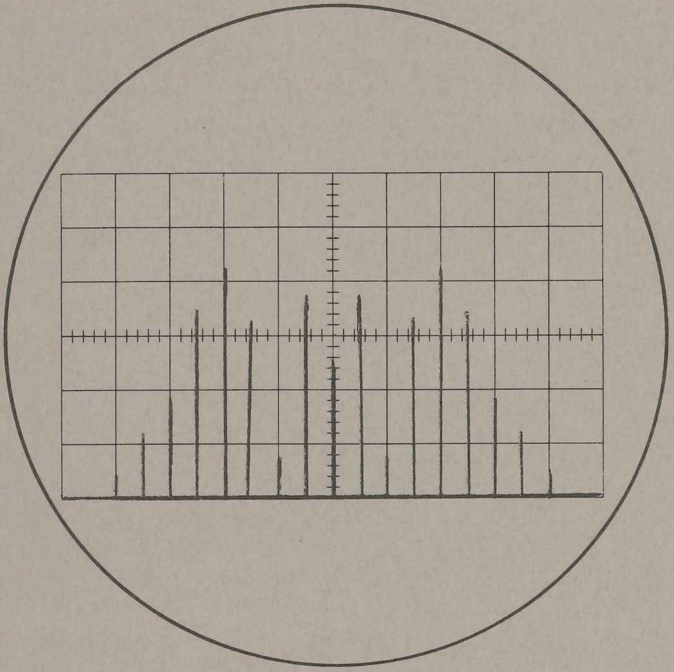
SPECTRUM ANALYZER NOTES #1



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Field Training
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FOREWORD

This publication is intended to only acquaint the reader with a series of specturm analyzers and of their evolution. The length of coverage on each type is not indicative of its simplicity, nor of the types most popularly used. At times, the text may dwell at length on a particular spectrum analyzer. This is only to prime the reader and cause less confusion later. The text and figures progressively lead the reader to some of the more refined systems manufactured today.

The material for this publication is adapted from the lecture by Morris Engelson, formerly of Pentrix, Inc., to the Field Engineer Candidates and Training staff on July 24, 1964.

SPECTRUM ANALYZERS

Original Lecture by Morris Engelson
Revision Edited by Bob Beville, Field Training

A spectrum analyzer is a device which will decompose a complex electronic signal into its various frequency components. A composite signal as in Figure 1, which is the sum of two sine waves of frequency F_1 and F_2, will be seen on a normal oscilloscope as just that -- a voltage-time waveform. The scope presents the complex signal as a function of time.

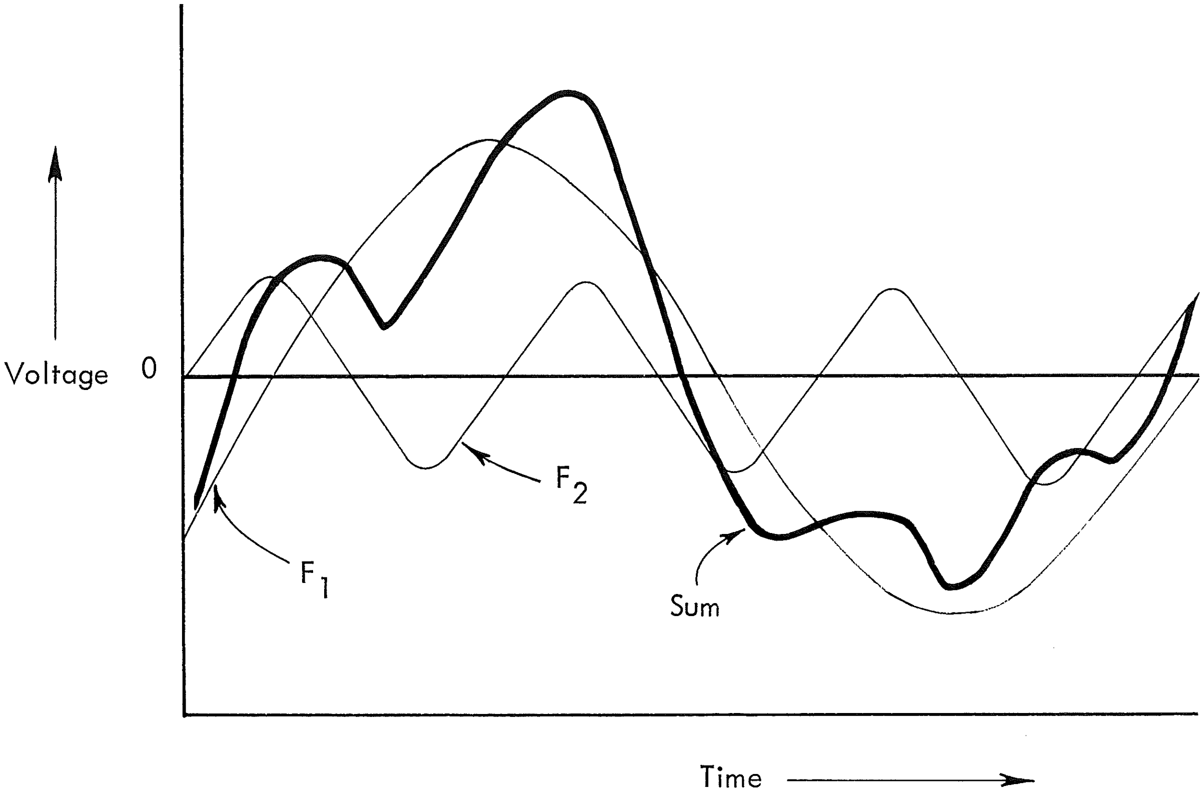


Figure 1 Composite Signal

The spectrum analyzer, on the other hand, does not represent signals as a function of time. Over the interval of the observation or measurement, we must assume that the signal has not changed in amplitude or frequency. These variables are our primary concern: What are the frequencies of our signal? What are the relative amplitudes of the various frequency components? What are these components telling us about the performance of our device?

A very simple spectrum analyzer would be a set of filters. Each filter would have a passband which covers a portion of the frequency spectrum of interest. The filters would successively increase in frequency while their passbands are made to overlap slightly, in order that no portion of the broad range of frequencies over which we intend to study is left gapping. (See Figure 2.) Inputs are connected together so that the complex signal will be common to all filters as shown in Figure 3.

