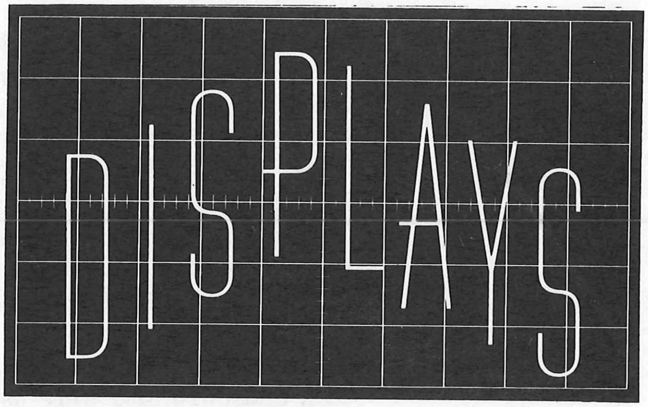
TEKTRONIX®

INTERPRETING SPECTRUM ANALYZER



INTERPRETING SPECTRUM ANALYZER DISPLAYS

Here's a portfolio of typical displays illustrating the versatility of spectrum analyzers in microwave measurement. By their clarity, these photos also provide a standard for proper instrument and equipment settings.

Morris Engelson
Project Engineer
Tektronix, Inc.
Beaverton, Ore.

SPECTRUM ANALYZER DISPLAYS illustrated in this article include

- Frequency stability (long- and short-term)
- Amplitude modulation
- Frequency modulation
- Pulse modulation
- ECM measurements
- Time-domain measurements
- Balanced modulator adjustment
- Antenna pattern measurements
- Video pulse spectra
- Wide-dispersion measurements

It is assumed that the reader is reasonably familiar with the operating principles of the superheterodyne spectrum analyzer. Therefore, the accompanying discussion stresses the interpretation of the displays rather than the procedures to generate them. For background reading, however, the appended bibliography is suggested.

All displays are actual, unretouched photos. Figures 1 through 33 were taken by Russ Myer of Tektronix using the following Tektronix instruments: spectrum analyzer plug-ins—1L10, 1L20, 1L30, 1L40; oscilloscopes—547, 549, 555, 564; time domain plug-ins—1S1, 3B4; signal sources—114, 184, 190. Hewlett-Packard signal sources 608, 612, and 8616 also were used. Figures 34 and 35 were taken by George Thiess of Microwave Physics Corp. with that company's MPR-X oscilloscope plug-in swept receiver.

In all photos each horizontal division is one cm.

Bibliography

Engelson, Weiss, and Frisch. "Oscilloscope Plug-In Spectrum Analyzers." *Microwave Journal.* March 1965.

Feigenbaum, M. H. "Introduction to Spectrum Analyzers." *MicroWaves.* April 1963.

Frisch, A., Engelson, M. "How to Get More Out of Your Spectrum Analyzer." *MicroWaves.* May 1963.

Myer, R. "Getting Acquainted with Spectrum Analyzers." Tektronix publication #A-2273.

Reference

1. Montgomery, *Techniques of Microwave Measurements* (New York: McGraw-Hill, 1945), RADLAB Series, Vol. XI.

Frequency stability

The spectrum analyzer can measure both long-and short-term frequency stability. But the measurement is limited by:

(1) Spectrum Analyzer Stability. Obviously oscillator stability cannot be measured if the unit under test is more stable than the oscillators used in the spectrum analyzer.

(2) Resolution Capability. The analyzer's ability to determine the type and/or source of the instability depends strongly on the instrument's resolution bandwidth. For example, we cannot determine whether an oscillator is FM'ing at a 60 or 120 cps rate when spectrum analyzer resolution is 500 cps.

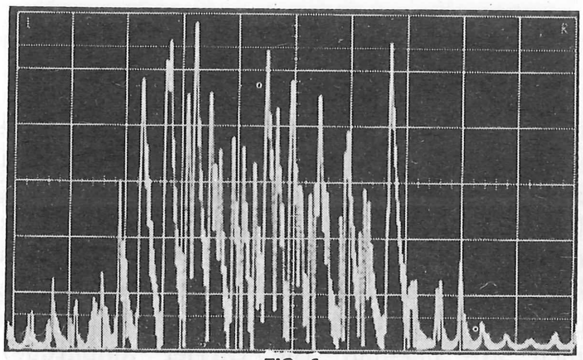


FIG. 1

Short-term stability. This measurement concerns fast frequency changes such as those caused by power-supply noise and ripple, vibration or other random factors.

Fig. 1 shows the random fm characteristic of a 3-Gc klystron. Spectrum analyzer dispersion is 2 Kc/cm and the resolution is 1 Kc. Oscillator fm is about 10 Kc—equivalent to 3 ppm.

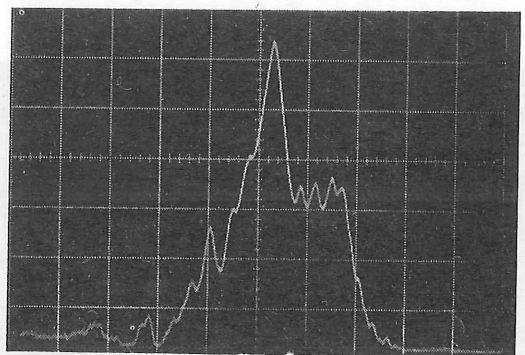


FIG. 2

A short-term stability measurement taken on a storage scope is shown in Fig. 2. A stored display is convenient because of the extremely slow sweep speeds necessary to narrow-dispersion displays. Dispersion is 50 cps/cm, resolution is 10 cps and the input signal is 60 Mc. The test signal has a spectral width of about 150 cps. This is equivalent to a stability of 2.5 ppm.

