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THE SIDEBAND TECHNIQUE OF R-F WAVE ANALYSIS

C. H. Bredall

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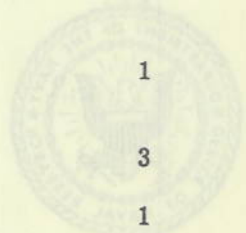
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ABSTRACT

A technique for analyzing complex radio-frequency waves utilizes a visual display of the carrier and sideband components on a cathode-ray oscilloscope. An instrument developed to confirm this technique is described, and some of the developmental problems and operational phenomena are illustrated by oscillograms. The value of such a technique is stressed with regard to spectrum economy, and application of the technique to the problems of intercept and identification is indicated. The analyzer accurately displays relative sideband power and spectrum occupancy and resolves sidebands as low as 20 cycles per second.

Analysis of amplitude-modulation characteristics of signal generators reveal and identify their deficiencies. Use of the technique is suggested not only for analysis of modulated waves in research, development, and test work, but also for the monitoring of transmissions in the interest of greater efficiencies and spectrum economies. A simplified version of this R-F Wave Analyzer is proposed for exclusive use of loran.

PROBLEM STATUS

This completes one phase of the general problem; work continues on other phases.

AUTHORIZATION

NRL Problem R10-26R (NR 510-260)

THE SIDEBAND TECHNIQUE OF R-F WAVE ANALYSIS

INTRODUCTION

Among the most important factors to be considered in electronics development are those which effect economies in spectrum utilization. A given type of modulation can be theoretically assumed to require a certain part of the spectrum for efficient utilization; yet, due to maladjustment of the system, the practical bandwidth required may be very different from the theoretical. The nearer to the ideal in spectrum economy, the more critical becomes the adjustment of the elements comprising the system. The necessary adjustments must, in general, be made in the field and can be made only by reference to test equipment that is sufficiently informative to indicate when the required operating conditions are attained. Thus, the test equipment must embody not only standards, but some form of analytical presentation of the spectral components. Current equipment includes frequency standards and signal generators. However, instruments for quantitative analytical presentation of spectral components are not available. Existing analyzers such as panoramic adapters are inadequate for sideband analysis because of nonlinearity of the frequency base-line, insufficient accuracy of sideband amplitudes relative to carrier amplitude, and insufficient resolution and stability. The equipment and techniques described in this report overcome these inadequacies and provide a reliable method for sideband analysis.

The technique is suggested for three general fields of activity: (1) the field concerning spectrum economy; (2) the field concerning the interception and identification of unknown signals and (3) the field concerning the achievement of all types of modulation including pulse characteristics of desired and undesired signal sources. An equipment to be useful for these applications requires broad initial scanning of the spectrum, with provision for detail scanning with high resolution when necessary, wide input frequency range, and provision for use at the signal source or at a remote point in which case a sensitive receiver might be necessary. An example of the first field is the determination of the spectrum occupancy of loran. The second field includes intercepting and identifying enemy signals by military units, and monitoring and detecting signals by groups such as the Federal Communications Commission. The third application is primarily of value in development and research; for example, the investigation of factors producing f.m. in amplitude-modulated signal generators.

In identification of signals, exact knowledge may sometimes be obtained and an idea may generally be secured as to the nature of the modulation. An operator may identify signals by familiarity with the more common spectra. A simple carrier and two sidebands can probably be identified as a constant tone amplitude-modulated signal from which he can determine carrier frequency, percent modulation and modulation frequency. The sideband spectral envelope of a simple pulsed signal may be observed and such characteristics as

repetition rate, carrier frequency and pulse width may be easily determined. Other signals, such as frequency-shift-keying, frequency modulation, etc. have characteristic spectra, and their modulation factors may be determined. In known signals, unwanted effects such as key clicks and spurious oscillation can be observed.

The techniques are most adaptable to waves purely modulated under steady modulating conditions. When the modulating frequencies and amplitudes are continually changing, as in the communication bands, analysis is more difficult. Yet even in this case, many characteristics may be determined, such as the bandwidth, the sideband amplitudes relative to the carrier, and the purity of modulation.

THE PROBLEM OF RESOLUTION

The subject of resolving-power limitations of radio-frequency spectrum analyzers has been well covered.¹ Others^{2,3,4} have considered in detail "ringing," which is the most serious limitation of this type of instrument. The nature of such an analyzer requires continuous automatic tuning through a given portion of the radio-frequency spectrum. For such an instrument to be of greatest value, it must rapidly scan this portion of the spectrum and, at the same time, have sufficient resolving power to separate closely-spaced signals or sidebands. The two requirements conflict but are most compatible when the rate of change of frequency of the sweep is very low. This can be accomplished by sweeping very slowly or by sweeping only a small band of frequencies. If this is done, however, the entire spectrum of the complex wave cannot be observed in a short time. The difficulty arises when tuned circuits having Q's high enough to give sufficient static selectivity are excited by rapidly changing frequency.

Consider a voltage due to a single spectral component arriving at the high Q circuit. The circuit is subjected to a signal with frequency changing at a linear rate and having constant amplitude when the frequency is close to the resonant frequency of the tuned circuit. The voltage across the circuit will begin to rise as the frequency approaches the natural frequency of the circuit. Each cycle of the applied voltage of varying frequency will tend to cause the circuit to "ring." These "ringing voltages" will add or subtract depending upon their instantaneous amplitude and phase relationships. This will continue until the exciting frequency is far from the natural frequency of the circuit. An example of this effect is shown in Figure 1 where the voltage across the circuit is plotted as a function of the frequency. In Figure 1a the frequency is changed at an infinitely slow rate, thus producing essentially the static resonance curve. Figure 1b shows the distortion of this voltage when the rate of change of frequency is high. The peak of the distorted curve will be relatively lower than that of the static curve and translated to the right. This phenomenon is treated mathematically by Barber and Ursell.⁴

¹ Williams, M., "Radio-Frequency Spectrum Analyzers," *Proc., I.R.E.*, Vol. 34, No. 1, 18-22, January 1946

² Hok, Gunnar, "Response of Linear Resonant Systems to Excitation of a Frequency Varying Linearly with Time," *J. App. Physics*, Vol. 19, No. 3, 242-250, March 1948

³ Barber, N.F., "The Optimum Performance of a Wave Analyzer," *Elec. Eng.*, Vol 21, 175-179, May 1949

⁴ Barber, N.F. and Ursell, F., "The Response of a Resonant System to a Gliding Tone," *Philosophical Magazine*, Vol. 39, No. 292, May 1948

If the circuit is energized by a spectral component sweeping across its resonant frequency before it is deenergized from the preceding component, the voltage produced by the second component and the residual energy will vary depending on the relative magnitudes and phases of the two energies. Patterns of erratic appearance will result from sweep to sweep due to relative phase changes. If the voltage pulses due to a train of spectral components overlap in this manner, a badly distorted representation of the complex wave spectrum will occur. It is possible to adjust the sweep rate and Q to eliminate this effect.

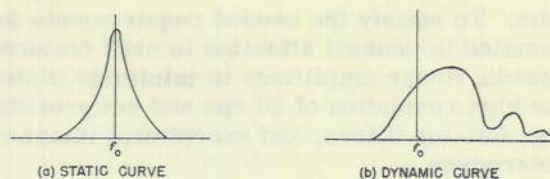


Figure 1 - Curves illustrate deterioration of response curve when rapidly swept

Sometimes it is not necessary to resolve individual sidebands. Considerable information about spectral occupancy may be obtained if the sideband envelope can be observed. In this case, the Q need only be sufficiently high to resolve the points of interest in the sideband envelope. This may be done when there are many sidebands and the adjacent sidebands are of approximately the same amplitude. Under these circumstances interference due to adjacent components may be tolerated and the integrated signal will produce a true indication of the sideband envelope.

GENERAL REQUIREMENTS

The foremost requirements for an instrument capable of providing accurate sideband presentation for wave analysis are:

- (1) Resolution sufficient to separate the lowest modulating frequency components encountered.
- (2) Accuracy sufficient to determine the amplitude and frequency of the components of a complex wave.
- (3) An accurately adjustable sweep width, wide enough in its maximum position to include all the major sidebands of the more common types of complex waves and sufficiently narrow in its reduced positions to provide detail inspection of closely-spaced sidebands.

It was decided to develop an equipment which would analyze signals from 1.7 - 28 megacycles. A maximum sweep width of 200 kilocycles was considered sufficient for the majority of complex waves. The resolution, as well as the sweep width, should be adjustable over a considerable range in order to obtain the advantages of as great a resolution as practical. The limit was found later to be a sweep width of 200 cps with sufficient stability to observe 20 cps sidebands.

BASIC PLAN

Outline

To achieve the desired characteristics, and confirm the theory of this technique, it was proposed that an analyzer be designed as shown in Figure 2 that would present the spectral components with relative magnitude plotted against frequency on the face of a cathode-ray

tube. To satisfy the needed requirements for satisfactory sideband analysis, the design resulted in unusual attention to such features as linear sweep circuits with wide range of speeds, linear amplifiers to minimize distortion, variable Q circuits which will permit the high resolution of 20 cps and yet provide rapid and wide frequency sweep for searching, flat-top filters, and exceptional image rejection since this equipment is a triple super-heterodyne.

In order to minimize inter-modulation, the signal is applied directly, with the signal from a low drift local oscillator, to a low-distortion mixer where an i-f signal centered at 3.4 Mc is produced. By using either the sum or difference output of the mixer, signals from 1.7 to 28 Mc can be viewed with an oscillator adjustable from 5.1 to 24.6 Mc. With proper precautions signals with components between 3.3 and 3.5 Mc may be observed. Since these signals are in the first i-f range, they may be introduced with the first local oscillator tuned well above this frequency. Preselection, if required, should be obtained with passive filters external to the R-F Wave Analyzer. The i-f signal passes through a 3.4-Mc filter with a 250-kc flat-top. A second local oscillator (centered at 3.14 Mc) is frequency modulated with the same linear sawtooth voltage which provides the horizontal sweep on the cathode-ray tube. The period of this sawtooth can be 1 second, 10 seconds, or longer by using a manual drive. The spectral width observed is determined by the frequency swing of the frequency-modulated local oscillator which can be varied from zero swing to ± 100 kc. The difference beat note is fed into a crystal filter peaked to pass 260 kc and have high attenuation for 250 kc.