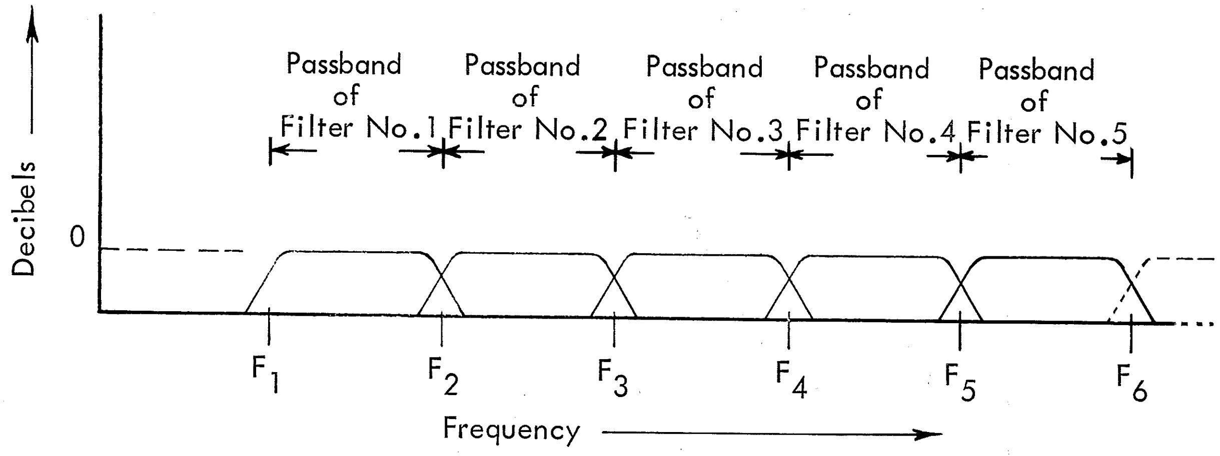


Figure 2 Filter Passband Characteristics

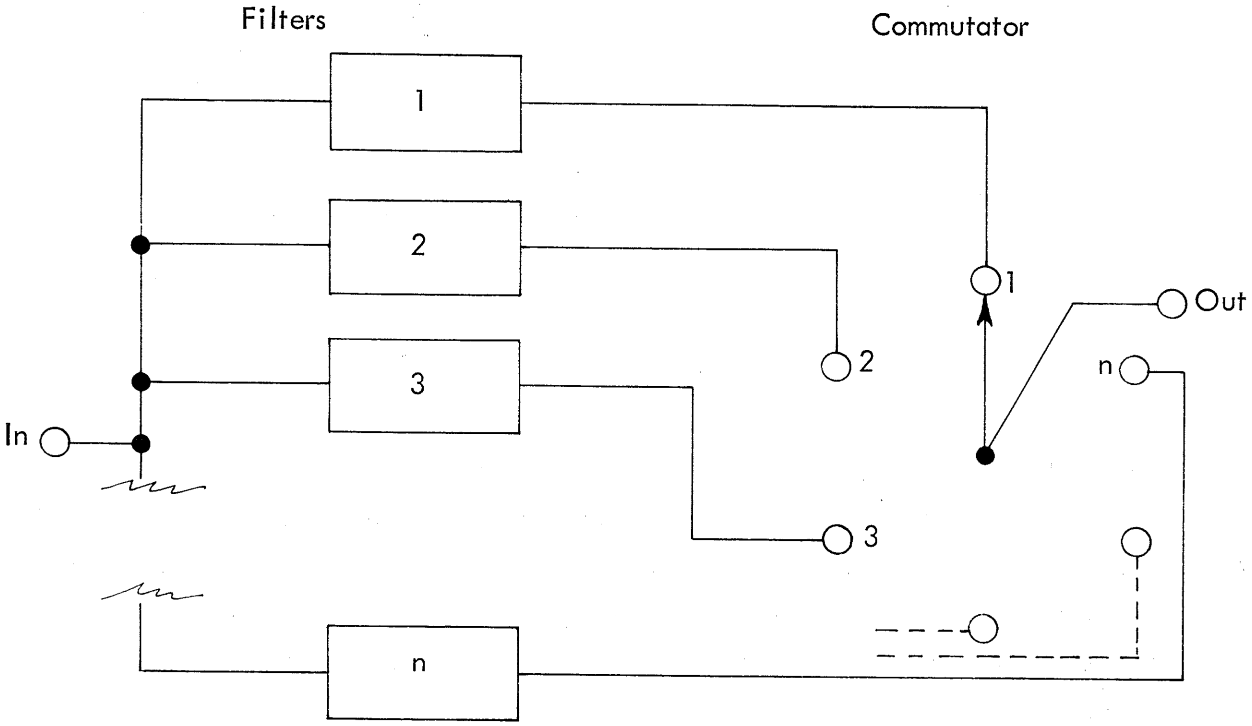


Figure 3 Simple Spectrum Analyzer

The outputs are connected to a commutator device, a system which will look at the output of each filter sequentially. This commutator device could be as simple as a multiple pole switch or a diode matrix or a Time Division Multiplexer. The commutator, then, is sampling the output of each filter, in turn, and in that time only will the output show a signal which is passing through that particular filter. Suppose our complex signal of Figure 1 had component frequencies, F_1 and F_2, that fell in the passbands of filters No. 1 and No. 3 respectively. At time t_1, the output is connected to filter No. 1, and its output is responding to the component frequency F_1 of the input. At time t_2, the commutator looks at filter No. 2, but the input signal contains no frequencies which fall inside its passband. Hence the output over the time t_2 is zero. At t_3, we are looking at the output of filter No. 3. Now, this filter is responding to the component frequency F_2, which we say fell in its passband. It had been responding to this frequency all the time we were looking at filters 1 and 2, but only now do we see that it is present. The commutator goes on and samples filters No. 4, 5 .... to filter No. n at times t_4, t_5 .... t_n but since no other filters are responding to the input frequencies, there are no further outputs. Figure 4 shows the output for each filter as they were examined, from time t_1 to time t_n. This figure would be the presentation on the screen of an oscilloscope if the output of the commutator were its input and if the sweep speed were adjusted properly. The amplitude of the presentation is indicative of the amplitude of that particular component of the input signal. We then know the relative amplitudes of the components, and from the time-sequenced switching we know in which passband they fall.