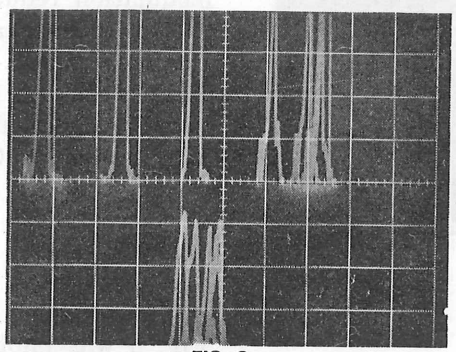


FIG. 3

Long-term stability. Here we show the measurement of frequency drift as a function of time. The procedure depends on the characteristics of the spectrum analyzer used. One could photograph the screen at given intervals, and compare the position of the signal on the various photographs. If the spectrum analyzer has an auxiliary vertical output capable of driving a paper chart recorder, a permanent record can be obtained without photography.

The use of a storage oscilloscope is even more convenient with the scope set on a single sweep and triggered at appropriate intervals, thus storing a complete record of drift on the crt.

For the storage-scope photo of Fig. 3, spec-drift after modifying the oscillator. Total drift trum-analyzer dispersion is 1 Kc/cm, and the input frequency is 60 Mc. The upper half of the screen shows the drift of an unstabilized oscillator as it was heated. The oscilloscope was manually triggered at one-minute intervals. The drift was about 2 Kc per minute during the first three minutes, but diminished in rate thereafter, becoming nearly stable by the sixth minute. The total drift is on the order of 6.5 Kc or 108 ppm.

Temperature compensation can be computed easily since the amount and direction of drift is known. The lower half of the photo shows the drift after modifying the oscillator. Total drift is now about 1 Kc, an improvement of 6.5:1.

Amplitude modulation

Modulation frequency and modulation percentage are the quantities usually desired in an AM measurement. Spectrum analysis is particularly useful in complex situations such as multi-tone modulation or overmodulation.

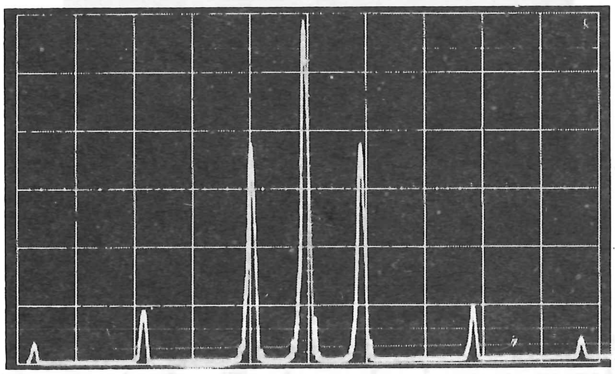


FIG. 4

Fig. 4 shows an overmodulated am signal. Note the characteristic AM spectrum, consisting of a carrier and two sidebands, and the presence of additional, unwanted sidebands. Spurious sidebands, together with primary sidebands where amplitude is greater than one-half the carrier (100% modulation yields sidebands which are one-half the carrier amplitude) positively identify overmodulation.

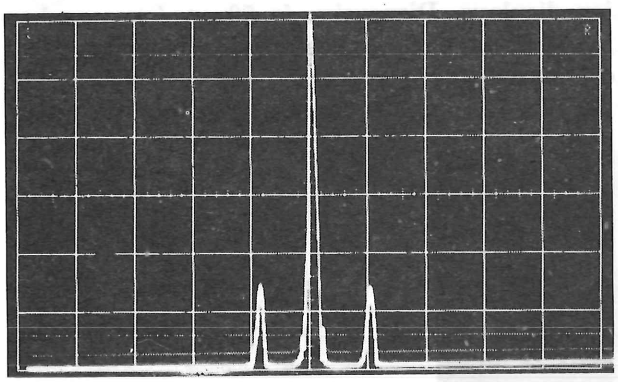


FIG. 5

Fig. 5 shows the same signal, but with the modulation reduced to 50%. The dispersion of the spectrum analyzer is 1 Kc/cm; the vertical display is linear. Thus, the modulating frequency is seen to be 1 Kc. Since the sideband amplitude is one-quarter that of the carrier, the modulation is 50%.

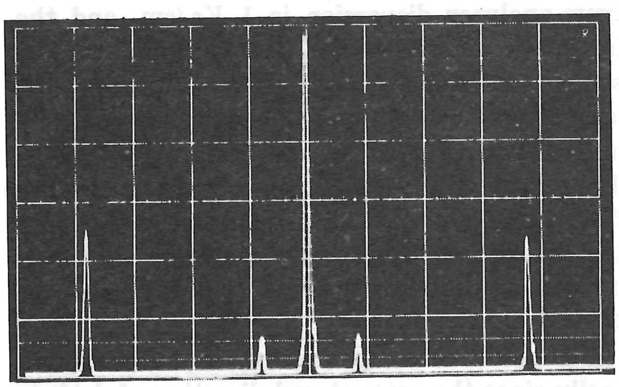


FIG. 6

Fig. 6 was photographed at a dispersion of 2 Kc/cm; vertical display is linear and center frequency is 60 Mc. Observe that the 60-Mc carrier is modulated at two frequencies: 1.6 and 7.5 Kc. Modulation is approximately 85% at 7.5 Kc and 20% at 1.6 Kc.

Overmodulation can be distinguished from two-tone modulation in two ways, evident by comparison of Figs. 4 and 6: (1) Spacing between over-modulated sidebands is equal while two-tone sidebands are arbitrarily spaced; (2) The amplitude of overmodulated sidebands decreases progressively from the carrier, but amplitude of two-tone sidebands is determined by the modulation percentage and can be arbitrary.