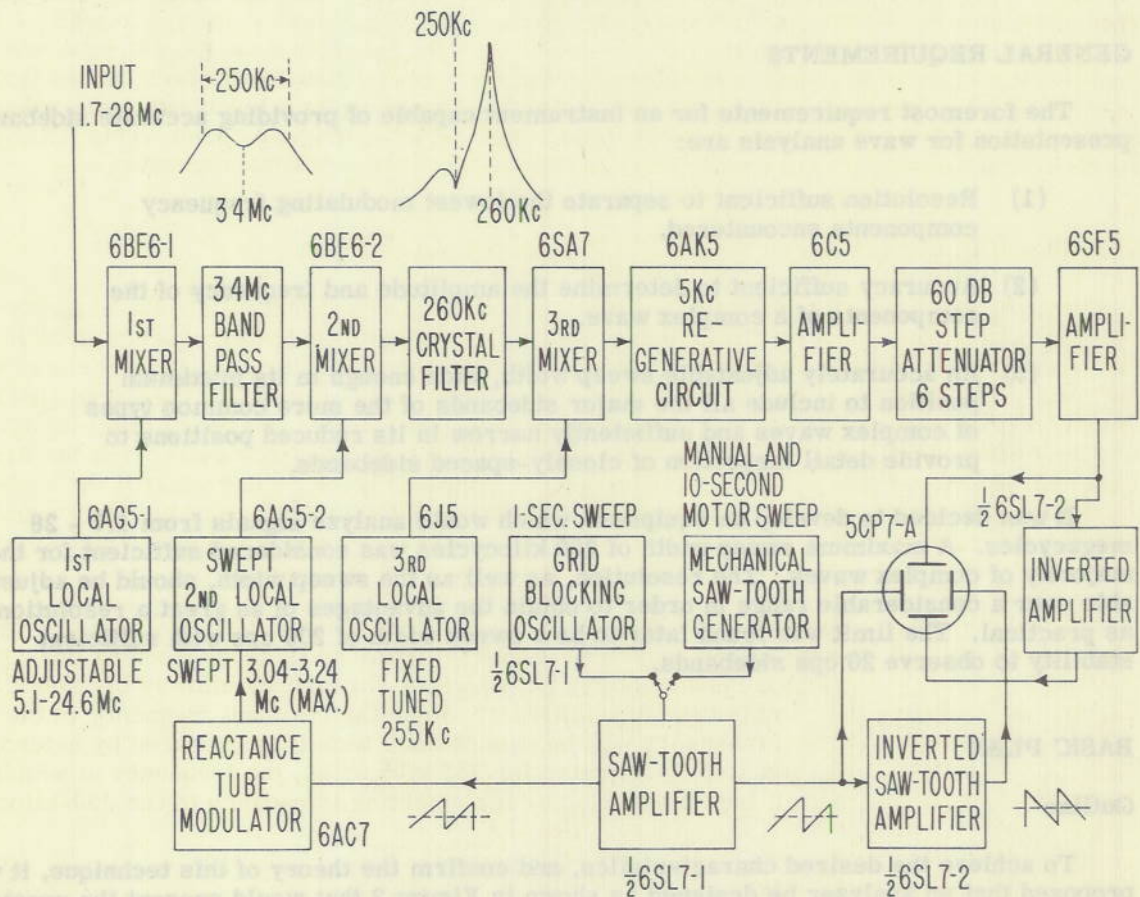


Figure 2 - Block diagram of the r-f analyzer

The 260-kc signal is heterodyned with a third stable oscillator set at 255 kc, producing a 5-kc beat note. There will be no image, since any 250-kc signal will have been highly attenuated by the crystal filter. The 5-kc beat note is amplified by a highly stable 5-kc regenerative circuit. The effective Q of this amplifier is adjustable to obtain the desired resolution. The signal passes through amplifiers and step attenuator to the vertical plates of the cathode-ray tube. Since the 5-kc beat note resulting from the various spectral components occurs in time sequence as determined by the instantaneous frequency of the frequency-modulated oscillator synchronized to the sweep on the horizontal CRT plates, a display of the spectral components of the signal may be observed.

First Local Oscillator, Mixer, and Intermediate Frequency Filter

The first intermediate frequency of 3.4 megacycles was chosen because an excellent linear 200-kilocycle sweep of the second local oscillator could be obtained. A lower first intermediate frequency would increase the problem of spurious responses, whereas a higher first intermediate frequency would increase the frequency stability problem of the first local oscillator. The desired input frequency range was achieved by the use of two first local oscillator ranges, 5.2 to 10.6 Mc and 11.4 to 24.6 Mc. Since there is no preselection, the signal may be placed either on the high side or low side of the local oscillator to obtain the 3.4 Mc intermediate frequency. This effectively produces four ranges of input frequency, 1.8 to 7.8 Mc, 8.6 to 14.6 Mc, 7.8 to 21.2 Mc, and 14.6 to 28 Mc. Use of the tuning dial, as explained under "Controls and Features," prevents ambiguity.

In order to prevent some spurious responses, the output of the first mixer passes through a 3.4-Mc filter which has sharp skirts and a pass band of 250 kilocycles whose amplitude response is flat within approximately 1.6 decibels over the 200 kilocycles used. This filter must be flat-topped to maintain correct relative amplitude of the spectral components.

Second Local Oscillator, Mixer, and Intermediate Frequency Filter

The 3.3- to 3.5-Mc signals from the band pass filter are introduced into the second mixer along with the swept oscillator energy. The second intermediate frequency is 260 kilocycles and is produced each time the swept oscillator is 260 kilocycles from the frequency of a spectral component. The second intermediate frequency is limited on the lower side by the necessity of providing sweeps up to 200 kilocycles. The center frequency of the swept local oscillator must be located more than half the full sweep frequency away from the first intermediate frequency in order to avoid image response. Figure 3 shows that if the center frequency of the swept oscillator, point x, is moved within 100 kilocycles of the 3.4 megacycle first i.f., its frequency will be equal to the first i.f. at the extreme right and two 100-kilocycle beats will result when remote sidebands are present on the input signal.

The output of the second mixer is passed through a crystal filter circuit which provides added selectivity and eliminates the undesired image. The image is suppressed by operating the third local oscillator at a frequency of 255 kc, which is a frequency midway between the resonant and antiresonant points of the crystal filter. Since the resonant frequency of the crystal is 260 kilocycles, this frequency will be passed each time it is produced by heterodyning. The crystal "rejection slot" is adjusted for 250 kilocycles, the frequency at which the crystal bridge is balanced, thus presenting a high rejecting impedance to the 250-kilocycle energy.

Third Local Oscillator and Mixer

In order to achieve great selectivity, the signal was reduced to a lower frequency of 5 kc. The 5-kc signal was obtained from a third mixer where the signal beats with the 255-kc third

local oscillator. No images will result in this circuit, since the preceding crystal filter reduced the image frequency, 260 kc, to a negligible amount.

Third Intermediate Frequency Filter

The final beat frequency of 5 kilocycles was chosen in order to achieve maximum selectivity compatible with other requirements. A consideration which limits the possibility of a very low final intermediate frequency is the picture composition. The lowest final beat frequency that may be used is determined by the fastest sweep period and the desired definition. A frequency is chosen which is just high enough so that its oscillations are indistinguishable when it is impressed on the vertical deflection plates when the voltage of lowest sweep period is on the horizontal plates.

The highest value of Q for the overall selectivity of the analyzer will be determined largely by the 5-kc circuit. The lowest modulation frequency sidebands to be separated will need a Q sufficient to reduce the sidebands to 40 db or more below the carrier when the latter is tuned for maximum response. Under these conditions the error of the presentation will be small for full scale deflection of the carrier. However, there are cases when the selectivity need not be so high. For example, sideband envelopes of loran transmitters or other similar transmitters where adjacent sideband components are of approximately the same amplitude may be presented. An unusual arrangement of a tuned and a regenerative cathode follower provides a "Q-multiplier" which is panel-controlled by a variable resistor.⁵ Stable Q 's as high as 3000 may be obtained in this 5-kc circuit. In order to use the potential definition of these high Q 's, an appropriate sweep rate must be chosen as previously discussed.

An attenuator with 6 10-db steps was placed after the 5-kc tuned circuit to provide a means for examining sidebands of low magnitude with respect to other signal components. The output of this attenuator goes to push-pull amplifiers which drive the scope's vertical deflection plates. By applying the unrectified 5-kc voltage directly to the CRT plates the possibility of distortion is reduced.

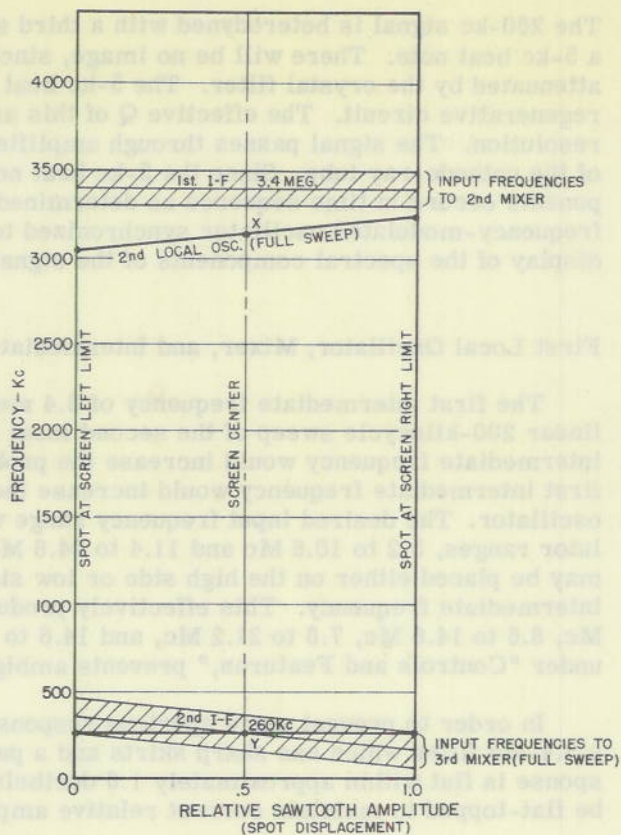


Figure 3 - Input and generated frequencies present in the analyzer - 2nd. mixer input to 2nd. i.f.

