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Wide Dynamic Range Field Strength Meter

This portable 90-dB dynamic range RF field strength meter is simple to build.

While reviewing the specification sheet for the venerable AD8307 logarithmic RF detector IC, I noticed that the output circuit type shown in a block diagram is a current source. It occurred to me that this feature could be easily utilized to drive a conventional analog meter directly. Although I enjoy building gear that utilizes modern day microcontrollers and wireless devices my thoughts became focused on how simple it would be to build a wide dynamic range field strength meter (FSM) by mixing recent and legacy technology. This article describes a portable 90-dB dynamic range RF FSM that is simple to build. In comparison to the traditional basic diode detector type FSM, this minimal component count instrument can be used to measure field strengths over a much wider dynamic range and with much better accuracy.

The Analog Devices AD8307 logarithmic detector used in this design has been available for a few decades and has appeared in many Amateur Radio projects in the past. This well-proven detector has been typically used in microcontroller-based RF power measurement applications where the output level of the detector is digitized and the resulting measurement displayed on an LCD screen. The simplicity of the design that is described here stems from the use of a legacy d'Arsonval panel meter that can be directly driven by the AD8307 without the need for any microcontroller or any additional active component circuitry.

The use of a legacy analog panel meter might seem somewhat archaic in our modern digital era. However, in my opinion, the analog meter greatly simplifies the design, is sufficiently accurate for a FSM, and perhaps most importantly, uses circuitry free of RF EMI. This factor is significant as during normal use this broadband sensitive instrument is very often in close proximity to the sense antenna. Thus an EMI-noisy digital design could result in sensitivity-limiting residual readings. Additionally, analog meters can be read at a glance and are easy to view in bright sunlight — a typical field measurement environment. Finally, while adjusting equipment to obtain maximum or minimum signal strength, analog meters provide a much easier to use peak or null signal strength indicator than a digital display.

Design Concept

The block diagram provided within the AD8307 spec sheet indicates the output circuit consists of a current source mirror providing an output current that varies at a rate of 2 μA per dB of input signal level change. This output current is usually passed through an internal 12.5 kΩ load resistor. The 2 μA current change within this load resistor results in an output voltage variation of 25 mV/dB. In more typical designs this voltage level is digitized via an ADC analog input of a microcontroller to permit digital processing. The different approach used here feeds the 2 μA/dB current source output directly to a low resistance 200 μA panel meter. The output voltage of the detector is shunted to near ground by the low resistance meter, which in this circuit design is connected in parallel with the internal load resistor. The detector 2 μA/dB output drive that is fed through the 200 μA meter (which has a 0-to-10 scale) results in a scale calibration of 10 dB per major division. Since I already had a good quality Weston 50 μA meter on hand that conveniently had both 0-to-10 and ± 5 zero-center scales, I adopted it for use here. I reduced the meter sensitivity to 200 μA by adding a suitable shunt resistance. The AD8307 and 200 μA panel meter along with a few surrounding passive components are all that are needed to build a reasonably accurate, wide dynamic range FSM.

Expanding the Scale

After experimenting with the prototype proof-of-concept basic circuit and confirming that it worked as expected, I decided that a 10:1 scale expander capability would be beneficial. The 90-dB wide dynamic range scale is very desirable for viewing the large variations expected from antenna pattern front-to-side lobe, front-to-back ratios, and for quick checks of transmitter ERP levels. However such a wide dynamic range scale doesn't lend itself well for viewing small level changes.

When using the 100 dB analog scale a 1 dB change corresponds to a shift of only about a needle width. In some cases 1 dB is not significant, for example if doing an antenna front to back test where the ratio might be around 25 dB then a dB or two, one way or the other, just doesn't matter much. But if tweaking an antenna for maximum gain or an RF amplifier for maximum output, +1 dB does matter as it represents about a 25% power change. To remedy this deficiency I added a simple op-amp add-on circuit with a gain of 10 that uses a potentiometer for setting a zero center reference. This provides a 10:1 scale expansion for performing relative power tests. When activated this circuit expands the scale to 1 dB per major division, which provides a good fine tuning indicator. The measurement needle width resolution becomes roughly a tenth of a dB — fine enough for most field strength measurement needs.

