The Utah Amateur Radio Club:

Highly sensitive and selective Field Strength Meter system

by Clint Turner, KA7OEI

Abstract:

A field strength meter is a very handy tool for locating a transmitter. A sensitive field strength meter by itself has some limitations, however: It will respond to practically ***any*** RF signal that enters its input. This property has the effect of limiting the effective sensitivity of the field strength meter, as any nearby RF source (or even ones far away, if the meter is sensitive enough...) will effectively mask the desired signal.

This property can be mitigated somewhat by preceding the input with a simple tuned RF stage and, in most cases, this is adequate. A simple tuned circuit does have its limitations, however:

Figure 1: *The Field Strength Meter (Mark II) and interconnect cable with the modified Icom IC-2A/T*

- It is only broadly selective. A simple, single-tuned filter will have a response encompassing several percent (at best) of the operating frequency. This means that a 2 meter filter will respond to nearly any signal within to the 2 meter band.
- A very narrow filter can be tricky to tune. This isn't usually too much of a problem as one can peak on the desired signal (if it is close enough to register) or use your own transmitter (on a nearby frequency) to provide a source of signal on which the filter may be tuned.
- The filter does not enhance sensitivity, unless an amplifier is used.

An obvious approach is to use a receiver. While many receivers have "S-meters" on them, very few of them have meters that are truly useful over a very wide dynamic range, most firmly "pegging" even on relatively weak signals. While an adjustable attenuator (such as a step attenuator or offset attenuator) may be used, the range of the radio's S-meter itself may be so limited that it is difficult to manage the observation of the meter and adjusting the signal level to maintain an "on-scale" reading.

Another possibility is to modify an existing receiver and interface it with something like the ***Wide Dynamic Range Field Strength Meter*** - and that is what is discussed here.

Picking a receiver:

When I decided to take this approach, I began looking for a 2 meter (the primary band of interest) receiver with these properties:

- ***It had to be cheap.*** No need to explain this one...
- ***It had to be synthesized.*** It's very helpful to be able to change frequencies...
- ***Having a 10.7 MHz IF was preferable.*** The reasons for this will become obvious...
- ***It had to have enough room inside it to allow the addition of some extra circuitry to allow "picking off" the IF signal.*** After all, that's the entire point of this exercise...
- ***It had to be easy to use.*** Because one may not use this receiver too often, it's best not to pick something overly complicated and would require a manual to remind one how to do even the simplest of tasks.

Another goal of the modification was that the radio had to work ***exactly*** as it was originally designed - that is, you can ***still*** use it as an HT!

Based on a combination of past familiarity with various 2 meter HTs and looking at prices on Ebay, at least three possibilities sprang to mind:

- The Henry Tempo S-1. This is a very basic 2 meter-only radio and was the very first synthesized HT available in the U.S. One disadvantage is that, by default, it uses a threaded antenna connection rather than a more-standard BNC connector and would thus require the user to install one to allow it to be used with other types of antennas. Another disadvantage is that it has a built-in non-removable battery. It's power supply voltage is limited to under 11 volts. *(The later Tempo S-15 has fewer of these disadvantages and may be better, but I am not too familiar with it.)*
- The Kenwood TH-21. This, too, is a very basic 2 meter-only radio. It uses a strange RCA-like threaded connector, but this mates with easily-available RCA-BNC adaptors. Its disadvantage is that it is small enough that the added circuitry may not fit inside. It, too, has a distinct limitation on its power supply voltage range and requires about 10 volts.
- The Icom IC-2A/T. This was, at one time, one of the most popular 2 meter HTs. It can operate directly on 12 volts, has a standard BNC antenna connector, and has plenty of room inside the case for the addition of a small circuit.

Each of these radios is a plain, thumbwheel-switch tuned synthesized, plain-vanilla radio. As you might have guessed, I chose the Icom (it is also the most common) and obtained one on Ebay for about $40 (including accessories) and another $24 bought an IC-8, an 8-cell alkaline battery holder (from Batteries America.)

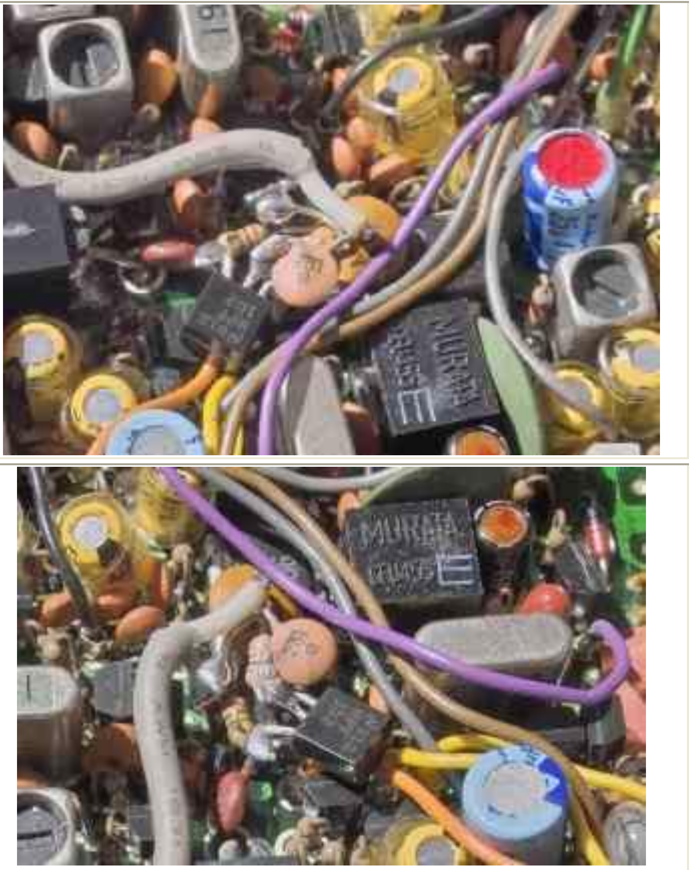


Figure 2 (top) *and* ***Figure 3 (bottom):*** *Two different view of the JFET buffer circuit tacked atop IC1.*

Modifying the IC-2A/T (and circuit descriptions):

This radio is the largest of those mentioned above and has a reasonable amount of extra room inside its case for the addition of the few small circuits needed to complete the modification. When done, this modification does not, in any way, affect otherwise normal operation of the receiver: It can still be used as it was intended!

An added IF buffer amplifier (see figure 7, below):

This radio uses the Motorola MC3357 (or an equivalent such as the MP5071) as the IF/demodulator. This chip takes the 10.7 MHz IF from the front-end mixer and 1st IF amplifier stages and converts it to a lower IF (455 KHz) for further filtering and limiting and it is then demodulated using a quarature detector. Unfortunately, the MC3357 lacks an RSSI (Receive Signal Strength Indicator) circuit - which partly explains why this radio doesn't have an S-meter, anyway. Since we were planning to feed a sample of the IF from this receiver into our field strength meter, anyway, this isn't too much of a problem.

We actually have a choice to two different IFs: 10.7 MHz and 455 KHz. At first glance, the 455 KHz might seem to be a better choice as it has already been amplified and it is at a lower frequency - but there's a problem: It compresses easily. Monitoring the 455 KHz line, one can easily "see" signals in the microvolt range, but by the time you get a signal that's in the -60 dBm range or so, this signal path is already starting to go into compression. *(-60 dBm is about the strength that one gets from a 100 watt transmitter that is clear line-of-sight at about 20 miles distant, using unity-gain antennas on each end.)*

The other choice is to tap the signal at the 10.7 MHz point, *before* it goes into the MC3357. This signal, not having been amplified as much as the 455 KHz signal, does not begin to saturate until the input reaches about -40 dBm or so, reaching full saturation by about -35 dBm. One point of concern here was the fact that at this point, the signal has less filtering than the 455 KHz, with the latter going through a "sharper" bandpass filter. As it turns out, while the filtering at 10.7 MHz is a bit broader, the 4 poles of crystal filter *do* attenuate a signal 20 KHz away by at least 30 dB - so unless there's another very strong signal on this adjacent channel, it's not likely that there will be a problem.

To be able to tap this signal without otherwise affecting the performance of the receive requires a buffer amplifier, and a JFET source-follower does the job nicely. Consisting of only 6 components (two resistors, three capacitors and an MPF102 JFET) this circuit is simply tack-soldered directly onto the MC3357 as shown in ***figures 2 and 3***. This circuit very effectively isolates the (more or less) 50 ohm output load of the field strength meter from the high-impedance input to the MC3357, and it does so while only drawing about 700 microamps (3-4% of the radio's total current when it is squelched.)

As can be seen from the pictures (***figures 2 and 3)*** all of the required connections were made directly to the pins of the IC itself, with the 330 pF input capacitor connecting directly to pin 16, supply voltage being pulled from pin 4, and pins 12 and/or 15 being used to get the ground connection. ***A word of warning:*** Care should be taken when soldering directly to the pins of this (or any) IC to avoid damage. It is a good idea to scrape the pin clean of oxide and use a hot soldering iron so that the connection can be made very quickly. Excess heat and/or force on the pin can destroy the IC! It's not that this particular IC is fragile, but this is care that should be taken. As can be seen from the picture and schematic, there is also a required inductor (value not critical - use anything from 10 to 100 uH) that is mounted ***at the microphone connector***.

Figure 4 (top): *Overview of the inside of the modified IC-2A/T showing the connection to the buffer circuit and cable routing.*
Figure 5 (bottom): *Close-up of the connection of the coax to the microphone connector. The 10-100 uH blocking choke is the green resistor-like component under the orange wire.*

Getting the signal outside the radio:

The next challenge was getting our sampled 10.7 MHz IF energy out of the radio's case. While it may be possible to install another connector on the radio somewhere, it's easiest to use an existing connector - such as the microphone jack.

