USEFUL INFORMATION FOR USERS OF TEKTRONIX INSTRUMENTS

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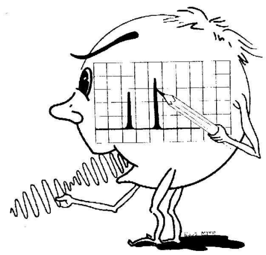
GETTING ACQUAINTED WITH SPECTRUM ANALYZERS



by Russ Myer
Tektronix Advertising Dept.

This article forms a conceptual basis for the understanding of Spectrum Analysis, thus preparing the reader for the several advanced works available on the subject written on the Engineering level.

Part I

WHAT IS A SPECTRUM ANALYZER?

At any given moment, there is an incredible amount of activity within that portion of the Electromagnetic Spectrum that we call the Radio Frequency Bands. These bands range in frequency from about 15 kc to 750,000 Mc.

Assume you have a special radio receiver capable of tuning over this entire range. At the lower end, you'll find maritime ship-to-shore, aircraft point-to-point, high-powered government and commercial transoceanic signals. Tuning higher in frequency, within the familiar 540-to-1600 kc broadcast band, dozens of commercial radio stations compete for your attention. Above these, you'll find more ship-to-shore, and, confined to relatively small portions of the spectrum, thousands of "ham" radio operators pursue their electronic endeavors. Also, interspaced throughout this short-wave band, you will hear much air-ground activity, government point-to-point, many foreign broadcast stations, the Voice of America (and Moscow!), police radio broadcast stations, and some experimental work.

Still higher in frequency, you'll find television stations, starting at 54 Mc, FM stations above 88 Mc and more television above 174 Mc. The area above 400 Mc, once considered experimental, produces myriad signals: microwave, telemetry and others.

These radio transmissions take various electronic configurations, ranging from single-frequency carriers to complex signals produced by changing these carriers in amplitude, frequency and phase.

Regardless of the shape of these signals and how they were produced, or "modulated", each one can be separated into individual sine waves. Each sine wave represents a single frequency. To examine the composition and quality of a signal, you would find it very helpful to extract each individual sine wave that it contains and display it alone on an oscilloscope. Seeing all the sine waves in a "group" picture, each standing alone, would enable you to analyze the complex signal. The instrument that performs this task for you is called a Spectrum Analyzer.

To use an example of a familiar but complex waveform which could be reduced to individual sine waves for analysis, consider an AM radio station. A broadcast transmitter radiates a single carrier frequency from its antenna. Intelligence (speech, music, tones, etc.) is superimposed on this carrier, varying its amplitude at an audio rate. Assume the station is transmitting a 1000-cycle test tone. The carrier frequency of the station is 1 Mc. This carrier is combined in the final stage of the transmitter with the 1000-cycle tone. The antenna, however, through the process of "modulation", is broadcasting not two, but *three* signals. Viewed on a conventional scope, the signal might look like figure 1a.

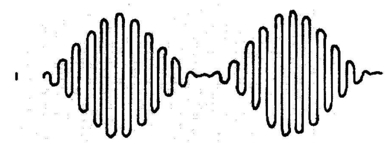


Figure 1a. Conventional oscilloscope display of 1000 kc carrier modulated by a 1000 cps tone.

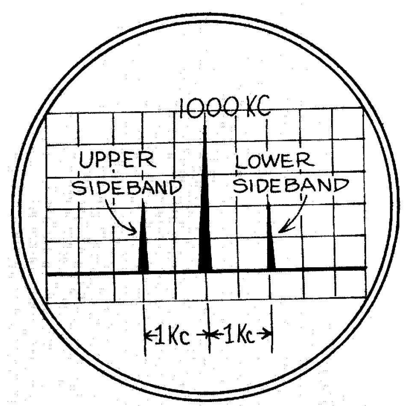
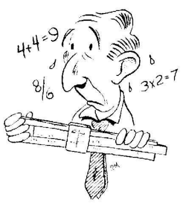


Figure 1b. Display of same signal using Spectrum Analyzer.

Electrically, the carrier is still occupying the 1-Mc spot in the spectrum. Exactly 1000 cycles below this frequency, however, at 999 kc, you will find a new signal, called the "lower sideband". 1000 cycles above the 1-Mc spot, at 1,001 kc, you'll find another signal, identical to the one at 999 kc, called the "upper sideband". The separation is exactly equal to the modulating frequency — the 1000 cycle tone. The Spectrum Analyzer is capable of displaying these three frequencies, individually, on the screen of a cathode-ray tube. Thus, the component frequencies may be individually studied, or "analyzed". Figure 1b shows how the Spectrum Analyzer would display them.



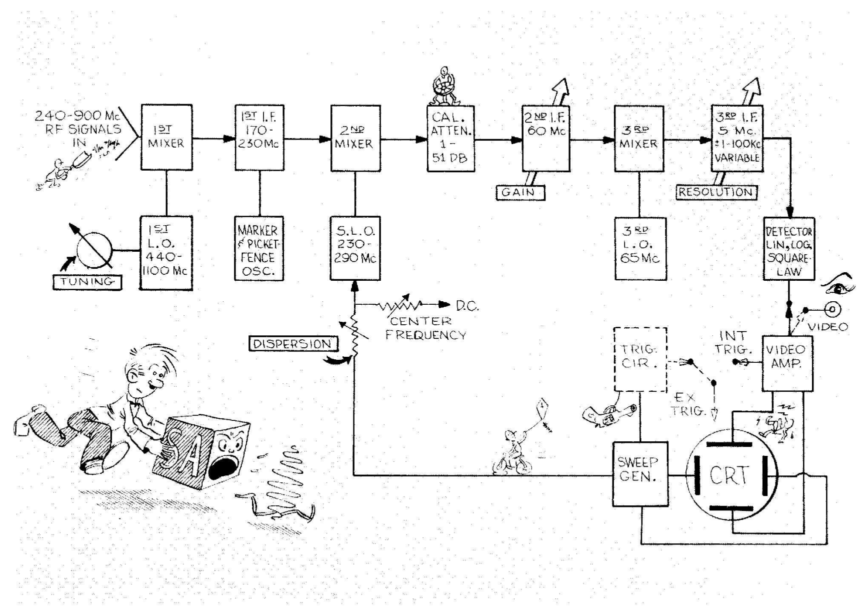
There is nothing difficult about the overall operation of the analyzer. The signals which we will use as examples, however, must be followed in detail through the different sections shown in the block diagram. To understand the conversion of input signals to signals of lower frequencies, you will find it helpful to perform the simple arithmetical computations dealing with the mixer and i.f. (intermediate frequency) sections.