Instrument Power

This instrument can be powered from either four internal AA cells or from an external 5 to 6 V source. Power supply design for the basic FSM circuit is simplified because the AD8307 output current calibration is not, within fairly broad limits, sensitive to supply voltage variations. A bench test confirmed that the supply voltage can be varied from 4 to 6 V without a noticeable change in detector output current for a given RF input level. There is no need for a voltage regulator. Coincidentally, the normal discharge curve for a 4-cell alkaline battery from fresh to end-of-life exhibits a voltage decline from 6 down to 4 V. A battery saving momentary push button power switch, intended for making short duration measurements, ensures the internal batteries are not left under load for extended periods. A switch and multiplier resistor are provided to also permit the use of the panel meter as a voltmeter with a 10 V scale for checking the power source voltage level.

For longer term RF level measurements external power can be supplied from any clean 5 to 6 V dc power source. For portability a suitable adapting USB cable would allow the use of a rechargeable lithium 5 V battery bank similar to those intended for cell phone power backup. The load is less than 20 mA, so a typical lithium pack should provide power for several days of continuous operation on a single charge. Not all USB battery banks are suitable for this application. Some designs emit switching-regulator EMI and/or detect this very light load as a disconnection resulting in auto shut-off after a short delay.

Circuit Description

Figure 1 is the schematic for the basic version without the scale expansion add on. For applications where scale expansion is not important this basic circuit is all that you need. When equipped with a 1:16 impedance ratio input transformer it will provide a reasonably accurate RF signal power measurement ranging from -80 to +10 dBm. Each major division on the 1-to-10 division scale represents a 10 dB change. Figure 2 illustrates the conversion chart of a voltage range from roughly 70 µV to 700 mV rms within a typical 50 Ω impedance circuit to dBm.

Most popular AD8307 power meter circuits use a simple unbalanced input design rather than harnessing the differential balanced input capability of this device. Commonly the simpler unbalanced design is obtained by shunting one input to RF ground with a bypass capacitor and by connecting the other input via a dc-isolation coupling capacitor to a 51 Ω input termination resistor.

