# Spectrum Analyzer - a Primer on What You Need and How to Use It

By Don Jackson, W5QN

Electrical Measurements

When analyzing or troubleshooting our gear, we have a number of instruments at our disposal. If the signal is constant over time, or its amplitude does not vary with time, a simple voltmeter will work. However, if the signal is more complex, and we wish to observe its exact behavior at any given points in time, we need an instrument that looks at the signal in the "time domain". The oscilloscope is such an instrument, and displays the signal in "X-Y" coordinates, with time on the "X" axis, and amplitude on the "Y" axis. Although this information is very useful for many measurements, it does not tell us anything specific about the spectral (frequency) content of the signal. To provide this information, we need an instrument that functions in the "frequency domain", which is where the spectrum analyzer comes in. The spectrum analyzer (SA) displays frequency on the "X" axis and amplitude on the "Y" axis.

The "Y" axis of a standard oscilloscope is always in Volts. However, the SA "Y" axis is usually expressed in decibels. Most commonly, the display is shown in dBm, where "0 dBm" is 1 mW, although "linear" and dBV are also available in some SA units. Using the decibel scale is very handy since this enables the operator to take advantage of the very large dynamic range of the SA. For example, if you set the SA for +20 dBm (100 mW) at the top graticule, you might still be able to see signals at -50 dBm (.01 uW) while simultaneously viewing a +20 dBm signal.

How Does An SA Work?

Early SA units were analog designs that were really just receivers that could be swept in frequency. The local oscillator of the receiver was swept over the desired frequency range with a sawtooth waveform that was also applied to the "X" axis of a display. The output of the receiver was then applied to the "Y" axis of the display. Figure 1 shows a very simplified block diagram of such an SA.

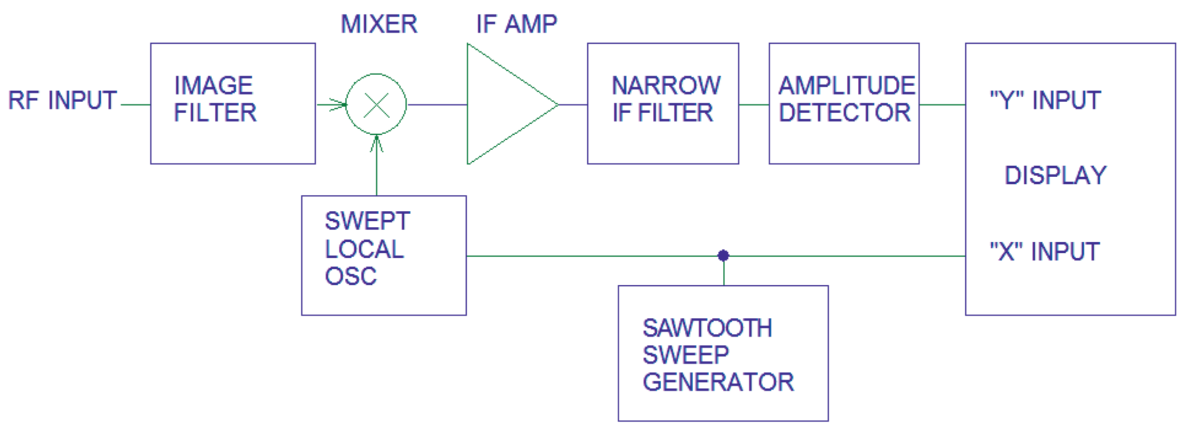


**Figure 1 – Analog Spectrum Analyzer Concept**

However, all (to my knowledge) modern SA instruments use a mathematical transformation process to achieve the same spectral display. The transformation enables conversion of a time domain version of a signal into its frequency domain counterpart, and vice-versa. It is named the Fourier Transform in honor of Joseph Fourier who initiated the mathematical concepts in the early 1800s. Modern analog-to-digital conversion techniques, coupled with Fast Fourier Transform (FFT) algorithms have allowed SA instruments to be designed and produced that are smaller and less expensive than earlier analog versions.

Why Use an SA?