There are several ways that a signal can be broken down into component sine waves. One method is to introduce the signal to a stack of filters, the inputs of which are paralleled. Each filter is tuned, in successsion, to a slightly different frequency than the others. The output of each filter will contain only that portion of the input which corresponds to the frequency it was tuned to. The drawback here is that for most complex signals, you would need hundreds of filters — a costly mechanical burden. Too, it is difficult to design filters with narrow bandwidths to produce good resolution between closely-related signal components.

The prism is also a simple spectrum analyzer. It takes the visible portion of the electromagnetic spectrum and breaks it up into its component frequencies, each representing a familiar color. There are chemical analogies, also, such as the chemist's ability to reduce complex compounds into their individual ingredients. The Tektronix Spectrum Analyzer performs an analysis by purely electronic means.

HETERODYNING

To continue our discussion of the analyzer, we will review, briefly, the principle of heterodyning. Years ago, Armstrong and his colleagues created the "superhet" receiver. They discovered that it was possible to feed two separate single-frequency signals into a non-linear device, usually a vacuum tube, and get *four* signals out! Using suitable filters, they found that besides the two original frequencies, they had a 3rd



Block diagram of typical Tektronix Plug-In Spectrum Analyzer.

frequency that was equal to the mathematical difference of the input signals. Also, they found a 4th frequency in the output — one equal to the sum of the two original signals. They applied this principle to the superheterodyne receiver, like one you probably have in your home today. The following example illustrates this concept, so necessary to the understanding of Spectrum Analyzers.

Tune in a radio station that has, let us say, a carrier frequency of 1080 kc. This frequency enters the front end of your radio and into a "mixer" tube. A local oscillator in your set, which follows the main tuning, generates a frequency of 1535 kc. This oscillator frequency also is fed into the mixer tube. In the output of this tube, as in the days of Armstrong, you have the two original frequencies *plus* the two new frequencies mentioned before: 2615 kc and 455 kc. The latter, 455 kc, is the one accepted by the tuned circuits of the intermediate-frequency stages of your receiver.

As we tune across the band, we simultaneously tune the local oscillator to a frequency exactly 455 kc above the frequency of the station tuned in. Thus, a highly-efficient i.f. stage can be designed which is responsive to a single frequency — the 455-kc difference between the local oscillator and the frequency present at the front end.

HOW THE ANALYZER WORKS

Tektronix Spectrum Analyzers, built as plug-in accessories for existing oscilloscopes, cover various frequency ranges. Currently, these cover frequencies from 1 Mc to 10.4 Gc (Gigacycles). One of these, the Type L-20, will analyze frequencies from 10 Mc to 4 Gc, in 5 bands. We will consider the range of frequencies covered by band 2 of the Type L-20, roughly 230 Mc to 900 Mc.

Refer to the block diagram of the analyzer. Incoming signals are introduced directly into the first mixer. As in your radio receiver, there is a local oscillator associated with the mixer. This oscillator is tuned by the front-panel control which also rotates the tuning dial indicating the frequency of the incoming signal. It tunes through a frequency range of 440 Mc to 1100 Mc. The output of the mixer is fed into the first i.f. stage. This stage is fixed-tuned to 200 Mc.

Therefore, any input signal that will mix with the local-oscillator frequency in the mixer stage and produce a difference frequency of 200 Mc will pass through the 1st i.f. For example, when the local oscillator (abbreviated L.O.) is tuned to its lowest frequency, 440 Mc (the main tuning dial reading 240 Mc), an input signal of 240 Mc will "beat" with this frequency in the mixer and produce the desired i.f. output of 200 Mc. Tuning the L.O. to 600 Mc means that there has to be an input signal of 400-Mc to produce a 200-Mc difference. The highest setting of the L.O., 1100 Mc, allows a signal of 900 Mc to produce the 200-Mc difference and appear in the first i.f. You will see that *any* signal tuned in from 240 Mc to 1100 Mc will produce the same 200-Mc difference.

The first i.f. is tuned to a center frequency of 200 Mc. The bandwidth of this circuit is fixed at 60 Mc. Therefore, any signals 30 Mc above or below the 200 Mc difference frequency will also pass through the i.f. This is important to the operation of the Spectrum Analyzer.

We will now follow 3 input signals through the analyzer. Their frequencies are: 280 Mc, 300 Mc, and 320 Mc. Assume you have set the tuning dial on 300 Mc, calling it the "Center Frequency". Actually, you have tuned the L.O. to 500 Mc. This produces a 200-Mc difference between the L.O. and the 300-Mc center frequency. This 200-Mc "beat" frequency falls in the middle of the i.f. tuned circuit. The input frequency of 280 Mc also is beating with the established L.O. frequency of 500 Mc. It produces an output from the mixer stage of 220 Mc. This falls within the 60 Mc bandpass of the i.f. stage. The input of 320-Mc also produces a frequency (180 Mc) that falls within the bandpass of the i.f. stage. You will see, therefore, that at the output of the first i.f. stage, all three input signals are present. They have the same 20-Mc separation but are reduced in frequency. Although converted in frequency, their relationship to one another has not been changed. It is important to realize one difference, however: The 180-Mc i.f. signal represents the *highest-frequency* input signal, 320 Mc. The 220-Mc i.f. signal represents the lowest-frequency (280 Mc) input signal. In other words, there is a reversal of relative frequency.