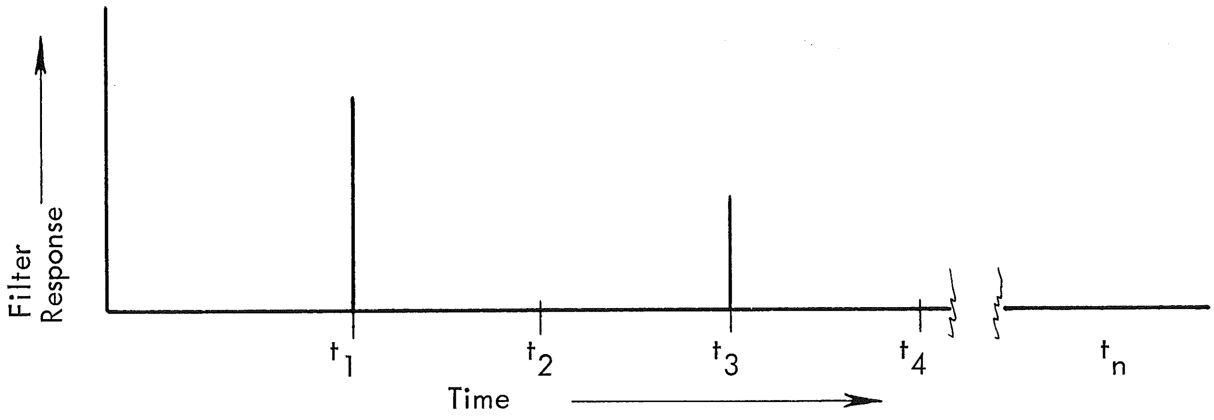
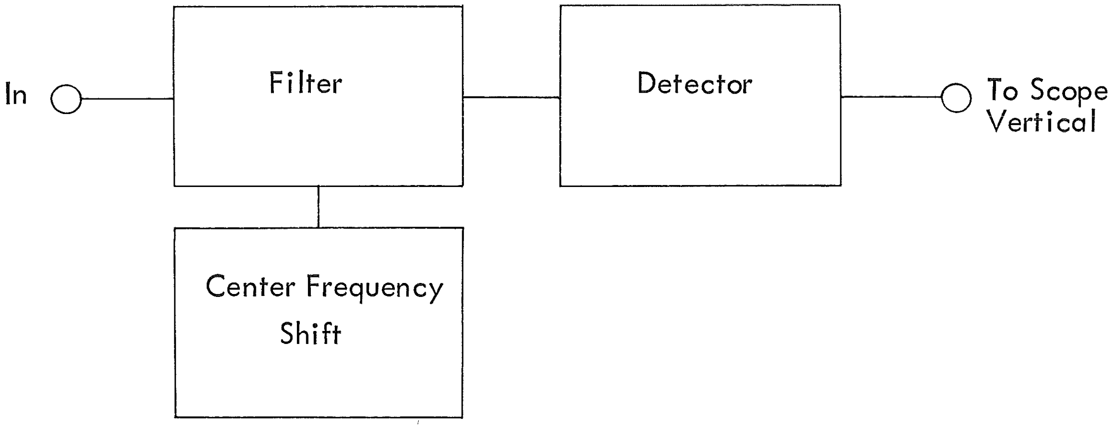


Figure 4 Response of Simple Spectrum Analyzer to Signal of Figure 1

This system is known as a Filter Spectrum Analyzer and many are actually manufactured. Several of its shortcomings will be pointed out. At time t_1, the output of the analyzer gave an indication of the presence of a signal which lies in the passband of filter No. 1. We then know there is a component of the input somewhere between F_1 and F_2, the passband of filter No. 1. Only somewhere. Theoretically, a filter could be built as narrow as you wish. Let's use filters with a passband of only half that of the first ones. Immediately, though, we have doubled the number of filters necessary to cover the frequency range we were studying.

The narrower the passband of each filter is made, the more we need. The closer F_2 approaches F_1 and F_3 approaches F_2 and so on, the finer the discrimination will be as to what the true frequency of any input component is. Theoretically, if the frequency coverage of interest is X, and the resolution between frequencies is Y, the number of filters will be a little less than $\frac{X}{Y}$ (because of passband overlap). So if you want to cover several thousand megacycles with a resolution between frequencies of a couple of kilocycles, you end up with thousands of filters. Thousands of filters would be expensive, bulky and the commutator device would be very complex.

We can get away from these switched filters by letting a filter do the switching. This system would have a single filter whose center frequency is adjustable over the frequencies of interest as in Figure 5. Here at t_1, the filter center frequency is located at f_1, and has a passband characteristic shown by the dashed lines. At t_2, the passband has moved to center itself at f_2 (passband at f_2 in dotted lines). This shifting continues at a constant rate until time t_5, where the center frequency is reset to its low end and shifting begins again.



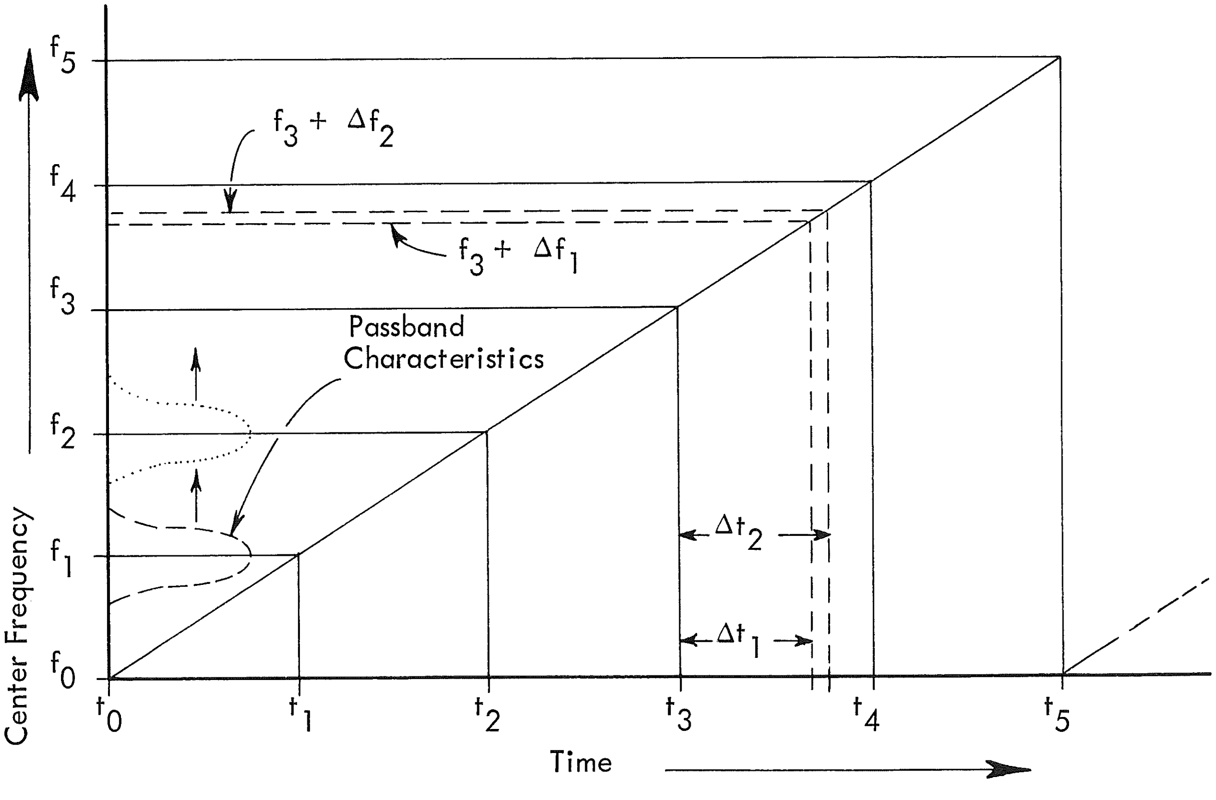


Figure 5 Swept Filter and Characteristic

The region of frequencies over which the filter is swept is now related to time by the center frequency-time characteristic. A linear characteristic will be optimum as viewed on the oscilloscope because equal increments in frequency will be displayed as equal increments in horizontal position. If the input contains a frequency component somewhere between F_3 and F_4, say $F_3 + \Delta F_1$, the output will not respond until the passband sweeps over that frequency at time $t_3 + \Delta t_1$.