⁵ Harris, Holton E., "Development of Coils and Circuits for Highly Selective Amplifiers," Massachusetts Institute of Technology Thesis, February 1947

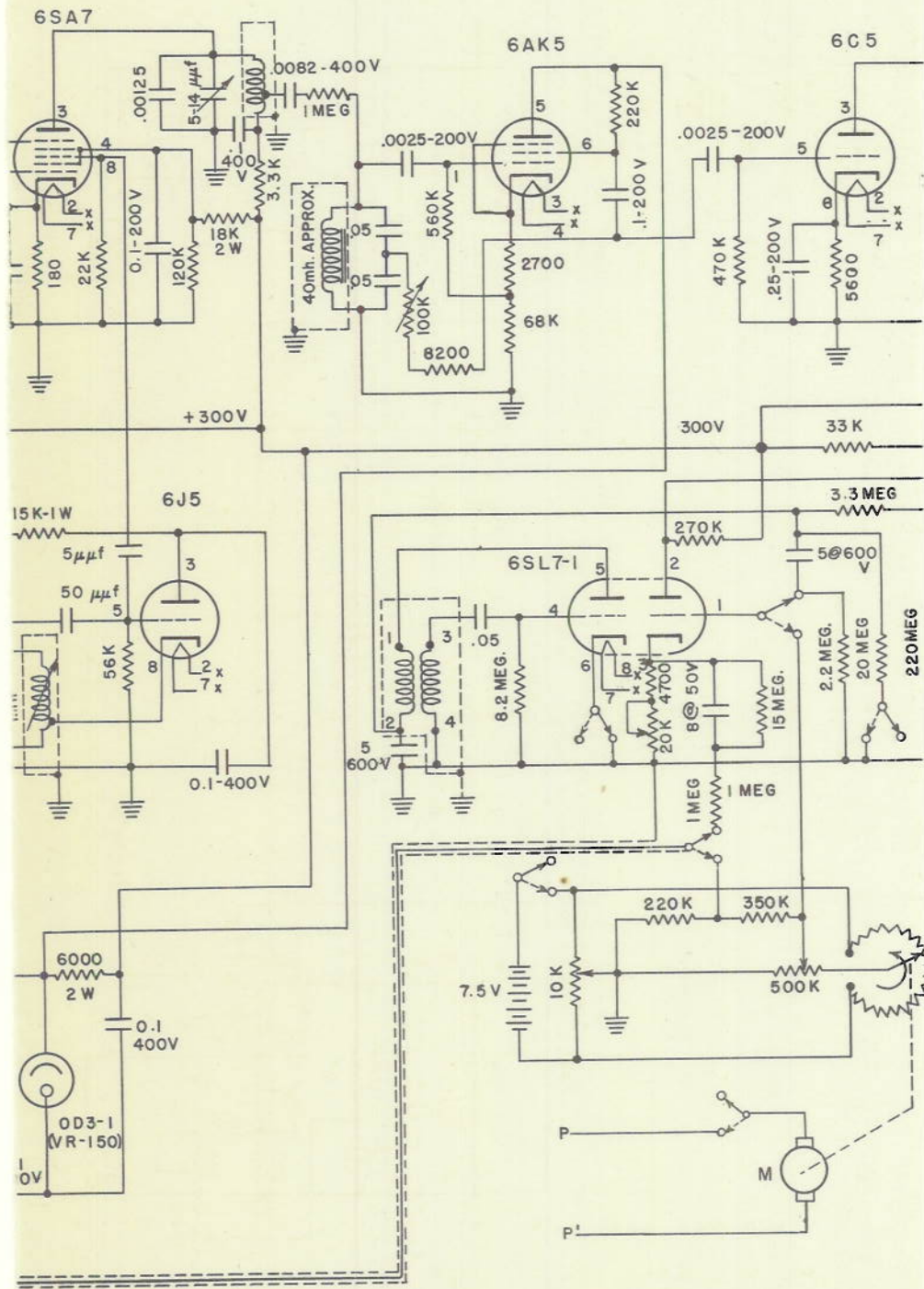
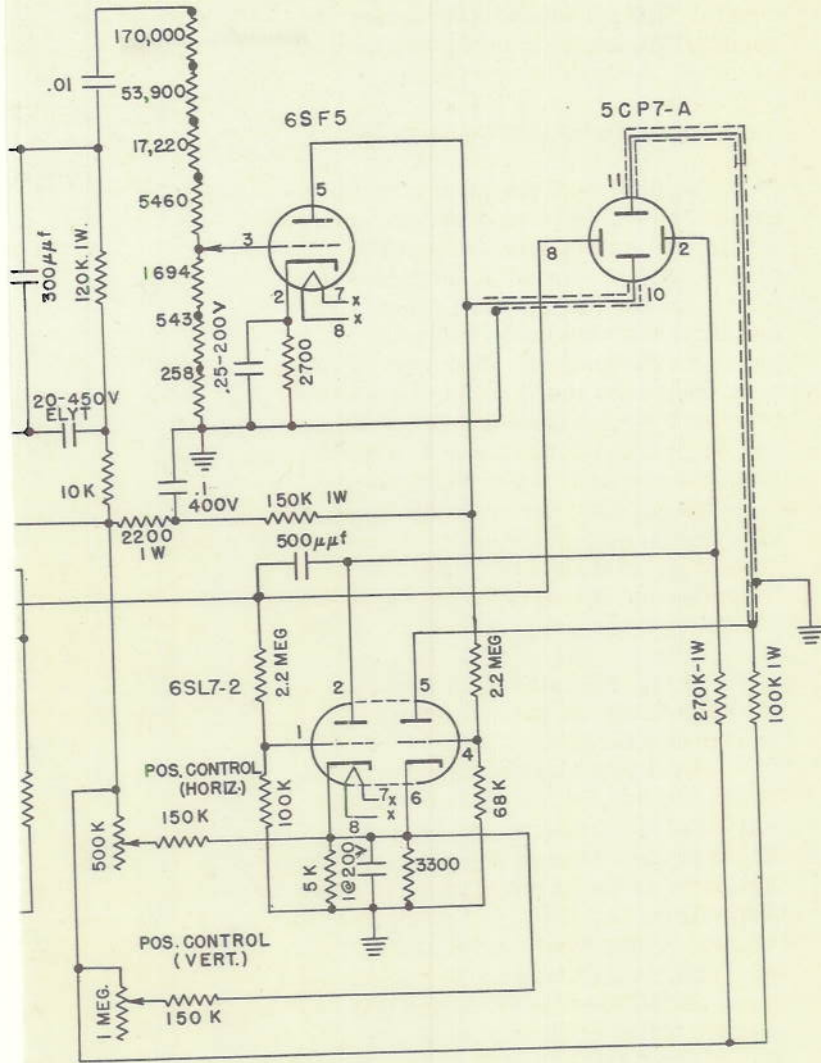


Figure 4(a) - R-f, audio and sweep circuits



POTENTIOMETER - 10K

ALL SWITCHES SHOWN AS BELOW IS ACHIEVED BY ASSET OF 2 GANGED WAFER SWITCHES (EACH 5 POLE - 2 POSITION - 6 POLES USED) SOLID LINES INDICATE POSITIONS FOR 1 SECOND SWEEP, DOTTED LINES ARE FOR THE 10-SECOND SWEEP AND MANUAL SWEEP

CAPACITORS ARE IN μf UNLESS OTHERWISE DESIGNATED



CIRCUIT DETAILS

A complete circuit of the experimental model is shown in Figures 4a and 4b. The cathode-ray tube employed is a Type 5CP7-A with a long-persistence screen. The cathode-ray tube face scale was made from 1/16-inch lucite sheet, dyed light amber to act as a filter. After engraving, the face scale was heated and pressed out to the normal contour of the cathode-ray tube face, thus reducing parallax.

The stability of the analyzer is dependent upon the stability of the local oscillators. If any one of the three local oscillators drifts appreciably, the picture will be displaced on the screen. This drift would be unnoticed for the larger sweeps, but when the sweep width is reduced, a small change of oscillator frequency shifts the picture. The 255-kc oscillator is very stable and introduces no difficulty. Since the first local oscillator is widely adjustable in frequency and operates at high frequency, it is subject to some instability. The second local oscillator, which is being swept, is fairly stable with small changes of supply voltage. However, since the frequency of the oscillator as influenced by the reactance tube circuit is a direct function of the transconductance of the reactance tube, close regulation of all supply voltages, including the filament, is a necessity for this tube.

The reactance tube circuit⁶ used to change the frequency of the Hartley Oscillator is shown in Figure 4a. The sawtooth voltage used for horizontal spot deflection on the cathode-ray tube is also applied to the grid of the 6AC7 reactance tube, thus varying its apparent inductive reactance linearly with time. Since this varying reactance appears in parallel with the oscillator tank circuit, the oscillator frequency varies with time. The linearity of frequency variation was found to be greatly affected by the constants of the phasing circuit. The 5- μmf capacitors were placed outside of the shield can when it was found that the distributed capacitance was comparable to their value. In order to insure good linearity the load impedance of the 6AC7 must be high. Therefore a high L-C ratio was chosen for the oscillator tank circuit, and the choke in the plate circuit of the 6AC7 was so selected as to be nearly resonant at the oscillator frequency. It was found that the frequency stability was greatly improved when a 5- μmf capacitor was connected between the grid and ground of the reactance tube.

In order to keep the center frequency of the sweep oscillator constant when the sweep width is varied, a 15-megohm resistor was placed across the coupling capacitor between the blocking grid sawtooth generator and sweep width control thus acting as part of a potential divider bias-correcting network for the reactance tube control grid.

A grid-blocking oscillator provides the one-second period sawtooth voltage. The motor and manual sweep voltages are provided by a potentiometer and a 7.5-volt C battery. These sweeps are quite linear. However, it should be noted that a nonlinear sawtooth voltage does not result necessarily in a nonlinear presentation on the scope. If the amplifiers and reactance tube are linear, the frequency change of the oscillator will be proportional to the displacement of the spot from the center of the scope. This means that the velocity of the spot on the screen will be the only variation with a nonlinear sawtooth. However, much variation of the horizontal spot velocity is undesirable since this will cause a trace of varying intensity. A high degree of accuracy requires a linear horizontal frequency base, which when properly adjusted appears similar to Figure 5. A signal amplitude-modulated at 20 kc and containing considerable f.m. is being fed to the analyzer with the sweep width at maximum (200 kc). There should be ten equal spaces between the pips due to the spectral components.

⁶ "Notes on Oscillators in Connection with Electronic Tuning for Panoramic Reception," Office of Scientific Research and Development, National Defense Research Committee, Division of Radio Coordination (15) Report 1138-1, March 8, 1944. Project RP-307. Panoramic Project L-60.

used as a fine adjustment for centering the signal after it has been tuned in to the center position. The full range of variation is approximately 30 kilocycles and it is particularly useful for narrow sweeps. Ordinarily this control should be set at its center position.

Sweep Time -

Two automatic sweep rates are provided: an electronic sweep of approximately 1 second* and a mechanical sweep of approximately 10 seconds.* The electronic sweep is obtained from a grid-blocking oscillator, and its linearity is improved somewhat by passing the sawtooth voltage through an amplifier operating on a curved portion of its i_p - e_g characteristic. The mechanical sweep is obtained by the use of a Telechron clock motor driving a modified 10,000-ohm wire-wound potentiometer. A manual drive is also provided for the potentiometer whereby the sweep time may be increased.

Q-Control -

A panel adjustment of the amount of regeneration introduced varies the effective Q. An optimum adjustment exists for each combination of sweep width and sweep time; for a given width and rate, the Q should be increased until "ringing" occurs and then reduced somewhat. Simplification of operation may be achieved by properly ganging the controls of sweep width and Q and providing the necessary circuitry for the sweep time. Such an arrangement would, however, become rather elaborate for this analyzer, with its wide range of sweep rates.