The three signals at the output of the first i.f. stage are now fed into a second mixer. See block diagram. This mixer is also associated with a local oscillator, and the output is fed into a 2nd i.f. stage. This stage is actually tuned to 59 Mc, but to simplify our example, consider that it is tuned to 60 Mc. The 2nd local oscillator is also tuned and covers a frequency range of 230 Mc to 290 Mc. The tuning is accomplished by electronic means, however. The oscillator frequency is "swept" through this frequency range by the application of an external sawtooth.

The inputs to the 2nd mixer stage always exist within the range of 170 Mc to 230 Mc. No other signals can get through the first i.f. Note that the 2nd local oscillator (Swept Local Oscillator — S.L.O.) sweeps through a range of 60 Mc — the band-width of the 1st i.f. Therefore, any signal from 170 Mc to 230 Mc, when combined with the 230-Mc to 290-Mc "sweep" of the S.L.O. will produce a 60-Mc difference frequency. The 2nd i.f. has a relatively narrow bandwidth and is sensitive only to this 60-Mc difference.

To illustrate how a swept oscillator produces the 60-Mc i.f. frequency, consider the 3 input signals to the 2nd mixer stage. The S.L.O. begins its normal sweep, starting at 230 Mc. To produce the desired i.f. frequency of 60 Mc there would have to be a 170-Mc signal present at the 2nd detector input. There is none, thus no i.f. frequency is produced. The S.L.O. continues its sweep and passes through the frequency of 240 Mc. This mixes with the 180-Mc input and produces the 60-Mc i.f. frequency. As it sweeps through 260 Mc and 280 Mc, it mixes with the other two inputs and also produces the 60-Mc i.f. frequency.

Thus, by using a local oscillator that sweeps a certain range of frequencies, input signals to the mixer can be made to enter the 2nd i.f. stage *one by one*, separated in time. *This is the important thing to remember about the operation of the analyzer.*

Skipping the 3rd mixer and i.f. for a moment, assume you have fed the output of the 2nd i.f. into a detector. As the signals appear one by one at the output of the 2nd i.f., they are rectified, giving positive pulses which will cause vertical deflection on the face of a crt. In our typical spectrum analyzer, the sawtooth that causes the the S.L.O. to sweep through its frequency range is the same one that drives the horizontal circuits of the oscilloscope in which it is used. Thus, you will observe the three input signals on the crt, with the horizontal axis representing frequency. Study the following example, referring to Fig. 2.

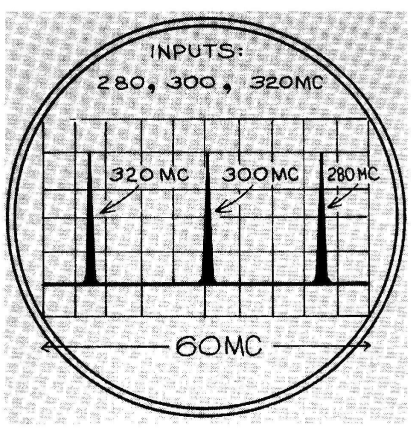
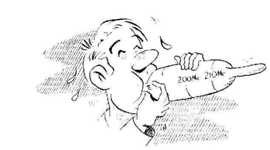


Figure 2. Crt display of output of 2nd i.f. (detected). Each cm = 6 Mc. Note that frequency is read from right to left on Spectrum Analyzer displays.

The crt spot begins its sweep at the 0 centimeter mark at the left-hand side of the graticule. The S.L.O., in step with the crt spot, is now at the low-end of its frequency range, or 230 Mc. No output is observed, as discussed above; the spot is not deflected vertically. The S.L.O. sweeps through a range of 60 Mc. Thus, a complete sweep of the horizontal represents 60 Mc also, and each major graticule line represents 6 Mc (assuming a normal 10-cm scan, of course). When the beam reaches a point 1.4 cm from the left-hand side, the S.L.O. is sweeping through 240 Mc. This produces an output corresponding to the 180-Mc input signal and the crt beam is deflected vertically. The beam then passes through the 5-cm mark at which time the S.L.O. passes through its mid-range, or 260 Mc. At this time, the crt beam is deflected again, indicating the 200-Mc input signal on the crt. Likewise, the 220-Mc signal is displayed at the 8.6-cm graticule line. The sweep is repetitive in normal operation and the result is a display similar to Figure 2. Note that the highest-frequency signal appears on the left-hand side. Frequency is read from *right to left.*



The previous example considered the S.-L.O sweeping through a 60-Mc range. This affords a "look" at a 60-Mc piece of the electromagnetic spectrum. The S.L.O. was set at maximum *dispersion* (range of frequencies swept by S.L.O.). The portion of the spectrum under analysis can also be narrowed. This is accomplished by decreasing the dispersion. If we set the dispersion at 20 Mc, the S.L.O. will sweep from 250 Mc to 270 Mc. Note that its center frequency is *still* 260 Mc, as before. Figure 3 shows the display obtained on the simplified spectrum analyzer, using this dispersion.

