Brass Tacks

An in-depth look at a radio-related topic

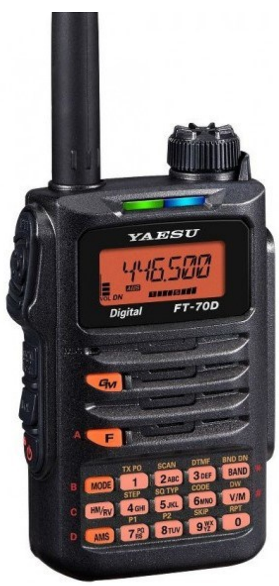
Instrumentation and test devices

We human beings seem to have this need to measure things, from the temperature of the room to the distance to Grandma's house. For some reason, we want to know our heart rate, the height of a tree, or how long it takes for paint to dry. There might come a time when you'll want to measure something on your radio, antenna, or other gear. ***Instrumentation*** is a word that means *device or software used to measure, test, and/or monitor something*.

In the world of amateur radio, we have a lot of scientific measuring devices available to us, but fortunately, only a small subset is truly useful to any practical extent. I mean, if people tell you that your signal isn't getting out like it used to, you'd probably like to know what changed, and how to test that. Let's explore the devices you as a licensed operator might care to use, and list a few others. The intention is to distinguish between the basic equipment you might need and that of a fully-equipped diagnostic facility. To that end, I've grouped this discussion into three categories, by instrumentation ***you must have***, those that are ***nice to have***, and ***others***.

Must-have measurement instruments

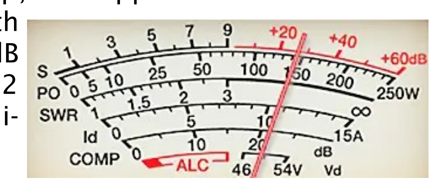
I've been asked many times what testing or measuring devices ***must*** be in our possession as a radio amateur, and my answer is often, ***none***. If you ***are*** a person who feels the need to measure or monitor something anyway, then I recommend this list:



- **S-meter**

An ***S-meter*** (signal strength meter) is built into most transceivers, to display the relative strength of the signal being received at the tuned frequency. So, an additional discrete measuring device is typically not needed, but I mention it here for completeness, because it's a meter that an operator should have, if any.

In the HT (handheld transceiver) example to the left, the S-meter is displayed as the dashed line across the bottom of the display. In this case, it appears the HT is displaying about an S8 signal strength. Also, below is an example of an S-meter that might appear on an HF (high frequency) transceiver, as a needle over a set of values. In this example, the S-meter values are displayed across the top, so it appears that the S-meter is measuring a received signal strength of about +27, which means "about 27 dB over S9" or 2 x 2 x 2 x 2 x 2 x 2 x 2 x 2 x 2 = 512 times the strength of a calibrated S9 signal.



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- **Power meter / “watt” meter**

A ***power meter*** displays the amount of RF (radio frequency) power (in watts) that’s being transferred somewhere, like from your radio to your coax, or from your tuner to your antenna. More often than not, such a power meter is built right in to your transceiver, so a separate piece of equipment to display measured power is not usually necessary. Still, it’s essential to know how much RF power your rig is attempting to deliver to the antenna, especially on a fixed station.

On many, if not most, HTs (handheld transceivers) and mobile units, the power meter displays a series of bars on a graph, similar to the S-meter mentioned above. Typically, this bar graph only presents a relative quantity, such as discrete “Po” or “PO” units. Obtaining a more accurate RF power reading will likely require a separate, external power meter.

An ***RF power meter*** displays the output of your transceiver somewhere along your transmission line (coax). Discussed later, a ***field-strength meter*** measures the RF power that your transceiver sends out through your antenna. Yet another type of power meter measures the amount of ***DC power*** that your transceiver and other equipment draws from your power supply. And there are other power meters, so referring to a “power meter” can be ambiguous.

Bird 43 wattmeter

Other types of watt meters include peak-reading, average-reading, and directional. I won’t go into detail about those here, but there’s one make that I would like to mention: the Bird wattmeter, because many have asked my opinion about it. It’s a very accurate and directional (can display how much power is being transferred in each direction) meter, and the Model 43 is considered the professional industry standard, and therefore very expensive ($700 to $1100 new). For most amateur needs, the Bird wattmeter is very much overkill, IMO.

