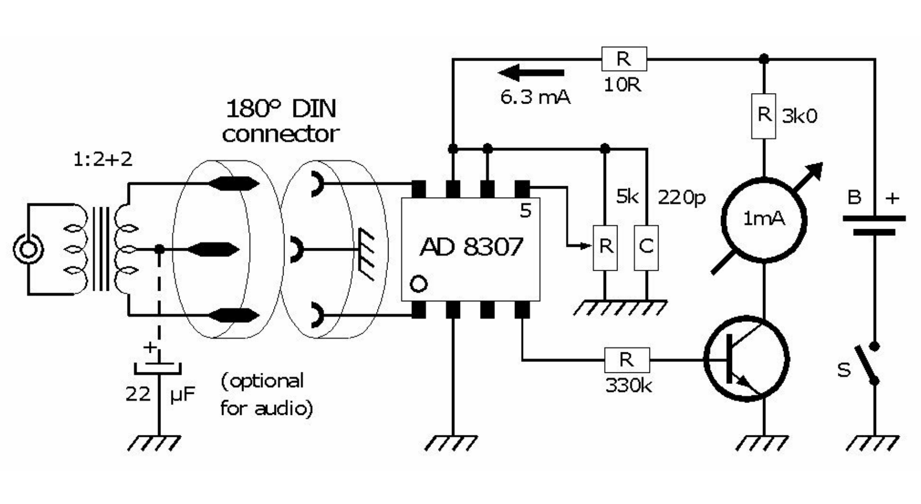

Fig 2: Circuit diagram of the Signal Detector.

3. Plugins

The inputs are purely differential, and although one is marked + and the other - in the data sheet, the output is the logarithm of the voltage difference between them. So either input polarity will result in a positive output. Inputting a differential sine wave will result in an output signal similar to a full-wave rectified wave if the frequency is low enough.

The tracks, on the circuit board, between the pins and the DIN connector, were cleared by hand using a pocket knife. Remove the copper under these pads, minimising the input capacitance.

Notice that the inputs are internally biased some 2.7V above ground and you can destroy the IC by forcing them below ground or above B+, maybe even to the B+. They can be forced to ground. Although the device is floating, when not connected to anything else, beware of touching un-insulated pick-up coils to points of high voltage or where static electricity can be discharged. By its very nature, this is an ESD sensitive device.

Even though the 5 pin, 180°, DIN audio socket is by no means a RF connector, I have found it very practical to use for projects like this. One can easily, and inexpensively, make all kinds of plug-in devices! There are low cost shielded cables available, with this type of connectors mounted. They are at least good for HF! For particular applications, buy a 2 metre long one and cut it in half! You now have two good 1m cables for your bridges or reflectometers!

According to the data sheet, the differential impedance of the inputs is some 1.1kΩ and 1.4pF to ground from either pin. Maybe the DIN connector and the circuit board add a pF between the pins?

In Fig 3 we can see some plug-in accessories. Pick up coils with 1 and 5 turns. The former is useable in detecting signals up to 1GHz, although the detector sensitivity is down quite a bit by then.

The plug-in with a balanced RF transformer (Mini Circuits T4-1) is a 4:1 (impedance) with no centre tap on either side. It is connected to a SMA connector

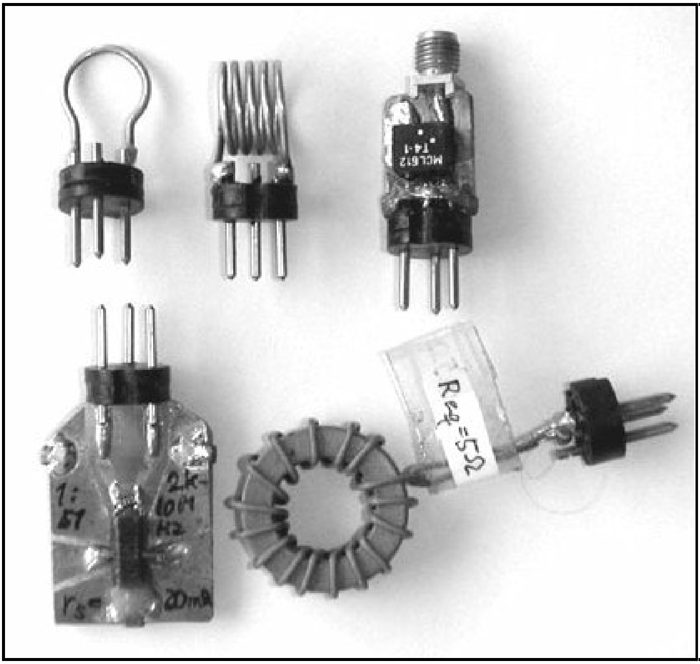

Fig 3: A selection of plug-ins for the Signal Detector. From left to right, top to bottom: single turn loop, 5 turn loop, Mini Circuits RF transformer, "small" current transformer, "large" current transformer.