Effective Resolution -

The resolution depends upon the sweep width, the sweep time and Q setting. Consult curves, Figure 10. Effective resolution of 20 cps and lower is possible with optimum adjustment of these parameters. The effective resolution for a given sweep rate was determined by increasing the effective Q and narrowing the sweep until at least 3 db resolution was obtained for adjacent sidebands of equal amplitude, and then broadening the sweep until fluctuations of amplitude of the order of 2 decibels result from overlapping of the sideband energies.

Input Level -

The input level depends upon sweep width, Q control, and to a minor extent the sweep rate. The input required for 200 kilocycles sweep, minimum Q, and sweep time of one second is about 9 millivolts for full presentation. For 200 kilocycles sweep, maximum permissible Q, and sweep time of 10 seconds, the necessary input is about 900 microvolts. It must be observed that the analyzer response is not linear for inputs greater than 0.2 volt. If the picture is kept within the vertical limits of the screen, such undesirable operation is impossible provided the

* These rates are based upon the traveling time of the spot from left to right over the exposed portion of the screen.

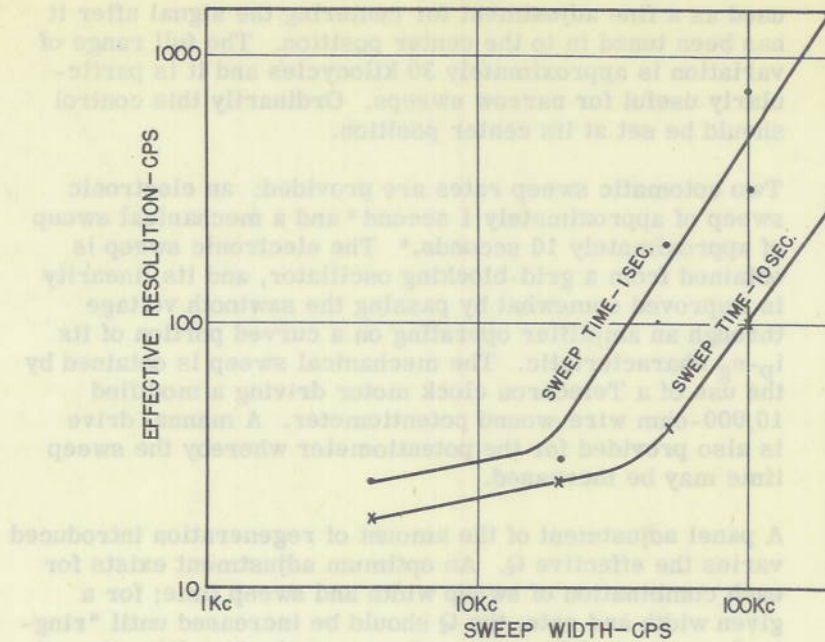


Figure 10 - Effective resolution attained by optimum adjustment of effective Q for two sweep rates and various sweep widths

attenuator is set at not more than 30 decibels attenuation with Q at minimum and sweep at maximum. A complex wave of the loran type requires special consideration in this regard.

Attenuator - Sixty decibels of attenuation are provided in six 10-db steps. The attenuator is located between the 5-kilocycle amplifying stages for simplicity and dependability. Care must be taken to avoid overloading the r-f stages. Operation on the 20- or 30-decibel steps will usually guarantee sufficiently low input voltage. The higher steps may be used for obtaining measurements of relative amplitude with the more sensitive conditions, i.e., higher Q and reduced sweep widths.

Cathode-Ray Tube Controls - Panel controls are provided for centering the vertical and horizontal sweeps of the CRT as well as focus and intensity. A control for regulating the amount of illumination of the face scale of the CRT is also provided.

DISCRETE FREQUENCIES SWEEP

For a mechanical sawtooth generator, it would be considered ideal to have a perfectly smooth, linear variation of voltage with time as shown in Figure 11(a). Numerous steps occur during one sawtooth cycle when a wire-wound potentiometer is used. In the R-F Wave Analyzer, the mechanically generated sawtooth voltage is formed by uniform unidirectional rotation of a large wire-wound potentiometer with a "spring-board" arrangement at the gap to provide very rapid fly-back. The wire-wound type was chosen because of its durability.

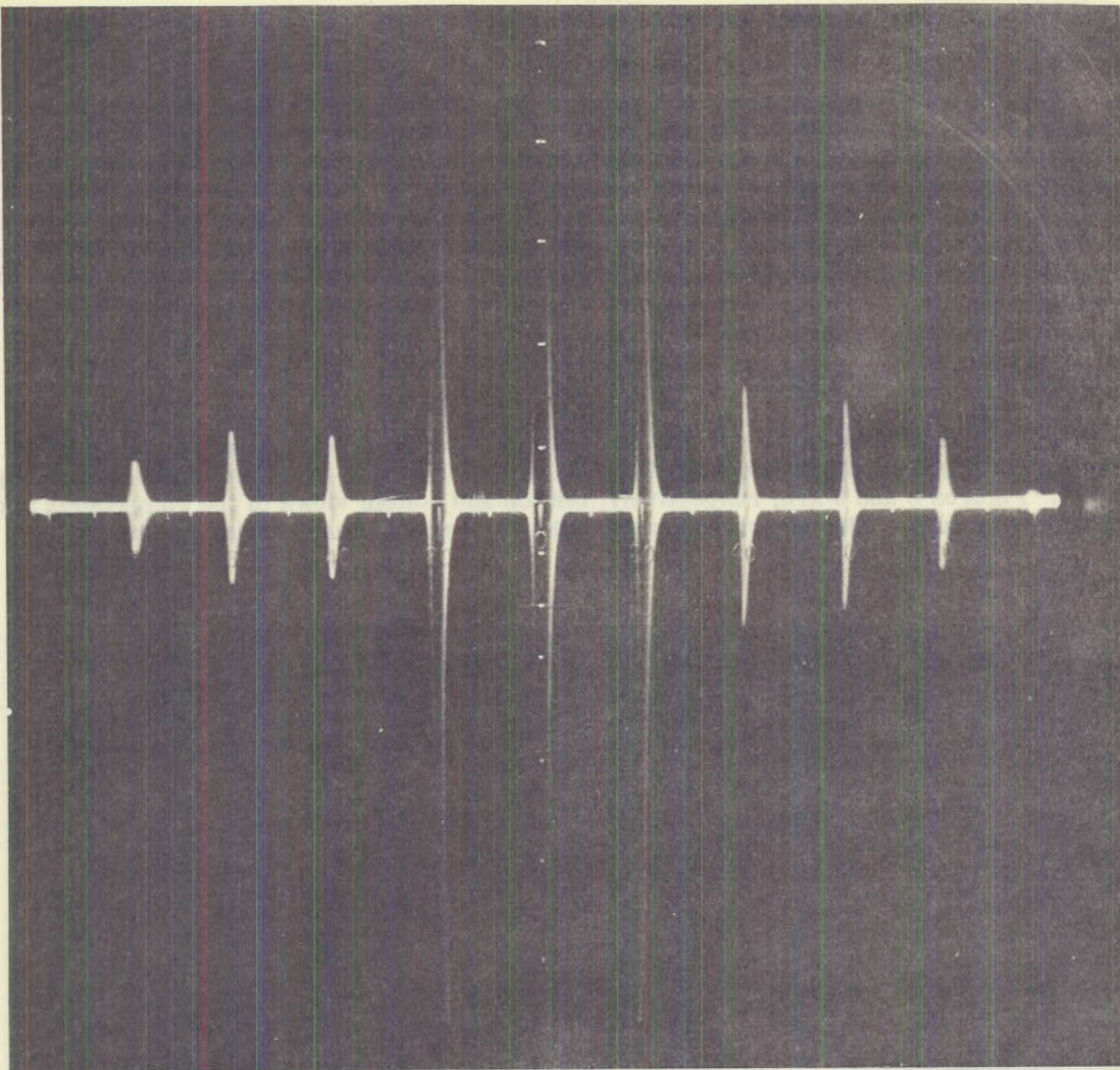


Figure 5 - A 20-kc amplitude modulated signal containing considerable f.m. is applied to the analyzer with full sweep width to illustrate linearity

A six-pole 2-position switch is necessary to accomplish all the desired switching when the sweeping is changed from electronic to mechanical. During the electronic sweep, the sawtooth voltage generated by the grid-blocking oscillator is coupled through large capacitors to the sawtooth amplifiers via the rotary switch. In this switch position, the motor is cut off and the load is removed from the 7.5-volt battery. For the 10-second sweep time, the switch (1) opens the cathode circuit of the grid-blocking oscillator (thus avoiding disturbances from this source), (2) connects the 7.5-volt battery to the driven potentiometer, (3 and 4) changes the inputs to the sawtooth amplifiers and reactance tube grids, (5) turns on the motor (subject to another switch in series which is operated from the hand crank), and (6) connects a voltage dividing arrangement across C_1 . This helps C_1 to maintain its charge,

thus reducing the stabilizing period when the switch is returned to the 1-second sweep position.

The 300-volt B supply shown in Figure 4b consists of a full-wave rectifier with a double π filter. Regulation is provided by two VR-150 voltage-regulating tubes connected in series and a constant-voltage line transformer. The total current drain is approximately 70 milliamperes with ripple reduced to about 0.01 percent. All filaments except those of the 6AC7 and the 6AG5 swept oscillator are powered by a 6-volt transformer. Since the tubes in the swept oscillator circuits are very susceptible to hum, they are provided with a 6-volt d-c filament supply. This power is obtained from a full-wave bridge-type selenium rectifier circuit.

FEATURES AND CONTROLS

A front panel view of the experimental model of the R-F Wave Analyzer is shown in Figure 6. The Dumont Oscillograph Record Camera Type 271-A is shown attached in Figure 7. Figures 8 and 9 are, respectively, the top and bottom views of the components and circuitry layouts. The general characteristics of the instrument are as follows.