If another frequency, $F_3 + \Delta F_2$, is nearby, the filter responds to it immediately following. How well can you determine that there are two input frequencies this close together? These two frequencies might both be inside the passband of the filter as it sweeps through them. This points out one of the weaknesses of this system. This filter is a passive device, and as such, possesses some insertion loss. The narrower the passband is made, the more readily a difference in two frequencies could be resolved, but soon this becomes impractical to design. Also, unmentioned until now, is the fact that a diode detector has been used in order to obtain responses of all input frequencies, even above 30 mc (beyond the bandwidth of the oscilloscope). The diode detector will have a threshold level to overcome in order to detect signals. Overcoming the insertion loss, and requiring that there be a certain minimum signal level at the detector input, dictates that this system is not very sensitive. Its ability to resolve the difference between two frequencies, called resolution, is a compromise with allowable insertion loss. The input signal might not have enough power in each of its component frequencies, hence the detector output is incomplete. Its utility, then, as a spectrum analyzer is limited. It is useful possibly as a searching spectrum analyzer - telling only the approximate frequency but nothing about the fine structure of the signals, its modulation or bandwidth.

> NOTE:
>
> At this point, the reader must be emphatically cautioned on a possible misconception in his thinking. This involves the long use of oscilloscopes in the horizontal time base mode of operation. It no longer is intended that the scope presentation be thought of in terms of time/cm horizontally, even though it is known that the spot on the screen of the CRT takes time to move. The horizontal axis, via some frequency-time characteristic like Figure 5, now corresponds to frequency. The time base generator is used, certainly, but what is viewed on the screen is something else.

The next variation in the evolution of spectrum analyzers has no center frequency swept filter. Its filter is a stationary one, and instead of bringing this filter to the frequency of the signal, the signal is brought to the frequency of the filter -- HETERODYNE! Figure 6 shows the block digram. The input is now fed into a mixer, where it beats with some frequency from a local oscillator.

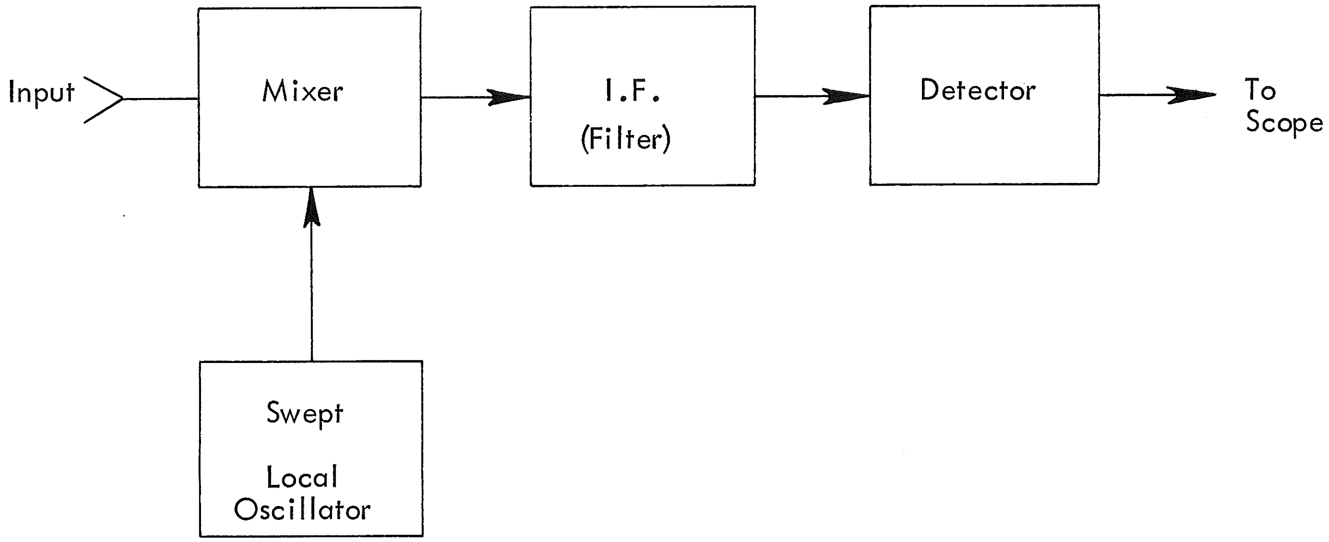


Figure 6 Front End Swept Local Oscillator Version

Application of the normal super heterodyne equation: the difference in local oscillator frequency and input signal frequency equals the intermediate frequency:

$$f_{L.O.} - f_{sig} = f_{I.F.}$$

will be used to its fullest. Both the signal and the local oscillator frequencies are varying. The local oscillator is swept over a range of frequencies of the input signal to be analyzed. When the difference is such that it falls in the passband of the I.F., we will see the detected output on the scope.

Spectrum analyzers using this swept local oscillator technique come in two varieties. Figure 6 is the front end swept variety, since the mixing is performed near the input. In the IF Swept Spectrum Analyzer, the heterodyne conversion with a swept local oscillator occurs later. Again, we have to bring the input signal to the frequency of the filter (IF), so a fixed local oscillator is placed in the front end. The fixed frequency local oscillator, however, is manually tuned, not swept.

This fixed frequency, when heterodyned with the input signals, will produce difference frequencies which lie in the passband of the wideband I.F. filter. Figures 7 and 8, with a numerical example, should be helpful at this time. Figure 7 is a frequency spectrum showing the range of the input, local oscillators and filters of a particular IF Swept Spectrum Analyzer.

Study the figure as you read the description of each region:

No. 1 Input frequency range. The range shown is 10 to 230 mcps. This is your radio, TV, FM transmitter, etc., which you want to analyze.