Frequency modulation

FM measurements generally concern modulation frequency, spectral width, index of modulation and deviation. A typical FM spectrum is shown in Fig. 7. Dispersion is 200 Kc/cm and the spectral width is about 1 Mc. The exterior modulation envelope, typically resembling a $\cos^2$ curve, identifies the frequency modulation. The interior envelope appears on the screen because the FM rate is of the same order as the analyzer's resolution bandwidth. Consequently sidebands are not resolved adequately and the trace cannot return to the base line at every pulse.

The same FM signal appears in Fig. 8 but the dispersion has been reduced to 10 Kc/cm and the resolution is 1 Kc. The double-envelope display does not occur and the sidebands are clearly visible. Modulation frequency is 10 Kc.

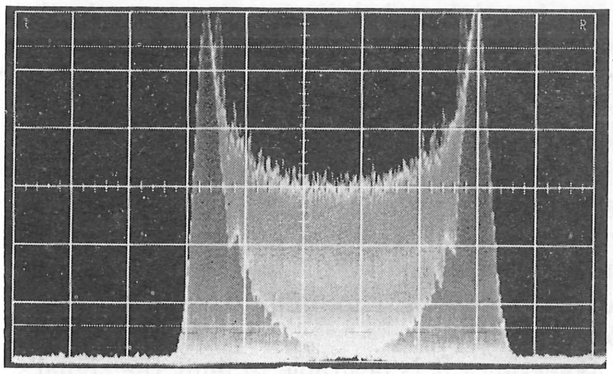


FIG. 7

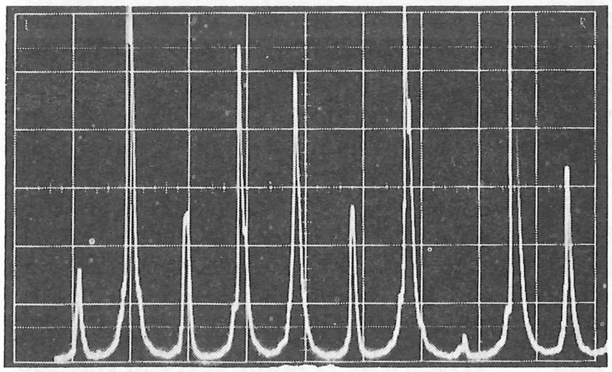


FIG. 8

Frequency deviation

There is no clear relationship between spectral width and deviation, since, in theory, the FM spectrum extends to infinity. But in practice, the spectral level falls quite rapidly as shown in Fig. 7. Experience indicates that the deviation is on the order of 1/2 the observed spectral width.

Very accurate deviation measurements can be obtained if the modulation frequency can be varied. It can be shown that for FM the carrier goes to zero at a modulation index (ratio of deviation to modulating frequency) of 2.4; other nulls occur at other modulation indices—e.g., the second null occurs at an index of 4.8.

This knowledge is the basis of a very powerful deviation measurement method known as the carrier null method. Figs. 9, 10 and 11 demonstrate this method. These figures were taken at a dispersion setting of 200 Kc/cm and a resolution of 100 Kc. Note that the spectral width is the same as in Fig. 7 but the modulating frequency has been increased so that individual sidebands can be resolved. In all three figures, the signal has been adjusted so that the carrier is at the center of the screen.

Fig. 9 shows a fairly large carrier. In Fig. 10, the modulation frequency is increased and the carrier level has decreased. In Fig. 11, the modulation frequency is increased further so that a null occurs at the position of the carrier. Since the observed modulating frequency is 200 Kc and since the observed index of modulation is 2.4, the deviation is 480 Kc.

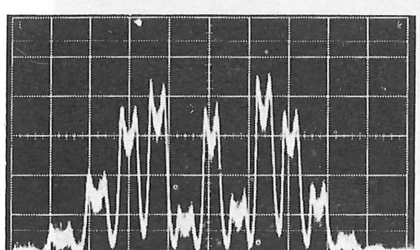


FIG. 9

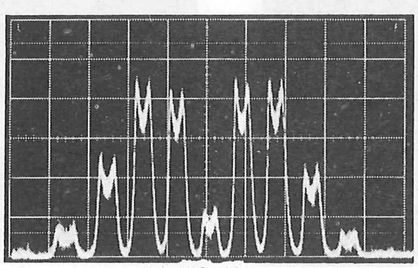


FIG. 10

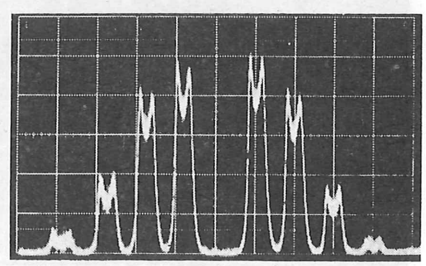


FIG. 11

Pulse modulation

Square pulses—A pulse-modulated signal generates a complex spectrum of the familiar sin x/x type. For example, a square pulse generates a spectrum described by sin $\pi ft/\pi ft$, where t is pulse width and f is frequency deviation from the carrier. Fig. 12 shows the spectrum of a 1-Gc carrier modulated by a 0.67-μsec square pulse. Observe that the spectrum is entirely above the baseline, whereas Fourier theory indicates that adjacent lobes should be out of phase by 180 deg. This phenomenon occurs because the spectrum analyzer is insensitive to phase. A second apparent inconsistency is that while the spectrum should be, in theory, solid, the display consists of vertical lines. This stems from the fact that the superheterodyne spectrum analyzer is not a real-time device. It takes many pulses to trace out the spectrum. Thus, each vertical line represents the sampling of one pulse.