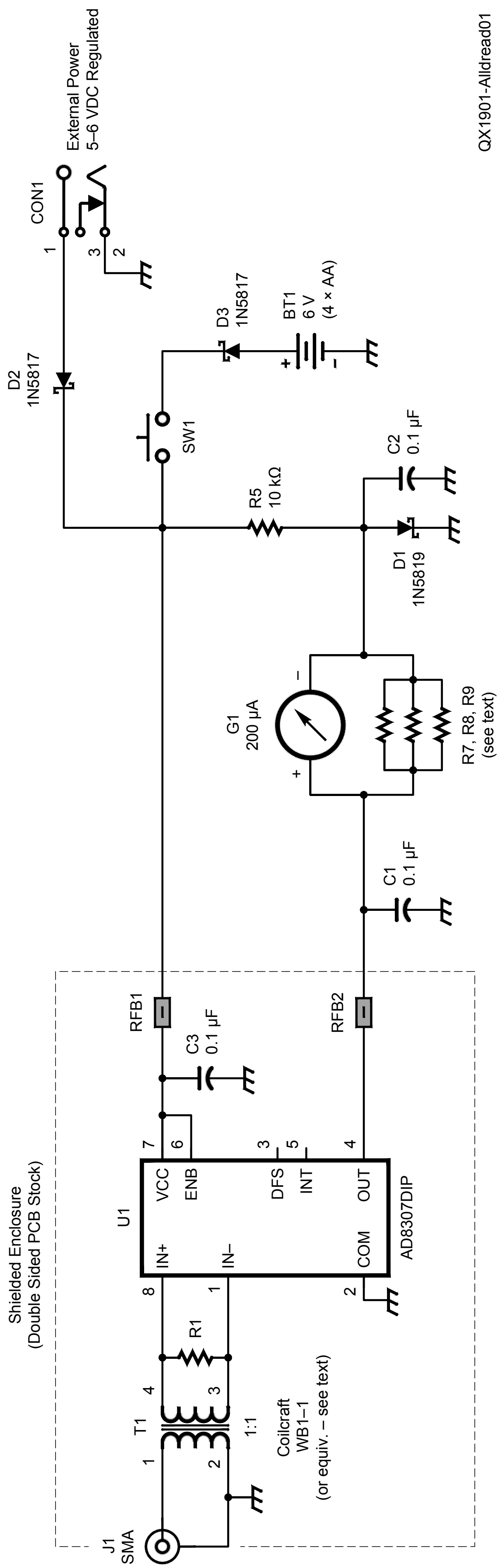

Figure 1 — Basic wide dynamic range field strength meter schematic.

This provides a simple broadband 50 Ω unbalanced input. For this application a transformer-coupled differential input offers some advantages. Transformer coupling that uses the balanced input to the IC offers improved common mode noise rejection, low frequency power line related noise isolation, input circuit protection from extraneous voltages and the opportunity to improve the sensitivity without the need for additional active components. The sensitivity improvement is obtained by more closely matching the detector differential input impedance of 1.1 kΩ to 50 Ω, by using a broadband step-up RF input transformer.

The instrument sensitivity is directly proportional to the impedance ratio of the wide band input transformer (T1 in Figure 1). The design trade-off for using a high step-up impedance ratio transformer is loss of high frequency response. This design uses a 1:16 impedance step up ratio. The frequency response (Figure 3) is flat within 1 dB across the LF and HF spectrum segments then rolls off 2 dB at 50 MHz and about 6 dB at 150 MHz. Although the roll-off is significant across the lower half of the VHF spectrum the instrument is still quite usable up to 150 MHz. Of course a calibration factor must be added if performing VHF absolute power measurements.

The 1:16 transformer steps up the 50 Ω input source impedance to 800 Ω. Compared to a transformer-less input design, this improves the instrument voltage sensitivity by a factor of 4, or 12 dB. The value of resistor R1 in Figure 1 depends on the transformer ratio. For example: with 1:1 use 51 Ω; with 1:4 use 240 Ω; with 1:6 use 430 Ω, with 1:8 use 620 Ω; and with 1:16 use 3 kΩ. In this case resistor R1 is 3 kΩ, which is connected across the 1.1 kΩ AD8307 differential input impedance and matches the 800 Ω transformer secondary impedance. This input circuit conveniently provides a close 0-10 scale meter calibration alignment that can be directly related to -90 to +10 dBm absolute power. Note that use of the -90 to -80 dBm bottom 10% region of the meter scale (0-to-1 area) is not recommended for obtaining accurate measurements, since that low level region is influenced by the AD8307 detector noise floor.

Figure 4 shows a frequency sweep of the input return loss. The input match is good with return loss greater than 14 dB (VSWR less than 1.5:1) up to 30 MHz. Then above 30 MHz the VSWR climbs to 2:1 at 50 MHz and 3.5:1 at 144 MHz. If performing a mismatch sensitive measurement above 30 MHz a 6 dB coaxial attenuator connected directly to the input should be used to improve the VSWR to 1.3:1 or better.