One of the goals of these modifications was to retain complete function of the radio as if it were a stock radio, so I wanted to be sure that the microphone jack would *still* work as designed, so I needed to multiplex *both* the microphone audio (and keying) and the IF onto the tip of the microphone connector. Because of the very large difference in frequencies (audio versus 10.7 MHz) it is very easy to separate the two using capacitors and an inductor: The 10.7 MHz IF signal is passed directly to the connector with the series capacitor while the 10.7 MHz IF signal is blocked from the microphone line with a small choke.

The buffered IF is conducted to the microphone jack using some small coaxial cable: RG-174 type will work, but I found some slightly smaller coax in a junked VCR. To make the connections, the two screws on the side of the HT's frame were removed, allowing it to "hinge" open, giving easy access to the microphone connector. The existing microphone wire was removed and the choke was placed in series, with the combination insulated with some heat-shrinkable tubing. The coax from the buffer amp was then connected directly to the "tip" of the microphone connector. One possible coax routing is shown in **Figure 4** but note that this routing prevents the two halves of the chassis from being opened in the future, unless it is disconnected from one end. If this bothers you, a longer cable can be routed so that it follows along the hinge and then over to the buffer circuit. ***Note:*** It is important to use shielded cable for this connection as the cable is likely to be routed past the components earlier in the IF strip and instability could result if there is coupling.

Interfacing with the Field Strength meter:

Using RG-174 type coaxial cable, an adaptor/interface cable was constructed with a 2.5mm connector on one end and a BNC on the other. One important point is that a small series capacitor (in the range of 0.001 to 0.1 uF) is required in this line somewhere as a DC block on the microphone connector: The IC-2A/T (like most HTs) detects a "key down" condition on the microphone by detecting a current flow on the microphone line and this series capacitor prevents current from flowing through the 50 ohm input termination on the field strength meter and "keying" the radio.

Dealing with L.O. leakage:

As soon as it was constructed, I observed that even with no signal, the field strength meter showed a weak signal (about -60 to -65 dBm) present whenever the receiver was turned on, effectively reducing sensitivity by 20-25 dB. As I suspected, I determined that this signal was coming from two places:

- The VHF local oscillator. On the IC-2A/T, this oscillator operates 10.7 MHz lower than the receive frequency.
- The 2nd IF local oscillator. On the IC-2A/T this oscillator operates at 10.245 MHz - 455 KHz below the 10.7 MHz IF.

The magnitude of these signals was about the same, roughly -65 dBm or so. Now the VHF local oscillator would be very easy to get rid of: A very simple lowpass filter (consisting of a single capacitor and inductor) would adequately suppress it, but the 10.245 MHz signal poses a problem as it is too close to 10.7 MHz to be easily attenuated enough by a very simple L/C filter without affecting it.

Fortunately, with the IF being 10.7 MHz, we have another (cheap!) option: A 10.7 MHz ceramic IF filter. These filters are ubiquitous, being used in nearly every FM broadcast receiver made in the past 10-15 years so if you have a junked FM broadcast receiver kicking around, you'll likely have one or more of these in them. Even if you don't have junk with a ceramic filter in it, they are relatively cheap ($1-$2) and readily available from many mail-order outlets. ***This filter is shown in the upper-right corner of Figure 7, below.***

Typically, these filters have a bandpass that is between 150 KHz and 300 KHz wide (depending on the application) at their -6 dB points and will easily attenuate the 10.245 MHz local oscillator signal by at least 30 dB. With this bandwidth, it is possible to use a 10.7 MHz filter (which, themselves, vary in exact center frequency) for some of the "close - but not exact" IF's that one can often find near 10.7 MHz like 10.695 or 10.75 MHz. The only "gotcha" with these ceramic filters is that their input/output impedances are typically in the 250-350 ohm area and require a (very simple) matching network (an inductor and capacitor) on the input and output to interface them with a 50 ohm system. The values used for matching are not critical and the inductor could be anything from 1.5 to 2.2 uH without much impact of performance (other than a very slight change in insertion loss.)

***Figure 6:** A close-up of the interconnect cable and the 10.7 MHz bandpass filter. The circuit was constructed in a small enclosure made of circuit board material and a piece of #12 wire was soldered to it, providing an anchor point for the strain reliefs on the coax.*

While this filter could have been crammed into the radio, I was concerned that the L.O. leakage might find its way into the connector somehow. Instead, this circuit was constructed "dead bug" on a small scrap of circuit board material with sides, "potted" in thermoset ("hot melt") glue and it can covered with electrical tape, heat shrink tubing or "plastic dip" compound, with the entire circuit installed in the middle of the coax line (making a "lump.") Alternatively, this filter could have been installed within the field strength meter itself, either on its own connector or sharing the main connector and being switchable in/out of the circuit.

With this additional filtering, the L.O. leakage is reduced to a level below the detection threshold of the field strength meter, allowing sub-microvolt signals to be detected by the meter.

Operation and use:

When using this system, I simply clip the receiver to my belt and adjust it so that I can listen to what is going on.

There's approximately 30 dB of processing gain from the antenna to the 10.7 MHz IF output, that is, a -100 dBm signal on the antenna on 2 meters will show up as a -70 dBm signal at 10.7 MHz. What this means is that sub-microvolt signals are *just* detectable at the bottom end of the range of the Field Strength meter.

The major advantage of using the HT as tunable "front end" of the field strength meter means that the meter has greatly enhance seletability and sensitivity - but this is not without cost: This detection system will begin to saturate at about -40 dBm, fully saturating above -35 dBm - which is a "moderately strong" signal. In "hidden-T" terms, it will "peg" when within a hundred feet or so of a 100 mW transmitter with a mediocre antenna.

When the signals become this strong, you can do one of several things:

- Detune the receiver by 5, 10, 15 or even 20 KHz. This will reduce the sensitivity by moving the signal slightly out of the passband. This is usually a very simple and effective technique, although heavy modulation can cause the signal strength readings to vary.
- Add attenuation to the front-end of the receiver. The plastic case of the IC-2A/T is quite "leaky" in terms of RF ingress, but it is good enough for a 20 dB inline attenuator to work

nicely and will thus extend usable range to -20 to -15 dBm. Although I have not tried it, an "offset attenuator" may extend this even further.

- When you are *really* close, you can forgo the receiver altogether, connecting the antenna directly to the field strength meter.

If you want to be really fancy, you can build the 10.7 MHz bandpass filter and add switches to the field strength meter so that you can switch the 20 dB of attenuation in and out as well as routing the signal either to the receiver, or to the field strength meter (using a resistive or hybrid splitter to make sure that the receiver gets *some* signal from the antenna even when the field strength meter is connected to the antenna.)

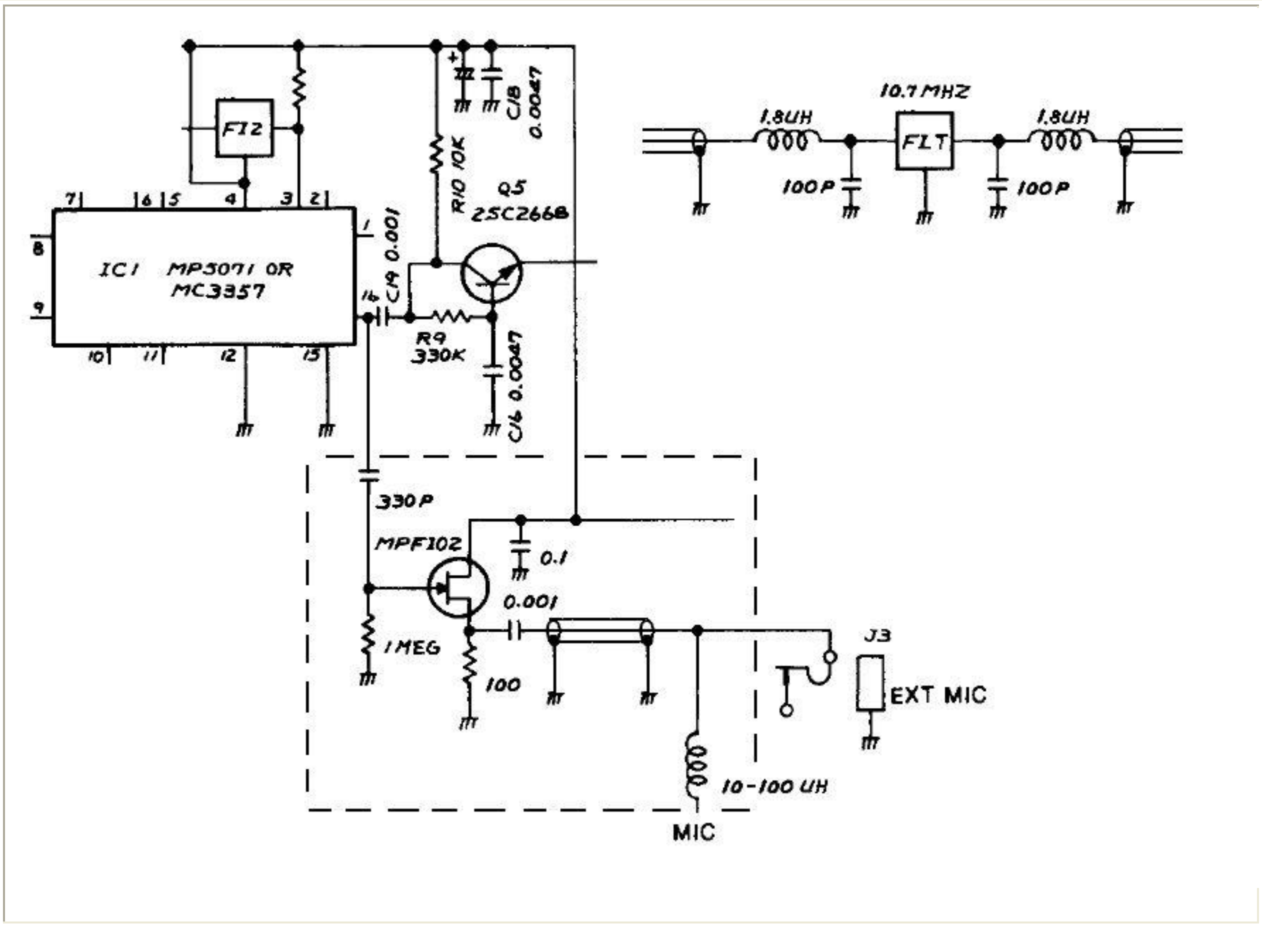


Figure 7: *Schematic of the buffer circuit and 10.7 MHz filter (upper right.) Added components are within the dashed lines.*