on the 1 side. Mini Circuits data sheet specifies the 3dB frequency range for this transformer as 0.2 to 350MHz. My measurements agree. In my version it is not properly terminated. With 50Ω on the 1 side and 1.1kΩ of the IC inputs on the 4 side, there is quite a mis-match. If one desire a better 50Ω input, one can put a 240Ω resistor across the DIN connector on the 4 side. Mini Circuits also have 16:1 (impedance) transformers that would fit better, but they quit at some 80 or 120MHz. Your choice.

For current measurements I have prepared a few toroidal current transformers. They work like textbook examples! I put a 50Ω resistor through the core and connected it to a signal generator. Applying 50mV should result in 1mA and it was easily detected! If I loosen either the ground end or the hot end of the resistor, the meter drops to zero. If I move the resistor around within the toroid, the reading is exactly the same. So it is truly the resistor current that is detected, not some capacitive coupling to the windings. This is true up to past 500MHz in spite of the “not RF proper” hookup! This ought to be a really good tool for to determine currents in antenna elements, at least up to the 70cm band. One can excite the antenna with a regular signal generator (or a sweep generator) and see the magnitude of the resulting current (Figs 4 and 5).

The toroid must be wound along its full length, not just over a sector of it. There must be a resistor across the winding, and the inputs to the detector are connected across this winding and resistor. As with all transformers, the turns ratio squared equals the impedance ratio. These transformers induce a “resistance” in series with the conductor measured. See the conductor through the toroid as a “one turn winding”! Assume there are 33 turns on the toroid, and 10Ω across it! The turns ratio is 1:33. The impedance ratio is thus $1:33^2$ or ~ 1:1000. The “resistance” transformed into the conductor is thus 10/1000 = 1/100Ω or 10mΩ. See it as a shunt with a transformer!

Fig 4: Signal Detector measuring current in an HB9CV antenna.

For pick-up of electric fields, as opposed to magnetic fields, one can plug in a wire antenna in one of the input holes, or simply offset a pick up coil so it contacts one input only.

One plug-in unit is a 1:1 audio transformer with centre tapped windings (Fig 6). The secondary CT is grounded to the DIN connector mid pin via a tantalum electrolytic (+ to CT). I am not sure this is needed, but it may keep some noise down. The primary has a twisted pair and a 3.5mm phono plug. This is very useful for receiver measurements, as the transformer prevents potential ground loops and stops common mode noise. The plug goes into the tape recorder or external loudspeaker outlet of the receiver. Measuring, and trimming, a FM receiver 20dB quieting, for example, is now really easy. Note the deflection from the noise at no RF in to the receiver. Apply a CW RF and adjust the level so the reading is lowered by 20dB! Read off the RF level! Done! Actually, this is only an approximately correct reading as the detector, measuring the noise, is not a true RMS detector, but the result on regular noise is not much different. This point, where the FM receiver is quieted some 10 - 20dB by the weak CW signal in, is a very good point at which to trim the front end, and to compare different pre-amplifiers. The point is very sensitive to signal levels; with a slope of almost 2dB on the output per 1dB in for some receivers, and the NF of the pre-amp is included in the measurement. Even if it has a 20dB gain, but no better NF than the receiver input in itself, comparing the receiver with and without the pre-amp by this method will be very revealing! All you need, besides the detector, is a good, stable generator with a calibrated output attenuator!

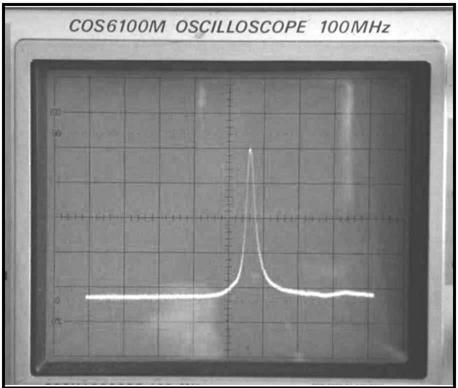

Fig 5: Output of antenna measurement on an osilloscope.