The logarithmic detector circuitry of

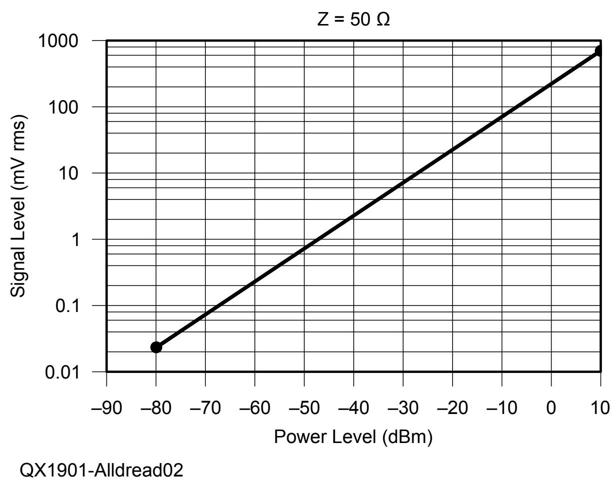

Figure 2 — Meter scale units conversion chart in a 50 Ω environment.

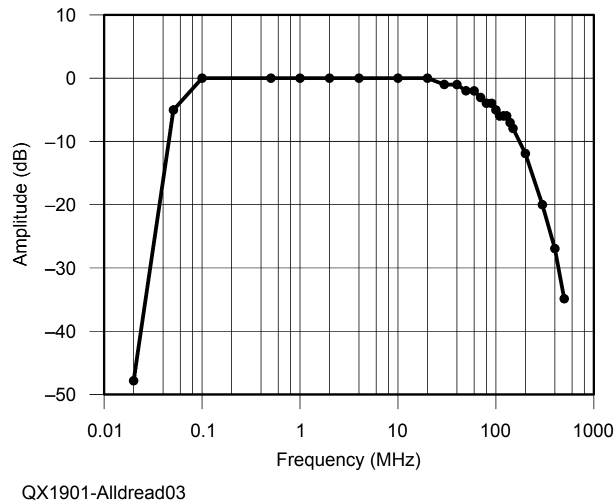

Figure 3 — Field strength meter frequency response.

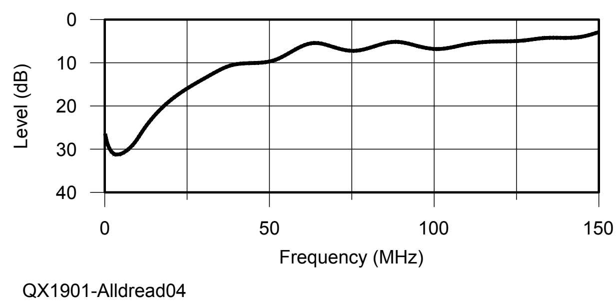

Figure 4 — Field strength meter input return loss frequency response.