Additional comments:

- At first, I considered using the earphone jack for interfacing to the 10.7 MHz IF, but quickly realized that this would complicate things if I wanted to connect something to the jack (such as pair of headphones!) while DFing. I decided that I was unlikely to be needing to use an external microphone *while* I was looking for a transmitter...
- I haven't tried it, but these modifications should be possible with the 222 MHz and 440 MHz versions of this radio, not to mention other radios of this type.
- Although not extremely stable, you can listen to SSB and CW transmissions with the modified IC-2A/T by connecting a general-coverage receiver to the 10.7 MHz IF output and tuning in. Signals may be slightly "warbly" - but they should be easily copiable!

A Wide dynamic range Field Strength Meter

Mark I

(Version 1.2)

by Clint Turner, KA7OEI

When direction-finding in close quarters, fancier direction-finding gear (if you have it) can become useless due to very strong reflections. In addition, it may be large, cumbersome, and very conspicuous. At this point one is often very close to the transmitter itself and it's just a matter of figuring out exactly ***which*** tree the transmitter is hidden in or ***which*** car has the radio with the stuck microphone.

At such close range, two (of several) possible options are an ***Offset Attenuator*** and a ***Field Strength Meter***. Each piece of equipment has its own set of advantages/disadvantages:

	Offset Attenuator w/receiver	**Field Strength Meter**
Selectability: (The ability to differentiate one signal from another on a nearby frequency)	The ability to single out one signal source largely based on the ability of the receiver being used.	Poor selectivity: The field strength meter, without additional filtering, will respond to *any* nearby. If there is another transmitter nearby on the same band, it may be impossible to provide adequate filtering to reject the "unwanted" transmitter.
Sensitivity: (How much signal it takes to get a usable reading)	Good Sensitivity: The sensitivity of the detection system is limited mostly by that of the receiver being used and the amount of intrinsic attenuation range available from the offset attenuator circuit.	Sensitivity depends on design: The simplest field-strength meters can detect a transmitter only when it is extremely close (within 10's of feet.)
Dynamic range: (How it responds to signals ranging from weak to very strong)	Range of metering limited by that of the receiver: Many FM HTs have S-meters that are nearly useless for determining anything about the strength of the signal. Often, they have only 10-15 dB of useful dynamic range, requiring constant adjustment of the attenuator to stay within range.	Capable of wide dynamic range, depending on design and implementation.
Ease-of-use:	Frequent readjustment of the attenuator is required to keep it from "pegging" the meter and/or to keep it from dropping too low to register. Signal strength meter is often difficult to see/use: Most HTs, if they have a signal strength meter at all, use a small number of segments on the display. This display is not only rather hard to see at times, but it usually offers poor resolution in terms of amplitude.	The operation is rather intuitive: The higher the reading, the closer you are to the transmitter. If you are building a field strength meter, you can put as large an analog meter as you like. The analog meter doesn't have the problem with a limited number of "segments" as do many digital displays.

Because one can't anticipate beforehand exactly what the situation might be, it's best to have a number of tools in your arsenal - and this may mean that you'll have ***both*** an offset attenuator with a receiver ***and*** a field strength meter.

"Conventional" field strength meters:

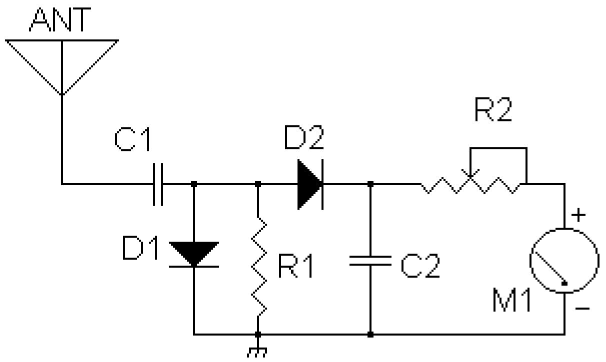


Figure 2: *A basic field-strength meter circuit. Typical components:*
C1 = 100 pF C2 = 0.001 uF; D1, D2 = 1N34 diodes; R1 = 10k; R2 = 50k potentiometer; M1 = 50 microamp meter.

A typical field-strength meter is shown in **Figure 2**. This is a simple passive (unpowered) circuit in which radio frequency energy is intercepted by the antenna, rectified to DC, and then used to directly drive the meter. The maximum sensitivity of this circuit is based primarily on several factors:

- The gain of the antenna: How much of the signal is actually intercepted.
- The sensitivity of the meter movement being used.
- The nature of the diodes being used.

For portable use, the antenna is usually a simple whip, but it could even be a directional array. When using this circuit, one would start out at a distance with the sensitivity set to maximum (R2 set to minimum resistance) and as one got closer and started to "pin" the meter, one would reduce the sensitivity as needed. As noted, this cannot detect weaker signals owing to the fact that there may simply not be enough signal to drive the meter. Not only this, a simple, unbiased diode detector has a very definite lower limit of detection range which, in practicality, limits its ability to even detect a low-powered (under a watt) transmitter to a few 10's of feet at the most.

Another not-so-obvious disadvantage is that this meter's useful dynamic range is, at most, only 20 dB or so - with the majority of this range being "crunched" in the bottom half of the meter scale. What this means is that one is required to constantly readjust the sensitivity control to keep the meter reading within range. In practical terms, this is quite a pain as one can experience "peaks and valleys" of signal strength in close proximity of the transmitter well in excess of 10 dB. What's more, with an adjustable potentiometer it can be difficult to tell, between adjustments of the sensitivity control, if one is actually getting closer or farther away from the transmitter as the "reference" point can be lost when one twiddles the sensitivity control.

Note: This version is modified from the original, including the following changes:

- Addition of an audible indication of field strength
- A modification of the connection at S2, the attenuator switch that leaves R17 connected at all times. *(See the E-field sensitivity discussion.)*

A higher dynamic range field strength meter:

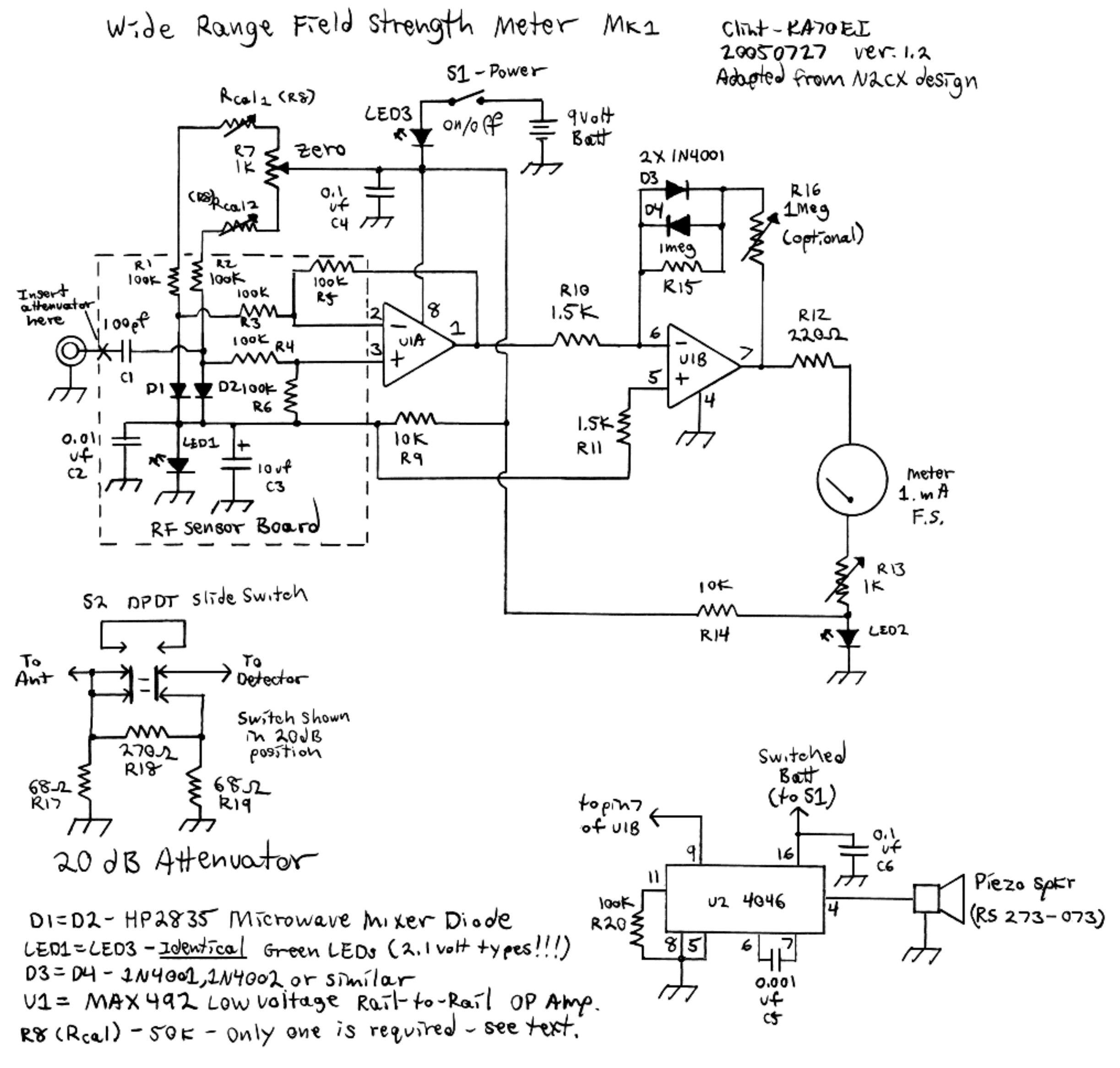


Figure 3: *Schematic of the wide-range field strength meter. Note that if an LMC6842 is used in place of U1, LED3 should be omitted - see text.*