No. 2 Front end local oscillator range. Manually tunable from 210 to 430 mcps in this case. These frequencies mix with the input to give the IF frequencies of region No. 3.

No. 3 Wideband IF filter. 170 to 230 mcps. Its passband characteristic is as flat as can be obtained to pass the same amplitude regardless of frequency.

No. 4 Range of Swept Local Oscillator. 229 mc to 289 mc. These frequencies will enter another mixer to beat with the output of the wideband IF. The sawtooth from the time base generator is the sweeping waveform. The rate is set by the speed control.

No. 5 Narrow Band IF Amplifier. Center frequency 59 mc, bandwidth approximately 1 mc. This filter receives the beat frequencies of region No. 3 and No. 4 from the swept mixer. It passes only those which are 59 mc ± .5 mc apart.

No. 6 Detector. Here the 59 mc signal is rectified and filtered to give a deflection to the vertical of the CRT.

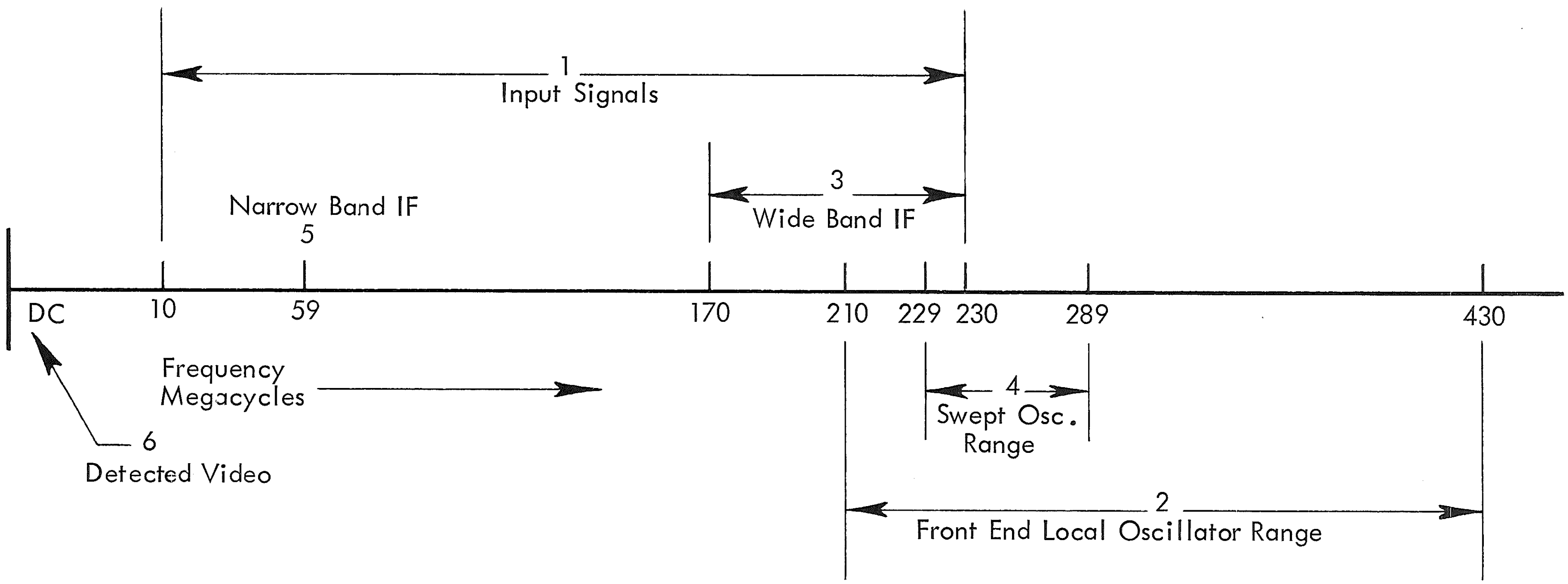


Figure 7 Frequency Spectrum - IF Swept Spectrum Analyzer

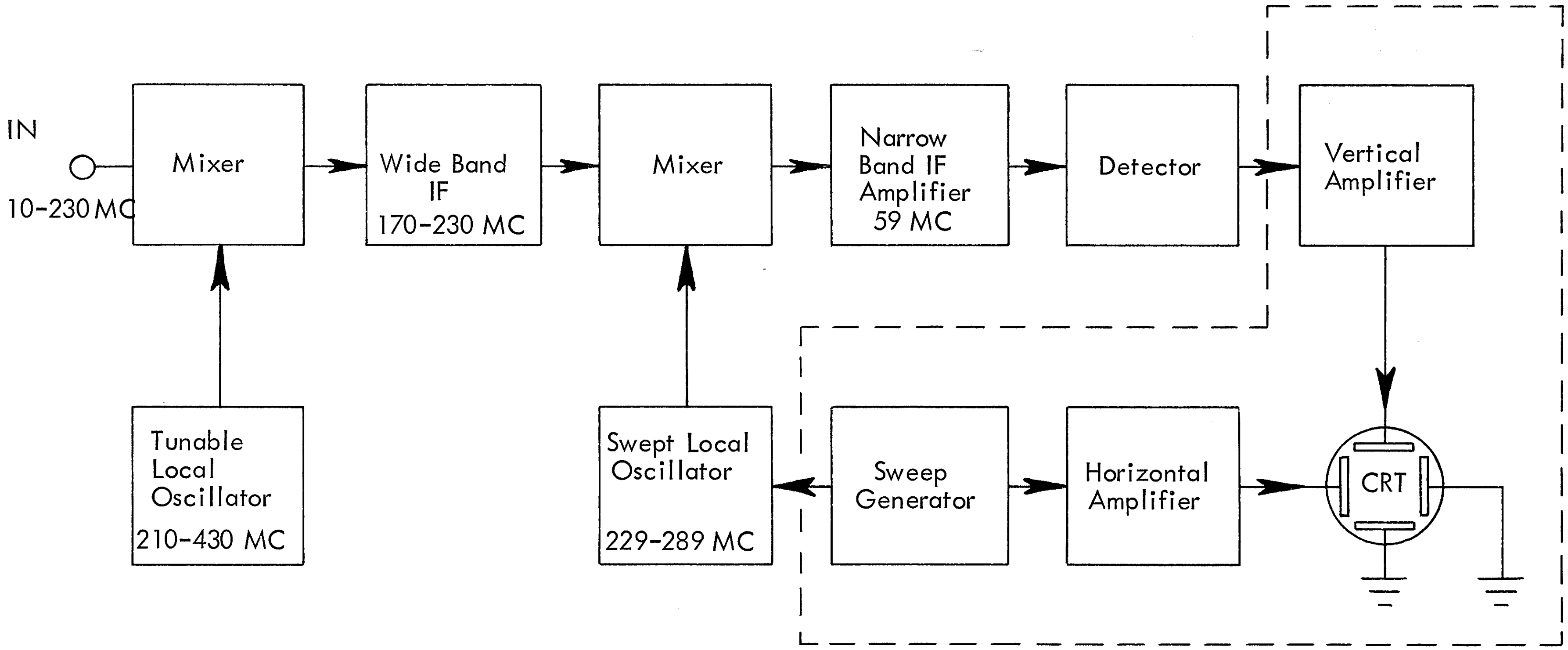
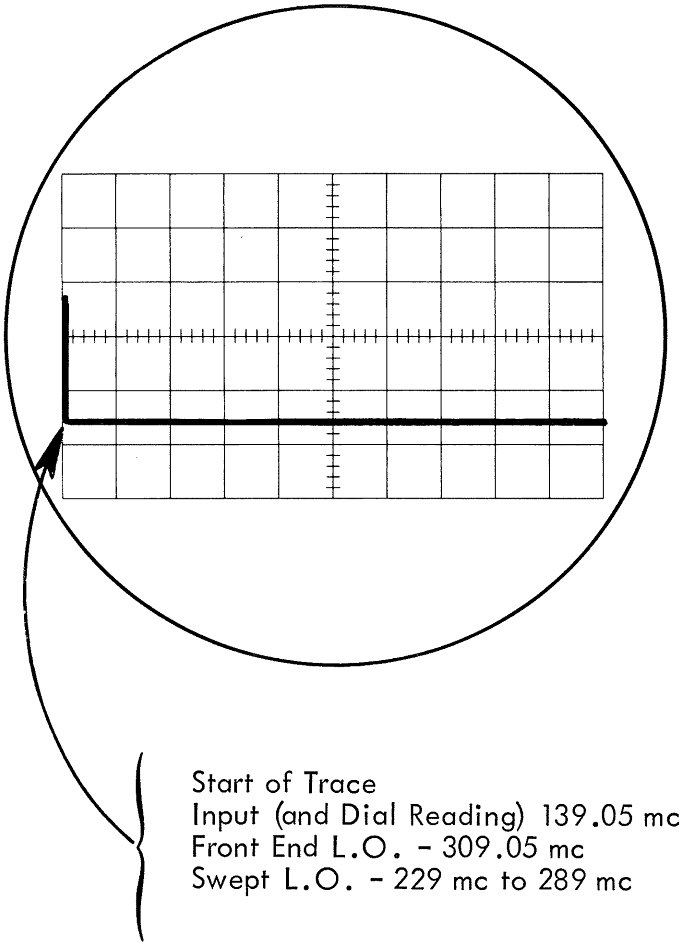