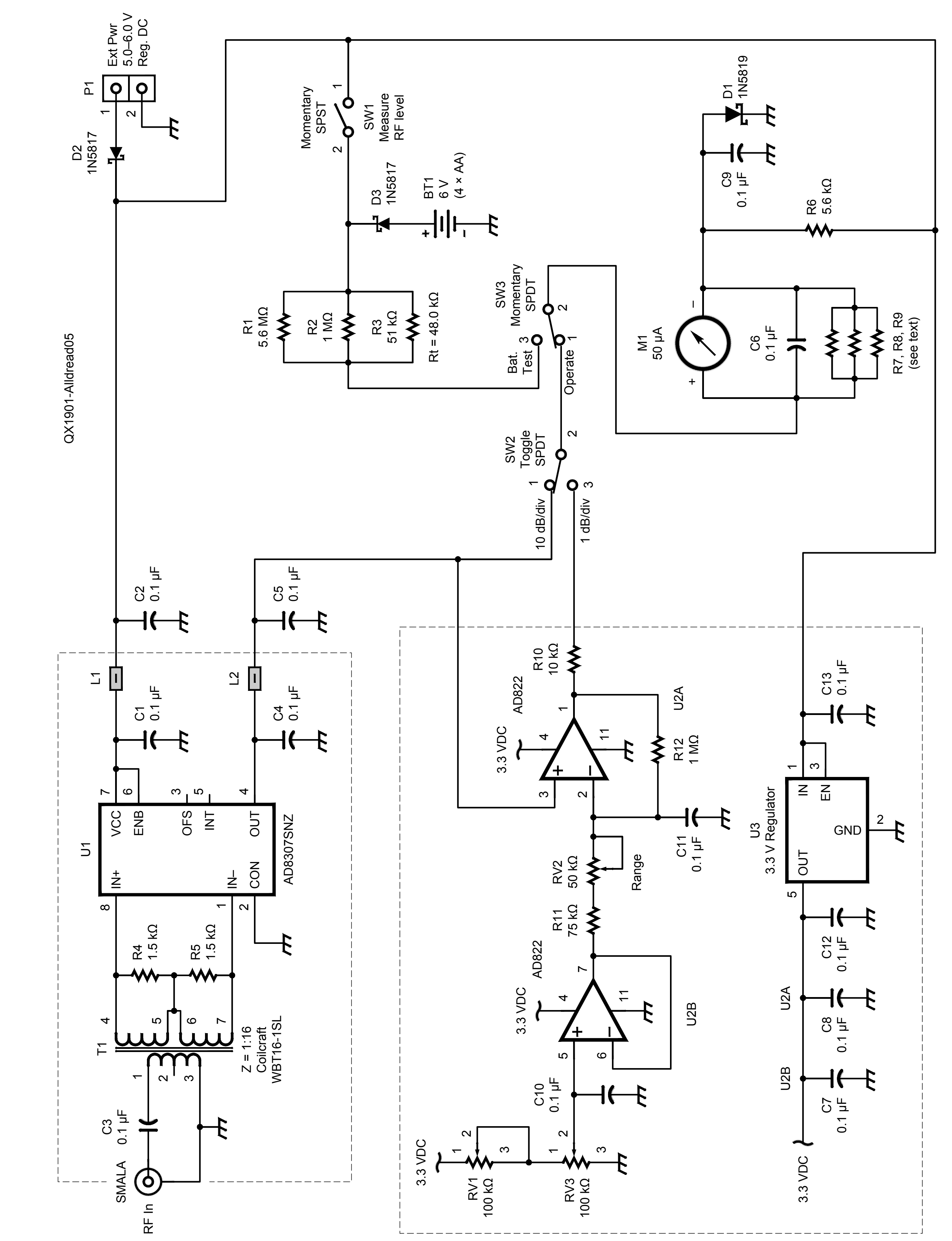

Figure 5 — Field strength meter schematic including the 10:1 scale expansion circuit.

Figure 1 is mounted in a separate RF-tight enclosure. For detailed information on the AD8307 logarithmic detector please refer to the exceptionally good data sheet[1] provided by Analog Devices. Feed-through ferrite beads and bypass capacitors are provided for both dc power source injection and the detector output to prevent any possible unwanted RF EMI ingress into the detector enclosure.

During idle conditions without any RF input there is a residual output voltage of about 0.3 V from the AD8307 detector. This output is generated by the noise floor of the high-gain logarithmic amplifier chain inside the IC. R6, C9 and Schottky diode D1 (Figure 5) within the meter ground return path have been provided here to prevent the residual noise generated output from occupying precious space on the meter scale. The forward voltage drop across D1 provides an offset bias of about 0.4 V. This prevents meter deflection during the idle state, and provides the desired zero meter reading with no RF input. Without this bias the idle noise related output would deflect the meter up to about 1 on the scale of 0 to 10 and the usable dynamic range of the meter scale would be reduced by about 10 dB.

Shunt resistors R7, R8 and R9 reduce the 50 μA meter full scale sensitivity to 200 μA. C6 prevents RF from entering the meter movement coils. SW3 is the momentary battery test switch and the parallel combination of R1, R2 and R3 provide a precise multiplier resistance of 48.0 kΩ, which with this particular meter provides an accurate 10 V scale for checking the source voltage and is a convenient means for checking the battery condition. Diodes D2 and D3 isolate the internal battery and external power sources.