When the S.L.O. begins its sweep at the dispersion setting of 250 Mc, the 180-Mc signal at the input of the 2nd mixer is heterodyned to a frequency of 70 Mc. This falls outside of the bandpass of the 2nd

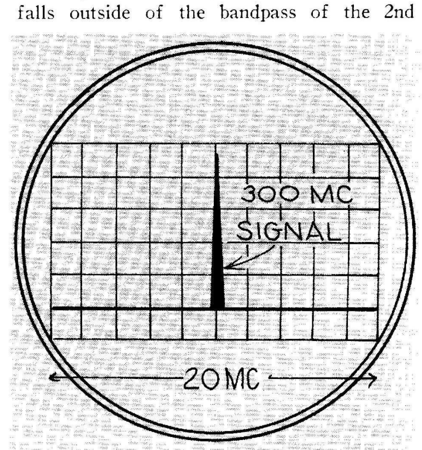


Figure 3. Dispersion, or bandwidth, set at 20 Mc. Each cm = 2 Mc.

i.f., which is tuned to 60 Mc. The 200-Mc signal produces a 50-Mc difference and is not accepted by the 2nd i.f., either. The 220-Mc signal produces an even lower beat; 30 Mc, which is well outside the bandpass of the i.f. As the S.L.O. passes through 260 Mc, the 200-Mc signal from the 1st i.f. produces the 60-Mc beat signal which is accepted by the 2nd i.f. The S.L.O. sweeps to 270 Mc and the same arithmetic proves that no other signal is displayed. Thus, of the original three signals, only one is displayed. The other two fall outside the area "scanned" by the S.L.O. In effect, we have narrowed the "window", through which we observe a portion of the spectrum, in order to take a closer look at it. (A good analogy would be a zoom movie camera that closes in on a subject.) As the dispersion of the S.L.O. is narrowed to sweep a smaller range of frequencies, we "close in" on the center portion of the output of the first i.f. As the observed portion still fills the entire horizontal sweep of the oscilloscope, the signal is spread out more. This gives better resolution in the case of closely-associated sine waves.

Figure 4 represents a display with the dispersion set at 10 Mc. Note that an upper and a lower side-band are beginning to emerge. Although at first we could not see them, these sidebands were associated with the 200-Mc signal all along. With a wide dispersion, the resolution was so poor, they all blended together. The following circuitry of the analyzer can spread, or resolve, these signals even more.

A front-panel vernier labeled "Center Frequency", controls a dc voltage to the S.L.O. This provides a slight shift of the S.L.O. center frequency. This is useful

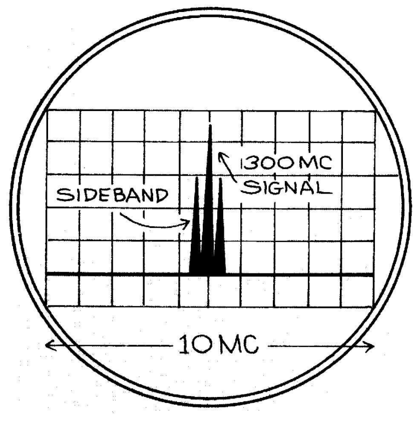


Figure 4. Dispersion set at 10 Mc. Note emergence of sidebands.

for lining up the display with a desired graticule line for subsequent measurement.

Because of the wide range of possible input voltages, a 1 to 51-db attenuator network is inserted between the 2nd mixer and the second i.f. In addition, the second i.f. also has a "Variable Gain" control on the front-panel.

A THIRD I.F. IS ADDED

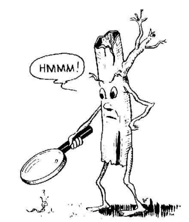
The output of the 60-Mc 2nd i.f. is still too broad for resolution of closely-associated signals. So we convert a 3rd time! A 3rd L.O., operating at a fixed frequency of 65 Mc, beats in the 3rd mixer with the 60-Mc output and produces an i.f. frequency of 5 Mc. This signal is fed into the 3rd i.f. which is fixed-tuned to 5 Mc. This i.f. has variable bandwidth and can be changed from 1 kc to 100 kc. Therefore, we can vary the resolution by changing the actual bandwidth of the i.f. stage. The output of the 3rd i.f. is fed to the detector.

THE DETECTOR CIRCUIT

All signals appearing at the input of the detector circuit are both positive and negative. We have no need to display the entire signal because one-half of it would simply mirror the other. So the signals are detected, or rectified, and passed on to a video amplifier.

The detector circuit provides three different outputs: LINEAR, LOARITHMIC, AND SQUARE-LAW. We'll consider each in turn.

The LINEAR output increases proportionally as the input increases. In other words, if an input voltage to the detector causes a crt deflection of 4 cm, doubling the input will cause a crt deflection of 8 cm.



The LOGARITHMIC output reflects a decrease in the gain of the detector circuit as the input is increased. This has the effect of compressing the larger input signals and increasing the dynamic range of the detector input. The output is proportional to the log of the input signal to the detector. The crt vertical deflection increases as the *square* root of the input voltage. This is equal to the db gain of the display. Increasing the input amplitude by a factor of 4 only doubles the height of the vertical display.

(Part 2, which concludes this article, will appear in the forthcoming June, 1965 issue of SERVICE SCOPE.)

TEKTRONIX PART-NUMBERING SYSTEM EXPANDED

We, at Tektronix, Inc., recently expanded our part-numbering system from six to nine-digit numbers. Several factors necessitated this change. One factor given major consideration was our desire to give ever more effective support to our customers. The expanded part-numbering system will work to that end.

What we've done is merely to expand the existing part number. The change won't require much getting used to on the part of the customer. (For example, parts categories will remain as they are.)

If a customer's original purchase order used six-digit numbers, here's how he can check his parts against the new numbering system:

Here is the familiar Tektronix part number as our customers know it:

524-268

All we've done is move the description digits (the three digits following the hyphen) one place to the right:

524- 268

Drop in a zero:

524-**0**268

and add a two-digit suffix:

524-**0**268-**00**

That's all there is to it.

This method will work for all Tektronix six-digit part numbers except those few having an alphabetical suffix — 154-058A for example. For help in converting these to the new nine-digit part numbers, please consult your local Tektronix Field Office, Field Engineer or Representative.

During the transition period to our new system, the numbers on the parts customers receive may not jibe with those on the invoice we send. When this happens, by just applying the above simple steps in reverse the customer will find it was the same old part number all the time.

We hope this information helps. In the meantime, we appreciate our customers' cooperation and thank them for their patience while we make this necessary change.

