The simple man's Spectrum Analyser
Spectrum Analyser theory

Why do you want a Spectrum Analyser?

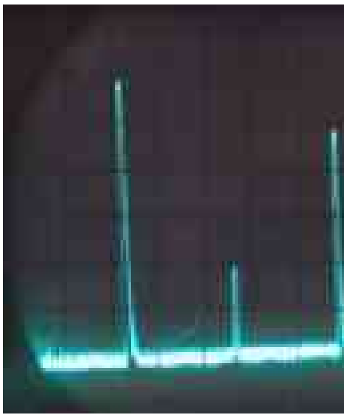
When you use an oscilloscope for the first time it is like a revelation. Suddenly you can see those waveforms you've previously known were there but been unable to see except in your imagination. Your oscilloscope is like a window into the private electronic world of your circuits. Before long you find your oscilloscope so useful in diagnosing faults that you can't imagine being without one.

Using a spectrum analyser for the first time is somewhat similar. In my case, I previously only had a 5MHz bandwidth oscilloscope. Working on anything at higher frequencies than that was a matter of hoping it worked. If it didn't, I could measure voltages etc but had no way of knowing if something was oscillating or not, etc. Ok, I could get a faster oscilloscope, but there are many things which just can't be observed on an oscilloscope, any more than you can observe waveforms on your voltmeter.

Condider building a linear power amplifier for your transmitter. Regulations specify that spurious signals should be more than 40dB below the wanted signals. Even if your oscilloscope has a high enough bandwidth to see the harmonics, you won't be able to see them directly. Here's an example.

{gallery}satheory/1{/gallery}

On the left is a pure sinewave, your ideal transmitter output at a single frequency with no spurious harmonic components. Centre: here's what your transmitter output looks like with the desired signal's 3rd harmonic present, just 20dB below the carrier. You can see



something's wrong, but you can't really say exactly what, still less quantify it. On the right: now the 3rd harmonic is 40dB below the carrier, right where your transmitter output is legal. No distortion of the waveform at all is visible on your oscilloscope. In fact, you might be forgiven for thinking faked the picture by reproducing the perfect (left) picture rather than bothering to adjust my spreadsheet and take a .gif off it.

Enter the spectrum analyser, which decomposes an incoming RF waveform into its individual frequency components. Pictured right is an example of what the spectrum analyser output might look like in the above example. This is the frequency spectrum of my old Heathkit signal generator, tuned to about 30MHz. This is the peak about 1/4 the way across the screen from the left. The display also clearly shows the 2nd harmonic near the centre of the screen, the prominent 3rd harmonic, and even the 4th harmonic at 120MHz on the far right of the screen. With a little careful calibration to known dB per screen division, the amplitude of these spurious outputs can be measured at a glance.

How a spectrum analyser works

A spectrum analyser is basically a superheterodyne radio receiver having an extremely wide frequency coverage. Rather than tuning to a fixed station, in the analyser the received frequency is swept over a wide range. The amplitude of the signals received at varying frequency are detected and displayed on the Y-axis of the oscilloscope screen. At the same time, the X-axis of the oscilloscope is swept from left to right in perfect synchronisation with the receiver frequency sweeping. The best way of accomplishing this is with an oscilloscope having an X input, which the majority (even cheap ones) do. However it is also possible to use oscilloscopes lacking X-channel inputs, by letting their usual internal sweep take control and synchronise it to the analyser output using the oscilloscope's external trigger input.

A logarithmic output is highly desireable. If we want to be able to see frequency components which may differ in amplitude by say 60dB, and we use an ordinary linear display, the smallest peaks are 1 thousandth the height of the largest. Hardly conducive to accurate measurement. On the other hand, if a logarithmic output is used, the screen output could be calibrated to say 10dB per division, and the small signal would be 6 divisions shorter than the largest signal, permitting good measurements to be made.

The "receiver" design must concentrate on slightly different priorities than a real radio receiver, due to the wide frequency coverage. In particular, it is more difficult to eliminate spurious responses when no bandpass filter can be used in the front end, and what is at one moment a spurious response, may just a little later in the frequency sweep be a frequency we want to be able to measure. It is therefore usual spectrum analyser practice to use a first intermediate frequency (IF) above the highest frequency to be covered. Selectivity at that high first IF is impossible to achieve to the necessary degree, so at least one more conversion must be used to a much lower 2nd IF, where finer selectivity filters can be used. In professional spectrum analysers with enormous range, 4 stages of conversion are commonplace.

The simple man's spectrum analyser

In this project I chose to use the SA602 (NE602) oscillator and mixer IC so beloved of radio amateurs. It doesn't give the world's best noise, intermodulation or dynamic range performance, but it does result in a nice simple and reliable circuit. I used a 1st IF of 145MHz. This gives me a frequency coverage of 0 - 140MHz, and requires a local oscillator sweeping 145 - 285MHz which hits about the maximum frequency that can be expected of the SA602. This one octave tuning range is also about the most that can be expected of a simple voltage controlled oscillator (VCO). A 145MHz triple tuned helical filter was also available, having 2MHz bandwidth and high stopband attenuation perfect for the 1st IF filter.

A second IF of 8MHz was chosen mainly to suit the quantity of 3-terminal ceramic filters I happened to have in my junk box. An alternative 2nd IF of 10.7MHz would suit the very commonly avialable broadcast FM radio filters. No changes to the circuit would be required for this modification, other than to appropriately adjust the 153MHz 2nd local oscillator to 155.7MHz.

{gallery}satheory/2{/gallery}

This block diagram shows the complete spectrum analyser. The input attenutator is extremely useful for reducing strong signals that would cause spurious responses in the analyser "receiver", and also for accurate display calibration and measurements. Preceeding the input attenuator is a unity-gain amplifier with high impedance input. This can be switched out to present a standard input impedance of 50-ohms, or switched in for high impedance signal sources.

The 10MHz crystal calibration oscillator produces harmonics right up to the maximum frequency range of the spectrum ananlyser and allows accurate calibration and measurements on the frequency axis. The low pass filter cuts out incoming frequencies above the maximum frequency coverage, reducing the incidence of spurious "image" responses.

SA602A IC's are used for both the swept 1st oscillator (VCO) and mixer, and the fixed 153MHz oscillator and 2nd mixer. The unity gain amplifier between the 1st mixer and the 145MHz helical filter converts the 1.5K-ohm output impedance of the SA602 to the 50-ohm impedance of the filter. Using another IC amplifier here avoids impedance matching circuits and further simplifies construction of the analyser.

Construction of the analyser is in separate modules which may be built and tested individually. The order of module construction is such that each module can be aligned and tested using the previous modules, building up the complete system until the builder has a working spectrum analyser. The diagram below is another version of the above block diagram, this time showing the interconnection between physical circuit modules.

{gallery}satheory/3{/gallery}