Figure 5 shows the FSM with the scale expansion add-on option. Voltage follower U2B provides impedance isolation for center zero potentiometer RV3. Trimpot RV1 limits the adjustment range of RV3. This circuit minimizes battery drain by permitting the use of high resistance potentiometers for the center zero setting. U2A provides the 10:1 voltage gain needed for scale expansion. U3 provides a regulated 3.3 V power source for this circuit. Unlike the AD8307 this circuit is source voltage sensitive. Switch SW2 provides switching between the 10 dB/div and the 1 dB/div relative power measurement modes.

Parts Procurement

All the parts are standard and available from most major distributors with the exception of the panel meter. If you wish a simplified construction approach that minimizes the need for soldering

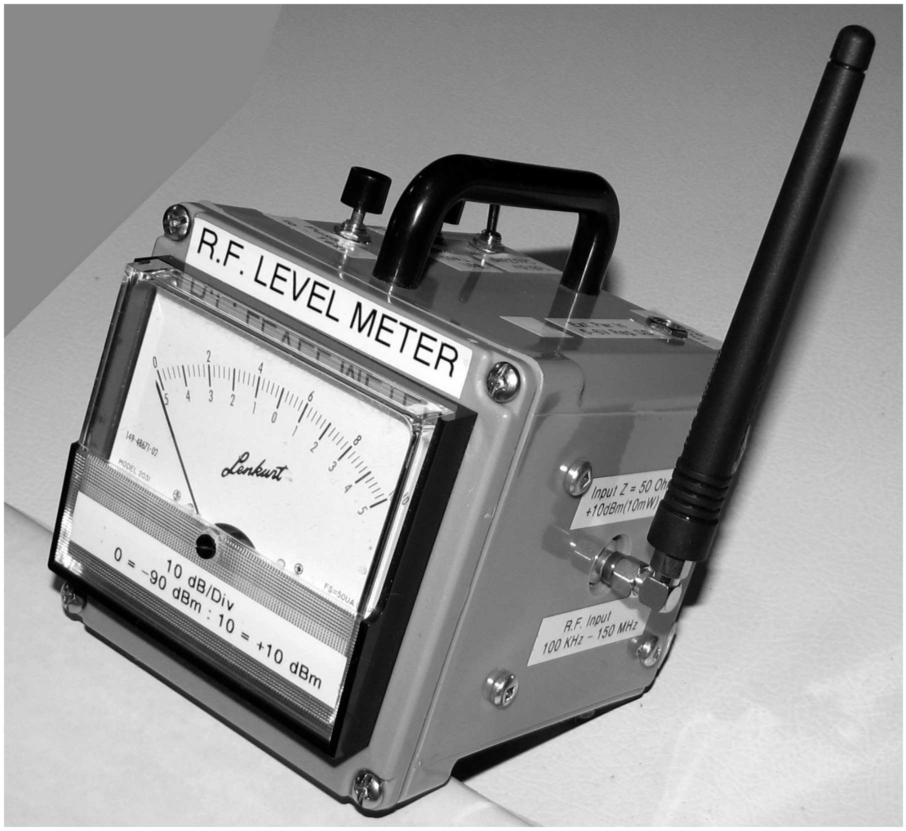

Figure 6 — Field strength meter housed in a 4-inch cube junction box.