It would be useful to have a field strength meter that not only had better sensitivity, but a means of increasing the dynamic range of what was represented on the meter itself, preferably to 40 dB or more. One such meter is shown in the schematic in **Figure 3**. The prototype had a useful range of about -45 dBm to +10 dBm, a range of about 55 dB.

Having a wider dynamic range involves added complexity, of course, and this circuit requires some explanation:

Identical diodes D1 and D2 are slightly biased through R1 and R2. Because these diodes are of the same type, they exhibit very similar temperature characteristics and will (hopefully) track each other thermally. With RF applied (through the 100 pF capacitor) only to D2, any RF that appears will cause the voltage at that point to change and this amount of change is buffered by U1A which is wired as a differential amplifier. To give appropriate credit, I spotted this dual-diode detector circuit on the *NJQRP web page* as the *NJQRP Sniffer* and have modified it for this purpose.

The output signal from U1A goes through R10 to U1B which is configured as a high-gain amplifier - but with a difference: Inserted into the feedback loop is a pair of back-to-back diodes, D3 and D4. It is the nature of diodes to respond in a non-linear way in which the voltage across them is logarithmically related to the current through them. In this way, the output of U1B will increase by "X" amount for every 10-fold increase in the applied voltage. The output of U1B is applied to an analog meter movement that displays the amount of signal present.

Also shown is an optional circuit consisting of U2, a 4046 CMOS PLL circuit. Using only the VCO, this converts the voltage output on pin 7 of U1A to an audio frequency in the range of 1-3 KHz, using a piezoelectric sounder.

A few parts details:

D1, D2:

These are likely to be the most critical components. I used a pair of HP 5082-2835 (often referred to "HP-2835") microwave mixer diodes, but other more commonly-available germanium diodes such as the 1N34, 1N60, 1N63, and 1N270 can work as well, but with reduced sensitivity. The microwave-type diodes will easily provide good response from low HF through 70cm while many of the germanium types will start to lose sensitivity on the higher bands. Extremely common diodes such as the 1N914/1N4148 may work, but at reduced sensitivity.

It is very important that these two diodes be as closely matched as possible! Precise thermal matching of the more expensive diodes is a bit easier, as their manufacturing tolerances are fairly tightly controlled, whereas this is usually not the case with inexpensive diodes, such as those of the 1N34 variety.

Another possibility is to use an IC that contains several matched diodes such as the CA3019 and CA3039 (and equivalents) but these are getting difficult to find and expensive. Another alternative would be to use some of the newer SMD dual-diodes, but more research would be required to determine suitable devices.

LED1, LED2:

To avoid using a split-polarity power supply, the "bottom" end of D1 and D2 is "lifted" above ground - in this case, by the amount of voltage drop across an LED and for best results a standard ***Green*** LED is recommended as it will provide about 2.1 volts of bias. When choosing an LED *make certain* that you do ***NOT*** use an "ultra bright" green variety as these use a different chemistry and require about 4 volts. While these may work OK, this higher voltage will reduce the amount of meter drive capability when the battery starts to weaken: When looking at the specifications, pick an LED with a "Vf" (forward voltage) of about 2.1 volts.

It is also very important that LED1 and LED2 be of the ***same*** type with the ***same*** voltage drop. The easiest way to assure this is to use two LEDs from the same package.

LED3 is actually present just to protect U1, which has a maximum voltage rating of 7 volts. It, too, should provide a voltage drop of about two volts, but it need not be "matched" to LED's 1 and 2. This LED may be mounted on the front panel as a "power on" indicator. Note that it will glow brighter with increasing meter reading as the circuit draws more current. With the current consumption of the meter's circuitry being only a few milliamps, do not expect it to be very bright. ***If an LMC6482 is used instead of a MAX492, this LED may be omitted as the '6482 has a 15 volt rating.***

R1-R6:

These are 100k resistors used for biasing the diodes. For the ultimate in stability, it is recommended that one use 1% surface-mount resistors, all mounted as close to D1 and D2 and each other as possible. If ordinary 5% 1/4 watt resistors are used, make sure that they are of the same type - preferably from the same package. While not absolutely necessary, you may want to sort and find six that are as closely matched to each other as possible.

Why go through all of this trouble? While the major potential source of drift is the diode pair (D1 and D2) it is prudent to minimize the other sources as well. One of the ways to do this, of course, is to use precision components in the first place, but placing them in as close physical proximity to each other as possible (so that they are at the same temperature) also helps.

Finally, another reason why one may consider the use of surface-mount resistors is due to their size: At the higher frequencies, their lower capacitance and inductance (as well as physical size) will help to improve the response - especially above 450 MHz.

D3, D4:

These diodes are responsible for the logarithmic response of the meter. While practically *any* silicon diode will work, one that is slightly oversized for the purpose (like the 1N4001 series) will have less tendency to drift due to thermal heating from the current flowing through it. While only one diode is required for a unidirectional logarithmic response, the second diode makes zeroing of the meter easier, preventing it from going "negative" as easily.

The Meter:

While the use of a 1 mA meter is shown, any meter with this (or lower) full-scale sensitivity should work. If a more-sensitive meter is used, R12 and R13 should be appropriately rescaled: R12's job is primarily to protect the meter movement should R13 accidentally be adjusted all of the way to zero ohms. The meter that I used was a 0-15 volt meter from Radio Shack. This meter is simply a 1 milliamp movement supplied with a resistor of approximately 15k for scaling.

U1:

While several op-amps were tried, the one of two (that I had on hand) that worked properly was the **MAX492** made by Maxim. This op amp is specifically designed for low-voltage operation with rail-to-rail voltage range on ***both*** input ***and*** output: Most other types of op-amps will simply not work. It is worth mentioning that ***if*** a split-polarity supply were used, a common, garden-variety op-amp would probably be usable, but this would require a pair of 9 volt batteries. Its disadvantage is that it has a ***maximum*** supply rating of 7 volts.

Another suitable ***and preferred*** device is the **LMC6482** by National Semiconductor. This device is functionally identical to the MAX492 except that it can tolerate a higher supply voltage (15 volts) than the MAX492. *Note: I did not have any samples of this device to try when I originally built this field strength meter.*

Rcal1, Rcal2 (R8):
Surrounding R7 (the "zeroing" pot) is shown two pots designated R8 and this is typically a 50k trimmer potentiometer and only ***one*** of the pots shown will be needed. Depending upon the exact match of D1, D2 and R1-R6, the "zero" point may be either "above" or "below" zero.

When constructing the unit, it is recommended that one *temporarily* replace ***both*** R7 and R8 with a single 50k-100k potentiometer for zeroing. Once it has been verified that the unit operates properly (and when it does, you will note that the zeroing adjustment is quite touchy) R7 and R8 is installed. When this is done, set R7 at mid-rotation and R8 is installed in ***only one*** of the noted positions and adjusted for meter zeroing. If meter zeroing *cannot* be achieved, move R8 to the *other* position and try again: You *should* be able to zero the meter *(**<u>IF</u>** it worked when you had the temporary 50k-100k pot installed)* with R8 in one of the two positions.

If, during typical operation, you note that a zero offset appears under certain conditions that cannot be "adjusted out" either increase the value of R7
(do not go higher than 5k) or, if the "uncorrectable offset" is always in the same direction, readjust R8 to "slide" the adjustment range of R7 a bit.

R16:
This is a "gain" control that is optional. With the logarithmic response of the meter, note that no matter what the setting of R16 might be, the "bottom end" of the meter reading will always represent about the same amount of field strength. What R16 *does* adjust is the amount of signal required to indicate full-scale. This *may* be useful if the signal is consistently weak, but it isn't really necessary and may be omitted. If you *do* chose to include R16, an "audio taper" or "S-taper" version is preferred to reduce the "crunching" of the gain adjustment to one end knob rotation - but if you use a pot with a non-linear taper, make sure that you connect it appropriately to utilize that feature.

Figure 4: *Top: The top view of the field-strength meter showing the antenna connection and the attenuator switch. Bottom: This shows the components of the 20 dB attenuator. (Yes, I know that it says "-20 dB) attenuation...)*

The 20 dB attenuator:

A useful addition to this meter is that of a switchable 20 dB attenuator. When getting very close to the transmitter - particularly if it's a fairly powerful one - the signal may constantly "peg" the meter. Being able to throw in a bit of extra attenuation allows one to be able to knock the signal down to something other than full-scale.