Simply looking at a transmitter's output on an oscilloscope doesn't tell us much about how well it is functioning. All we see is the signal in the time domain, and very little can be gleaned about spectral aspects such as harmonic content or spurious emissions. However, looking at the transmitter output with a SA, we can see the harmonic output - as well as other undesired spectral content such as internal local oscillator signals, and spurious oscillations. SA instruments allow us to see signals at very low levels, typically 60 dB, or more, below the amplitude of the primary output signal.

What Measurements Can We Perform?

There are numerous observations that can be made using an SA. A few are listed below:

- Transmitter harmonics
- Spurious oscillation evaluation
- Two-Tone linearity tests
- Noise analysis
- EMI analysis

Probably the most important use of the SA is to fully characterize transmitting equipment. Considering that your transmitter signal is going to be out there in the public RF environment, it is critical that you are able to confirm it is putting out a clean signal, with harmonics and spurious outputs within manufacturer and FCC specifications. The SA is THE instrument for this job.

SA Terms and Definitions

- Frequency: Center frequency of the displayed spectrum
- Span: Width of the spectrum displayed (stop frequency minus start frequency)
- Resolution Bandwidth (RBW): Sets the closest frequency separation discernible on the display
- Phase Noise: Noise contributed by the SA internal components (primarily the oscillators)

Obviously, you will need an SA that covers the frequency range of your equipment including reasonable harmonics. RBW is important if you plan to perform measurements such as two-tone tests, in which you must be able to measure spectral components that are just a kHz or so apart. For this task, you need an RBW of 300Hz or less.

What Practical SA Instruments Are Available?

For the audio frequency range, your best bet is to download one of many free FFT software programs to use with your computer audio card. The one I've found to be the best for my purposes is from SpectrumLab. It is loaded with features and even has the ability to output various test signals from your audio card. It is possible to use this software to perform two-tone tests on a transmitter. Using a mixer and local oscillator (a frequency synthesizer in my case), I converted the RF output of my S-Line down to the audio band. SpectrumLab produced the two-tone input to the 32S-3, as well as analyzing the audio output from the mixer. The results were quite good. Of course, you must be sure that all levels are adjusted so that additional distortion is not created in the mixer or the computer audio card. (Editor's Note: If there is enough indicated interest in this approach, there may be another article on this technique in the future.)

For the RF frequency range, there are a lot of old analog SA units out there, primarily HP and Tektronix. The HP-141T with the 110MHz or 1200MHz RF plug-in is very nice for amateur use. However, you should make sure the CRT is in good condition, as finding a replacement is likely to be a real challenge. As with all used gear, condition is a huge part of the equation. A decent HP-141T seems to go for around $500, depending on condition. Tektronix also produced a number of SA plug-ins for their oscilloscopes, so that could also be an option.

There are also many FFT SA units available today as USB modules that plug directly into your computer USB port. These are interesting units, and vary in price from less than $100 to over $1,000. I've never actually used one, but it is clear you will want to read the unit specifications carefully to make sure you get a unit that will do what you want. For example, many units do not cover the HF frequency range. Also, many units do not have the resolution bandwidth required for two-tone audio measurements. For example, Triarchy ($529) and RF Instruments ($330) have units with frequency coverage down to 1MHz, but their minimum RBW is only in the 50kHz range. Signal Hound has units that fill the bill, but they are over $900. So, be careful when purchasing.

Another option to consider is the Rigol DSA-815, which came on the market a couple of years ago. It is a stand-alone SA that has most all the features an amateur typically needs. It has an input frequency range of 9kHz to 1.5GHz, and resolution bandwidths from 100Hz to 1MHz. Considering that comparable SA analog units with these features were priced in the $50k to $100k range, the Rigol's price of $1,295 is very reasonable. For an additional $200, you get the "tracking generator" option, which allows the DSA-815-TG to function as a scalar network analyzer. This is very handy for measuring the frequency domain characteristics of 2-port networks such as amplifiers or filters. You can read a review of the unit in the February 2013 issue of QST.

Care and Feeding of Your SA

Whatever your choice of SA, the primary threat to its health is too much input power. Considering the SA is often used to characterize a high powered transmitter, there is a huge potential for blowing out the front end of your SA. It cannot be too strongly stressed that you ensure the power you apply to the SA is within its specification limits. When using an SA to measure transmitter characteristics, you must always use a device that reduces the power to an acceptable level. On the surface, an obvious way to do this is with a resistive attenuator. A broadband 60 dB attenuator would do nicely to reduce that 1 kW output to 1 mW. However, this is not that easy a solution considering the attenuator will be required to dissipate that 1 kW. For this reason, we don't see very many 60 dB, 1 kW attenuators. You will find an occasional Bird Dummy Load in the 100-500 watt range that has a sampling port output. These can be very useful if you can find one.