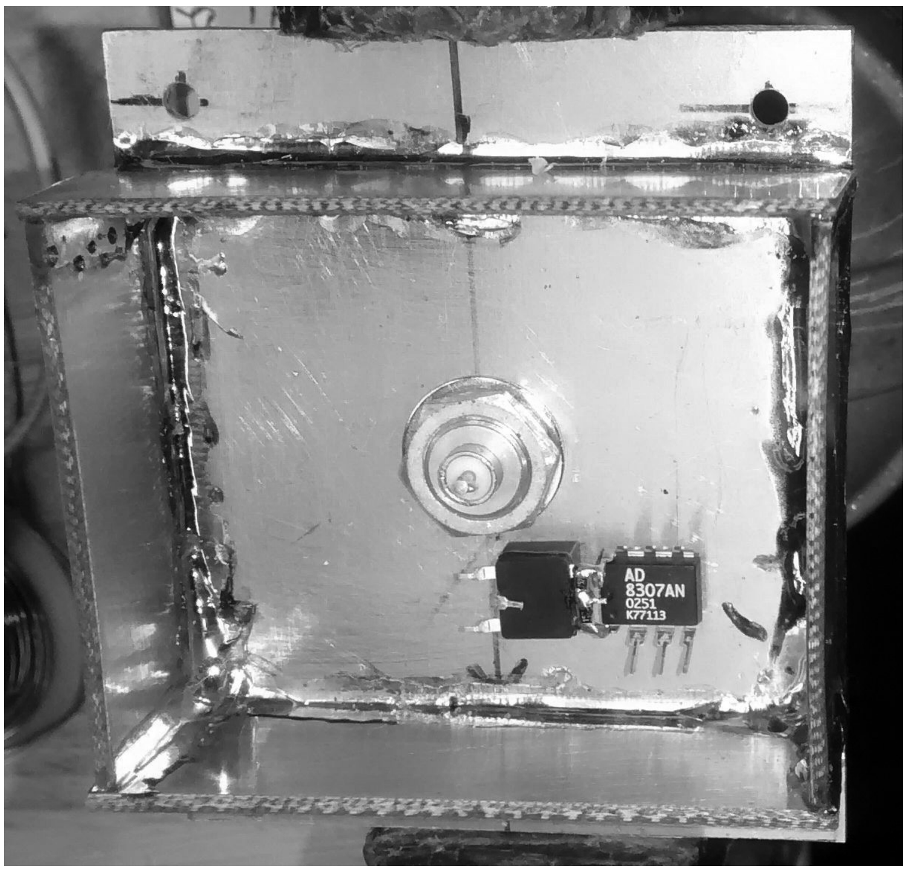

Figure 7 — "Dead bug" mounting style of the AD8307 RF detector, and the 1:16 wideband step-up transformer.

components, and you are willing to trade off some sensitivity for a bandwidth extension benefit to 500 MHz, there are inexpensive assembled AD8307 PCB modules available from online Asian sources.

These modules are complete with an SMA RF input connector and some even have shielded detector circuitry. The cost of the modules is about the same as an AD8307 IC alone from North American suppliers[2]. Using this approach about all that you would need to make a basic wide dynamic range FSM is the AD8307 module, a case, a battery-holder, switches and suitable panel meter along with a few leaded components.

Some distributors have stopped selling mechanical panel meters in favor of modern day digital display alternatives. Others still sell legacy panel meters but at sticker-shock prices, in some cases exceeding $100. However at the time of this writing meters manufactured in Asia are still sold online for less than $10. While browsing[3] eBay I noticed a 4", 1.5% class, 100 µA meter with a usable 0-100 scale that has major scale marks every 10 µA. It could be used here with a suitable shunt to lower the sensitivity to 200 µA — the needed shunt resistance should equal the meter resistance. Surplus equipment commonly used good quality panel meters that could be used for this application.

I used a 4" by 4" by 4" electrical junction box (Figure 6) for the case. These relatively inexpensive high volume production, sturdy, sealed boxes were available from Home Depot stores for about $10 at the time of this writing. This particular box initially had rear wall mount tabs that were easy to snap off. The carrying handle is a $0.50 plastic drawer handle from Home Depot.