The magnetic fields from a resonator, fed -30dBm at 500MHz, is easily detected! (Fig 7)

4.

Applications, Reflectometer

You can make a simple but good Scalar Network Analyser (Reflectometer) with one Directional Coupler and a VCO (both available at Mini Circuits) in addition to this detector. An oscilloscope sweeps the VCO, or another slow oscilla-

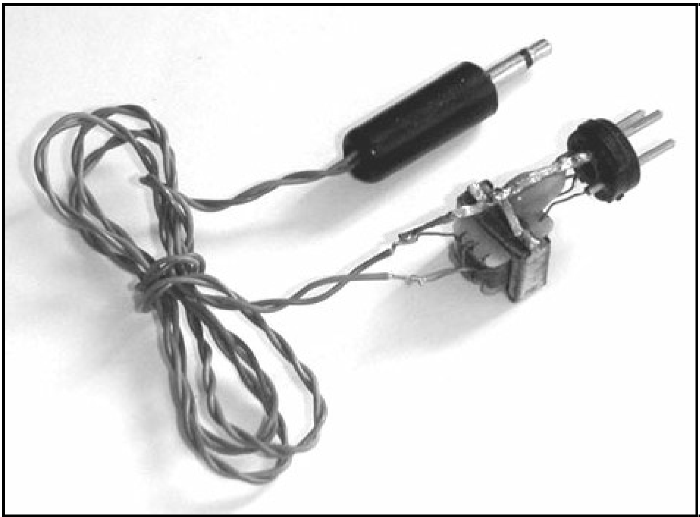

Fig 6: Audio transformer plug-in for Signal Detector.

tor sweeps them both. The RF signal reflected from, or transmitted through, the device under test is detected and nicely plotted on a logarithmic graph that can be up to 70 - 80dB deep with this detector! Connect the scope vertical input to the AD8307 pin 4, using a probe.

A few tips for the builder: the second tone from the VCO may be at some -20dBc (relative to the carrier) so when you tune your DUT to a Return Loss to better than 20dB, you will see a flat bottom on the graph! It is the second tone (and others) for which the DUT is not a good match! The detector is sensitive to them as well. A 50Ω terminating resistor will terminate all energy and a return loss of 35dB or better is a good result, verifying the function. (Notice that return loss is a loss, so it is already negative!)

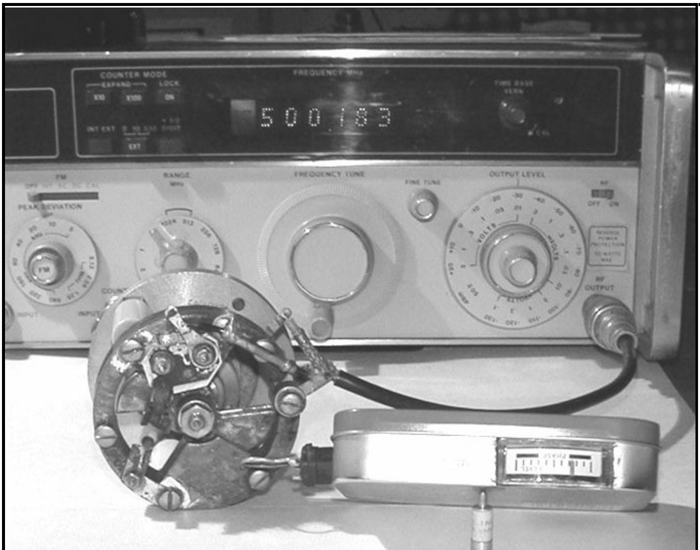

Fig 7: Measuring the magnetic field from a resonator fed only -30dBm at 500MHz. The deflection on the meter is clearly visible.