Figure 8 IF Swept Spectrum Analyzer

Figure 8 is a block diagram of the IF Swept Spectrum Analyzer. You have been led through it, block by block, according to the frequencies of each, from input to CRT presentation. An example now should clarify many points. Suppose you have a transmitter with a carrier frequency of 139.05 mc. You wish to analyze the transmitter output for modulation, deviation and bandwidth. With proper coupling, you have fed a portion of the transmitter output into the analyzer. Let's consider ourselves with just seeing the 139.05 mc carrier frequency presentation, and think of the sidebands another time. (Features on analyzers which enable modulation, deviation and bandwidth measurements will be discussed later.)

You have begun looking at the CRT presentation with the Front End Local Oscillator at 210 mc. A necessary operation adjustment is that the sweep generator of the scope is made to free-run (stability control full clockwise or triggering mode in automatic). The presentation so far has only been free running traces. Manually, you tune the Front End Local Oscillator up in frequency until it reaches 309.05 mc. Until this time, the beat frequencies out of the front end mixer have been below 170 mc. Now, at 309.05 mc, their difference is 170 mc which is the lower passband frequency of the wideband IF. Passing through the wideband IF, the signal mixes with 229 mc at the time the sawtooth of the sweep generator has set that swept local oscillator frequency at 229 mc (Figure 8). The 170 mc and 229 mc mix at that instant and produce a signal of 59 mc, the narrow band IF frequency. This is amplified and fed into the detector, and the dc derived produces a deflection in the vertical system of the scope. Since the beginning of the sawtooth waveform determined the 229 mc frequency of the swept oscillator and also determined the position of the trace on the face of the CRT, the detected video will be a pip on the left side of the screen. The sawtooth continues on, sweeping the swept oscillator to 289 mc, and sweeping the CRT beam across the screen. At the end of the trace everything is reset (blanking, hold-off, etc.) and when the sweep generator free runs again, the presentation is repeated. Figure 9 is what you will see.

The reader should verify for himself what the presentation will be when the front end local oscillator is manually tuned to, say 339.05 mc and to 369.05 mc. Add a pair of sidebands and verify their position with respect to the carrier.



Start of Trace
Input (and Dial Reading) 139.05 mc
Front End L.O. - 309.05 mc
Swept L.O. - 229 mc to 289 mc

Figure 9 CRT Presentation for Example in Text

Won't you have trouble seeing sidebands on the presentation when the 10 cm screen represents 50 mcps? It's time, then, to explain a few of the controls on the spectrum analyzer. The sawtooth swept local oscillator is driven above and below a certain center frequency determined by the setting of the Center Frequency control. Let's suppose it is tuned for a center frequency of 259 mc. The Dispersion control in our example was wide open. This means the complete sawtooth waveform is applied to the swept oscillator taking it from 229 mc, through 259 mc, the center frequency, to 289 mc as shown in Figure 10, Waveform A. For the given wide dispersion, we would see something like Waveform C, a CRT presentation that displays a window 60 mc wide. As the dispersion control is turned from wide to narrow, the amount of sawtooth fed to the swept oscillator becomes less and less, yet still applied around that center frequency set by the center frequency control. Waveform B is the sawtooth for a narrow dispersion. Suppose those corresponding sawtooth voltages sweep the oscillator from 257 mc to 261 mc,

