The LogProbe Logarithmic Detector

Here is a design case history describing a versatile measurement accessory with many RF applications

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During the last few years, some attractive RF detector ICs have become available. An IC in itself, of course, cannot be used directly for the many daily test and measurement challenges on the lab bench. Thus, an instrument to meet these challenges needed to be designed. This article introduces the LogProbe® a versatile logarithmic detector with a wide frequency and dynamic range.

In contemplating the design of such an instrument, no such device was known to exist, so "prior art" was not of much use. Several points had to be addressed if the instrument was to become an acceptable general purpose tool, including power supply, enclosure, system considerations, output signal conditioning, manufacturing cost and ease, and internet friendliness.

Design requirements for each feature

Power supply — The detector IC runs on 5 volts. It would be useful if the instrument could run on all kinds of voltages. A series regulator that can handle >30 volts would suffice.

Enclosure and system — The detector was visualized to be used with all kinds of "probe tips." The problem, then, is to identify a connector format that will accommodate those probes but that is inexpensive and available worldwide. The chosen connector should not require an enclosure any larger than necessary. These requirements are set by several applications foreseen from the outset.

With a differential input on the IC, one obvious use is to connect a floating pick-up coil for detecting magnetic (RF) fields. In general, this excludes coaxial connectors. Another use is to ground one input and connect a small wire to the other input to detect electric fields. The convenience of just plugging in a wire or pin speaks for a female connector.

Other applications will connect a signal via a coaxial connector, with or without a 50 or 75 ohm internal termination. Thus, an adapter must be designed. Another suggestion may be the implication of a tuned input circuit for sensitizing the detector for one frequency range.

The same housing as an adapter might be used for a 20 dB preamplifier for small-signal work, or a directional coupler for measuring return loss from filters and antennas using a sweep or signal generator.

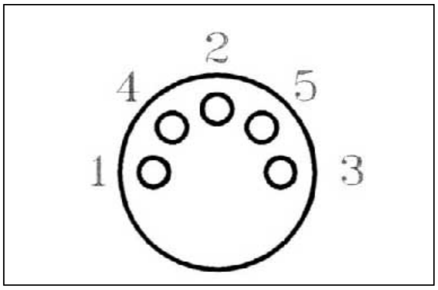
Non-RF uses may also be considered. An accelerometer will need a charge amplifier, and a fiber optic detector needs a photo detector and a transconductance amplifier. With the large dynamic range, a logarithmic detector is an excellent bridge detector; could we possibly make an entire "plug-in" RF bridge? More applications are likely to be found and developed in response to the user's own applications.

Obviously, the right connector body type needed to be chosen from the start. It had to be flexible, small and rugged, as well as shielded, since the detector is very sensitive.

Output signals — Output signals from detector ICs do not have a good scale factor or much drive capability. Thus, an output amplifier is needed. Since a dual op amp takes as much room as a single one, at least in an 8-pin package, one could let the second one perform DC offset of the output to almost 0 volts for no input signal. With a possibility of >30 volts applied, the op amp will have to be able to handle this or run off of only 5 volts. As we will see later, an output voltage of 10 volts may be desirable, so the >30 volt option is really the only choice.

Cost and manufacturing — If the entire device could be built on a printed circuit board that fits into a strong connector body, many of the goals would be reached.

Internet support — Recently, a product does not seem to be considered a product unless it has a web site. A name suitable for the product and a web site both were both of prime importance. Thus, the the name LogProbe was chosen; fortunately, the trade name and the site name both were available.



▲ **Figure 1. LogProbe front view showing connector pins.**

▲ **Figure 2. Both a 3-pin and a 5-pin plug fit into LogProbe.**

▲ **Figure 3. A simple pickup for magnetic fields.**

▲ **Figure 4. The same device as a pickup for electric fields.**

The final design choices

For the enclosure, a DIN audio connector housing by Preh-Werke, Bad Neustadt, Germany, was chosen. It is a one-piece cast metal device, strong enough to survive rough handling, and the DIN format is a common standard throughout the world. It is economical and compatible with many mating plugs. Connector and enclosure problems were both solved with one product.

The inherent symmetry of the connector is appealing, using the center pin for ground and the outermost two for the differential input signal. This leaves two pins in between, which is fine since any active plug-in will need power. I elected to put out the input supply V+ direct through to pin 4. Pin 5 can be used for the output signal from the detector output amplifier. This is not initally connected, since it causes the output to be noisy if the input is open. The customer can easily add this internal wire if he wishes, making the entire device independent of the cable at the other end. It can be a temporary plug in itself for some other instrument! (See: Output on pin 5)

Another advantage of the DIN audio connector format is that the 3-pin 180 degree version fits in a 5-pin 180 degree receptacle, leaving the "in-between" positions open. A passive device can use a 3-pin plug and an active device the 5-pin plug.