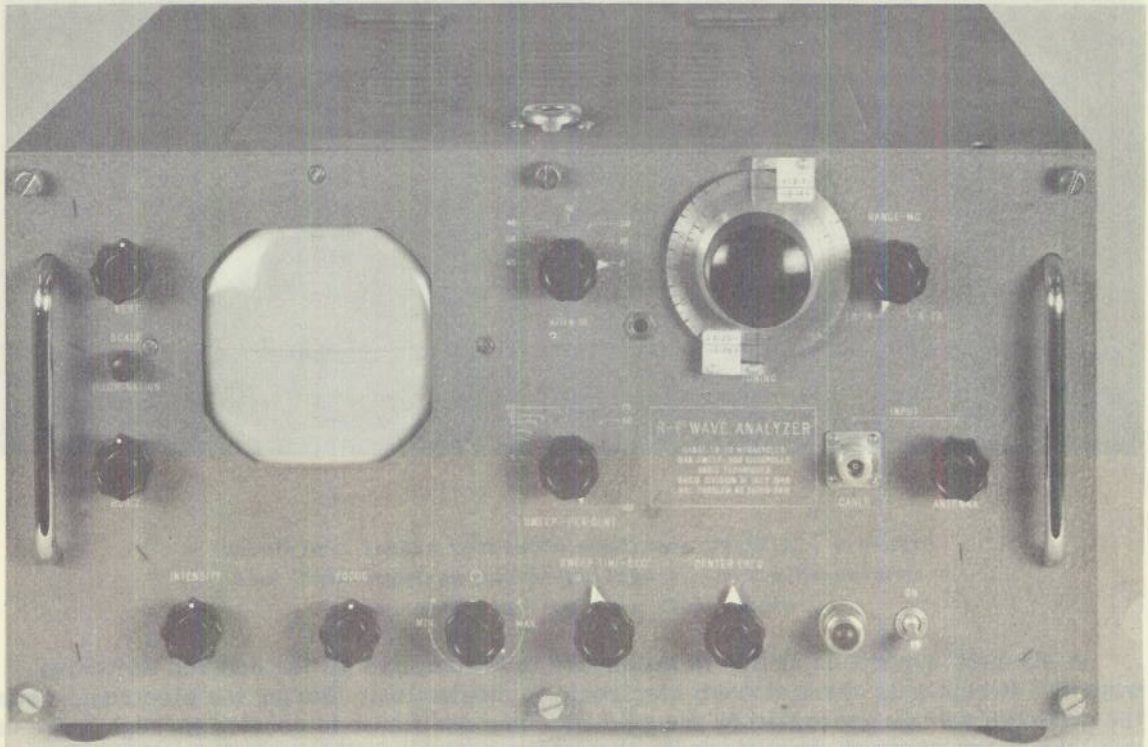


Figure 6 - Panel view of r-f wave analyzer

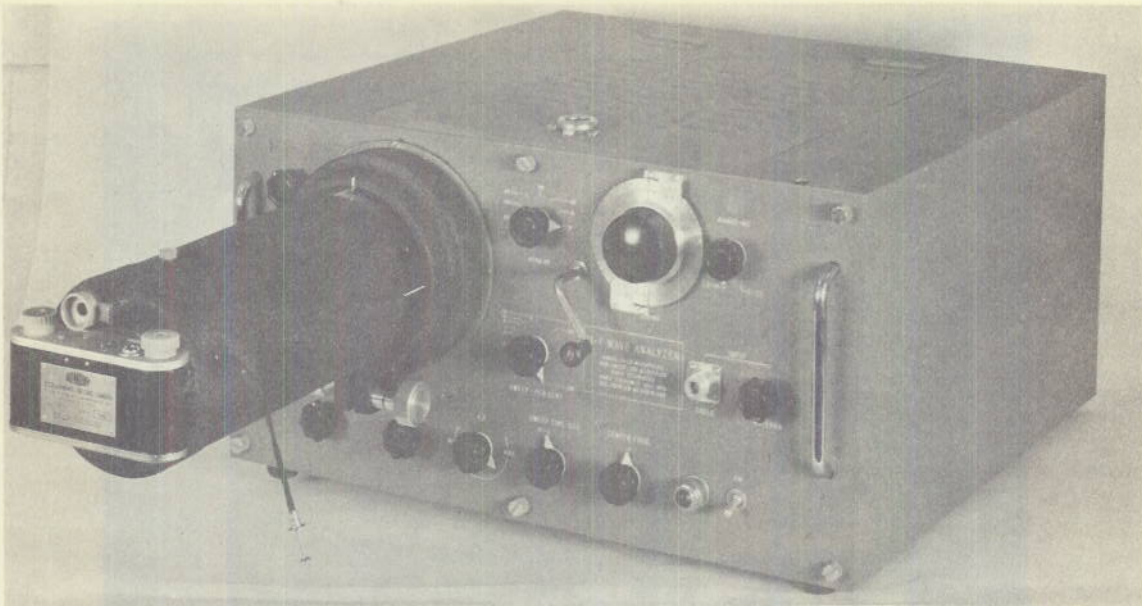


Figure 7 - The r-f wave analyzer with the Dumont oscillograph record camera attached. Crank is inserted for manual sweep

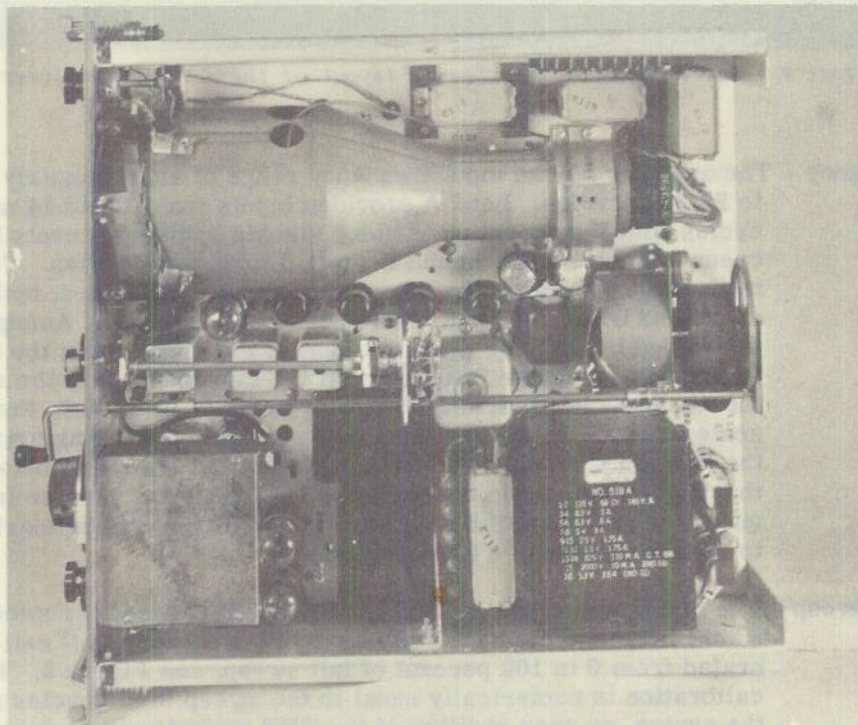


Figure 8 - Top view of chassis layout of the r-f wave analyzer

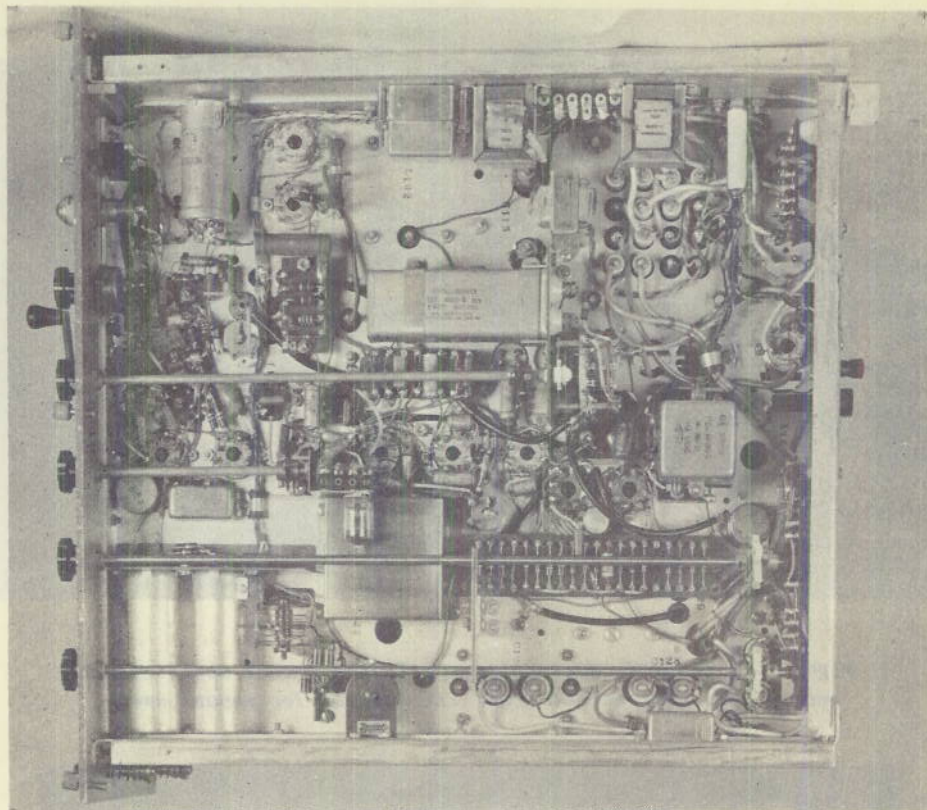
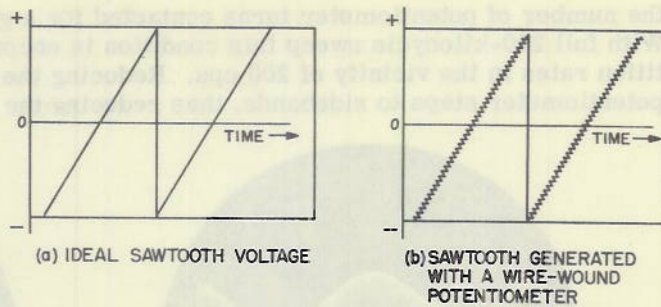


Figure 9 - Bottom view of the chassis layout of the r-f wave analyzer

Input Frequency - The analyzer has an input frequency range of approximately 1.8 to 28 megacycles. Band A provides inputs from 1.8 to 14 megacycles with the exception of some signals with components between 3.3 and 3.5 Mc ; band B from 8 to 28 megacycles. This wide range is attained by introducing input frequencies, both above and below the first local oscillator frequency. Ambiguity is avoided by noticing the movement of the signal when the dial is moved to a higher frequency. If the movement is to the right, the - + scale is used, and if the movement is to the left, the + - scale is read. In the latter case, the signals appearing toward the left are the highest frequency signals. It should be noted that the instrument is not expected to identify the carrier frequency of the wave; the frequency dial is to be used primarily to assure display of a known carrier.

Frequency Sweep - The maximum sweep is 200 kilocycles. The sweep (or sweep width) is adjustable by a panel control (sweep-percent) calibrated from 0 to 100 percent of full sweep, see Figure 6. The calibration is numerically equal to the sweep in kilocycles from the center, or zero position of the CRT scale to either extreme since this portion of the screen represents 100 kilocycles at 100 percent or full sweep. A control called center frequency is

Figure 11 - Ideal and actual sawtooth voltages mechanically generated



The windings of this potentiometer are uniform in resistance and spacing but, being finite in number, produce a voltage variation such as shown in Figure 11(b). Actually there are many more steps for each sawtooth cycle than shown in the figure since the potentiometer has approximately 1000 turns of wire.