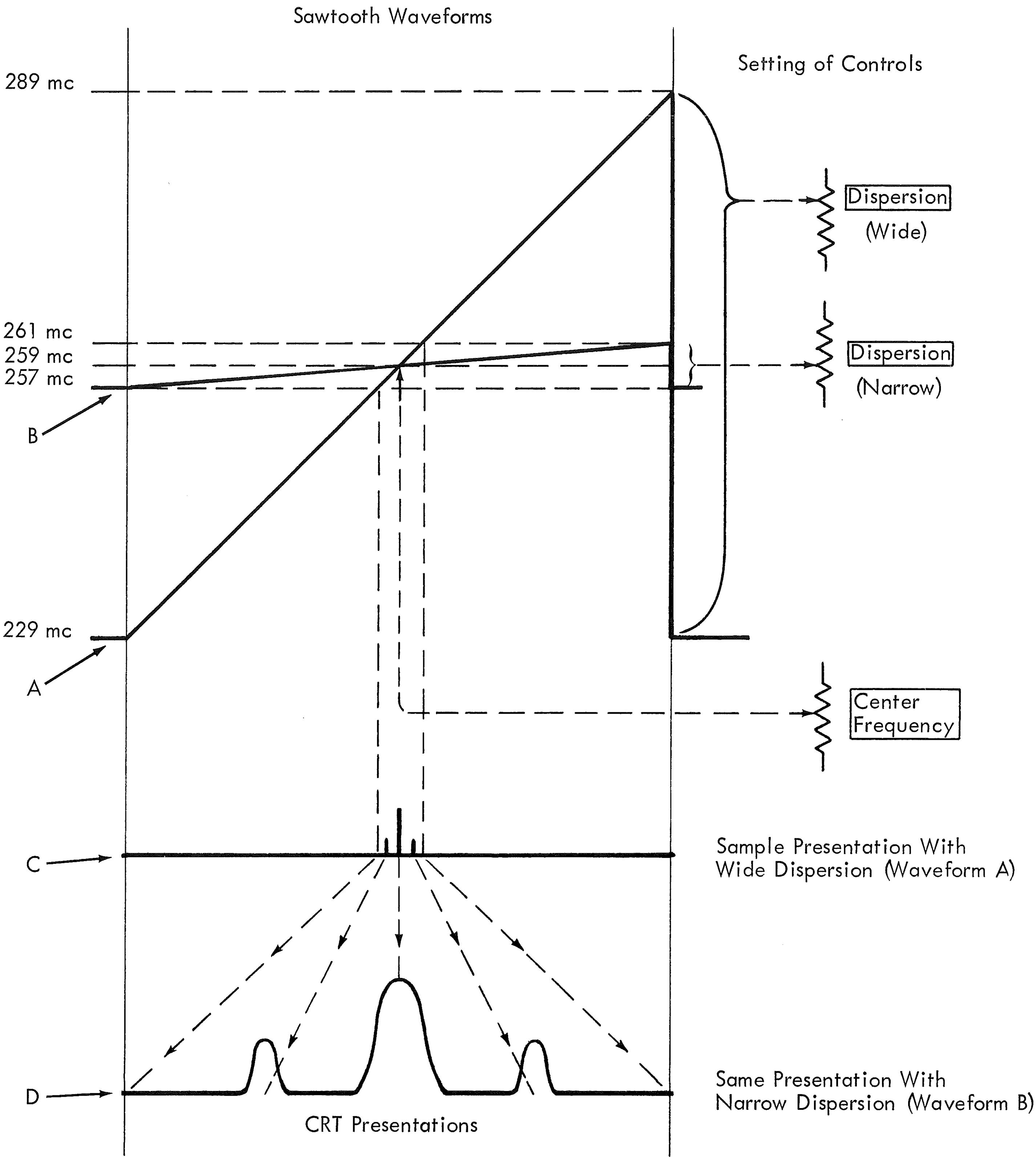


Figure 10 Dispersion and Center Frequency Controls

or a 4 mc window. This means that the presentation 2 mc below the center frequency now starts at the left edge of the graticule (where the sweep unblanked) and the 4 mc window now fills the 10 cm screen as shown in Waveform D. Readers should realize the similarity in this dispersion control and the horizontal magnifier control in the normal Y-T operated scope as it affects the CRT presentation. The dispersion and center frequency controls can vary the width of the window and the center frequency around which it is sweeping.

Again, the resolution of this spectrum analyzer system is questionable. To see this, go through the example again with input information at both 139.05 mc and 138.55 mc. With the front end local oscillator at 309.05 mc, the beat frequencies are 170 mc and 170.50 mc respectively, both the latter being inside the wideband IF band. These two, at the instant the swept local oscillator is at 229 mc, give 59 and 59.5 mc respectively. Both of these are applied to the detector, and the DC response derived is from the rectification and filtering of them simultaneously. An instant later, when the swept local oscillator is at 229.5 mc, the beat frequencies are 59.5 and 59 mc, and here we go again.

This system then has responded to two frequencies 0.5 mc apart, yet only given an indication that one signal was present.

To "resolve" this problem one more mixer and local oscillator will be used. Figure 11 is the same as Figure 8 with this addition shown. The 54 mc local oscillator is a crystal oscillator circuit driving a mixer amplifier. The other input to the mixer amp is the 59 mc information from the narrow band I.F. Their mixer products, 5 mc information, is now fed to a 5 mc I.F. amp. In this amplifier is located a control called the <u>Resolution</u> control, which broadens or narrows its bandwidth. At wide resolution the bandwidth is greatest, 100 kc; at narrow resolution, 1 kc. Should we still want to discriminate between those frequencies, 138.55 mc and 139.05 mc, we would adjust the dispersion control to narrow (thereby making a narrow window, let's say a 4 mc window). This means the swept local oscillator is swept from 2 mc below to 2 mc above its center frequency. Again, let's set the center frequency control to 259 mc. You tune the front end local oscillator to 339.05 mc, which mixes with 139.05 to give 200.00 mc.