- **SWR meter**

An ***SWR meter*** is an instrument that displays the ***standing wave ratio*** of your antenna system. That is, it compares the amount of power being delivered to a load (“forward power” or “incident power”), with the amount of power being reflected by the load (“reflected power”), due to an impedance mismatch, the case in which the impedance of the load does not perfectly equal that of the source. Because an SWR meter can measure the forward power, an additional power meter is more than often not needed at the same point.

An SWR meter requires power from the transceiver to work, and so must be inserted in the feed line between your transceiver and your antenna. Then, it’ll display the SWR value as you transmit on your radio. Many transceivers, especially HF rigs, have SWR meters built into their displays, and will show the values while you’re transmitting and if the *SWR meter* is selected.

Today’s SWR meters tend to come in any of three flavors of readout displays: digital, gauge, and cross-needle. A digital

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readout displays numerals for forward power, reflected power, and the SWR. A "gauge" meter displays the SWR by a needle across the dial, like the S-meter in an HF transceiver. A cross-needle display shows the forward power by one needle and the reflected power by the other needle, and you can read the SWR where the two intersect.

Cross-needle SWR meter

The SWR meter is good for a "sanity-check"; that is, provides a quick and easy way to visualize your antenna system SWR *at one particular frequency*. To get the "bigger picture" requires an instrument that can display the SWR for an entire band, for example. That's the job of an antenna analyzer.

- **Antenna analyzer**

An ***antenna analyzer***, like the RigExpert AA-170 to the left, measures a number of things about your ***antenna system***, which includes your coax, tuner / matching, and antenna, without the need of any applied signal from your transceiver. Among the important quantities measured is the ***SWR bandwidth***, which is the range of frequencies for which the detected SWR is 2.0:1 or lower.

If you're the type of person who plans to make more than two or three antennas, then I highly recommend an antenna analyzer be part of your arsenal. On one hand, they can be expensive; on the other hand, if you're a regular antenna builder, you can justify the cost, especially for their convenience if you need to take many measurements while tuning your antenna.

One instrument that has taken the antenna analysis world by storm is the ***NanoVNA***. It's a true VNA (vector network analyzer), and its ability to perform antenna analysis, coupled with its very low price tag, has made it nearly indispensable to the amateur crafter. It does have somewhat of a learning curve, but I believe its low price and high functionality outweigh the time and effort you invest.

- **Multi-meter**

Once in a while you might want to measure your battery or solar panel voltage, your wall socket (house current) voltage, the resistance in your connections, or whether your coax has a short in it. If you do, a ***multi-meter*** might be what you need. But if you only need to measure voltage, why not just get a voltmeter? Because today, the technology makes it easy to combine several measurement functions into a single instrument, so meters that measure properties like voltage, current, and resistance tend to be packaged together.

As mentioned, a multi-meter is so-called because it can perform several functions, most typically that of a ***voltmeter*** (measures voltage),

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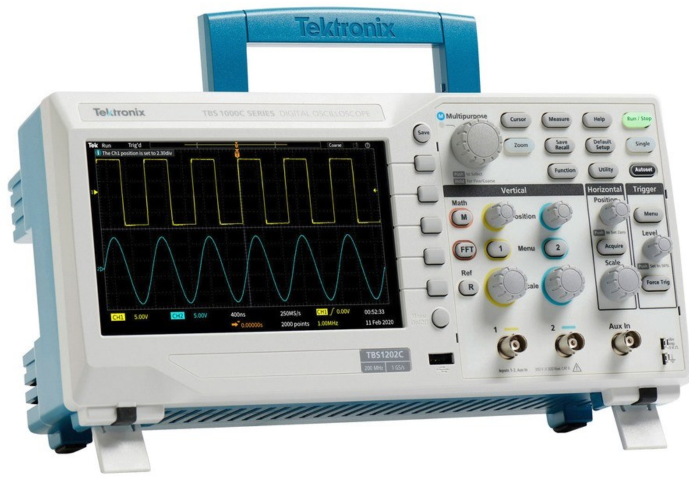
ohmmeter (measures resistance), and ***ammeter*** (measures current), then display their measured quantities. More sophisticated multi-meters can measure and display other interesting properties, such as power, continuity, temperature, humidity, wind speed, and more.

It honestly doesn't matter whether your multi-meter is modern (***DMM : digital multi-meter***), analog (***VOM : volt-ohm meter***), or something more ancient (***VTVM : vacuum tube voltmeter***), as long as it works reasonably well for your needs. A DMM is my choice of multi-meter, but its biggest drawback is its inability to display more than one value per interval, like every second. This hides values that might occur between those interval samples, like voltage spikes in your power supply.