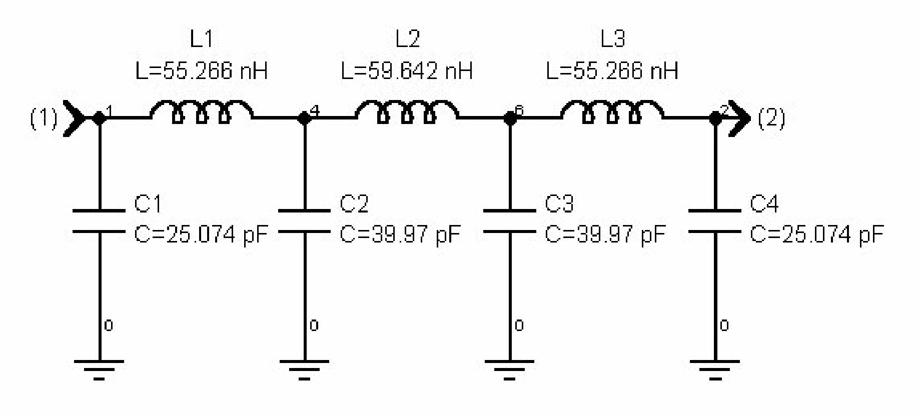

Fig 8: Circuit diagram of the low pass filter.

For good results you will probably need a low pass filter. When using a 100 - 200MHz VCO the filter should be at 200MHz of course, and a 7 pole Chebyshev filter is easy to build and will do very well. Let us settle for a 0.3 dB pass band ripple! Courtesy of Eaglewares GENESYS it is a matter of seconds to calculate it! (Figs 8 and 9) This is for 50Ω in and out. Here it may be good to keep in mind that a filter like this is not the filter you think it is unless it is reasonably well terminated!

The output from a VCO, like the ones I

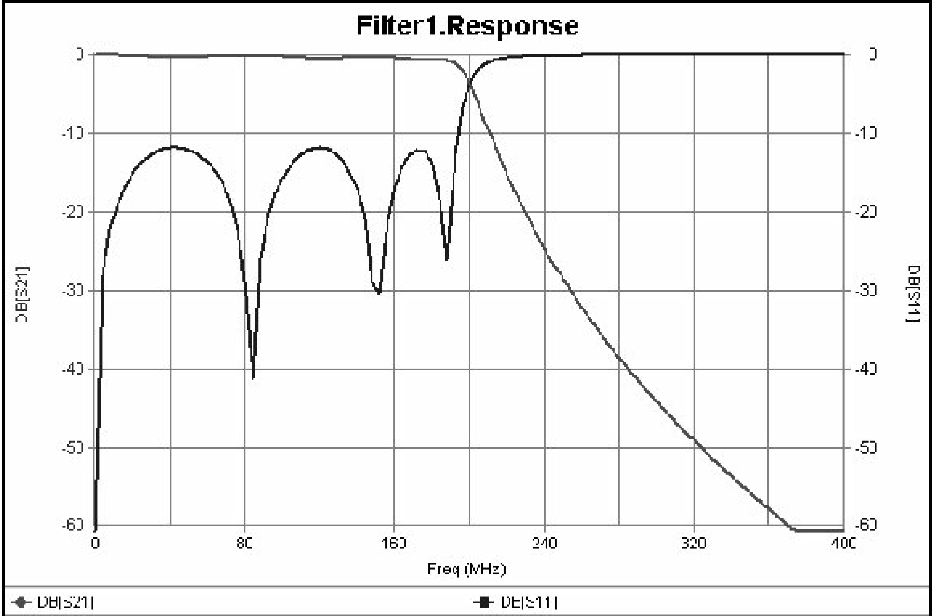

Fig 9: Response curve of the low pass filter.

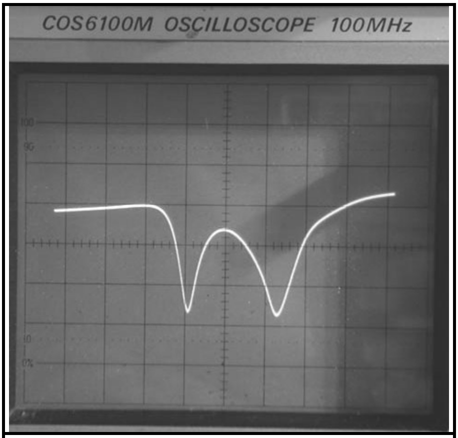

Fig 10: Return loss of a band pass filter. The span of the display is about 50MHz. It shows that the filter is no good because the return loss rises to zero between the dips, it should dip through the entire band.