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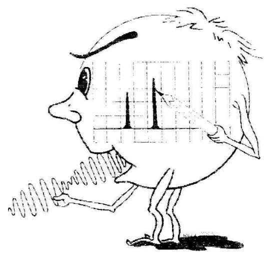


GETTING ACQUAINTED WITH SPECTRUM ANALYZERS

by Russ Myer
Tektronix Advertising Dept.

This is the second and concluding half of an article intended to form a conceptual basis for the understanding of Spectrum Analysis. The first half of the article appeared in the April, 1965 issue of SERVICE SCOPE.

Editors Note:

Part 1 of this article, presented the author's thoughts on Spectrum Analysis to as far as the detector circuit of a spectrum analyzer. Part I concluded with a short explanation of two of the detector circuit's three outputs—the linear output and the logarithmic output.

Here in the June, 1965 issue of SERVICE SCOPE, Part 2 begins with a brief review of decibels. This is intended to give the reader a better understanding of the logarithmic output.

We suggest that a refresher reading of Part 1 *before* continuing on to Part 2 will allow the reader to more readily associate himself with the author's thoughts presented here in the second half of the article.

Part II

DECIBELS

To give you a better understanding of the logarithmic output, let's briefly review decibels.

A decibel is one-tenth of a bel. A bel is the same thing as a power of ten. Thus: 50 db is equal to 5 bels. This is the same as 10 to the 5th power, or 10^5.

If we increase the power level of a signal by 60 db, we increase it 10^6 times—a gain of 1,000,000. Increasing a one-watt signal by 60 db increases it to one million watts!

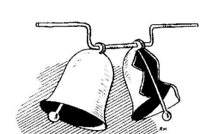
Remember that db merely expresses the difference between two power levels. By itself, it means nothing, nor does it represent any actual quantity of power. If the example above were 1 micro-watt, a 60 db gain would bring the power up to 1 watt. So the same 60 db expressed a difference of almost 1 million watts in the first example and only 1 watt in the second!

Gains of whole bels, 1, 2, 3, etc. . . . can easily be calculated in the head. 1 bel (10 db), for example, means a power gain of 10^1, or ten. 2 bels, (20 db), means a power gain of 10^2, or one hundred. And so on.

EXPONENT	MULTIPLY BY	EXPONENT	MULTIPLY BY
.1	1.25	.6	4.0
.2	1.6	.7	5.0
.3	2.0	.8	6.3
.4	2.5	.9	8.0
.5	3.16		

Figure 5. Fractional Exponent Multipliers.

Unfortunately, gain is not always expressed in even numbers of bels. What about a gain of 33 db? This is a gain of 3.3 bels, or $10^{3.3}$. Reviewing math, this means 10^3 times $10^{.3}$. 10^3 is easy: 1000. What about $10^{.3}$? For this, you'll have to refer to the table of fractional exponents. See Fig. 5. From the table, you'll see that 0.3 corresponds to 2. So 10^3, or 1000, is multiplied by 2. A 33 db gain, therefore, is equal to a gain of two thousand.



Assume that an amplifier has an input of 200 milliwatts. The gain is 33 db. The output, in watts, would be 400 watts. (0.2 x $10^{3.3}$)

Db's are also used to express a loss. We can still consider, in the case of our example, that the difference between two signals is 33 db, but as we now desire to express a loss in power, the figure of 2000 must be divided into 1 to obtain its reciprocal. In this second case, our initial power of 200 milliwatts must be multiplied not by 2000, but 1 divided by 2000, or 0.0005. This reduces our 200 milliwatts to 100 microwatts.

To express a difference in voltage levels, more commonly used in oscilloscope work, the number of bels used as exponents, is divided by 2. Example: a voltage gain of 44 db gives an exponent of $10^{4.4}$. Dividing the exponent by 2 gives a new number: $10^{2.2}$. This is $10^2 \times 10^{.2}$, or 100×1.6, or 160. Increasing any voltage level (RMS) by a factor of 160 produces an increase in power of about 25,000 times. This is proved by the relationship $E^2/R(160^2)$.

The power formula, $P = E^2/R$ indicates that power increases as the square of the voltage (resistance remaining the same, of course). The oscilloscope is a voltage-operated device; therefore, increasing a vertical signal by a factor of 2 requires a signal 4 times the power of the original.

So much for decibels. Let us return now to the detector circuit and its 3rd or SQUARE-LAW output.

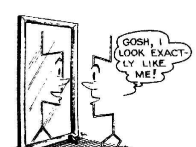
To expand vertical signals, the analyzer's detector is operated in the SQUARE-LAW mode. In this manner, the output voltage is the *square* of the input voltage. Doubling the input causes the output to increase *four* times. Tripling the input causes the output to increase 9-fold!

The advantage of this circuit can easily be seen. Input signals of nearly the same amplitude are expanded and can be measured more accurately on the crt. Also, the crt now measures relative input *power*. Doubling the input power doubles the vertical deflection. Thus, the square-law mode causes the output to behave exactly the opposite of the logarithmic mode.

THE VIDEO AMPLIFIER

The detector circuit is followed by the Video Amplifier. Signals are fed into the amplifier and applied, push-pull, to the crt vertical-deflection plates. To increase the versatility of the spectrum analyzer, video signals can be fed directly into the amplifier, by-passing the i.f. and detector portions of the instrument. This allows an oscilloscope display of ordinary time-based signals.

IMAGES AND OTHER SPURIOUS SIGNALS



Until now, we have assumed that only the signals appearing in the area of the center frequency are presented on the crt display. Unfortunately, this is not always the case. Other signals also sneak through the analyzer and are displayed.

Assume you have set the tuning dial at 300 Mc to observe a signal of that frequency on the crt. Since 300 Mc is the center-frequency signal, it will appear at the center graticule line. Assume further that along with the 300-Mc input, another signal with a frequency of 700 Mc is present at the input.

Since the first L.O. operates 200 Mc higher than the desired input signal, it will be oscillating at 500 Mc. This frequency beats with the 300-Mc input to produce the 200-Mc difference which is allowed to pass through the 1st i.f.