Figure 7 shows the dead-bug style mounting of the AD8307 RF detector along with the 1:16 wideband step-up transformer made by CoilCraft. Note the two 0805 size surface mount type 1.5 kΩ resistors (R4, R5 in Figure 5) are soldered in series across the transformer secondary pins. These RF components are mounted within an RF-tight enclosure made from double-sided F10 PCB stock. The transformer is mounted close to the centered SMA connector to minimize the connection length to the primary pins.

I built the 10:1 scale multiplier circuit PCB (not shown) on tenth-inch grid prototype PCB stock. I used 8-pin sockets for the regulator and amplifier ICs, and #30 AWG wire-wrap wire to interconnect the components.

Measurement Procedure

The use of this meter is very intuitive. Simply connect the RF source or sense antenna to the input. When using the wide dynamic range scale, just press the momentary power button switch when the input signal to be measured is present and note the meter reading. Each major division is 10 dB, and 0 on the scale represents -90 dBm. For example, if the meter reading is 3.2 then the signal is 32 dB above -90 dBm, or -90 + 32 = -58 dBm.

If you need to know the approximate level in micro-volts, use the graph in Figure 2, which shows that -58 dBm is about 280 µV rms across 50 Ω impedance.

For reasonably accurate measurements at VHF a 6 dB attenuator should be connected to the meter input to improve the match. Then 6 dB must be added to the measured signal level along with the frequency dependent calibration factor shown in Figure 3.

As previously mentioned, readings that fall within the bottom 10% of the scale (from 0 to 1) are influenced by the noise floor of the AD8307 detector thus the accuracy of this region of the scale is compromised.

More precise relative readings with the 10× scale multiplier installed can be activated with the scale toggle switch. In this mode the meter must first be center-zeroed with the level of the reference signal by adjusting the zero potentiometer for a mid-scale reading. Then the new expanded scale sensitivity becomes 1 dB/div with a measurement range of about ±5 dB. This is very useful for observing small level changes.

Conclusion

This FSM is quite useful for making quick checks of RF field strengths. Although it is not a highly accurate instrument that measures all signal parameters, it is simple and easy to use for quickly checking that ERP levels are normal. With the AD8307 logarithmic detector, the FSM is relatively stable and offers a much wider dynamic range than a simple diode detector FSM. This instrument could possibly be useful for communications teams involved in public service events. It could provide a means just piror to activity commencement for quickly confirming that handheld radios and mobiles are ready to operate at normal ERP levels.

*Tom Alldread, VA7TA, became interested in electronics when still in grade school. In his teens, he repaired radio and television sets, obtained his Amateur Radio license at age 19. He obtained his Commercial Radio Operator certification upon graduating from technical college a year later. Tom subsequently graduated from the Capitol Radio Engineering Institute Engineering Technology program. He worked as a microwave, multiplex and VHF radio equipment maintenance technician, an instructor, an engineering standards and design specialist, and in the Middle East as an adviser for long distance network operations management. Tom is now retired and lives on Vancouver Island with his wife Sylvia, VA7SA. Tom, a member of RAC, enjoys operating CW, designing equipment, and supporting emergency communications. For the past decade he has been the net manager for the SSB/CW 20 m Trans-Canada Net (**www.transcanadanet.com**). He is interested in microcontroller development projects associated with RF technology and Amateur Radio. Tom received second place award in the Luminary 2006 Design Stellaris contest, and first place in the 2011 Renesas RX contest. He is also interested in computing, RVing, hobby farming and bicycling. Tom maintains the **www3.telus.net/ta/** web page.*

Notes

1 **www.analog.com/media/en/technical-documentation/data-sheets/AD8307.pdf**.

2 Search "500MHz-RF-Signal-Power-Detector-AD8307-Module-Field-Detection" at **www.ebay.com/**.

3 Search "DC-0-to-100uA-Class-1-5-Accuracy-Panel-Analog-Ammeter- Ampere-Meter" at **www.ebay.com/**.