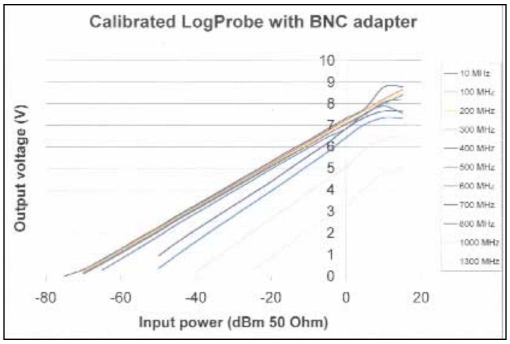
The output should have some sensible scale factor. I decided upon 10 dB/V. For the full dynamic range of 92 dB (9.2 V out plus a little "at the bottom" for no input condition), this requires at least a 10 volt supply. A 9 volt battery will do quite well, except for the uppermost 5-10 dB of range. As a matter of fact, 5 volts are already usable for the first ~30 dB. Each customer can provide whatever supply they like. Each LogProbe is delivered with a 9 volt battery, which should do until the customer identifies his needs and chooses a wall plug transformer, a couple of 6 volt Lithium batteries or other power supply.

The current consumption is 20 mA; the output amplifier has a ±40 mA drive capability; and there is a 50 ohm resistor in series with the output line, eliminating capacitive load problems. If operated with very high input voltages and large output currents, the internal 5 volt regulator may shut down thermally, but it will restart after it has cooled down.

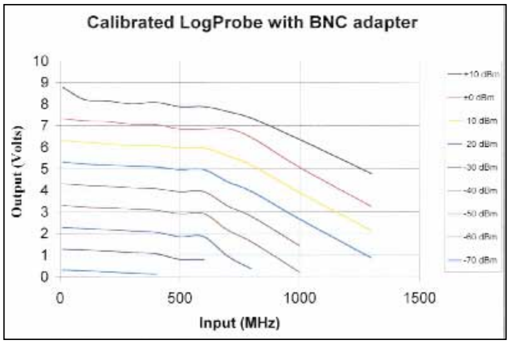
A prototype BNC adapter was built with an internal 50 ohm termination, and the sensitivity was measured over frequency as far as the available source allowed. In the plot in Figure 5, the output voltage is entered for several frequencies and for each 5 dBm from 10 MHz to 1.3 GHz. In Figure 6, the same set of data is presented, but with the power as a parameter.

We can see in the first diagram how linear the response is and in the second how it is almost flat to 600 MHz (a 3 dB rolloff), and thereafter dropping by about 6 dB/100 MHz. The temporary BNC adapter may be the cause of much of this. An improved design has not yet been tested.

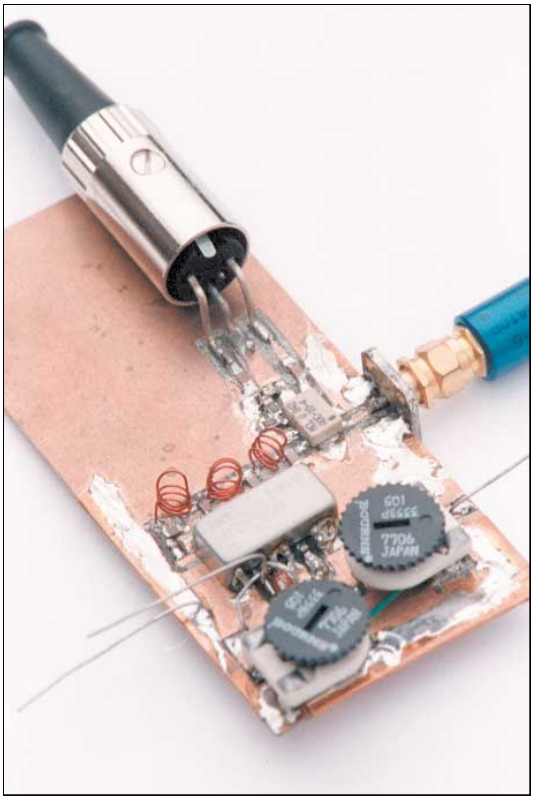
We can also see how the output signal for very small input levels actually reaches 0 volts. I have since adopted the practice of adjusting the output to 5 volts for –30 dBm at 100 MHz. This leaves the output level at a few hundred mV with no signal. This way, very small levels can be detected, even if they are not yet driving the detector into the "linear dB" region. A range of 20 to 30 μV can be detected, and the "linear dB range" covers from about 55 μV to 2.2 V, a dynamic range of 92 dB.