Nice-to-have measurement instruments

Some useful instrumentation might not be as essential to your needs as those in the previous section. That could be due to their usage frequency, their utility, or being out-of-reach due to their price. Here are some measuring tools that might come in handy (assuming you know how to use them), but can probably wait until you really need them or can afford them:

- **Oscilloscope**



An ***oscilloscope*** (often abbreviated as an *o-scope*) is a laboratory instrument that can display a signal waveform (shape of a periodic wave), even a complex one. The advantage of viewing a signal waveform is that it provides a snapshot of the signal during one period, allowing you to see an entire cycle of its voltage transition as a function of time. This way, you can be sure that the waveform is correct (square wave, sinusoidal, modulated carrier, etc.) and not a distorted (clipped, over-damped, etc.) version of it, allowing you to quickly test, verify, isolate, and debug a circuit if the signal is not as expected.

The proper operation of an o-scope requires more than a casual knowledge of electronics by the operator, who is often an electronics technician. An o-scope is a must-have device for a person who spends quite a lot of time developing, building, and testing electronics, but not as necessary to a person who simply dabbles in basic antenna-building.

- **Field strength meter**

A few years ago, the FCC published updated guidelines on RF exposure, and gave us more than a year to comply with them. Most of the guidelines could be met by making a few station assumptions, but if you really wanted to be certain about the RF radiation you're exposing your family and neighbors to, you would need to perform some actual testing. This requires the use of a ***field strength meter***, which can display the relative RF electric field strength of a transmitted signal for a specific frequency at a specific height and distance from an antenna.

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One helpful thing that can be learned from a field strength meter is the radiation pattern of an antenna, if that's important to you. And that could be important if you suspect your antenna pattern takeoff angle might be pointed too high to reach distant stations, or if your radiation pattern is a little more directional than you'd like it.

Field-strength meter

A field strength meter is nothing more than a simple receiver that's sensitive to the electric field at a particular frequency, regardless of mode. Professional field strength meters have been used to measure and verify the signal strength of broadcast radio and television stations as it's received over large distances, such as counties or small states. For amateur purposes, because most field strength meters are mode-agnostic, it's best to test your field strengths by using a transmitted carrier, such as with AM, CW, or FM.

- **Spectrum analyzer**

Another useful tool is the ***spectrum analyzer***. While an oscilloscope measures and displays voltages over a period of time, a spectrum analyzer uses an FFT (Fast Fourier Transform) to convert the signal from the time domain to the frequency domain. This converted display allows you to visualize the behavior of a signal across a wide range, or spectrum, of frequencies.

The spectrum analyzer is useful for exposing problems such as harmonics (multiples of a signal frequency) and spurious (imitation) emissions that your radio might be transmitting in a band outside the amateur or other bands of interest. It can also used for identifying noise and other interference sources because the spectrum analyzer displays a graph of signal strength per frequency, and interfering signals will appear as spikes or relatively strong signals at the culprit frequencies.

Similar to the NanoVNA, the ***tinySA*** is a miniature, hand-held version of a fully equipped spectrum analyzer, that's proving to be a viable, useful, and inexpensive alternative to the standard instrument. Its frequency coverage isn't as large, and it has fewer features than the standard spectrum analyzer, but if you need to examine amateur signals by a frequency spread, the tinySA might be in your future.

The tinySA

- **VNA**

One instrument that many RF engineers consider indispensable is the ***VNA*** (vector network analyzer). Think of your transceiver, your feed line (coax), tuner, and antenna as part of a network of components, some active and some passive (don't require external power to make them work). Erratic voltages and currents, like you might measure with an oscilloscope, can be difficult to display at high frequencies, so a VNA can accurately display the power and phase of a signal as it travels through the network.

Measuring the signal power and phase in one direction provides part of the network picture,

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but the signal also needs to be evaluated in the opposite direction for properties such as reflection. So, instead of disconnecting and then reconnecting your network in the opposite direction, the VNA provides two ports to facilitate this. For this reason, a VNA is also known as a ***two-port analyzer***.

High-frequency electrical networks can become very complex without much effort. The VNA helps simplify the complexity by use of what's known as S-parameters (scattering parameters). These values help detail how high-frequency energy propagates through an electrical network. They offer comprehensive insight into the linear behavior of RF and microwave components, and provide the very bases for filter, transmission line, and amplifier design.