Now we can manipulate the spectrum analyzer controls to determine the characteristics of the signal. In Fig. 12 the spectrum analyzer dispersion is 1 Mc/cm and the vertical display is linear. For a square pulse the theoretical pulse width $t = 1/f_o$, where f_o is the spectral sidelobe width. From Fig. 12, $f_o \simeq 1.5$ Mc. Therefore $t = 0.667$ μsec. Assuming that the vertical display is perfectly linear, we find that the ratio of main lobe to first sidelobe is 6:1.2. This is equivalent to 14 db. More accurate measurement using the spectrum analyzer's calibrated attenuators gives a ratio of 13 db. Theoretically, the main lobe is 13.2 db greater than the first side lobe.

Fig. 13 shows the same signal but with the dispersion set to zero. (This means that the sweep is only in time rather than in frequency; the analyzer is now a microwave receiver with a CRT readout). The display is merely a set of equally spaced lines. Since each line represents a pulse, the pulse rate can be easily measured. Here the scope is sweeping at a 1-msec/cm rate; one cycle of the modulating pulse requires 1 msec. The pulse rate is therefore 1 Kc.

As previously indicated, it is not the lines themselves, but only their envelope that is of interest. Sometimes it is advantageous to present an integrated display showing only the outline of the spectrum. Such a display, shown in Fig. 14, is obtained by using a post-detection (video) filter. This kind of display has several advantages: The baseline and its accompanying glare are eliminated and weak signals are more apparent. Noise is reduced automatically by integration and anomalies are removed. On the other hand, band-width and sensitivity are reduced (often by 1 to 5 db). Sweep speed also decreases.

Sometimes it is desirable to limit the signal's spectral width by filtering, pulse shaping, etc. It then becomes important to identify low-level signals. This is accomplished by operating the analyzer in its logarithmic mode so that low level signals are enhanced relative to large signals. In the logarithmic display of Fig. 15, the main lobe and the first eight side lobes are discernible.

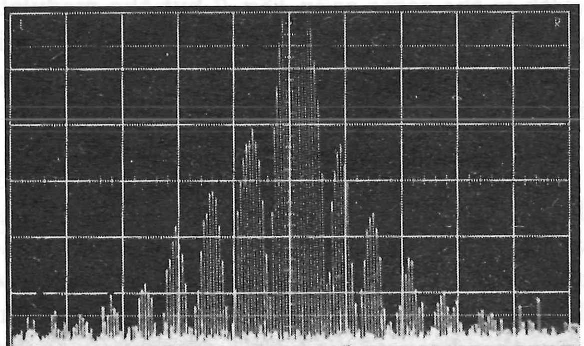


FIG. 12

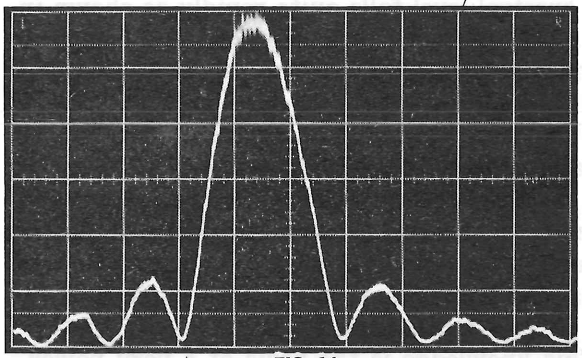


FIG. 14

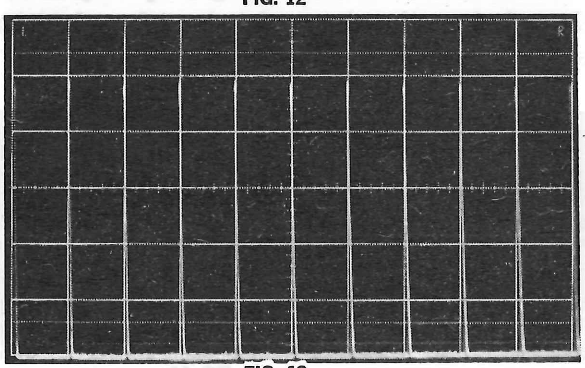


FIG. 13

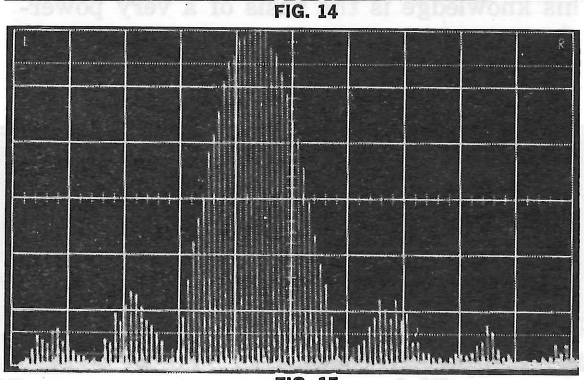


FIG. 15

Pulses in the presence of FM

All signal sources, regardless of how carefully designed, have a certain amount of incidental FM. This limits the type of pulse modulation that can be used.