Taking an r-f signal pulsed at the rate of 20 cps as a practical example, there are sidebands spaced every 20 cps in the spectrum. If full sweep of 200 kilocycles is employed, there are 10,000 sidebands in this sweep range. Since this 200-kilocycle range is being swept during one complete rotation of the potentiometer, the amplitude of the sawtooth and sidebands may be plotted versus time and frequency on expanded scales as shown in Figure 12. It is assumed that the time elapsed between turns is less than 20% of the time during which the turn is contacted. In this case there will be 10 sidebands swept through for each voltage step produced by the potentiometer windings. At first inspection, the arrangement would appear to give serious "ringing" due to the extreme slope from A to B. No doubt "ringing" does occur during this time and distorts the amplitude of two or three sidebands; however, the time is relatively short between A and B and these distorted sidebands probably have insufficient intensity to appear on the screen.

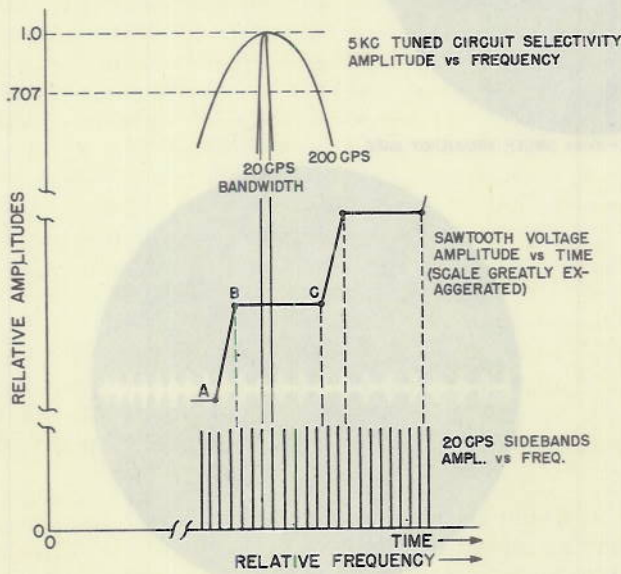


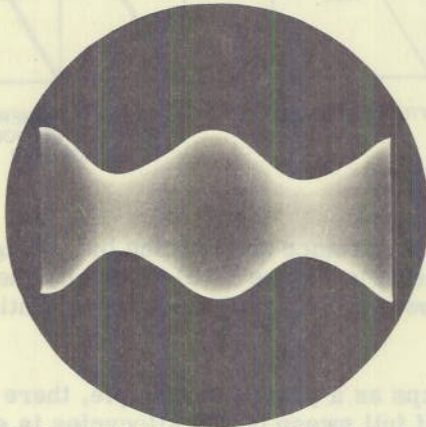
Figure 12 - Illustrating the effect of irregularities in the sawtooth sweep caused by potentiometer windings

From B to C it may be seen that the sweep frequency is constant for a relatively long period of time, i.e., df/dt equals zero. If during this period from B to C, with 20 cps selectivity, the swept oscillator does not exactly tune in one of the eight sidebands as shown, the amplitude will be modified accordingly. The irregularity of the presentation of Figures 16 and 17 may be due to this effect. If the passband is increased to, say, 200 cycles as shown in Figure 12, several of the sidebands will be included and a more uniform response will result, as in Figures 14 and 15.

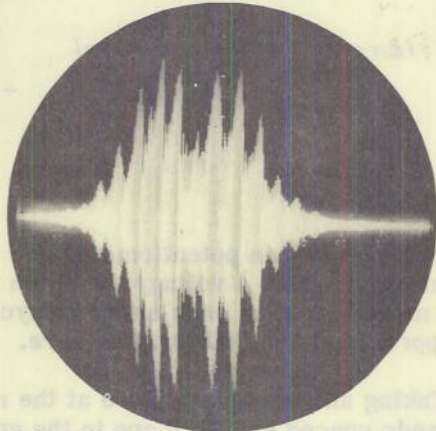
Going to the other extreme of sideband spacing, when high modulating frequencies or pulse rates are used on the input signal, there will be several potentiometer turns contacted for each sideband appearing and peak tuning is assured.

It is evident that discrete frequency sweeping introduces difficulties only when the number of sidebands swept approaches

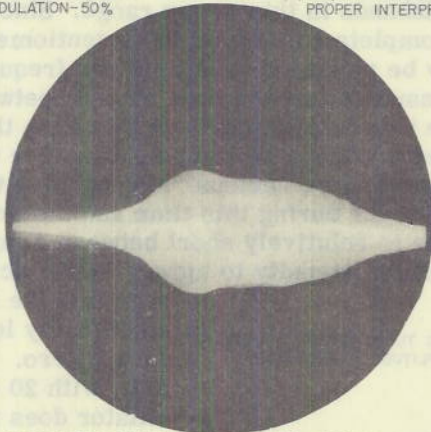
the number of potentiometer turns contacted for a given increment of horizontal spot travel. With full 200-kilocycle sweep this condition is encountered in practice only with pulse repetition rates in the vicinity of 200 cps. Reducing the sweep width will increase the ratio of potentiometer steps to sidebands, thus reducing the distortion from this source.



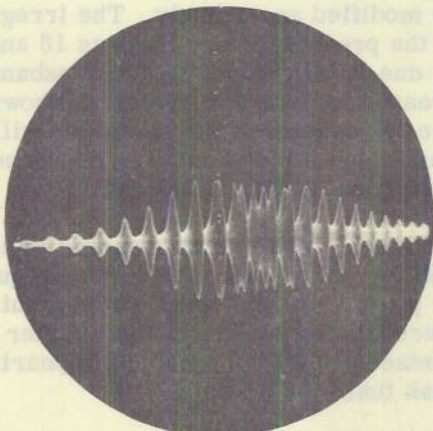
(a) MODULATION ENVELOPE. CONVENTIONAL OSCILLOSCOPE, TIME BASE 13cps. 20cps MODULATION-50%



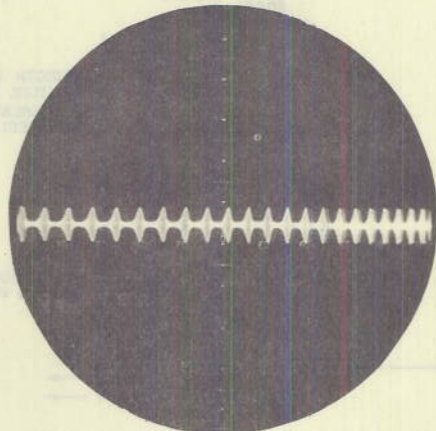
(b) 20cps SIDEBANDS—10sec SWEEP, FREQUENCY BASE, PROPER INTERPRETATION



(c) SIDEBAND ENVELOPE—10sec. SWEEP, FREQUENCY BASE



(d) DISTORTED SIDEBAND ENVELOPE—1sec. SWEEP, FREQUENCY BASE.



(e) DISTORTED MODULATION ENVELOPE—ZERO FREQUENCY SWEEP, TIME BASE 1cps.

Figure 13 - Proper and improper analysis of an r-f wave having very low modulation frequency or pulse repetition rate

SPECIAL CONSIDERATIONS FOR COMPLEX WAVES WITH MODULATING COMPONENTS BELOW 200 CPS

When modulating frequencies below 200 cps are present in the complex wave being presented, there is a possibility of erroneous interpretation. The well-known oscilloscopic method of measuring modulation percentage is indicated in Figure 13(a), in which a 3.4-megacycle carrier is shown which is 50% amplitude modulated with a modulating frequency of 20 cps. Figure 13(b) made with the R-F Wave Analyzer, shows the 20-cycle sidebands using the 10-second sweep rate and a high Q setting. It is interesting to note how Figure 13(a) fails to show any distinction between a wave properly amplitude-modulated and one which, as shown in Figure 13(b), has considerable frequency modulation. Figure 13(c) was made under the same conditions as Figure 13(b), but with a reduced Q setting so that the sidebands were not resolved, while in Figure 13(d) conditions were the same as for Figure 13(c) but with the fast sweep rate. Now, it is possible to mistake the undulated contour for true sidebands since the picture may repeat identically with each sweep; however, if the sweep width is reduced to zero, the picture shown in Figure 13(e) will result. The presentation is actually of the same nature as that shown in Figure 13(a), i.e., it shows a distorted modulation envelope of the carrier with the horizontal axis now acting only as a time base. The carrier in this case has been reduced by triple heterodyning to 5 kilocycles but the modulating frequency is still 20 cps. (Note: there are more cycles appearing in Figure 13(e) than in Figure 13(a) since the sweep time is much longer.) The envelope as shown in Figure 13(e) has been distorted by passage through the high-Q 5-kilocycle tuned circuits. The picture obtained under the conditions of Figure 13(e) depends upon the part of the spectrum of Figure 13(d) that is tuned in when the sweep is reduced to zero. For the example given, the analyzer is tuned slightly to the high frequency side of exact center frequency, thus accounting for the large variations of amplitude. For an adjustment exactly on center frequency, and with a Q sufficiently high to reduce the sideband amplitudes, the envelope may be made almost constant in height with zero sweep width.

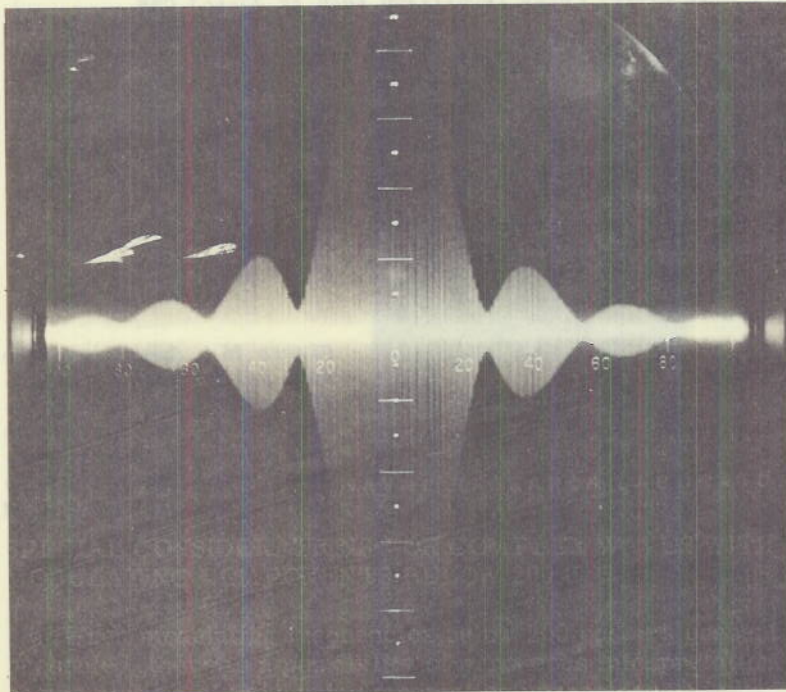


Figure 14 - Spectrum of the type TDP-1 loran transmitter operating at 1.85 megacycles. Pulse repetition rate is 20 cps. The approximate selectivity used is 200 cps. Full sweep used - base reads directly in kilocycles. High frequencies are at the left of the picture