But . . . . the difference between the 500-Mc L.O. and the 700-Mc input is *also* 200 Mc! So, it too is introduced into the 1st i.f. and, as you would expect, appears on the crt — exactly super-imposed on the 300-Mc signal at the center graticule line. Now, set the dial slightly to either side of the 300-Mc center frequency. This causes the signals to move from the center graticule area. However, each signal goes in the *opposite* direction!! A little arithmetic will prove why.

Moving the L.O. to 530 Mc, for example, (tuning dial reading 330 Mc, of course) produces a beat of 230 Mc for the desired input signal of 300 Mc. As the output of the 2nd i.f. is swept through its range of 170 Mc to 230 Mc, it's obvious that the true signal now will appear on the extreme right of the crt. The L.O. frequency of 530 Mc also beats with the 700-Mc input and produces a difference frequency, or beat frequency, of 170 Mc. This causes it to appear to the extreme left of the crt.

This illustrates an important rule: Tuning the L.O. (main tuning dial) to a higher frequency causes the true signal to move to the right of the crt; unwanted signals move to the left. These undesired responses are called "images," or "spurious" responses.

As signals above and below the center frequency of the 1st L.O. can produce beat frequencies, either of the two could be called the "true" signal, depending upon how we labeled the tuning dial. We simply choose to call signals below the frequency of the L.O. *true responses* and all signals above it, the image signals. The i.f., of course, doesn't know the difference.

Another type of spurious response that shows up on the crt is caused by input signals that fall within the bandpass of the first i.f Any input signal falling within the range of 170 Mc to 230 Mc will be displayed. This is called *i.f. feedthrough.* This type of spurious signal is the easiest to identify. Moving the tuning dial either direction does not shift the display on the crt. This is because the 1st L.O. does not beat with any input signal to produce the response.

Figure 6 shows two unknown signals on the crt of the scope. Note their positions on the graticule. The dispersion is set at 50 Mc. Thus, each graticule line represents 5 Mc. First attending to signal A, move it to the center graticule line. This will determine the center frequency of the signal as read on the tuning dial. Assume that

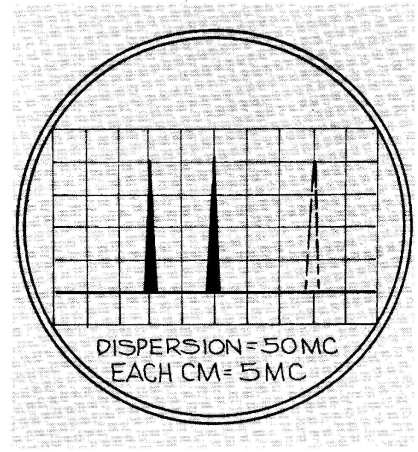
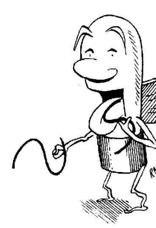


Figure 6. Display after shifting image to center of graticule. This illustrates how two signals, separated by 390 Mc, show up only 10 Mc apart on the crt.

it was necessary to tune the dial higher in frequency. The signal moved higher in frequency, also (towards the left). This identifies signal A as a spurious, or image, response. Reading the tuning dial gives us a figure of 205 Mc. We know the L.O. is operating 200 Mc above the tuning-dial reading, so it must be oscillating at 405 Mc. The image, therefore, is 200 Mc above that, or 605 Mc!

Signal B was moved to the right (down in frequency) to be located at the center graticule line. The tuning dial would now read 215 Mc, which is the frequency of the true input signal.

HARMONIC SPURII



When the operation of the Spectrum Analyzer is considered, remember that any complex waveform is the algebraic sum of a number of pure sine waves. The analyzer permits the display of these individual sine waves on an oscilloscope. The horizontal sweep represents some continuous frequency range.

Any sine wave passed through a nonlinear device, such as a tube or a transistor, will be accompained in the output by a new set of frequencies called *harmonics.* These frequencies will be exact multiples of the original, but of decreasing amplitude. The second harmonic, for example, of a 200-Mc signal, is 400 Mc; the 3rd, 600 Mc, etc.

Here is where we can get into trouble with our typical spectrum analyzer. Originally, we spoke of all the signals present at the output of the first mixer: the original L.O. frequency, the original input signal, the sum of the two, and the difference, which was the one selected for i.f. amplification. We also learned that any signal

170-Mc to 230-Mc *higher* than the L.O. frequency would also produce a beat that fell within the bandpass of the first i.f. And, finally, there was i.f. feedthrough.

But, unfortunately, there are other spurii which can show up on the crt screen.

The mixer will produce harmonics of its two input signals, (original signal and L.O.) which are present in the output. Harmonics of the L.O. are of particular interest to us now. For example, assume the L.O. could be set at 300 Mc to show a 100-Mc input signal on the crt. The second harmonic of the L.O. is 600 Mc. If there were a 400-Mc signal of equal strength at the input of the analyzer, it, too, would produce a 200-Mc difference and be displayed on the crt! Because of the decreased amplitude of the harmonic, however, the crt presentation would be less than that of a true-response presentation. (Bear in mind, however, that the 400-Mc signal could have a signal strength several times that of the true signal and show up as a larger amplitude presentation than the true one).

Also, an 800-Mc signal, if present at the input, would beat with the 2nd harmonic of the L.O. and produce the 200-Mc i.f. difference signal. Likewise, the 3rd harmonic of the L.O. — 900 Mc — could beat with a 700-Mc input, or a 1,100-Mc input and produce the 200-Mc i.f. frequency!

Fortunately, these harmonic-caused spurii can be easily recognized. Increasing the L.O. frequency by 100 Mc, for example, increases the 2nd harmonic by 200 Mc, and the 3rd by 300 Mc. Thus, harmonic spurii move across the screen faster than true response or images.