Fig. 16 shows a carrier with incidental FM deliberately applied. Analyzer dispersion is 5 Kc/cm and FM spectral width is on the order of 12 Kc. Fig. 17 shows the carrier with the FM removed. (The large signal in the center of the main lobe is due to a poor on-off ratio in the modulator. This phenomenon is discussed in another section.) Fig. 18 shows the combination of FM and pulse modulations. Note that the signal is not symmetrical and that the side lobes are uneven. An extensive discussion of pulsed RF in the presence of FM is found in Montgomery.[1]

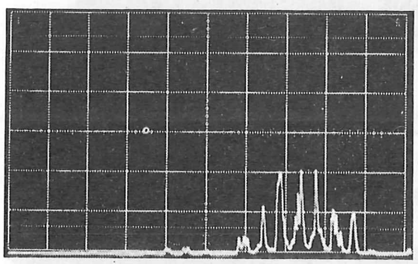


FIG. 16

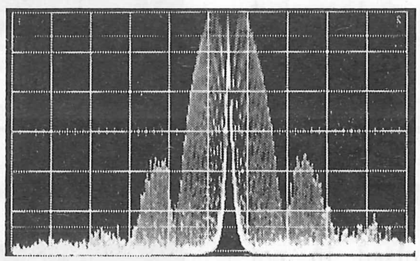


FIG. 17

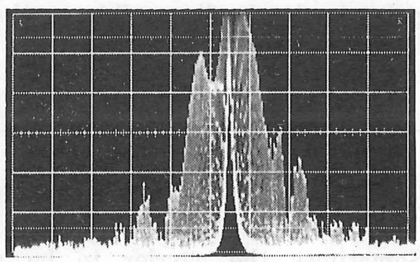


FIG. 18

Effects of pulse shaping

Spectral width can be controlled by several means, including that of pulse shaping. The effect of pulse shape on spectral distribution is illustrated in the following spectrum analyzer displays. Fig. 19 shows the conventional sin x/x spectrum of an RF signal modulated by the square pulse of Fig. 20.

Fig. 21 is the RF spectrum of the assymetrical triangular pulse in Fig. 22. Note that the sidelobes in Fig. 20 are considerably lower than those in Fig. 18.

Fig. 23 is the RF spectrum of the symmetrical triangular pulse shown in Fig. 24. Note that this spectrum is almost completely devoid of sidebands. As the effective pulse width changes, so does the width of the main lobe. The spectrum analyzer dispersion was adjusted between Figs. 19, 21 and 23, so that the main lobe would continue to occupy approximately the same number of divisions—this to better illustrate the disappearance of the side lobes.

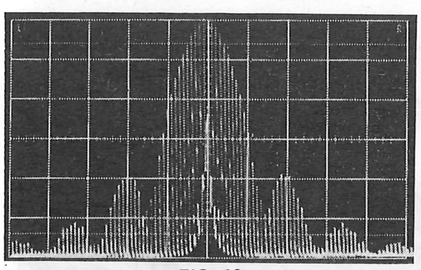


FIG. 19

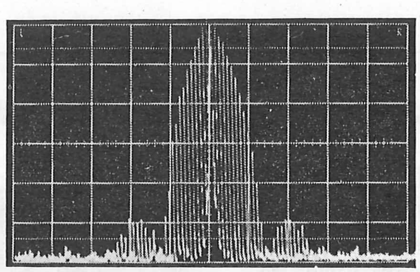


FIG. 21

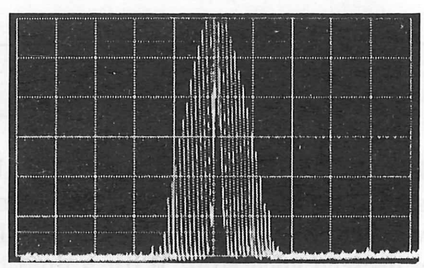


FIG. 23

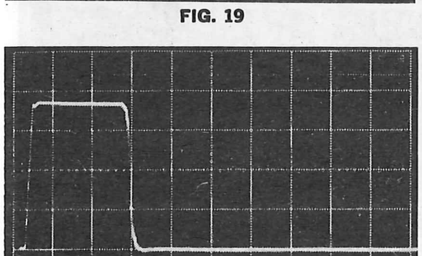


FIG. 20

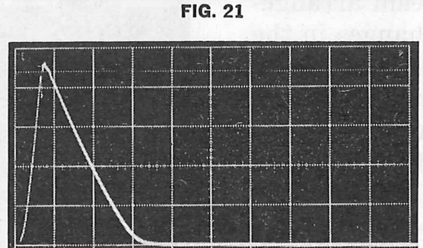


FIG. 22

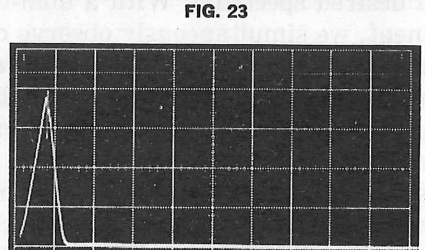


FIG. 24

ECM measurements

In countermeasure work, intelligence is sometimes transmitted so as to be masked by another signal. An example is the transmission of information at the null point of a pulsed RF signal. Fig. 25 shows transmission of a 100-Kc-wide signal at the null point. The pulsed RF signal has been expanded using the scope horizontal magnifier control. The cw signal at the null point is clearly discernible on the analyzer but less so to a ferret receiver.

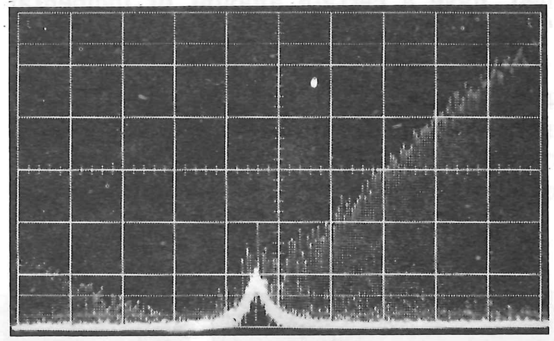


FIG. 25

Pulse modulator on-off ratio

Sometimes the carrier to be pulsed in not turned off completely during the pulse off time. This results in a combination of cw and pulsed signals. Measurement of on-off ratio is complicated by the fact that the spectrum analyzer has higher sensitivity for cw signals than for pulsed signals. The ratio in sensitivity is $3/2\ t\beta$, where t is pulse width and β is spectrum analyzer's 3-db bandwidth (resolution bandwidth).