Additionally, if you are getting very near a high-powered transmitter, there is the possibility that the detector diode may get burned out if you accidentally get the transmitting and receiving antennas too close to each other.

Note that the "ideal" resistor values are closer to 62 ohms and 240 ohms (instead of 68 ohms and 270 ohms, respectively) but the values shown are more likely to be found in one's resistor drawer and represent about 1 dB of difference from ideal.

It is important to note that a simple attenuator such as this, built onto a subminiature slide switch, will start to degrade badly above 500 MHz. On the unit that I built, I observed a consistent 21 dB of attenuation from 1 MHz through 2 meters, dropping to 18 dB at 70cm and going down to about 11 dB at 1 GHz. This is due to the inductance/capacitance of the resistors being used as well as cross-coupling between sections of the switch.

Note that R17 *(as well as R19 through R18)* is connected at all times. This provides not only a DC path to ground at all times to prevent static buildup, but it also provides something closer to a 50 ohm termination even when the attenuator is switched out and it reduces the response to extraneous E-fields - *See the E-field discussion below.*

The audible indicator:

Another useful addition is that of an audible indicator of field strength and this is done by using U2, a 4046 CMOS PLL (the *non-HC version)* with VCO. The voltage from pin 7 of U1B is fed into the VCO tuning pin of U2 and as the signal strength goes up, so does the pitch of the tone generated.

With the components as shown, the pitch of the tone varies from about 1.2 KHz at zero scale to approximately 2.5 KHz at full scale - but these values may be easily adjusted: Increasing the value of R20 or C5 will lower the pitch while resistive scaling of the voltage at pin 9 (using, say, a 10k-100k pot) will reduce the frequency swing. *(Another resistor may be added at pin 12 to change the frequency range, but you should refer to the 4046 data sheet for this information.)*
Note: It is recommended that a mylar or a good quality ceramic capacitor be used for C5 to avoid excessive pitch change with temperature. If you use a ceramic disc type, avoid one marked with a 3-character code beginning with a "Y" or "Z" (e.g. Y5P or Z5U)

The frequency output of the VCO is fed directly into a piezoelectric transducer - chosen for small size and light weight - which is mounted in the enclosure with a hole to the outside world aligned with the hole in its plastic case. This transducer must ***not*** be of the sort that beeps merely with the application of supply, but rather it's simply used as an electronic speaker. Note that the frequency range of this transducer is very limited, with very poor response below 1 KHz or so, hence the design range. For mounting the transducer, I simply drilled a hole in the enclosure that was about 1/3 larger than that in the transducer (it is important to avoid obstructing the hole as this can greatly reduce its efficiency) and used silicone to hold it in place. Typical transducers also have tabs, allowing them to be mounted with two small screws on the outside of the case, if that is your preference.

If you choose to use a normal speaker, be careful to place it such that its magnet does not skew the meter movement. Also note that U2 *cannot* directly drive a speaker: A simple resistor-capacitor-transistor circuit will be required to provide adequate drive. It is also worth noting that piezoelectric sounders such as this are incapable of reproducing audio much below 1 KHz. If the drive signal is lower frequency than this, one primarily hears harmonics of the drive signal as well as a signal based on the "click" of the rising/falling edge of the square wave drive signal.

You will note that the range of tone exceeds that of the meter: Even if the meter is pinned backwards or full scale, you may still be able to hear a pitch change with the differing signal strength. What this means is that if you are not using the meter visually, you could purposely "pin" the meter backwards - or set it upscale - as well as adjust the gain control (if you included it) to set the pitch range of the audio.

This circuit can run directly from the 9 volt battery and does not need to be regulated. Note that the pitch range will change somewhat with battery voltage, but unless you have perfect pitch and calibrate signal strength to a particular musical note this is unimportant. The worst-case current consumption of U2 was measured at 800 microamps at 9 volts and because of this I chose not to add an on-off switch just for the indicator: If there is a reason to mute the tone, a switch may be added, or a piece of tape (or a finger) can be placed over the hole to greatly reduce its loudness.

In **Figure 5** (top) the circuit board for the audible indicator is mounted horizontally, just below the meter, while the piezoelectric sounder is on the bottom of the case, against the battery.

A few more construction details:
Figure 5 (bottom) shows details of the detector board, with the two diodes located directly below the disk ceramic capacitor, C1. While not easily visible, it is *just* possible to make out C2, a surface-mount 0.01 uF capacitor behind LED1 and C3 is the surface-mount tantalum below it. The sharp-eyed observer may note that schematic calls for C1 and C3 being 100 pF and 10 uF capacitors respectively, but these values are not critical: C1 could be anything from 68 to 220 pF while C3 could be anything from 4.7 to 22 uF. If you don't have a surface-mount capacitor for C2, try to keep the leads as short as possible - especially to the "RF Ground" and this will optimize sensitivity and high frequency response.

Constructing the unit:

It is strongly recommended that this meter be housed in a shielded (metal) enclosure to assure that any signals registering on the meter are those that are entering via the antenna connector.

The unit was with the circuits on separate circuit boards, with the "detector board" being a small piece of double-sided glass-epoxy circuit board. Landings were simply cut onto this smaller board to isolate them and the components soldered down. The other board is the meter/amplifier board and this was a small piece of perfboard.

The antenna connection was simply via a BNC connector and short lengths of miniature coaxial cable connect the attenuator and the detector circuit.

Voltage regulation:

If you use the MAX492:

Other than limiting the voltage on U1 to 7 volts (for the MAX492) with LED3, there is little voltage regulation that is required. The circuit should work fine with a battery voltage down to at least 6 volts. Note that the dropping battery voltage will also affect any calibration done to the unit.

If you use the LMC6482:

Because the LMC6482 can easily tolerate through 15 volts, it may run directly from the 9 volt battery with no problems.

If you calibrate the unit in dBm or just want a bit of extra stability, you may wish to include a 5 volt regulator - in which case you would leave out LED3. A standard 78L05 will work but note that it will start to lose regulation when the battery voltage drops below 6.75 volts or so - a voltage at which the battery still has 1/3 of its life left.

If you want the ultimate in low-dropout regulation, a special low-current regulator like the LM2936Z-5.0 (available from Digi-Key and other places.) If you use this regulator, you will need to put a 1-10 uF capacitor on the *battery* (input) side of the regulator ***and*** a good-quality 100 uF capacitor on the *output* side of the regulator, located very close to it. Failure to add this large output capacitor may result in an oscillating regulator rather than a stable one. The cheaper LM2931Z-5.0 will also work, but it in itself consumes nearly as much current as the rest of the circuit - and this current goes up when the battery gets down below 5.5 volts or so.

Getting parts:

- The HP-2835 diodes may be obtained from several places, but a consistent supplier is ***Downeast Microwave*** as the HSMS2800.
- One supplier of the MAX492 and the LMC6482 *(preferred)* dual-op amp is ***Digi-Key electronics***. Make certain that you get the DIP version - unless you plan to build a version with surface-mount parts.

Calibration of the unit:

If you have access to a calibrated signal generator, by all means, use it to test the general performance of the unit. On the unit that I constructed (using HP-2835 diodes) I started getting usable readings below -45 dBm with the detector starting to saturate above +10 dBm. In testing, I observed that the unit was flat to within +-6 dB (or better) from 1 MHz to 1 GHz with the attenuator switched out. As mentioned above, the attenuator's accuracy suffers badly above 500 MHz. In testing, the unit also responded to the small amount of leakage from a microwave oven (at approx. 2450 MHz) from well across the room.

If you are going to put calibration marks on the meter, it is best to have installed a low-power 5 volt regulator to eliminate that particular source of drift. When adjusting calibration, it is also best to do it at room temperature as one definite shortcoming of the simple log-amp circuit shown is that it is susceptible to temperature drift *(because of D3 and D4)* in terms of "dB per meter-unit," with the meter reading high at lower temperatures. *(Note that this is not the same as "zero drift": The drift caused by D3 and D4 only affects the magnitude of the readings and not the zeroing.)* For this reason, calibration will only be reasonably accurate at the temperature at which the calibration was performed (and within +- 10 degrees F.) If this unit is used simply as a field strength meter (and is not used for absolute measurements) then this calibration drift will not be much of an issue as all you need is a consistent indication of "stronger" and "weaker."

While it is certainly possible to construct a circuit that can compensate for some of this thermal drift, this was not done in order to preserve the relative circuit simplicity. Note that some of this "sensitivity drift" is also due to the fact that the intrinsic sensitivity of the detector diodes (D1 and D2) will also change slightly over temperature, but this effect is less than that of the drifting of D3 and D4.

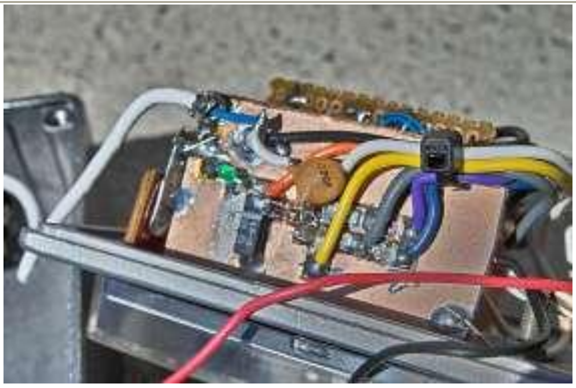


Figure 5: *Top: The "guts" of the field-strength meter. Pieces of self adhesive weather stripping foam are used to pad and contain the battery. Bottom: A close-up view of the "detector" board.*

If you do *not* have access to a calibrated signal generator, you'll have to do the best you can by adjusting R13 (with R16 - if you use it - to zero ohms) such that you get a full-scale (or nearly full-scale) meter reading when transmitting on an HT a few feet away.