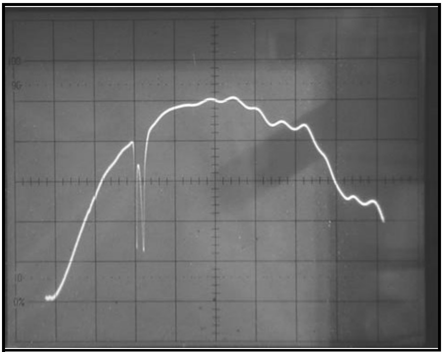

Fig 11: Return Loss of a band pass filter. The span of the display is some 500MHz. It shows that the filter has no spurious responses in this range.

have suggested, has a lot of output power. The POS-200, in "½ crystal can", covers 100 - 200MHz and produces an output of 10dBm! Harmonics are typically -24dBc for this one and for $12 you can probably not make a better one yourself! While you are planning the shopping list anyway it is a very good idea to include a few of their small, fixed, attenuators. Padding the filter on each side with a 5dB attenuator will leave -2dBm for output (a dB is lost in the filter!) and ensure a good operating environment for the filter as well as a good 50Ω output port for the analyser.

The reason for padding the filter with attenuators is that neither the VCO, nor the load, may be very accurately 50Ω.

We can see that at 150MHz the second harmonic (300MHz) will be approximately ~45dB down. -24dBc was promised in the spec already, it will now be -69dBc, and the signal is very pure and good enough for our measurements! For the third harmonic the filter will of course attenuate even more, some 80 - 90dB.

This filter can be realised with 24 and 39pF capacitors and all coils wound with three turns of 0.5mm Cu on a 5mm mandrel. The first and last coils are spread to 2.7mm length, the middle to 2.4mm. 27pF (instead of 24pF) works, but not as well.

The return loss of this filter, approximately 12dB, cannot be improved. Selecting a lower pass-band ripple would improve it, but the skirts of the filter would worsen! It is good enough and a result of how much pass band ripple it was calculated for! The resulting cut-off is pretty good though, and it is all a set of compromises!

One way to realise the filter is to build it on a little piece of PCB laminate. FR4 is fine! Temporarily terminate one end with two 100Ω resistors, one each way to ground! This is a lot better than one single 50Ω resistor! Even when using small SM components.

Put your Network Analyser (Reflectometer) to the other end and tweak the coils for best (lowest reading) of return loss in the pass band! This is a better, and more sensitive, way than to tune for maximum transmission. Which in the end should be checked anyway of course. This filter will have an Insertion Loss of some 0.4dB for most of the band and 0.6dB at worst.

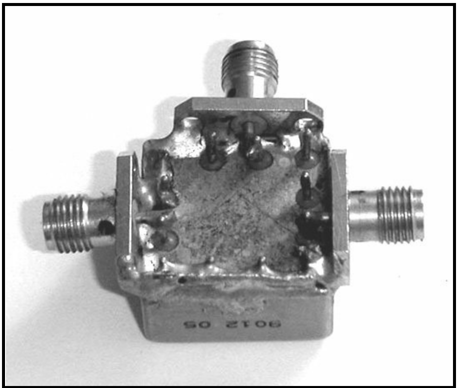

Fig 12: Mini Circuits reflectometer P/N: PDC-20A-5.

The filter in Figs 10 and 11, swept as I suggested, was intended to keep some strong FM station out of the receiver while I picked up 137.62MHz Weather Satellite signals. For reasons long forgotten, it is too wide, 120 - 140MHz, and not very good, as you can see. But it kept the 94.1MHz out...

It may well be beneficial to build filters of this topology as a “fish skeleton” with the inductors lined up as a backbone and each capacitor realised by two components in parallel, one to each side ground plane. This will also allow for tweaking odd component values. 10pF + 15pF (or 12 + 13) is 25pF for example. And 22 + 18 = 40.