▲ **Figure 5. Response with frequency as a parameter.**



▲ **Figure 6. Response with power as a parameter.**



▲ **Figure 7. The VCO, low pass filter and directional coupler with LogProbe plugged in.**

Applications

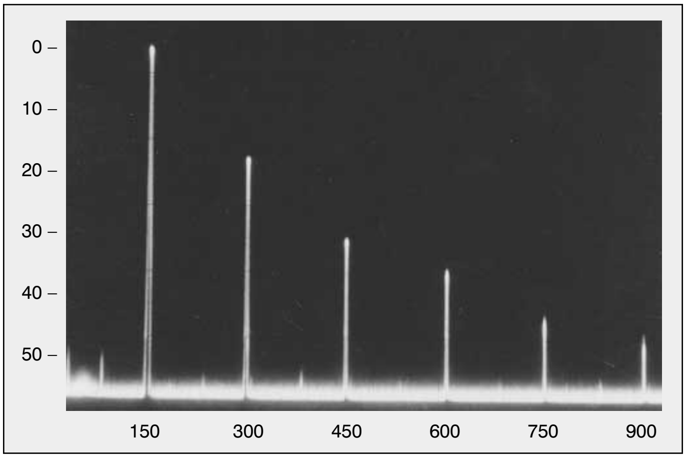
As a scalar network analyzer — I put together a 100 to 180 MHz VCO (Mini-Circuits JTOS-200), tuned by the oscilloscope sweep output, and a directional coupler (Mini-Circuits ADC-10-4) to measure the reflected signals from objects. LogProbe can be plugged in via three short 1.2 mm diameter wires sticking up from the circuit board. Figure 7 shows the setup.

The VCO output signal has a strong harmonic content. For accurate measurements, especially of return loss ($|s_{11}|$), they must be removed with a low pass filter.

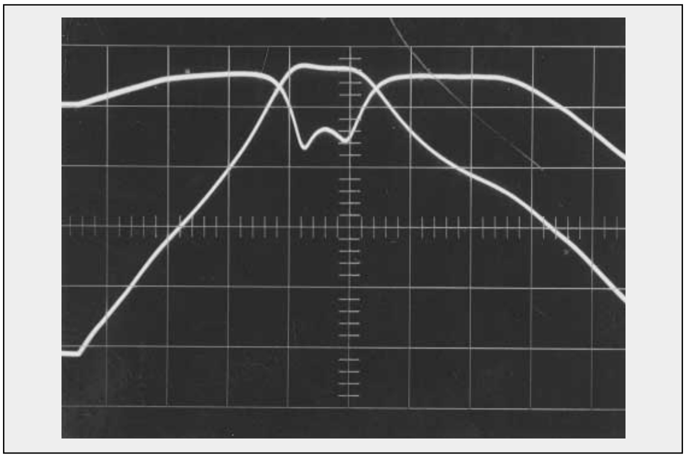
When the JTOS-200 is set to 150 MHz, the second harmonic is only 20 dB lower (Figure 8). If a load is well-tuned for 150 MHz, with a return loss (RL) of about 30 dB, the RL for the 300 MHz tone may be near zero. This limits the RL measurement at 150 MHz to –20 dB. A 5th order LP filter for 200 MHz was built to follow the VCO, and the result was more pleasing.

A bandpass filter for 137 MHz was the test circuit. The output was terminated and the RL $|s_{11}|$ was measured. Its output was then connected to the LogProbe via the BNC adapter and the $|s_{21}|$ plot was double-exposed onto the same scope camera film.