In testing, the unit responded with "reasonable" flatness to about 1 GHz and became somewhat inconsistent in its flatness (with peaks and valleys) at 2.4 GHz. The unit continued to respond up through 12.4 GHz (the frequency limit of the available test gear) but its sensitivity was very erratic, no doubt owing to the fact that the internal wiring and layout is simply inappropriate for such frequencies.

Using the unit:

When first switching on the unit, always disconnect the antenna and zero the meter. Note that the meter zero will drift slightly after the unit is first powered up, and it will also drift slightly with temperature, so it is a good idea to check it periodically. Another thing that you will notice is that, with no signal present, the meter will "wiggle" slightly (the magnitude being of a needle width or less) at the bottom end of the scale. This is to be expected and is caused by the normal (and unavoidable) noise produced by *any* semiconductor device and is, in fact, the factor that limits the intrinsic sensitivity of this (or any) simple diode-based RF detector.

One of the first things that you'll notice is that the zero drift affects *only* the bottom-end of the detector range. This is true because of the nature of the log-amp: Weak signals are amplified while stronger ones are seemingly attenuated. Because the overall drift is fairly small, it only shows up in the "low end" of the readings.

With a small rubber duck connected, you'll likely observe a signal strength reading even if you don't happen to have a signal generator or transmitter nearby. Depending on your precise location, you will likely be detecting any nearby broadcast radio/TV stations (or other transmitters - including your own!) Note that because this meter is completely untuned, what you are detecting could be anywhere in the range of AM broadcast through cellular telephone frequencies. It is worth mentioning that, for this reason, you should *not* be talking on a cell phone while using it!

If you get close enough to the transmitter that the signal is consistently above half-scale to two-thirds scale, it may be time to switch in the attenuator. Experience has shown that, with the attenuator switched in, a nearly full-scale reading indicates that you are probably within an arm's length of the object of your search. In a test, the meter was connected to a 1/4 wave magnetic-mount antenna near the rear of the car roof and a 50 watt 2 meter signal was transmitted into a 5/8 wave mag-mount antenna at the front of the car roof (about 8 feet apart.) With the 20 dB attenuator switched in, the meter was "almost" pegged.

When using this (or any) field strength meter, you may want to have a choice of two different antenna:

- A directive array. This could be a small yagi or quad, or it could even be a simple shielded loop antenna. A gain antenna will allow detection of a transmitter at a greater distance and can provide a directional indication of the transmitter's location, but it can be somewhat large and conspicuous. A shielded loop can offer directivity, but its best attribute is its deep null, and it takes practice to effectively use it.
- An omnidirectional antenna. This would probably take the form of a simple rubber-duck antenna. This is smaller and less conspicuous than a directional antenna but is less-sensitive. While it does not have any predictable directional characteristics, one can use the "body-shield" method to ascertain the general bearing of the transmitter.

Detecting cell phones and wireless LANs:

While this unit has fairly good sensitivity at Cell, PCS, and wireless LAN frequencies (approx. 800, 1800, and 2400 MHz, respectively) don't expect it consistently register such devices very well. These devices typically use digital modulation schemes and, unless transferring a lot of data (or unless you are talking on it, in the case of a cell phone) their transmitters have a very low duty cycle.

Because this meter does not have peak reading capability, one may only see the meter "jump" briefly - if it moves at all. Additionally, if you are very near a cell site, the transmit power from a cell phone may be only a few microwatts as they transmit *only* as much power as they need. While peak-reading capability could have been added to this meter, it would have made it more sensitive to things like wireless LANs and cell phones - possible sources of confusion when looking for a hidden ham transmitter.

Comment on E-field sensitivity:

You might notice that R17 is shown as always being connected on S2, even when set to the "0 dB" attenuation setting. The reason for this is that without R17 (and, to some extent, R18 and R19 as well) as a swamping resistor, this circuit will act somewhat like an E-field detector, with the antenna input acting on even very high impedance signals such as those that might be seen using a standard 2 meter rubber duck in the presence of a strong field from an AM broadcast station or an HF transmitter.

If this connection were not made, one would likely notice more than a 20 dB drop in signal when the pad was switched in as those signals off-resonance (e.g. *not* 50 ohms) would be heavily swamped.

If you do *not* include the 20 dB attenuator, you may want to include a similar swamping resistor of 47-100 ohms (value not critical) to prevent an excessive E-field response. If, in fact, you don't mind this response, you may leave it out. Note that by not having something connected to the input that terminates your sense antenna in something resembling 50 ohms, you may not be taking advantage of your antenna's resonance and its bandwidth-limiting response and increase the likelihood of your detector "seeing" signals that are far off-frequency from your sense antenna's resonance.

Further improvements:

There is little doubt that this field strength meter could be improved. A few possibilities:

- Temperature compensation. It is likely that the majority of thermal drift in the reading could be compensated with the addition of a thermistor. Perhaps I will try this at some point...
- Use of a different detector. There are a number of logarithmic amplifier chips (such as the Analog Devices AD8307 - which is available in DIP form) on the market nowadays that can provide well over 50 dB of dynamic range at frequencies of up to at least 500 MHz. *(Such a unit is used in the **"Mark 2" meter**.)* This chip has onboard temperature compensation.
- The input to the diode detector is a *terrible* match to 50 ohms. A slightly better match (and an improvement in sensitivity) could be obtained by using a 1:4 wideband balun on the input (between the attenuator and the diode) and such a balun could easily be constructed using the core from a 75 to 300 ohm TV balun. Note, however, that the balun will affect the frequency response at the low and high ends somewhat, but this may (or may not) be a disadvantage!
- A preselector. As it is, the field strength meter will respond to practically any transmitted signal, regardless of frequency. Adding additional filtering would limit its response to the band of interest. If a preselector is used, one could also incorporate improved matching.

A Wide dynamic range Field Strength Meter

Mark II

by Clint Turner, KA7OEI

This unit is an updated version of the "Mark I" version of the Wide Dynamic Range Field Strength Meter. While the basic function is the same, it has several critical differences:

***Figure 1:** The as-built prototype of the "Mark II" field strength meter.*

- It uses a specialized integrated circuit, the Analog Devices AD8307. This chip is designed specifically as a logarithmic amplifier for use through 500 MHz.
- Using the AD8307, it has a wider dynamic range than the "Mark I" version (85 dB versus 55 dB) and it has built-in temperature compensation.
- Because of the different nature of this type of detector - and the fact that it has temperature compensation - means that there is no need for a "zeroing" control.

One disadvantage of this approach as compared to the diode approach is that the AD8307 has a lower frequency response than the diode. The frequency limit of the "Mark I" meter is dictated pretty much by the diodes themselves along with their physical layout and related components: There is no reason why the earlier version could not be constructed to work through 10 GHz or so - but the AD8307 is falling flat by the time you get to 1 GHz, making it unsuitable for detecting wireless LANs or PCS-type cell phones.

Circuit description:

Figure 2: *Inside the field strength meter, showing the placement of the circuit board, battery, piezoelectric speaker, RF connector, and switches.*
Click on image for a larger version.

The 20 dB attenuator:

A useful addition to this meter is that of a switchable 20 dB attenuator shown below in Figure 3. When getting very close to the transmitter - particularly if it's a fairly powerful one - the signal may constantly "peg" the meter. Being able to throw in a bit of extra attenuation allows one to be able to knock the signal down to something other than full-scale. Additionally, if you are getting very near a high-powered transmitter, there is the possibility that the detector may damaged if you accidentally get the transmitting and receiving antennas too close to each other.

This attenuator is built around S1, a subminiature DPDT slide switch. Note that the "ideal" resistor values are closer to 62 ohms and 240 ohms than the more standard 68 ohms and 270 ohms, respectively, but the values shown are more likely to be found in one's resistor drawer and represent about 1 dB of difference from ideal.

It is important to note that a simple attenuator such as this, built onto a subminiature slide switch, will start to degrade badly above 500 MHz. On the unit that I built, I observed a consistent 21 dB of attenuation from 1 MHz through 2 meters, dropping to 18 dB at 70 cm and going down to about 11 dB at 1 GHz. This is due to the inductance/capacitance of the resistors being used as well as cross-coupling between sections of the switch.

The logarithmic amplifier/detector:
The heart of this meter is U1, an Analog Devices AD8307 logarithmic amplifier. This IC contains numerous cascaded RF amplifiers, each connected to a detector output. The weaker signals are amplified by all of these amplifiers in series and by the time the signal gets to the last one in the chain, it has been amplified considerably and can be detected. As the signal gets stronger, the amplifiers farther down the chain start to get saturated and can no longer provide any more output - but the "earlier" amplifiers have not yet saturated and continue to contribute to the output.

In this manner, a very wide range of signals can be detected, with good accuracy, and with a single IC. Inside U1 is a fairly sophisticated compensation network that provides good temperature compensation and stabilization. With this internal circuitry, the output of the log amp stays within 1 dB over a very wide temperature range and a "zeroing" control is not even required.

Figure 3: *A close-up of the top of the unit showing the input connector and switchable 20 dB attenuator .*

Meter drive circuit:

The output of U1 is a voltage (derived from a current source and a resistor) that is buffered by U2A and then sent, via scaling resistors R5 (and R10) to the meter, M1. Only one half of U2 is used, but the other half could be used if, for instance you wished to provide additional offset, scaling or even drive to an external device.