Fig. 26 shows a typical pulsed RF signal generated by a modulator that has a poor on-off ratio as indicated by the large signal within the main lobe. Dispersion is 0.5 Mc/cm (pulse width 1.3 μsec), resolution bandwidth is 100 Kc and the vertical display is linear. To find the on-off ratio we compute the loss in pulse sensitivity relative to cw:

$$3/2\,(1.3)\,(10^{-6})\,(10^{5}) = 1.95 \times 10^{-1}$$

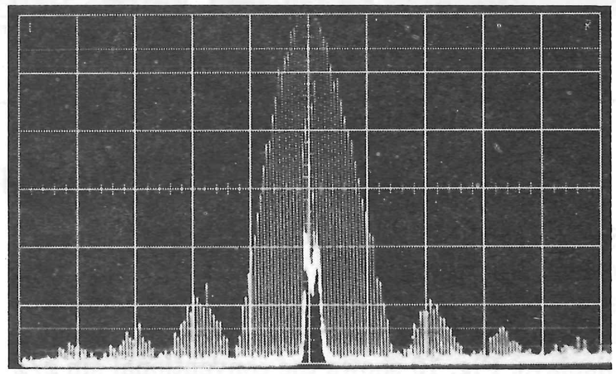


FIG. 26

$$\ldots 20 \log_{10} 1/0.195 = 14.2 \text{ db}$$

Next, from the vertical deflection in Fig. 26, the cw signal amplitude is 1/3 that of the pulsed signal's. This is equivalent to a difference of 20 $\log_{10} 3 = 9.5$ db. The total on-off ratio is $9.5 + 14.2 = 23.7$ db.

Dual-beam spectrum analysis

It is sometimes useful to simultaneously observe both the RF spectrum and modulating waveform, as when shaping a pulse to generate a desired spectrum. With a dual-beam arrangement, we simultaneously observe changes in the modulating pulse and the resultant frequency spectrum. With microwave sampling scopes we can observe both the modulated carrier and the modulating pulse in time domain. Fig. 27 shows a dual-trace display of a 1-Gc carrier modulated by a 1-μsec pulse. The upper trace is in time domain at 1 μsec/cm. The lower trace is in frequency domain at 1 Mc/cm.

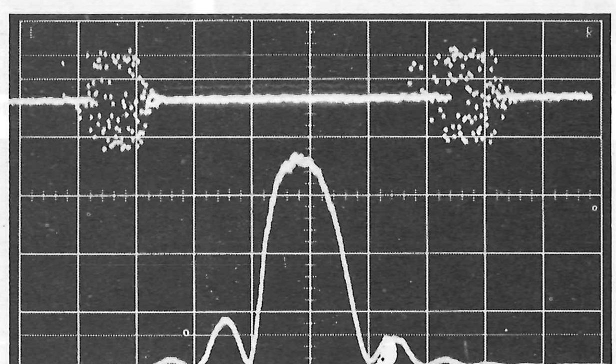


FIG. 27

Time-domain measurements

Some spectrum analyzers can function both in time and frequency domains. Such instruments are not meant to replace oscilloscopes, as their sensitivity is rather poor (100 mv/cm) and their input impedance is low (50Ω). In microwave systems, however, where detectors like to be terminated in 50Ω, useful information can be obtained with such analyzers. Fig. 28 is a double-exposure photo showing the time domain characteristics of the modulating pulse as the upper trace and the output spectrum as the lower trace. The same display could have been obtained with a dual-beam oscilloscope.

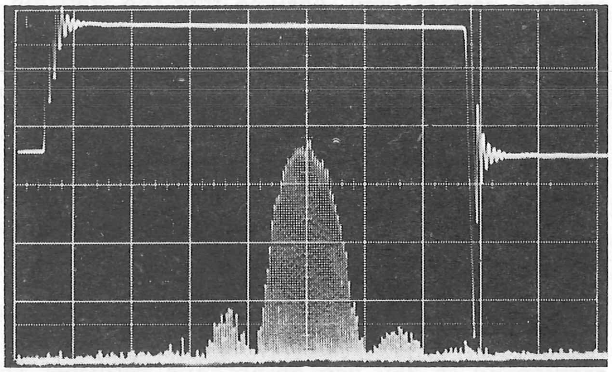


FIG. 28

Balanced modulator adjustment

Balanced modulators often are used to impose suppressed carrier modulation. Figs. 29 to 31 illustrate how this application can be monitored by a spectrum analyzer. Fig. 29 shows a modulator that is not well balanced. The carrier is almost as large as the sidebands. The balance controls are now adjusted to an intermediate stage of performance as shown in Fig. 30. The fully adjusted system, with the carrier almost entirely suppressed, yields the spectrum of Fig. 31.