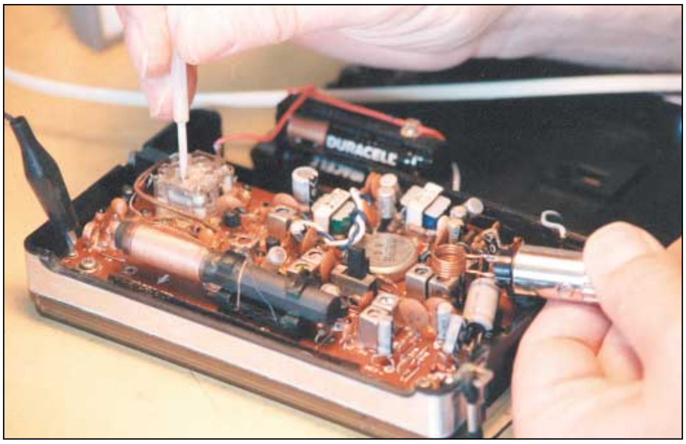
On both traces, the vertical scale is 10 dB/cm. The bandpass filter has, at best, only a ~10 dB RL and can clearly use some tweaking. On the left edge we can see the $|S_{21}|$ flatten out at –47 dBc. This is most likely the level of the second tone going through the lowpass filter, reflecting from the test bandpass filter as it should. (The sweep start is ~100 MHz, the second tone is ~200 MHz, barely reduced by the lowpass filter.) The RL from the pass region of a filter is a very sensitive indi-



▲ **Figure 8. JTOS-200 output set to 150 MHz.**

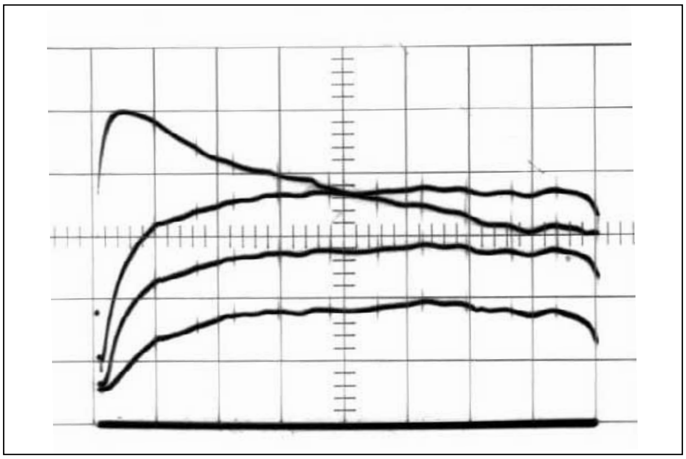


▲ **Figure 9. Plot of the output of a BP filter.**



▲ **Figure 10. When coupling to some IF transformers, one can pick up enough signal with a coil outside the ferrite core trimmer hole.**

▲ **Figure 11. LogProbe fitted with a larger toroidal coil (useful for antenna element current measurements).**



▲ **Figure 12. The oscillogram results from a current transformer used directly on a 50 ohm adapter.**

cator of how well the filter is tuned.

Tuning up RF and IF circuits — With LogProbe's sensitivity, it is easy to pick up a signal with a small piece of wire in one input. Holding the wire near the collector of an IF or RF transistor (or the plate pin of a tube, for the more nostalgic among you) while applying a swept source to the receiver input is a useful method that speeds up the work and presents almost no load of the circuits to be tuned. The large dynamic range makes this method possible with one instrument, detecting the weak signals near the receiver input to the near volt levels at the end of an IF strip.

On some IF transformers, one can even pick up enough signal with a coil outside the ferrite core trimmer hole, as shown in Figure 10. Current monitoring with LogProbe connected to a toroidal coil will suffice. LogProbe also works with a larger toroidal coil, e.g. for antenna element current measurements (Figure 11).

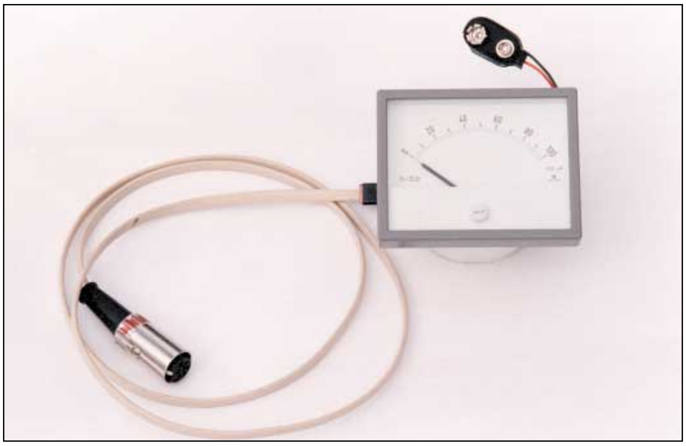
Remember that a current transformer must always be terminated with a low resistance. It can thus be used directly on a 50 ohm adapter. If the toroid has 7 turns and the measured currents pass through once, the 1:7 turn ratio reduces the 50 ohm adapter load by 1/49 in series with the current carrying line, or about 1 ohm.