This is a lot of filter talk for a detector article, but if you want to make a Reflectometer, this is what you will face sooner or later, so you may just as well plan for the filter from the beginning! It

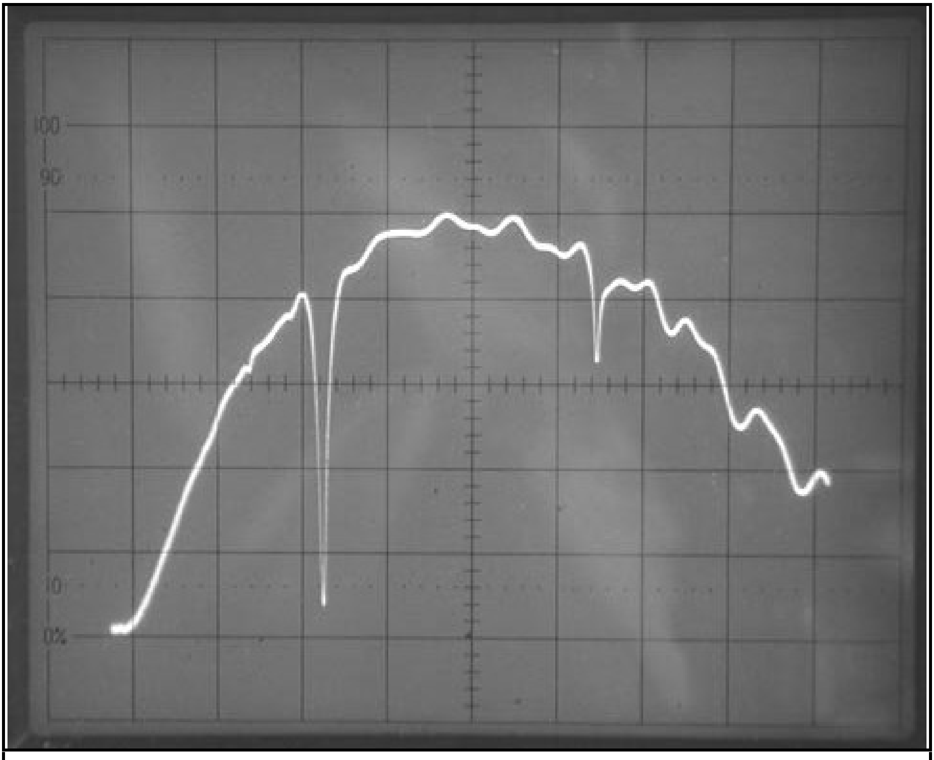

Fig 13: Return Loss of the 145MHz HB9CV antenna shown in Fig 4. The span is approximately 500MHz. The main dip is at 145MHz with a small dip at 450MHz.

does not cost much anyway.

With the low cost of VCOs and home built filters, one might as well make one little board for each octave of interest (Fig 12). The sweeper, directional coupler and the detector can serve all of them. It will be a lot simpler, and less expensive, than to try to make some one clever device covering DC to light...

The sweep is about 0 - 500MHz and we can see the 3f entry where the antenna (HB9CV) goes into resonance again. The match at 145MHz is better than RL 20dB, or near "perfect" (Fig 13).

5.

Conclusion

A very inexpensive detector with a wide range of applications has been described. It is simple project to complete, and it can be as fancy or elaborate as the constructor desires.

The very wide dynamic range, up to 92dB, and logarithmic ("linear dB") output is very attractive to the experimenting amateur and has a wide range of applications. Not only for measurements, but for such things as level control of signal sources as well.

The detector is virtually frequency independent up to 500MHz and predictable to 1GHz.

It may be said that: "If you want to gain a more intimate insight in your little projects, try writing an article about them!" As I wrote this, and took the pictures, it became clear that a simple plug for to connecting the output to a scope, or a recorder, would be a good idea. I added an RCA plug and found that the 1MΩ input of the scope loaded down the output of the AD8307 so I only got some 40dB range on the meter (and the scope). Therefore, the OP I mentioned earlier is probably more than a good idea! Skip the transistor all together!

Pick a resistor between the OP output and the meter so the meter gives a full deflection for the full input to the AD8307, about 2V differentially. Or select it to give some nice dB scale factor on your meter! Also: put a 100Ω or so in series with the OP output and the plug to the scope/recorder. This way the OP will never see a capacitive load (=> instability!) with long, shielded, lines.

Finally: it was a good move to add a few kΩ trim pot (10kΩ would be fine) to pin 5! The DC level of the output can now conveniently be adjusted and no diodes are required... Sensitivity remained unchanged by this.

6.

References

[1] The AD8307 is a very versatile circuit and it has so many abilities that I cannot list them all here. I suggest that you download the 20 page PDF data sheet from http://www.analog.com or

http://www.analog.com/Analog_Root/productPage/productHome/0%2C2121%2CAD8307%2C00.html

[2] Mini Circuits http://www.minicircuits.com