For generations, the rules for RF engineers were simple: frequency-domain measurements (output frequency, band power, signal bandwidth, etc.) were done by a spectrum analyzer, and time domain measurements (pulse width and repetition rate, signal timing, etc.) were done by an oscilloscope.

As the digital revolution made signal processing techniques easier and more widespread, the lines between the two platforms began to blur. Oscilloscopes started incorporating Fast Fourier Transform (FFT) techniques that converted the time-domain traces to the frequency domain. Spectrum analyzers began capturing their data in the time domain and using post-processing to generate displays. Still, there were some clear distinctions between the two platforms. For example, oscilloscopes were limited in sample speed. They could see signals down to DC, but only up to a few GHz. Spectrum analyzers could see high into the microwave range, but they missed transient signals as they swept.

What if you needed to see a signal in the time domain with a carrier frequency of 40 GHz or capture a complete wideband pulse in X-band? As technologies in EW, radar and communications move ahead, the demands on the test equipment become greater.

As more possibilities have opened for RF and microwave equipment because of new digital processing technologies, they have also increased opportunities for test equipment. Spectrum analyzers and oscilloscopes can do much more than they could even a few years ago, and as they expand in capabilities, the lines between them become blurred and sometimes even erased.
Changes in technology

The digital revolution has changed the way spectrum analyzers and oscilloscopes work at a fundamental level.

Spectrum analyzers

Most spectrum analyzers now have an all-digital signal processing (DSP) section. Like a classic spectrum analyzer, the incoming signal is down-converted to a much lower Intermediate Frequency (IF). This signal is sampled, digitized by an Analog-to-Digital Converter (ADC) and processed using DSP techniques. The spectrum analyzer now provides two modes of operation: sweeping the LO to see signals across a wide range or “pausing” the LO to simultaneously see everything within the analysis bandwidth allowed by the sampling rate.

The main advantages of this technique are improved accuracy and reliability: with the analog components replaced by digital processing, the uncertainties inherent in the analog components can be greatly reduced. Classic spectrum analyzer components like Resolution Bandwidth (RBW) filters and log amplifiers are now implemented digitally and made more accurate and repeatable.

Two additional advantages are given by “pausing” the local oscillator and collecting data around one frequency. The first is the ability to view a wideband signal in the time domain. Because the signal is now sampled and digitized, it can be displayed in the time domain, just like an oscilloscope. The main difference here is the spectrum analyzer data has been down-converted, so the displayed data is relative to the center frequency of the measurement. The second is the ability to see the phase information of the signal. By performing some basic DSP, the phase of signals like communications signals and radar chirps can be demodulated and analyzed. Some manufacturers refer to spectrum analyzers with this capability as “signal analyzers” to reflect this new ability to demodulate and analyze the signals riding on the carrier.

The signal analyzer still has an important limitation: the sampling speed of the ADC in the digital IF section. This limits the analysis bandwidth to no more than a few hundred MHz.

Figure 1. Simplified block diagram of a spectrum analyzer.
Oscilloscopes

Like the IF section of a signal analyzer, signals incident on the oscilloscope’s front end are sampled and processed digitally, but at much higher rates. There are now real-time oscilloscopes that can sample at speeds up to 160 GSa/s, allowing the oscilloscope to see signals from DC up to 63 GHz.

There are some considerations that can limit the usefulness of this architecture. One is the avalanche of data that results from such fast sampling. Hundreds of gigabytes of data are generated per second, and typically only fractions of a second can be captured and analyzed at one time if the full bandwidth is used. Data processing techniques like segmented memory can extend the capture time, but this technique only works for pulsed or repeating signals. Another consideration is that high-speed ADCs usually only offer 8 bits of resolution, unlike the 14 or 16 bits in signal analyzers. If you are looking for low-level signals across a wide frequency range (e.g., a spur search), the spectrum analyzer has an advantage, but for most communications and radar applications, the differences between the two boxes may not be significant.

The right instrument for the job

Although the two technologies overlap, there are some basic differences:

**Carrier frequency and signal bandwidth:** The most important parameter to consider is the bandwidth of the signal you want to analyze. If your signal is within the bandwidth of the spectrum analyzer and the carrier frequency is higher than a few GHz, it is often the better option. The spectrum analyzer’s lower sample rate will allow you to capture and analyze data for a longer time. Also, spectrum analyzers are typically less expensive than their oscilloscope counterparts at frequencies of 10 GHz or more. However, if you need to analyze signals wider than a few hundred MHz or to see rise and fall times below 20 ns, the oscilloscope is the better choice.