The audible indicator:

A useful addition to this device is an audible indicator. When I am using the field strength meter, I find myself listening to the tone much more than looking at the meter, as one can walk and look around for the signal source without having to glance continually at the meter face. Personally, I would *not* want to use a meter without one.

The VCO (Voltage Controlled Oscillator) portion of U3 is used to provide a tone pitch that is proportional to the strength of the detected signal. The voltage from the output of U2 is rescaled using resistors R6, R7, and R8 to a frequency range that is comfortably reproduced by the piezoelectric speaker, SPK1.

Note that it is necessary to use R6-R8 for scaling or else the range of frequencies would range from too low to be useful (e.g. clicking from the speaker) to tones high enough to bother dogs. This resistor arrangement "centers" the voltage in a range that is more-or-less in the middle of the high speech range. You may wish to vary R6-R8 slightly to suit your tastes and to accommodate variations in U3 and C7.

If you have never used a piezoelectric speaker before, it may seem to you to behave oddly. Unlike "normal" speakers (e.g. those with magnets, cones, etc.) these respond best to mid-high audio frequencies. Not only that, to maximize efficiency, they have a chamber and a hole to be broadly resonant in their intended frequency range. Because the drive signal from U3 is a square wave, it is extremely rich in harmonics and because of this one may hear predominantly harmonics when the frequency is lower (e.g. lower signal levels.) In practice, this isn't a problem as most people can distinguish the pitch changes anyway. If you choose to use a more conventional speaker, note that U3 *cannot* drive it directly and a simple circuit will be needed to provide good output. This drive circuit could be as complex as an audio amplifier (perhaps based on an LM386) or it might be as simple as an emitter follower and resistor.

Note that no "on/off" switch is shown for the audible tone generator. This circuit draws less than 1 mA from the battery - a fraction of the total. If you need to silence the tone, simply covering the speaker's hole with a finger will work, but it would be very easy to add a simple on/off switch.

Constructing the unit:

Figure 4: *A close-up of the back side of the switchable 20 dB attenuator and input connector.*

The schematic is shown in Figure 7, farther down the page.

It is strongly recommended that this meter be housed in a shielded (metal) enclosure to assure that any signals registering on the meter are those that are entering via the antenna connector.

As can be seen from the pictures, all circuits were constructed on phenolic "perfboard" and the ICs were socketed. While the use of perfboard and IC sockets can contribute to degraded accuracy at higher frequencies *(see the commends in "Using the unit" below)* absolute accuracy was not considered to be of extreme priority as this instrument was designed simply for the detection of RF.

Nevertheless, there are a few building techniques that can greatly enhance the accuracy when using perfboard techniques at UHF:

- Use a layout that promotes as short interconnections as possible. For the RF inputs, it just makes sense to place the input blocking capacitors and terminating resistor (C1, C2, and R4) as close to the IC as possible.
- Use physically small components. Don't use very large ceramic capacitors for C1 and C2, for example, but use the smaller, low-voltage types.
- Use a low-profile IC socket. These are the most common types found these days.
- Use a heavy, short ground bus for the DC/RF return between the RF input and the IC's ground pins, as noted in the picture and on the schematic.

Keeping these in mind, connections were quite short and laid out close to the IC. Once you "get past" the RF portions, however, layout is no longer as critical and conventional audio/HF layout techniques may be used.

Clearly, if you wanted to obtain performance that was as close to the intrinsic accuracy of the chip, the best course of action would be to lay out a proper double-sided circuit board (with through-holes and vias) and use exclusively surface-mount components. On the unit that I built, I happened to solder a surface-mount capacitor on the bottom of the IC socket, but this may be overkill *(and I had the capacitor, anyway...)*

The connection from the RF input was simply via a BNC connector and short lengths of miniature coaxial cable. These short lengths of cable connect not only the input connector to the attenuator, but from the attenuator to the circuit board as well.

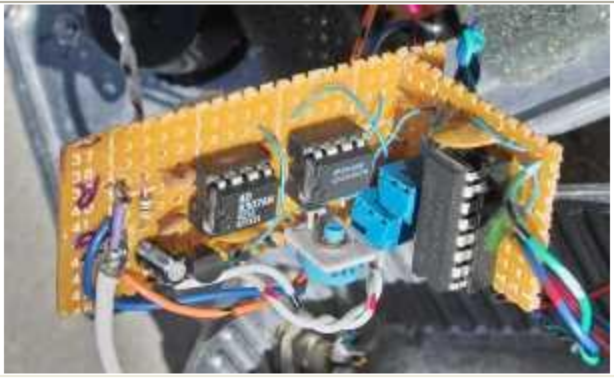
When mounting the piezoelectric speaker, make sure that the hole in the enclosure is at list half again as large as the hold in the piezo speaker itself. If they are the same size - or if the hole in the enclosure is smaller than the one on the speaker - efficiency may suffer greatly due to the broad, self-resonance of the piezo being dampened. Note that an on/off switch was not provided for the sounder/speaker. If this is desired, one may use the switch to either interrupt the output from pin 4 of U3, or simply have it remove the power from U3, pin 16 and save a milliamp or so.

Constructing the 20 dB switchable attenuator:

The use of short leads is a must for best performance of the attenuator. As can be seen from ***figure 4***, the "ground" of the resistors and the coax was soldered directly to the body of the attenuator switch which, in turn, is fastened to the shielded enclosure. Soldering to the switch can, however, present a problem: It is steel, and electrical solder does ***not*** adhere well to steel using standard rosin flux.

To get a good connection to the body of the switch, one needs a *hot* iron to allow connections to be made quickly and avoid melting the plastic components of the switch. In addition, one needs to scrape the metal clean with sandpaper or a knife, removing any paint, lacquer, and/or oxide coating at those areas where a connection will be made. Finally, to make a reliable solder connection, a flux more aggressive than that found in electrical solder ***must*** be used. The preferred flux is a strong *acid* flux used for soldering to stainless steel, but it turns out that the paste flux used for plumbing will also work.

When done soldering to the steel switch body, verify mechanically and electrically (with an ohmmeter) that you haven't overheated the switch and melted the plastic components within and that the switch operates properly. At this point, it is a good idea to remove any remaining flux to prevent chemical corrosion and for this task I typically use cotton swabs and denatured alcohol.



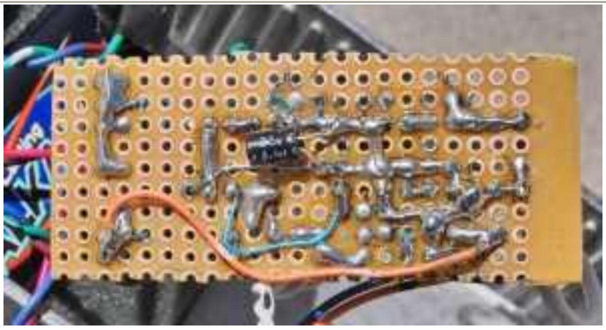


Figure 5 (top): *The log amp (main board) and the audible tone generator (the board at the right-angle.)*
Figure 6 (bottom): *The bottom of the main board. The RF input is on the right.*

Obtaining parts:

The majority of the parts are commonly available, but here are a few pointers to obtaining some of those that may not be in your junk box:

- The AD8307AN may be obtained from ***Digi-Key electronics***. Make certain that you get the DIP version - unless you plan to build a version with surface-mount parts.
- The LMC6482IN dual op-amp may also be obtained from ***Digi-Key electronics***. Again, make sure that you get the DIP version (if you want it) when ordering.
- A **MAX492** *(available froms **Digi-Key**)* may be substituted for the LMC6482IN but note that the MAX492 has a ***maximum limitation of 7 volts***. This isn't a problem, but it means that the "V+" connected to pin 8 of U2 ***must*** be connected to the +5 volt output from the voltage regulator. *(Once again, make certain that you get the DIP version - unless you plan to build a version with surface-mount parts.)*
- The meter shown is a 1 mA meter movement obtained from Radio Shack. This is disguised as a 15 volt DC meter (supplied with a scaling resistor) and is part number **22-410**. Other meter movements may be used, provided that R10 is recalculated to limit the maximum current to the meter to a safe value should R5 be "turned up" all of the way.
- The piezoelectric sounder is a 2-lead type *(without internal drive circuitry)* and is Radio Shack part number **273-073**.
- Switches S1 and S2 (power and attenuator) are from a "6 piece slide switch kit" which is Radio Shack part number **275-327**.

Mounting components:

The most time-consuming portions of construction involve putting the project into its case. The specified meter comes with a hole template: One needs to make sure that the corners of the meter do not interfere with the screws used to hold the case together.

The holes for the meter and slide switches were creating using the "drill 'n file" method in which smaller holes are drilled corresponding with the component being mounted and then enlarged (by breaking/cutting pieces of the enclosure "between" holds) and squared or sized up using a set of needle files (available at many hardware stores or even Radio Shack.) ***After*** the larger holes have been sized properly for the meter and switches, additional holes are drilled for the mounting screws.

Calibrating the unit:

If you have test equipment:

If you have test equipment, calibration is very straightforward: Using a frequency generator anywhere from 1 MHz to 200 Mhz, feed a +10 dBm signal into the input and set the "full scale" pot (R5) for a full-scale reading! One would then adjust the signal generator 10 dB at a time, noting each one on the scale. *(You would, of course, have the 20 dB attenuator switched out...)*

If you don't have access to a signal generator that is capable of at least +10 dBm, you can extrapolate the reading as follows:

- Set the output of the signal generator to, say, -60 dBm and note the reading.
- Set the output of the signal generator to -50 dBm and note the difference in the reading. Do the same at -40 dBm.
- Taking the differences between the readings you can determine the average size of 10 dB steps and extrapolate where a reading of +10 dBm would be and adjust R5.