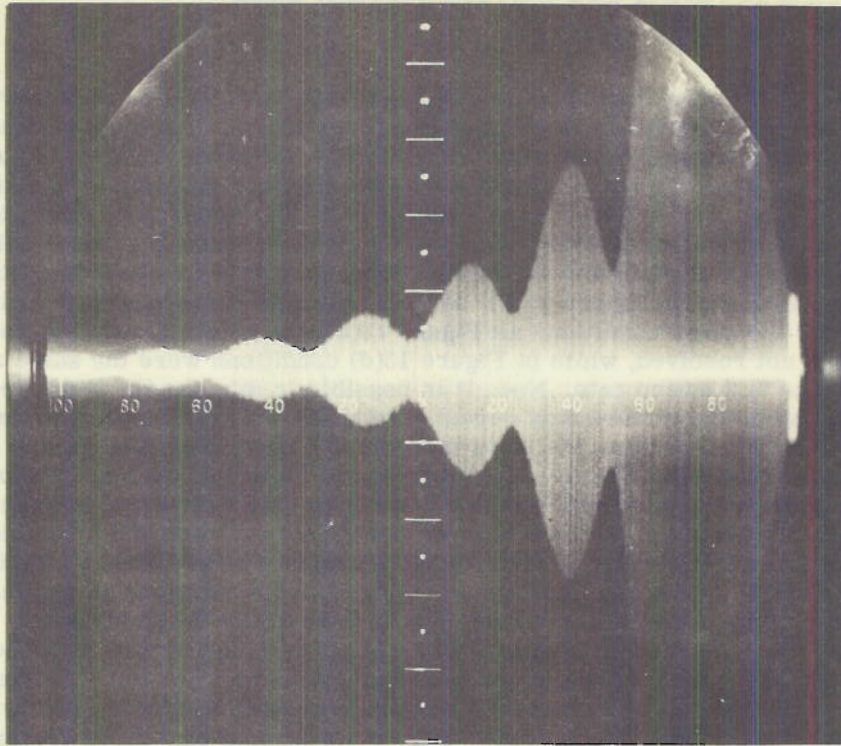


Figure 15 - Detail view of the high frequency sidebands of the type TDP-1 loran transmitter. Center frequency amplitude is 9 decibels above full scale. Pulse repetition rate is $33\frac{1}{3}$ cps

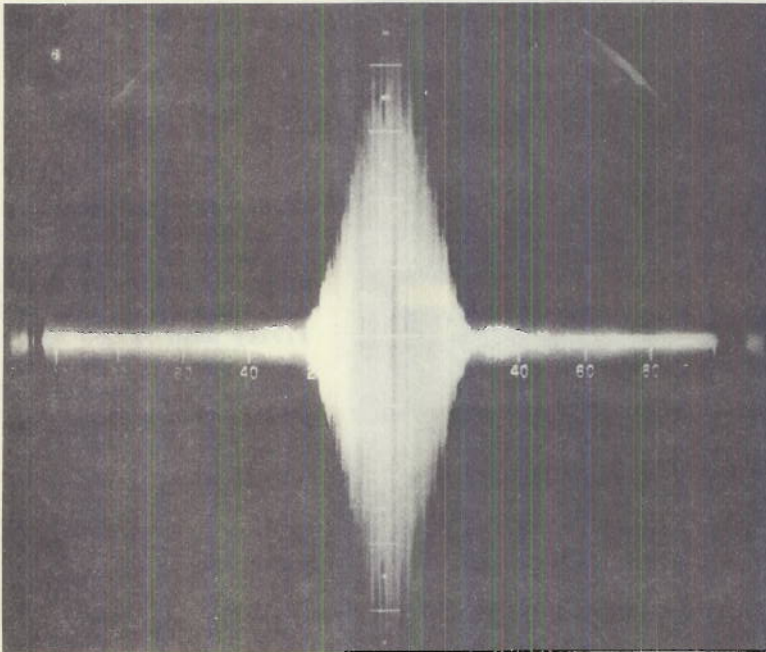


Figure 16 - Spectrum of the type T-137 loran transmitter operating at 1.95 megacycles. Pulse repetition rate is 20 cps. The approximate selectivity used is 20 cps. Full sweep used

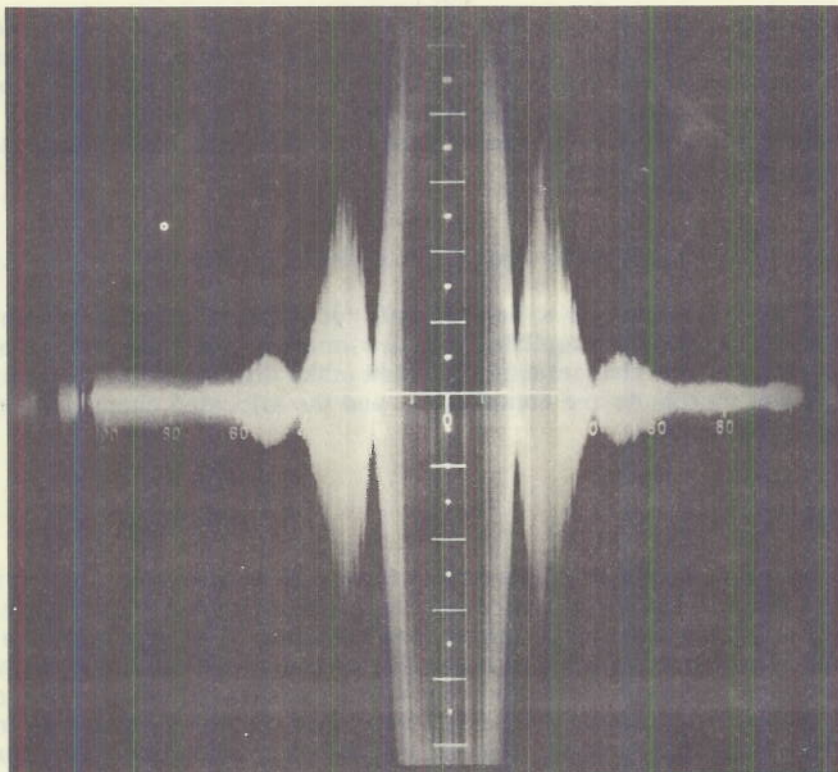


Figure 17 - Expanded amplitudes of the T-137 loran transmitter sidebands. Center frequency amplitude is 20 decibels above full scale

SPECTRUM ECONOMY - THE LORAN SPECTRUM

The spectra produced by two types of loran transmitters are shown in Figures 14 through 17 and are excellent examples of the value of the R-F Wave Analyzer as an aid in spectrum conservation. Figures 14 and 15 show the spectrum of a typical World War II loran transmitter, Model TDP-1. It may be noted that the amplitude of the sidebands approximately ± 70 kc from the center frequency is reduced only about 30 decibels below the center frequency level and in Figure 15 the amplitude of the sidebands is still within approximately 35 decibels of the center frequency amplitude 150 kilocycles from the carrier. The superiority of the T-137 loran transmitter in regard to spectrum width is readily seen in Figures 16 and 17. The amplitude of the T-137 sidebands is reduced by approximately 50 db at ± 75 kilocycles from center frequency and is even lower beyond these points. (Note: both transmitters are somewhat better than indicated here, since there is some distortion produced with the expanded views.) During development work on loran equipment⁷ and other transmitters the analyzer may be employed to display instantly the effects of changes made in circuit parameters, filters, etc. Optimum characteristics may thus be incorporated with a minimum of time expended.

⁷ Instruction Book for Navy Model TEH Loran Transmitting Equipment NAVSHIPS 91116 Contract NXsr-90770 Navy Dept. BuShips

After development of a transmitter, the analyzer may be employed to monitor the equipment, thus assuring proper operation and spectrum occupancy. Used in conjunction with accurate standard frequency signals (which could easily be introduced on the same screen), the analyzer would furnish complete information on the transmitter at hand. Such an arrangement would permit safe operation of transmitters located much closer together in the spectrum than is now possible.

PROPOSED MODIFICATIONS AND SIMPLIFICATIONS FOR A LORAN ANALYZER

If the R-F Wave Analyzer is to be used only for loran monitoring and development purposes, several significant simplifications and improvements may be made. The spectrum of the loran bands has two characteristics which make this possible: the amplitudes of immediately adjacent sidebands are comparable, and the allocated channels cover relatively narrow bands of frequencies.

Input Circuits

Since the loran transmitter bands extend from 1.80 to 2.00 megacycles, and 65 to 240 kilocycles, the front end of the analyzer may be modified as shown in Figure 18. However, the range of the analyzer was made larger than required. The inputs for the 1.80- to 2.00-Mc range would pass directly into the mixer fed by the swept oscillator, with the center frequency of the swept oscillator variable from 2.10 to 2.30 megacycles. This center frequency control would function by changing the 6AC7 reactance tube bias voltage as in the R-F Wave Analyzer center frequency control, but with a wider range of adjustment. Good frequency-sweep linearity should easily be obtained over this range of center frequencies for sweeps up to ± 100 kilocycles.⁸ A ganged variable resistance in series with the sweep control potentiometer would probably be necessary in order to assure the same maximum sweep for all settings of the center frequency control. The calibration for input center frequency would be engraved on the panel opposite this control. A very stable fixed-frequency local oscillator set at 1.76 megacycles would be provided to build up the low frequency inputs to the 1.80- to 2.00-Mc input range together with a bandpass filter to avoid spurious responses.

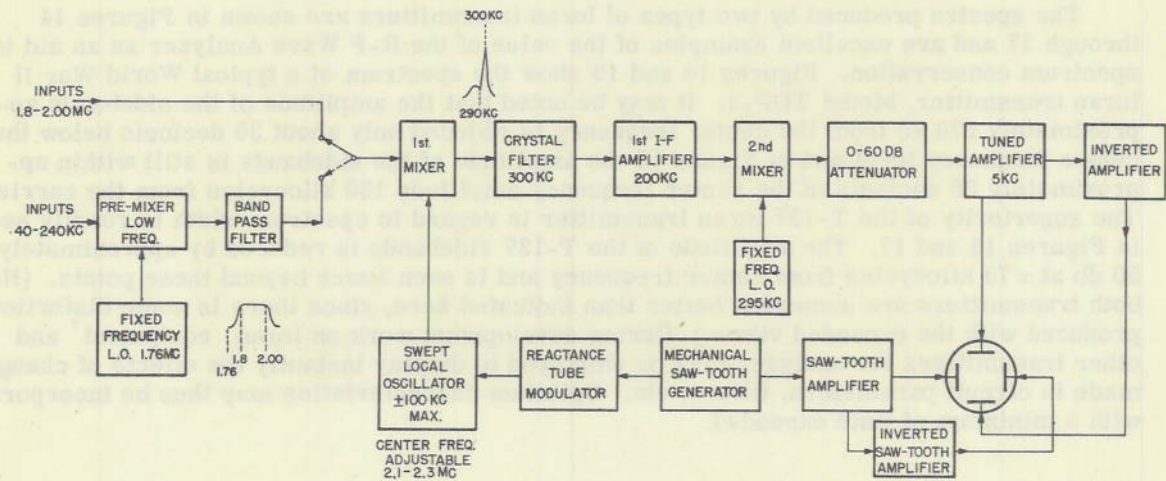


Figure 18 - Block diagram of the proposed loran analyzer

⁸ OSRD Report 1138-1, *op. cit.*

Crystal Filter and I-F Amplifier

The i-f frequency should be high enough to avoid images but sufficiently low to permit a low second oscillator frequency. About 300 kilocycles would appear to be a good compromise. An i-f amplifier should be introduced to provide an additional 20 decibels or so gain for observing sidebands of low amplitude with the relatively low maximum permissible input voltages.