The next option usually considered is to use a 1 kW dummy load, with a "capacitive tap" device connected to its input. Such a device is usually a coaxial "T" connector with an adjustable probe that can be positioned close to the center conductor of the connector. This technique is handy, as it can be set to tap off a very small amount of power from the main line to the dummy load. However, this is not a "broadband" device. Since it approximates a small capacitor connected to the coaxial line, its frequency response is that of a high pass filter. If you are only interested in observing a single frequency, this is fine. However, consider the case where you desire to measure the level of various harmonics of your transmitter. The capacitive tap has an output with a "6 dB/octave" frequency response. For example, let's assume you wish to confirm that your transmitter meets its specification of -50 dB for all harmonics. Using your SA, you set a reference level for the fundamental frequency (7 MHz for example) of 0 dB. You now look at the second harmonic (14 MHz) and can see that it is only at -44 dB. Even worse, the $4^{th}$ harmonic (28 MHz) level is at -38 dB. Although it would appear that your transmitter is out of spec, it actually is not. Taking into account the 6 dB/octave increase in signal level, the $2^{nd}$ and $4^{th}$ harmonics are both actually -50 dB below the fundamental. So, is there a better solution than the capacitive sampler?

Assuming we want to sample a high power transmitter output, and feed that sample to a SA with 50Ω input impedance, the best approach is probably to use a sampler designed around a current transformer. These can produce a reasonably flat frequency response over several octaves. You can read about how they work at http://www.g3ynh.info/zdocs/bridges/Xformers/part_1.html and design a suitable sampler yourself. It is also interesting to note that Warren Bruene's coupler design, used in the well-known Bruene directional coupler, uses the current transformer concept. Warren describes details of the transformer in his April 1959 QST article "An Inside Picture of Directional Wattmeters".

I've always wanted such a sampling device, but never got around to acquiring one. Of course, you can purchase one, but they can be very expensive (Magnelab CT-B unit for $590, for example) unless you can find a great deal on a used unit. Being curious and frugal by nature, I decided to try my hand at building a suitable unit. I designed it to handle 1500W input, with a sampled output 50 dB below the input.


**Figure 2– Don's Homebrew 50 db Sampler**

The sampled output port is designed to have a source of 50Ω to provide a match to 50Ω test equipment. If you are transmitting 1500 Watts, the output of the sampler is 15 mW (+11.8 dBm), which

# Spectrum Analyzer (Cont'd)

should be well within the maximum input limits of an SA. Also, since the sample port source impedance is 50Ω, you can add low power coaxial attenuators to the sample port to accurately lower the power even further if you wish.

Although something of a breadboard version, its performance is pretty impressive. The sample port small signal frequency response was measured to be .58 MHz to 145 MHz (at -1 dB down). From 1.7 MHz to 128 MHz, the response is flat within about .25 dB. The .58 MHz low end was very close to the design target. The high frequency end is difficult to predict in the design phase since it is a function of the distributed capacitance of the transformer winding and other subtle affects. However, the 145 MHz result is certainly satisfactory for typical HF use.