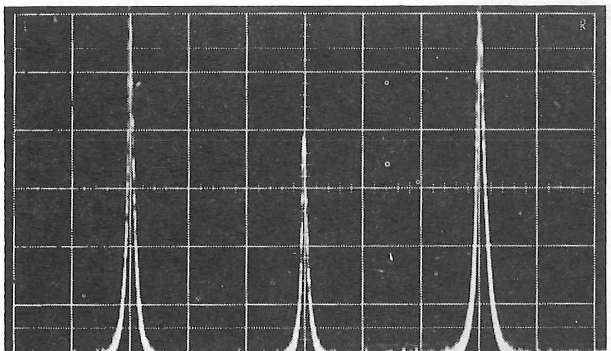


FIG. 29

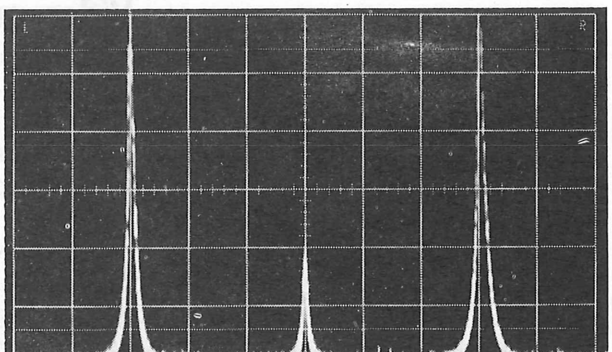


FIG. 30

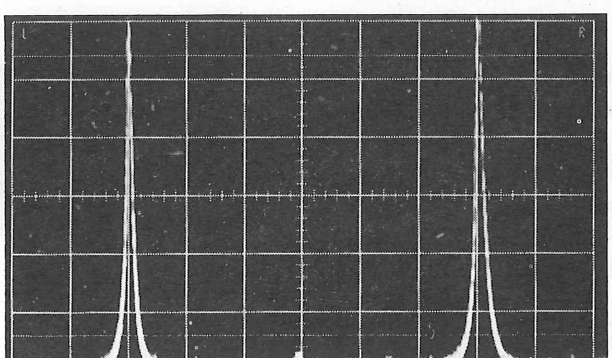


FIG. 31

Antenna pattern measurements

The spectrum analyzer also can be used to provide antenna pattern data. Assume that the transmitting antenna under test is stationary. A transmitted pulse is picked up by a receiving antenna and displayed on the analyzer as a typical sin x/x spectrum. If the analyzer's input frequency is centered on the main lobe and the dispersion reduced to zero we get a set of equal amplitude lines across the screen. Each line represents one transmitted pulse.

Fig. 32 shows such a simulated antenna pattern. The ten horizontal screen divisions correspond to 360 deg of antenna rotation, 36 deg per division. Since the vertical display is linear with voltage we can compute amplitude differences directly. Thus, 3 db is 0.707 of maximum deflection or 0.707 x 5.8 = 4.1 divisions.

The main lobe of the pattern is about one horizontal division wide at the 4.1 division height and the antenna therefore has a beam width of about 36 deg. The center of the screen corresponds to the 180-deg position. The ratio of main lobe deflection (5.8 divisions) to that at 180 deg rotation (0.2 divisions) is the antenna's front-to-back ratio, which for this antenna is 11.6, or 21.3 db.

One precaution: the receiving antenna must have very low sidelobes and a narrow beam width in comparison to the transmitting antenna so as not to affect the recorded pattern. Keep in mind also that the analyzer must be swept quite slowly to record the pattern. A paper chart recorder or storage scope can, therefore, be very helpful. Fig. 32 was displayed on a storage scope.

Assume now that the test antenna is rotating. A very strong signal is received when the pickup antenna is located in the main lobe of the transmitting antenna pattern; signals are weaker in the sidelobes and minimal in the pattern nulls. If the spectrum analyzer is swept very slowly, so slowly in fact that one sweep corresponds to 360 deg of antenna rotation, the crt screen can be calibrated in degrees to display a complete antenna pattern.

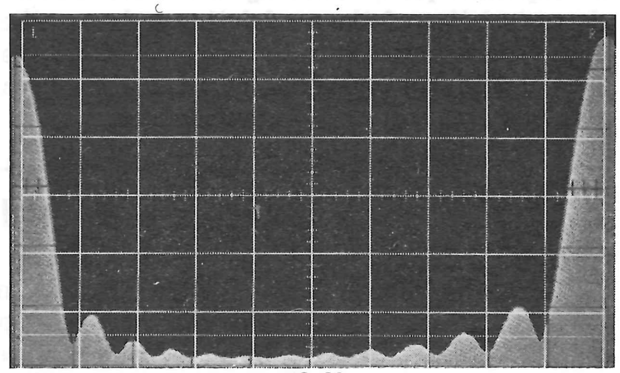


FIG. 32

Video pulse spectra

It is sometimes useful to examine the Fourier spectrum of a video-pulse train directly, without modulating a carrier. Whereas in a pulsed RF signal the spectrum is centered around the carrier frequency, the spectrum for a video pulse goes to zero frequency.

Most spectrum analyzers having wide dispersions cannot display such low frequencies. However, some spectrum analyzers using balanced mixers for local oscillator suppression are suitable. Fig. 33 shows the spectrum of a 0.4-μsec pulse. Analyzer dispersion is 2 Mc/cm.

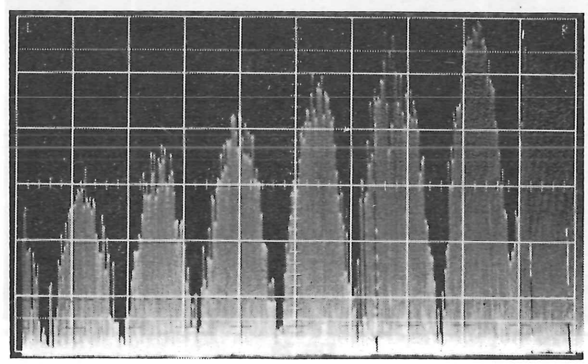


FIG. 33

Wide dispersion measurements

A new class of spectrum analyzers having gigacycle dispersions recently has appeared on the market. The accompanying figures illustrate two applications of these new devices. Fig. 34 shows eleven signals spaced at 1 Gc intervals from 2 to 12 Gc. Analyzer dispersion is 10 Gc.