Assume inputs of 700, 400 and 100 Mc. The L.O. is set at 300 Mc to display the 100-Mc signal at the center of the crt. The dispersion is set at 10 Mc, each centimeter representing 1 Mc on the crt. At the center of the crt, only one signal is observed. Actually, three signals are present — the true signal which is L.O. minus the input frequency of 100 Mc, 2 x L.O. minus the input frequency of 400 Mc and 3 x L.O. minus the input frequency of 700 Mc. All these differences are exactly 200 Mc! See Figure 7.

Tuning the L.O. up 1 Mc in frequency will shift the true signal, 100-Mc, exactly 1 division to the right (remember that tuning higher in frequency shifts true signals towards the minus-frequency or right hand side of the crt). The 1-Mc shift upward caused the 2nd harmonic to increase 2 Mc, and this moved the 400-Mc input *two* divisions to the right! The 3rd harmonic increased by 3 Mc, and the 700-Mc signal appeared three divisions to the right of center. Assuming inputs of equal signal strength, the 2nd harmonic signal would be less than the amplitude of the true response and the 3rd harmonic signal amplitude would be

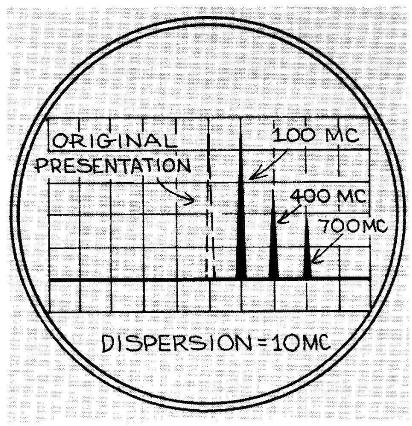


Figure 7. Display showing effects of moving tuning dial up 1 Mc to recognize and separate spurii from true response.

less than the second. Observe that, unlike images, moving the L.O. up in frequency causes these harmonic spurii to move in the same direction as true responses.

MARKER OSCILLATOR

A feature of the spectrum analyzer is the Marker Oscillator. It generates a 200-Mc signal which is fed into the 1st i.f. of the analyzer. You can use it to determine relative frequency or frequency difference of signals observed on the crt.

You'll remember that the center frequency of the 1st i.f. is 200 Mc. The marker frequency of 200 Mc is injected into the i.f. and will exist at the center of the bandpass of the i.f. You can say, therefore, that the 200-Mc marker indicates the center frequency of the i.f. and is displayed at the center graticule line of the crt. The marker appears as a spike, or "pip", much like the time marks used to calibrate oscilloscopes.

A front-panel control, the "Frequency-Difference Control," allows the marker to be tuned to either side of its 200-Mc midrange, usually plus or minus 30 Mc (170 Mc to 230 Mc). Figure 8 gives an example of the use of the marker.

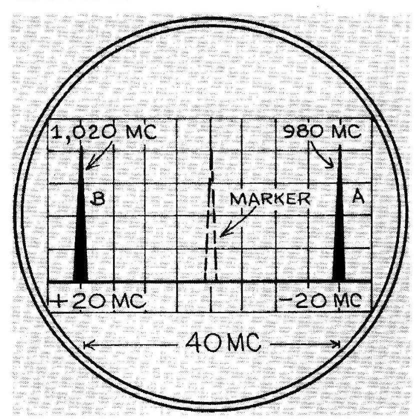
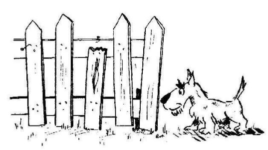


Figure 8. Dispersion is 50 Mc. Each cm = 5 Mc. Marker reads frequency difference.

First, line up the marker "pip" and the signal at "A". The control reads —20 Mc. Moving the marker over to signal "B" and lining them up, the control reads +20 Mc. The frequency difference is 40 Mc and that is the frequency difference between signals "A" and "B". Assume the main-tuning dial is tuned to 1,000 Mc. The dispersion is set at 50 Mc. Each graticule mark now represents 5 Mc. No signal appears at the center graticule line, which represents the center frequency. Therefore, no input at 1000 Mc is present at the input of the analyzer. However, there is a signal 4 graticule lines to the left of the center one. This signal is 20 Mc less than the 200-Mc center frequency, or 180 Mc, and corresponds to an original input of 1,020 Mc. The signal on the right, "B", is 20 Mc greater than 200 Mc and is produced by an input of 980 Mc. Remember to read frequency from right to left!

As we have seen previously, spurious inputs will also produce similar signals on the crt. An input of 1,380 Mc will produce a signal similar to "A" and an input of 1,420 Mc will produce one similar to "B". Note that in the case of these and any images, frequency is read from left to right, in the normal fashion. You can, of course, identify true signals by shifting the main-tuning dial and observing which way the signals move on the crt.



The marker-oscillator output can be frequency - modulated, also. Two modulating frequencies are available on this typical analyzer: 1 Mc and 100 kc. When modulated, the 200-Mc marker signal now becomes a complex waveform which the analyzer will break down into individual sine-wave components (which is what our analyzer does to all complex waveforms!). These are displayed on the crt as pips, spaced equally apart. These pips extend to the right and left of the marker center-frequency displayed on the crt. The separation between the pips is equal to the modulating frequency that caused them. In other words, with a dispersion of 10 Mc and the marker set on 200 Mc, a modulating frequency of 1 Mc will create a "pip" at each graticule line. These pips are called the *"picket fence."*

VERTICAL AMPLITUDE MEASUREMENTS

Look at the graphical view of the bandwidth of the 1st i.f. (Figure 9). The center frequency is 200 Mc. The bandwidth limits are 170 Mc to 230 Mc and is expressed in db variation, usually ±3 db. The figure shows that the flat portion of the curve can vary between minus 3 db and plus 3 db. This is a 6-db variation! Per-

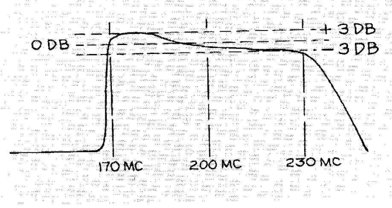


Figure 9. Bandwidth of 1st i.f., reproduced on crt by sweeping constant input signal over 60 Mc range. Note that despite constant input, there is a 6 db variation between 170 Mc and 230 Mc.

haps at the 170-Mc point, the response is +3 db. At the 230-Mc point, it could be —3 db. A single, constant-input signal, swept from 170 to 230 Mc, will produce an output to the detector that varies between +3 db and —3 db. Obviously, this same signal viewed on the crt would assume a varying vertical deflection at different points along the horizontal axis although the input had not changed at all. Therefore, it is important that all measurements using the Spectrum Analyzer be made with the signal under measurement lined up at the center graticule line. Thus, a constant output from the detector is assured.