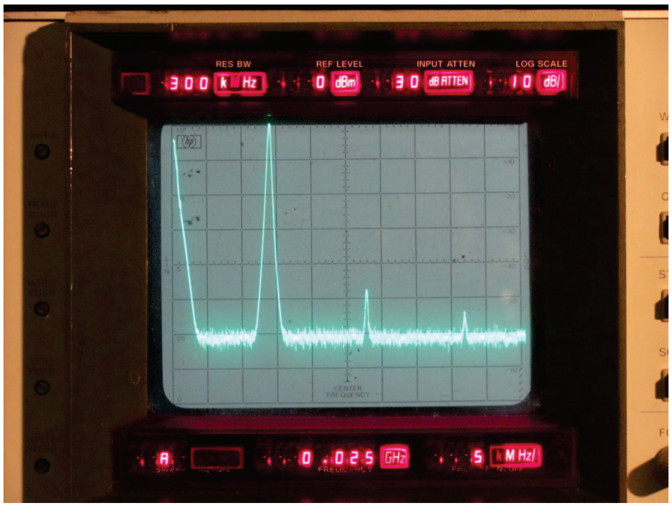


**Figure 3 – 32S-3 Harmonic Content using HP 8565A**

The mid-band coupling factor was measured to be so close to the 50dB design target that luck had to be involved! Let's just say the coupling factor is very predictable from the design equations. Insertion loss of the main line was measured to be less than .06dB up to 170 MHz (as read from the plot of Figure 7 in the construction article). A more complete discussion of the sampler design and construction appears elsewhere in this issue of the *Signal*.

Figure 2 is a photo of my own SA, an old HP-8565A, which is a nice unit, but is only specified over the 10MHz to 22 GHz frequency range. The lower limits are not exactly optimum for HF use. Nevertheless, I set it up with my new RF sampler to display the output of my 32S-3, operating at 100 Watt CW output on 20m. You can see that the fundamental power level read on the SA display is 0 dBm (1 mW), which is 50 dB below 100 Watts. As well, the $2^{nd}$ harmonic is 47 dB below the fundamental, and the $3^{rd}$ harmonic is 55 dB below the fundamental. By the way, the 32S-3 $2^{nd}$ harmonic spec is 40 dB. Also, we can see there are no undesired oscillations or other components in the output signal.

Operating Technique

As with all sophisticated test equipment, you should carefully read the manual concerning its proper use. There are a couple of common errors that operators typically might make when using an SA.

The first applies to analog SA designs, and involves the relationship between Sweep Speed and Resolution Bandwidth. Without going into detail, there is a maximum Sweep Speed that can be used for a given selected RBW. If this Sweep Speed is exceeded, the amplitude of signals on the display will decrease, and the amplitude calibration of the SA will be invalid. For best results, start with a slow Sweep Speed and increase until you see the signal amplitude decrease. Then reduce the Sweep Speed one increment from that point. Although most SA units automatically set the Sweep Speed as the RBW is changed, some may not, or the "automatic" feature may be overridden.

The second potential error applies to all SA designs and is encountered when performing tests involving system linearity. Such tests include harmonic and 2-tone intermodulation testing. The problem is that you must ensure that the SA is not adding its own distortion to the distortion of the device under test. Most SA units have a switchable passive attenuator at the RF input that is usually variable in 10 dB steps. While observing the display containing desired and distortion component, note their relative levels. Now switch the attenuator to a higher attenuation value. For example, you might have started with an attenuator setting of 10 dB. Switch to 20dB attenuation and note whether ALL the displayed signals decrease 10 dB in level. If they do, the SA is not adding significant distortion to the measurement. However, if the distortion products change by something other than 10 dB, the SA is adding to the distortion. You must then continue increasing the attenuator setting until you see proper behavior of all the signals on the display.

Actually, there are third and fourth – all too common - errors that are more, let's say, mundane in nature. All too often, while using a SA, "it" happens. You either get the attenuation wrong – easy to do, or you transmit into your SA without the sampler in line after using the SA and tracking generator to work on your transceiver-receiver side. Only a large dose of care will prevent these two last occurrences.

Conclusions

Without a doubt, a spectrum analyzer is a very useful piece of equipment to have on the bench. It provides a way of looking at signals in the frequency domain that an oscilloscope cannot. As such, the SA is very useful for a wide variety of tasks, and nearly indispensable for transmitter work. Be sure you understand what you want from the SA before investing money. And, to protect that investment, be absolutely sure you do not damage it by applying too much input power.
Cheers,

de Don, W5QN

Author's Note: As this article progressed, I finally bowed to temptation and bought myself a Birthday and Christmas present combined. I am now the proud owner of one of Rigol's offerings.

The Rigol Model DSA815-TG (the –TG signifies it has the tracking generator installed) shown here was acquired and used to repeat many of the measurements already taken. You can see more of what this machine can do in the article on the construction of the 50 db sampler in this issue. Suffice to say here that the Rigol products bring new meaning to the words "Bang for your buck".