Fig. 35 shows the harmonics of a 900-Mc transistor oscillator. The spectrum analyzer is sweeping from 1.7 to 12.5 Gc. We observe that this oscillator has substantially no output beyond the 6th harmonic.

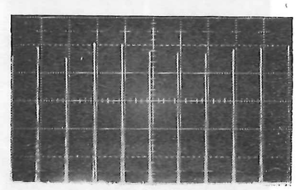


FIG. 34

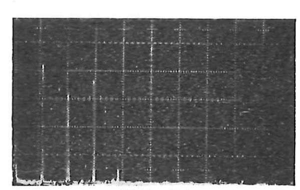
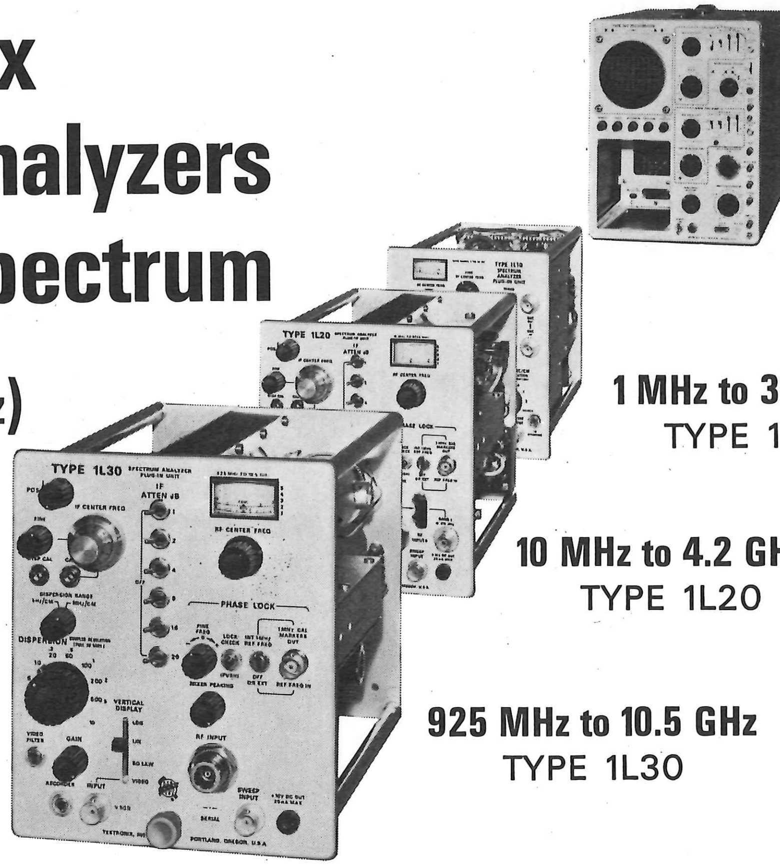


FIG. 35

Tektronix spectrum analyzers cover the spectrum

(1 MHz to 10.5 GHz)



1 MHz to 36 MHz
TYPE 1L10

10 MHz to 4.2 GHz
TYPE 1L20

925 MHz to 10.5 GHz
TYPE 1L30

And they're all designed by Tektronix specifically for use in Tektronix oscilloscopes

Features of Tektronix Spectrum Analyzers
(Types 1L20 and 1L30)

- Internal phase lock
- 100 MHz calibrated dispersion
- 1 kHz resolution
- ±1 dB display flatness

With any Tektronix oscilloscope that accepts letter and 1-series plug-ins, plus one of these spectrum analyzer plug-ins, you can extend the measurement capability of your laboratory to include spectrum analysis in the frequency range between 1 MHz and 10.5 GHz.

The Tektronix combination of spectrum analyzer and oscilloscope lets you make simple and accurate frequency measurements directly from the CRT display. The availability of many other plug-ins makes the oscilloscope an even more versatile laboratory measurement instrument.

Tektronix offers an outstanding measurement value in an oscilloscope-spectrum analyzer package, particularly when its cost is compared with a typical single-purpose spectrum analyzer.

TEKTRONIX SPECTRUM ANALYZER CHARACTERISTICS

	TYPE 1L10	TYPE 1L20	TYPE 1L30	TYPE 3L10
	(for use in Tektronix oscilloscopes accepting letter and 1-series plug-in units)			*(for use in Type 561A, 564 and 565 oscilloscopes)*
Frequency Range	1 MHz to 36 MHz	10 MHz to 4.2 GHz	925 MHz to 10.5 GHz	1 MHz to 36 MHz
Minimum Sensitivity	—100 dBm	—110 dBm to —90 dBm	—105 dBm to —75 dBm	—100 dBm
Calibrated Dispersion	2 kHz/cm to 10 Hz/cm	10 MHz/cm to 1 kHz/cm	10 MHz/cm to 1 kHz/cm	2 kHz/div to 10 Hz/div
Resolution	1 kHz to 10 Hz	100 kHz to 1 kHz	100 kHz to 1 kHz	1 kHz to 10 Hz
Incidental FM	IF: 5 Hz LO: 25 Hz + 1 Hz/MHz dial frequency	With internal phase lock, less than 300 Hz		IF: 5 Hz LO: 25 Hz + 1 Hz/MHz dial frequency
Display	Log, linear, linear X10 and video	Log, linear, square law and video	Log, linear, square law and video	Log, linear and video
Price	$1200	$1995	$1995	$1300

For a demonstration in your own measurement environment, call your nearby Tektronix field engineer, or write:

Tektronix, Inc.,
P. O. Box 500,
Beaverton, Oregon 97005.

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