If you don't have any test equipment:

If you don't have any test equipment handy, the goal is to make as much of the range of the instrument as possible appear on the meter:

- Start off with R5 set only about 1/4 of the way up from the "ground" end and make sure that the 20 dB attenuator is switched out.
- Using a 2 meter HT, set it to ***low power*** (or anything from 0.1 to 0.5 watts) and, with a rubber duck antenna connected to the field strength meter, key it up within a foot or so of the meter and move it around a bit. Get a "feel" of what the "maximum" reading will be, adjusting R5 downward if the meter pegs.
- Adjust R5 so that the "maximum" signal just barely pegs the meter.
- You are done!

While this second method isn't scientific, but it will guarantee that you'll get the full range from the field strength meter.

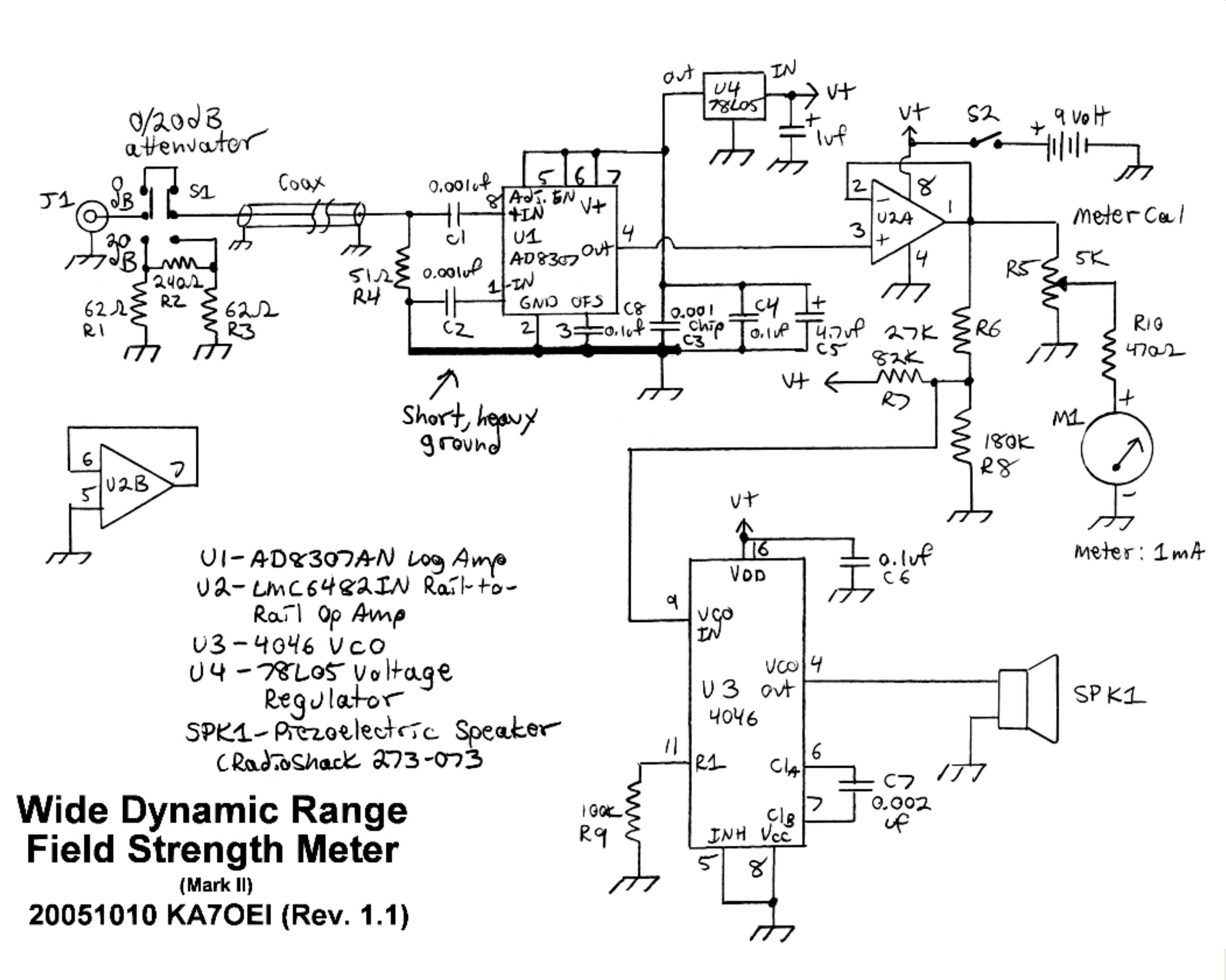


***Figure 7:** The schematic of the "Mark II" Wide Dynamic range field strength meter.*

Using the unit:

When first switching on the unit, always disconnect the antenna and note where the minimum reading will be. This meter does ***not*** have a "zeroing" control but you'll also notice that even with no signal applied, it will still read upscale from zero a bit. This reading is largely due to the intrinsic noise of the input detector stages (e.g. thermal "background noise") of the chip and is not a malfunction. Because the meter reads in decibels, you cannot possibly ever get to "zero" (no signal) anyway, so once has to decide, at some point, what the "minimum reading" can be. In this case, the sensitivity of the AD8307 itself is the limiting factor and this is typically around -75 dBm, varying slightly with temperature and from unit-to-unit.

With a small rubber duck (or ***any*** antenna) connected, ***you'll likely observe a signal strength reading even if you don't happen to have a signal generator or transmitter nearby***. Depending on your precise location, you will likely be detecting any nearby broadcast radio/TV stations (or other transmitters - including your own!) Note that because this meter is completely untuned, what you are detecting could be anywhere in the range of AM broadcast through cellular telephone frequencies. It is worth mentioning that, for this reason, you should *not* be talking on an HT (or even a cell phone) while using it!

In metro areas, you may find that you will get a reading from distant transmitters - ***even if the 20 dB attenuator is switched in!*** Keep in mind that the signals being received may be ***anything*** from AM broadcast band through UHF TV stations that your antenna just happens to be able to pick up. In such a metro area, it may be worth building a bandpass filter, tuned to pass only those frequencies (near) those of interest. If there is enough room, a set of such filters may be built into the unit - or they may be outboard modules connected between the field strength meter and the antenna lead.

If you get close enough to the transmitter that the signal is consistently above half-scale to two-thirds scale, it may be time to switch in the attenuator. Experience has shown that, with the attenuator switched in, a nearly full-scale reading indicates that you are probably within an arm's length of the object of your search. In a test, the meter was connected to a 1/4 wave magnetic-mount antenna near the rear of the car roof and a 50 watt 2 meter signal was transmitted into a 5/8 wave mag-mount antenna at the front of the car roof (about 8 feet apart.) With the 20 dB attenuator switched in, the meter was "almost" pegged.

When using this (or any) field strength meter, you may want to have a choice of two different antennas:

- A directive array. This could be a small yagi or quad, or it could even be a simple shielded loop antenna. A gain antenna will allow detection of a transmitter at a greater distance and can provide a directional indication of the transmitter's location, but it can be somewhat large and conspicuous. A shielded loop can offer directivity, but its best attribute is its deep null, and it takes practice to effectively use it.
- An omnidirectional antenna. This would probably take the form of a simple rubber-duck antenna. This is smaller and less conspicuous than a directional antenna but is less-sensitive. While it does not have any predictable directional characteristics, one can use the "body-shield" method to ascertain the general bearing of the transmitter.

The AD8307 has built-in temperature compensation so that over the expected temperature range (freezing to hot) it will be stable to be within 1 dB. Accuracy over the entire frequency range will likely be somewhat worse than this, owing to a few factors:

- The frequency response of the AD8307 itself. This will be down by a dB or so by the time you get to 500 MHz.
- Losses/mismatch in the circuit layout. When you get up to several hundred MHz, it takes very careful layout and selection of components to avoid stray losses. The AD8307 is good enough that these losses start to come into play. Using perfboard, as shown in the prototype, it is very difficult to provide a low-loss layout, but careful attention to detail can minimize these.
- The input attenuator circuit. The prototype uses a 20 dB switchable attenuator using a standard subminiature slide switch and resistors. These components were not designed for optimum performance at frequencies of several hundred MHz and the performance of this attenuator will suffer in terms of added losses (on the "zero" attenuation setting) as well as cross-coupling through the switch (when in the 20 dB setting) which will reduce the attenuation from 20 dB to something lower, typically in the 15-18 dB area, depending on exact component layout.

Maximum input signal level and the response above 300 MHz:

The AD8307 is rated to respond properly to signal levels up to +17 dBm (50 milliwatts) input: Higher than this exceeds the recommended rating of the chip and could cause damage. Above 200-300 MHz or so this chip will start to compress at +10 dBm and by the time you get to 500 MHz, however, the AD8307 will start to "compress" above about +5 dBm. While no damage will be done, this is worth noting so that one can know to switch in the 20 dB attenuator.

Detecting cell phones and wireless LANs:

The AD8307 used in this device starts to lose sensitivity above about 500 MHz and is down several dB by the time one gets to the Cell Phone band (below 900 MHz) and the sensitivity drops like a rock above 1 GHz. For this reason, it will not easily detect PCS-type phones or wireless LANs as well as the ***Mark I*** version can.

Note also that digital cell phones and wireless LANs often have very short duty cycle transmissions: This circuit does not have any sort of "peak/hold" detector and very brief transmissions may not be noticed.

Additional comments:

The use of the AD8307 in ham radio project is, by no means, unique: Doing a web search on this part will yield several hits showing some interesting projects, from field strength meters to power meters. This project was designed to be about as simple and usable as practical, while retaining the benefits of this device.