Although you're not likely an RF engineer, you might still find a VNA useful in antenna modeling, feed line analysis, phasing, and for measuring a number of important properties, such as impedance, return loss, insertion loss, and SWR. *Phasing* is important if you want to construct an array of antennas to improve its overall gain. It can also be used in troubleshooting such problems as EMI, jitter, ground bounce, and crosstalk.

- **Power monitor**

Unlike a power meter, mentioned above, a ***power monitor*** measures and displays the voltage, current, and sometimes other properties of your power line, whether that's DC (direct current) into your radio or single-phase AC (alternating current) into your power supply and amplifier. Many power monitors have the ability to interrupt the power under an adverse condition, such as over-current or a brown-out. If you live in an area of frequent brown-outs or poor power conditioning, a power monitor such as a UPS (uninterruptible power source) might help you.

DC power monitor

One type of power monitor not only displays voltage and current, but also power consumption by your equipment. An immediately useful application of a DC power monitor is at your solar charge controller, where the monitor can give you some idea of its conversion efficiency.

Other measurement instruments and thoughts

I'm not going to discuss every piece of instrumentation available to us, but this short list represents some that might be useful, depending on your needs:

- **Frequency counter** (detects the frequency of an unknown signal)
- **Thermometer / temperature gauge**
- **Logic analyzer / logic probe** (compares the states and timing of several digital signals)
- **Battery tester** (gives you an idea of battery charge level and remaining life)
- **Service monitor** (combination device that can measure signal-to-noise ratio, modulation integrity, tone encoding, spectrum analysis, and more)

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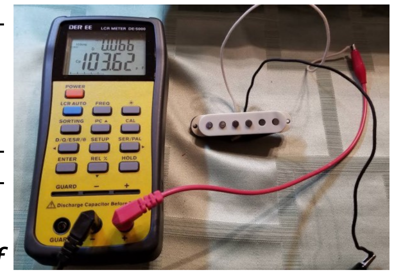
- **LCR meter** (one that can measure the inductance of inductors, the capacitance of capacitors, and impedance.

Instrumentation calibration



The DE-5000 LCR meter

Your test instrument is only as good as its calibration. Maintaining good calibration on your equipment can provide accurate results, but there are a few trade-offs to think about.

1. One of the first considerations to calibration is the ***cost of performing the calibration***. If you can calibrate it yourself, then you've saved on hiring a professional and the cost of shipping the device to the calibration lab. But if the calibration procedure is so difficult that you need to a) take a week to learn it and b) purchase special calibration equipment to get it done, you might need to ask yourself whether the calibration is all that necessary, and if it is, then whether you should eat the cost of having the lab do it after all.
2. The finer your accuracy demand, the more often and "closer to spec" you'll need to calibrate your test instrument. If your power ("watt") meter displays between 60 watts and 70 watts during a test transmission, when your mobile radio is set for the full 65 watts, it's probably not in need of calibration. Even though it's a little off, it probably reads "good enough" for what you need.
3. Some instruments, such as the pixel-displayed S-meter on your fancy HF transceiver, might be quite difficult (meaning *impractical*) to calibrate, and is not likely worth the cost and effort to send in the unit to get it done. If you find that one of your test devices (such as an SWR meter) seems ***way*** off, and yet it's nearly impossible to calibrate it (because it's built into a software application, for example), the problem might be with something else (like your antenna).
4. The factory calibration performed for many modern devices likely never need re-calibration unless they've been damaged in some way. Most high-quality DMMs, for example, arrive fully calibrated, and so probably never need to be re-calibrated.
5. The calibrations mentioned above are "factory" calibrations; that is, each is performed typically by a professional, to ensure an instrument's accuracy. The last calibration is a "per-use" calibration; that is, a minor calibration performed by you, before using the device that day. For example, an oscilloscope requires an expensive and detailed professional calibration by a trained expert, while a NanoVNA requires you to run through its brief calibration procedure before using it, to compensate for variations in temperature, vibrations, and humidity.

Summary

Any testing or measuring device or software can be considered instrumentation. Most instrumentation can be considered non-essential to your particular needs, but even the essential ones are likely few, if any. Calibration is often an after-thought that many (amateurs and professionals alike) overlook, yet can be important, but its cost versus benefit must be taken into account.

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