The oscillogram in Figure 12 (4 exposures) shows an application of just this (but using a very small toroidal coil). The three horizontal traces are the base currents into a transistor, swept from 0 to 500 MHz with a 10 dB level difference between each trace. The source level is then returned to the middle trace and the current probe is moved to the collector (RF grounded), and a graph shows the results. We can see that the current gain at the peak, ~50 MHz, is close to 30 dB higher than the middle base current trace, and at ~250 MHz, the collector current is about 9 dB stronger. So, the current gain at 250 MHz for this transistor is ~9 dB. Vary the bias conditions and see the gain vary in real time on the screen.

In another practical use, a friend needed his satellite dish adjusted. A directional coupler and LogProbe did the job quickly. Even though LogProbe does not have much sensitivity left at the high end of the downconverted band, there is enough at the lower end (950 MHz) so that the dish can be aligned.

Output on pin 5 — Imagine that you have built some kind of signal or sweep generator and you want to maintain a level output amplitude. Connect the LogProbe output to pin 5 internally and provide a 5-pin plug on the generator. You can now incorporate LogProbe and supply power through pin 4, signal(s) on pin(s) 1 and 3, ground on pin 2, and you can get a control signal for a PIN diode attenuator on pin 5. When using LogProbe for other uses, unplug it and use it. The only drawback is that the output signal gets a bit noisy for pin 3 open and there are no signal conditions. If you use one input only, use pin 1 and ground pin 3.

If the LogProbe is permanently hooked up to a meter



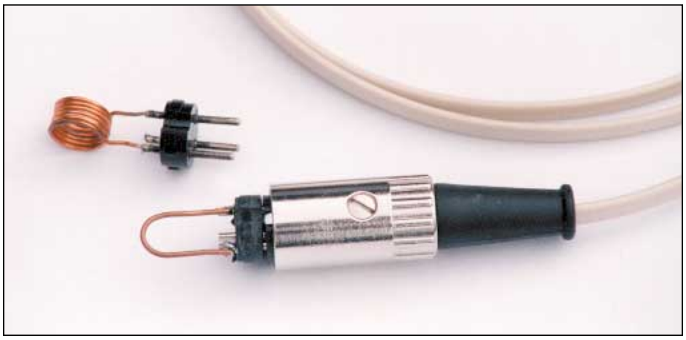
▲ **Figure 13. LogProbe is permanently hooked up to a meter, and if one needs to look at the response with an oscilloscope, the probe is clipped to the back of the meter.**

(FS = 10 volts) and we to look at the response with an oscilloscope, simply clip the probe to the back of the meter. With a BNC adapter (preferably without the 50 ohm termination), one can even use a regular 10:1 oscilloscope probe and get flat response within the limits of the probe's performance. The load on the tested circuit is then ~9 Mohms plus the capacitance of the probe. The input impedance of the LogProbe is 1.1 kohms differential, in parallel with ~3 pF. An inserted DIN plug adds about 2 pF. Plugged in, the 6-turn coil (350 nH) resonates at approximately 250 MHz.

Limitations

The inputs of the LogProbe have no protection against overvoltages. Protection circuits would compromise both sensitivity and frequency response. If needed, one can easily make a protection for both inputs with four diodes and a 5 volt Zener diode fed via a resistor from the V+ at pin 4. Do not expose the inputs to voltages outside $0<V_{IN}<5$.

The usefulness of this device does not extend down to DC. For frequencies below a few MHz, the output "ripples" at twice the input frequency. Both positive and negative input signals will give a positive output signal.



▲ **Figure 15. Plugged in, the 6-turn pickup coil resonates at ~250 MHz.**

▲ **Figure 14. A regular 10:1 oscilloscope probe can be used with a BNC adapter.**

Conclusions

The LogProbe is not just a detector, it is an instrument in itself and the heart of a whole measurement system that will continue to grow as more attachments are developed. As it allows for unusual and efficient methods in measurements and trouble shooting, it is a rule maker and a rule breaker. ■

References

When reading this article, it may be useful reading to study the data sheets of some ICs performing these functions. Data sheets for the Analog Devices AD8307, AD8309 and AD8313 will be quite helpful.

Author information

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Pressebo Electronics' web address may be accessed at www.pressebo.com, and the LogProbe information is at www.logprobe.com. LogProbe is a registered trademark of Pressebo Electronics.

▲ **Figure 16. LogProbe with a directional coupler.**