**Voltage (power) resolution and noise floor:** Data resolution may also be a consideration. Typical spectrum analyzers sample data at 14 bits, where typical oscilloscopes are 8-bit devices. Also, unlike the spectrum analyzer, the oscilloscope has a wide-open front end (no filtering), and more broadband noise can find its way into the measurement. This can be a problem in environments that contain high levels of noise or background signals. For many applications, data processing techniques in the oscilloscope can reduce or eliminate this difference.

**Number of channels of data:** The spectrum analyzer is a one-channel device. Oscilloscopes are typically two- or four-channel devices. Although spectrum analyzers can be connected coherently, this is not trivial or inexpensive. For measurements made over two, three or four channels, an oscilloscope has a natural advantage.

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![Figure 2. Simplified block diagram of a 4-channel oscilloscope.](image-url)
Examples

To illustrate the practical effects of these distinctions, here are some of the advantages and disadvantages of spectrum analyzers and oscilloscopes for common signals:

Radar signals (static carrier frequency): Typical radar signals are of relatively low bandwidths (<100 MHz) but high carrier frequencies. If the bandwidth fits within the analysis bandwidth of the spectrum analyzer, then it is the logical choice. The signal analyzer will offer higher resolution and longer capture times, typically for a lower price. For wider radar signals, an oscilloscope may be needed to see the entire signal at once without sweeping.

Frequency-hopping signals: If the signal is hopping within the analysis bandwidth of the signal analyzer, gap-free data can be collected for several seconds (in some cases, several minutes or hours using an external RAID array) vs. several milliseconds for a high-speed oscilloscope. If the frequency range of the hopping signal is wider, the user will need to move to an oscilloscope.

Wideband communications signals: A high-speed oscilloscope can be a great tool for demodulating and analyzing communications signals with symbol rates higher than 100 MHz. Measurements of signals at Ka and Ku bands with symbol rates of several GHz are common.

Small signal searching: The key to searching for spurs and other low-power signals is limiting the amount of noise in the measurement. The signal analyzer’s ability to perform a narrowband sweep over a wide range of frequencies, thereby filtering out most broadband noise, makes it an ideal tool for small signal searches.

Multi-channel signals: For some applications like Phased Array Radar, Multiple Antenna Detection systems and MIMO communications, it may be desirable to analyze and compare a dozen or more signals in parallel. Here the oscilloscope has the natural advantage of being a 4-channel device, with time-coherent channels.

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<table>
<thead>
<tr>
<th></th>
<th>Spectrum analyzer</th>
<th>Oscilloscope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis bandwidth</td>
<td>Up to a few hundred MHz</td>
<td>Up to the highest frequency of the instrument</td>
</tr>
<tr>
<td>Microwave frequencies</td>
<td>Yes</td>
<td>Yes, but more expensive</td>
</tr>
<tr>
<td>Length of capture</td>
<td>Seconds or minutes</td>
<td>Milliseconds</td>
</tr>
<tr>
<td>Demodulation/analysis</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fast rise/fall times</td>
<td>20 ns</td>
<td>5 ps</td>
</tr>
<tr>
<td>Multi-channel signals</td>
<td>Requires multiple boxes and synchronization</td>
<td>4 channels within one box, more channels can be achieved with multiple boxes or digitizers</td>
</tr>
</tbody>
</table>

For more than 4 channels, the right choice might be to set aside both of the technologies we have been discussing and go with an array of digitizers. Without the overhead and additional components found in spectrum analyzers and oscilloscopes, digitizers can be a compact and cost-effective solution for analysis of multiple channels. The disadvantage is usually the additional labor needed to configure them and process the data.

As a result of the incorporation of digital signal processing techniques inside spectrum analyzers and oscilloscopes, the lines that distinguish the two technologies have become blurred to the point where for some applications, the best spectrum analyzer might be an oscilloscope, and the best oscilloscope might be a spectrum analyzer. In either case, the user will find that today’s instruments are far more capable and powerful than those available even a decade ago.

Figure 3. Comparison of the two platforms for some typical parameters.
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