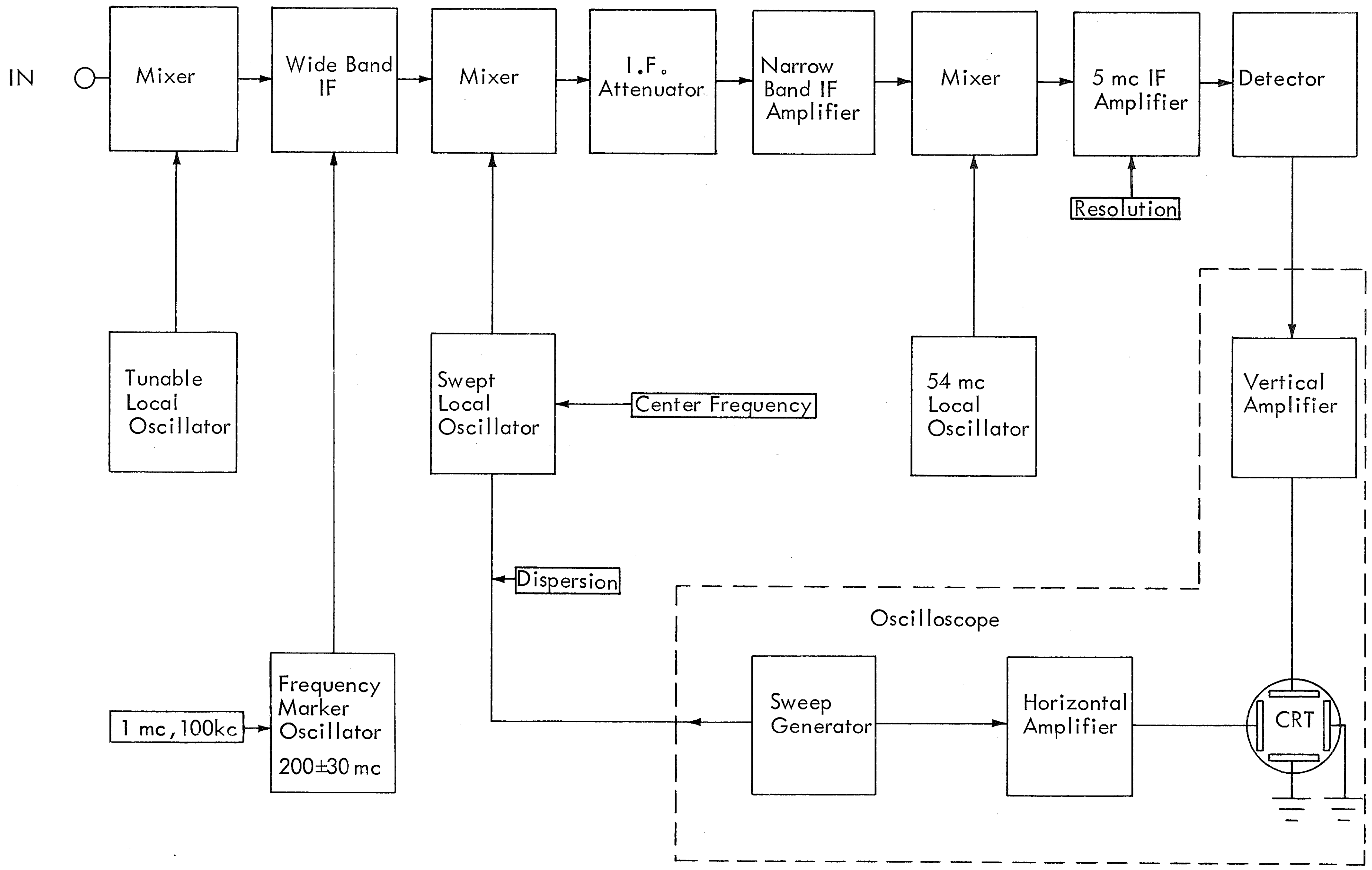


Figure 11 IF Swept Spectrum Analyzer With Resolution Circuit

200.00 mc is in the center of the wideband IF. It mixes with the S.L.O. at 259 mc to produce 59 mc. 59 mc and the 54 mc generate 5 mc, which is detected and a vertical deflection on the CRT results as the beam crosses the center vertical graticule. (Reader: verify this position and the deflection which is the response to the 138.55 mc signal now. Check these numbers: 339.05, 138.55: 200.50; 259.5, 200.50: 59; 59, 54: 5). The CRT trace with a 4 mc window can surely display the different in 0.5 mc. And we have not touched this resolution control, yet. How then has the resolution control helped? Figure 12 shows the display with wide and narrow resolution. The difference is the bandwidths of the 5 mc IF amplifier, whose bandpass characteristic is shown beside the two displays.

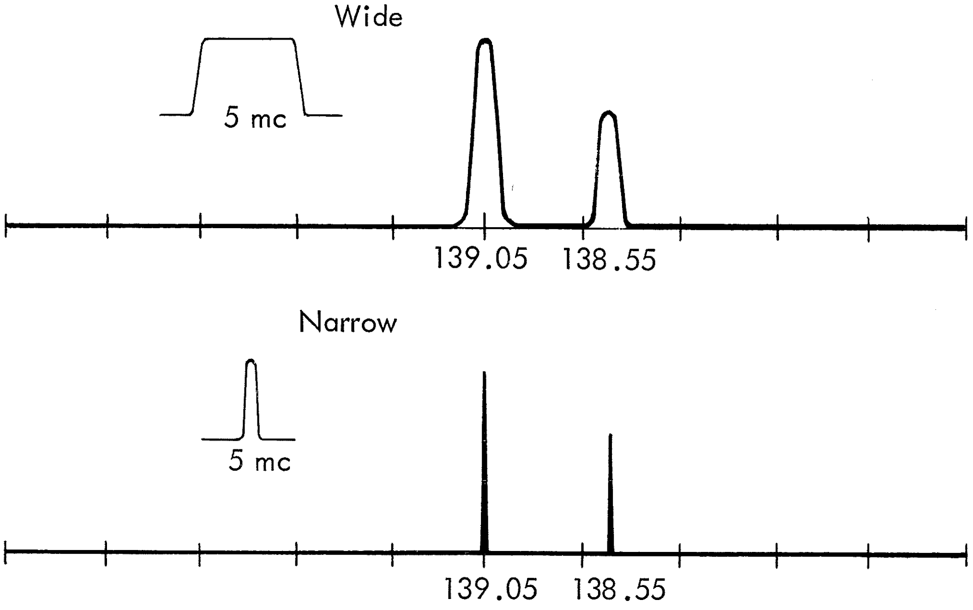


Figure 12 Wide and Narrow Resolution

The amplitudes of the two signals are purposely made different to explain another feature of the spectrum analyzer. In Figure 11, you will notice an I.F. attenuator following the swept oscillator mixer. This is a means of measuring the relative amplitude of signals. By inserting fixed amounts of attenuation, the larger signal is brought down to the (former) amplitude of the smaller one.

How was the CRT display adjusted to a 4 mc window? A feature which enables you to determine the width in megacycles of the display, and thereby make frequency difference measurements, is the frequency marker ("picket fence"). An oscillator (200 ±30 mc) which is frequency modulated at either 1 mc or 100 kc is injected into the wideband IF. From this point on, it appears that a signal at the input has produced this carrier and its sidebands. The markers appear in the CRT display with the regular input information.

By switch, a number of different modes of vertical display may be selected. These modes are: Linear, a linear amplification of the signal; Log, a logrithmic compression of the signal; Square Law, a square law expansion of the signal; Video, to insert an external video signal. In video, the spectrum analyzer circuitry is bypassed, and the signal is direct to the CRT at .1 volt/cm with a bandpass determined by the main frame. The operator will select the vertical display which will enhance the interpretation of his modulated RF signals.

Conclusion:

Many of the basic blocks and features of some spectrum analyzers have been covered from a functional point of view. Any further study would enter the realm of technicalities such as rigorous mathematics, actual schematics, and the ability to interpret the spectrum waveforms. The reader in pursuit of further learning is directed to other sources of information. Volume 1, Programed Instruction, Radio Frequency Measurements, Tektronix, Inc., is recommended.