To measure relative differences in amplitude of signals displayed on the crt, we use the calibrated attenuator of the analyzer.

Assume you have a crt display of two signals of different amplitudes. The detector is in the linear mode. The largest signal is reduced, with the attenuator, to the original amplitude of the second signal. The difference is noted on the attenuator. This is the relative difference. For signals of greatly different amplitude, the log mode of detection may be used. If the input signals were nearly the same amplitude, the square-law detection mode could be used.

This discussion has presented the over-all operation of a typical Tektronix Spectrum Analyzer. Although the company's product line features several different models covering other portions of the electromagnetic spectrum, some of which operate a little differently than explained here, they all do one basic thing. They break down complex waveforms and display them on an oscilloscope as individual sine waves on a frequency time base.

The End

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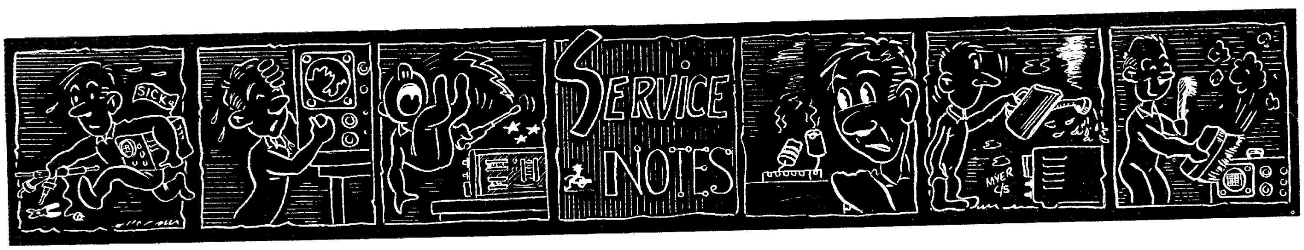
He came to Tektronix, Inc. in April of 1962 and worked in the Test and Calibration and Customers Service departments before transferring, recently, to the Advertising Dept. as a technical writer.

The Editor.



TYPE L-20 PLUG-IN-UNIT SPECTRUM ANALYZER—APPLICATIONS ABOVE ITS SPECIFIED FREQUENCY RANGE

The Type L-20 Spectrum Analyzer's specified upper frequency is 4 Gc. You can, however, use the instrument for applications up to 12 Kmc, at reduced sensitivities. You will need to compute the dial setting for any input frequency from a knowledge of the local oscillator frequency; and, you can compute the local oscillator frequency from the dial setting on Band 2 (fundamental operation) using this equation:

$$\frac{F_{rf} + 200}{n} = F_d + 200$$

Where

F_{rf} = Input signal rf frequency

200 = IF Frequency

n = harmonic number of local oscillator,

Band 2 Dial Reading	n = 5 Kmc	sens —dbm	n = 6 sens —80 dbm Kmc	n = 7 sens —75 dbm Kmc	n = 8 sens —70 dbm Kmc	n = 9 sens —66 dbm Kmc	n = 10 sens —63 dbm Kmc	n = 11 sens —60 dbm Kmc
230	1.95	—85	2.38	2.81	3.24	3.67	4.10	4.53
240	2.00	—85	2.44	2.88	3.32	3.76	4.20	4.64
250	2.05	—85	2.50	2.95	3.40	3.85	4.30	4.75
260	2.10	—85	2.56	3.02	3.48	3.94	4.40	4.86
270	2.15	—85	2.62	3.09	3.56	4.03	4.50	4.97
280	2.20	—85	2.68	3.16	3.64	4.12	4.60	5.08
290	2.25	—85	2.74	3.23	3.72	4.21	4.70	5.19
300	2.30	—85	2.80	3.30	3.80	4.30	4.80	5.30
320	2.40	—85	2.92	3.44	3.96	4.48	5.00	5.52
340	2.50	—85	3.04	3.58	4.12	4.66	5.20	5.74
360	2.60	—85	3.16	3.72	4.28	4.84	5.40	5.96
380	2.70	—85	3.28	3.86	4.44	5.02	5.60	6.18
400	2.80	—85	3.40	4.00	4.60	5.20	5.80	6.40
450	3.05	—85	3.70	4.35	5.00	5.65	6.30	6.95
500	3.30	—85	4.00	4.70	5.40	6.10	6.80	7.50
550	3.55	—85	4.30	5.05	5.80	6.55	7.30	8.05
600	3.80	—85	4.60	5.40	6.20	7.00	7.80	8.60
650	4.05	—85	4.90	5.75	6.60	7.45	8.30	9.15
700	4.30	—85	5.20	6.10	7.00	7.90	8.80	9.70
750	4.55	—85	5.50	6.45	7.40	8.35	9.30	10.25
800	4.80	—85	5.80	6.80	7.80	8.80	9.80	10.80
850	5.05	—85	6.10	7.15	8.20	9.25	10.30	11.35
900	5.30	—85	6.40	7.50	8.60	9.70	10.80	11.90

Chart 1. Chart for determining the value for n in the equation $\frac{F_{rf} + 200}{n} = F_d + 200$.