5-Kilocycle Amplifier

It is considered unnecessary to provide the regenerative type of selective circuit used in the general-purpose R-F Wave Analyzer. Single tuned circuits, each with a Q of about 40, in the plate circuits of the second mixer and the first stage of the 5-kilocycle amplifier should provide sufficient selectivity for accurate sideband envelope presentation. It may be seen that the envelope shown in Figure 19 made with about 20-cycle resolution (defined as visible separation of the half-power points of 20-cycle adjacent sidebands of equal amplitude) is equivalent to the spectrum shown in Figure 15 which was made with 200-cycle resolution. Furthermore, both presentations compare favorably with a point-by-point plot made of the same spectrum. Individual sideband resolution for loran presentation is considered unnecessary since adjacent sidebands are so nearly equal in amplitude.

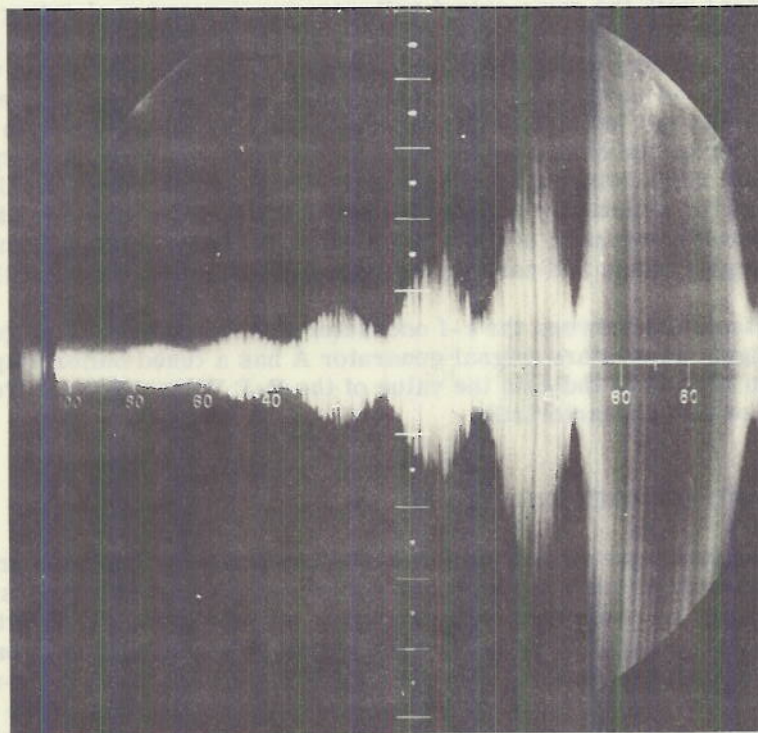


Figure 19 - Picture made with the same signal shown in Figure 15 but with an approximate circuit selectivity of 20 cps. Center frequency amplitude is about 13 decibels above full scale

Sawtooth Generator

Since any sweep time less than 5 seconds is considered too rapid for useful display of loran spectra, it is proposed that the electronic sawtooth generator be eliminated in the Loran Analyzer. Whereas the 10-second sweep may be adequate, it would be desirable to have two automatic sweeps, a 5-second sweep for direct viewing and a slower sweep for photographs, in addition to the manual sweep. The control for the automatic sweeps could be in the form of gear switching or motor speed control. A compromise could be made consisting of a 5-second motor sweep and the manual sweep for use with photographs.

MODULATION CHARACTERISTICS OF SIGNAL GENERATORS

It has been observed by use of the R-F Wave Analyzer that signals from amplitude signal generators are usually not purely amplitude-modulated and may carry spurious modulation frequencies such as the 60-cps power frequency, plus components of frequency modulation. The degree of improper modulation is in general greatest for high carrier frequencies, high percentage modulation, and low modulating frequencies. It is believed that the improper modulation is a combination of a.m. and f.m. which is evidenced by nonsymmetrical distribution about the carrier and the introduction of new sidebands.^{9,10}

Figures 20(a) through 20(e) show the sine wave modulation characteristics of several different generators with the same output voltages, carrier and modulating frequencies, and percent modulation (the percent modulation was reduced for two of the generators in order to keep their spectra within the screen limits). Signal generator A, when properly aligned, was found to be essentially free of frequency modulation within the frequency range of the analyzer and for modulation frequencies as low as 60 cps with 30% modulation. Other generators observed have appreciable f.m. present even with 1000-cps modulation of 50% and become much worse as the modulating frequency is reduced. Under certain conditions the carrier is actually reduced to zero amplitude and only the sidebands are present. Considerable variation of modulation characteristics may be found with a single generator by changing bands and carrier frequency, as shown by Figures 21(a) and 21(b).

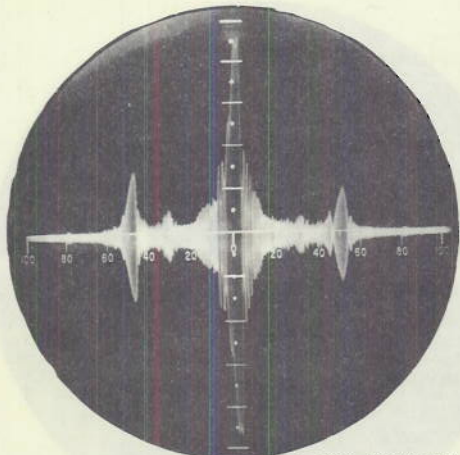
Insufficient isolation between the r-f oscillator and the modulated stage apparently exists in most signal generators (signal generator A has a tuned buffer amplifier). However, the only intention here is to indicate the value of the R-F Wave Analyzer Technique for the rapid evaluation of this characteristic.

CONCLUSIONS AND RECOMMENDATIONS

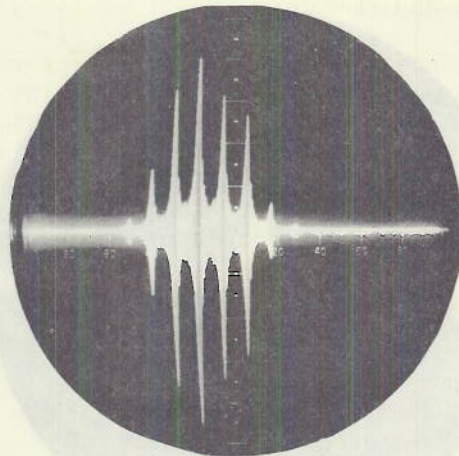
The analyzing technique employing the R-F Wave Analyzer has been proved practical for use with loran transmitters and amplitude-modulated signal generators. Its success in this work suggests its usefulness in the analysis of any signal source within its present or extended frequency range. In order to secure complete analysis of a complex r-f wave, it is necessary to provide means for separation and measurement of the a-m, f-m, and p-m components of such a wave. Whereas such an instrument might prove invaluable in certain applications, it is evident that the R-F Wave Analyzer described, which is capable of giving quantitative analyses with essentially pure amplitude modulation or pulsed r.f.,

⁹ Roder, Hans, "Superposition of Two Modulated Radio Frequencies," *Proc. I.R.E.*, Vol. 20, p. 1962-70, Dec. 1932

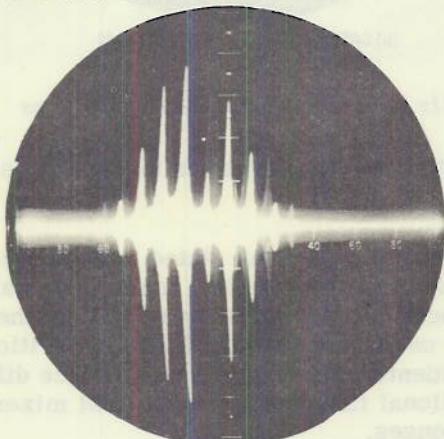
¹⁰ Roder, Hans, "Amplitude, Phase, and Frequency Modulation," *Proc. I.R.E.*, Vol. 19, p. 2145-76, Dec. 1931



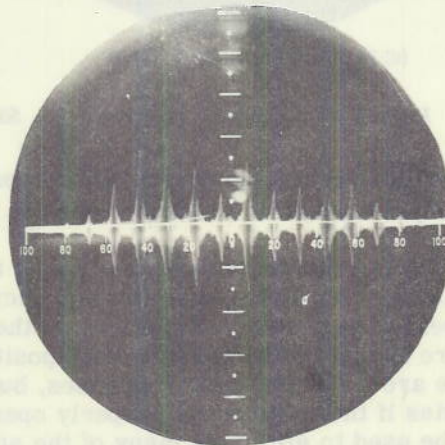
(a) SIGNAL GENERATOR A—30% AMPLITUDE-MODULATED AT 100cps. THE CARRIER FREQUENCY IS 3.4 Mc. NOTE THE SPURIOUS 60cps SIDEBANDS



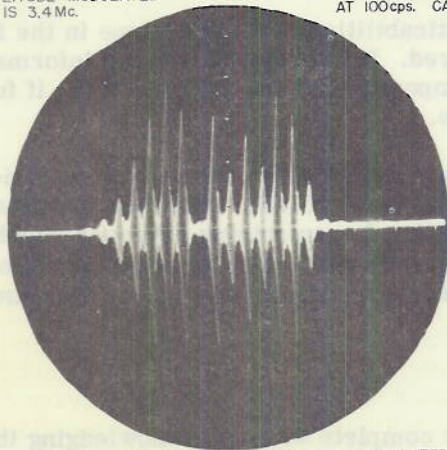
(b) SIGNAL GENERATOR B—50% AMPLITUDE-MODULATED AT 100cps. CARRIER FREQUENCY IS 3.4 Mc.



(c) SIGNAL GENERATOR C—50% AMPLITUDE-MODULATED AT 100cps. CARRIER FREQUENCY IS 3.4 Mc.



(d) SIGNAL GENERATOR D—30% AMPLITUDE-MODULATED AT 100cps. CARRIER FREQUENCY IS 3.4 Mc.



(e) SIGNAL GENERATOR E—8% AMPLITUDE-MODULATED AT 100cps.

Figure 20 - Comparison of five generators of different types and manufacture

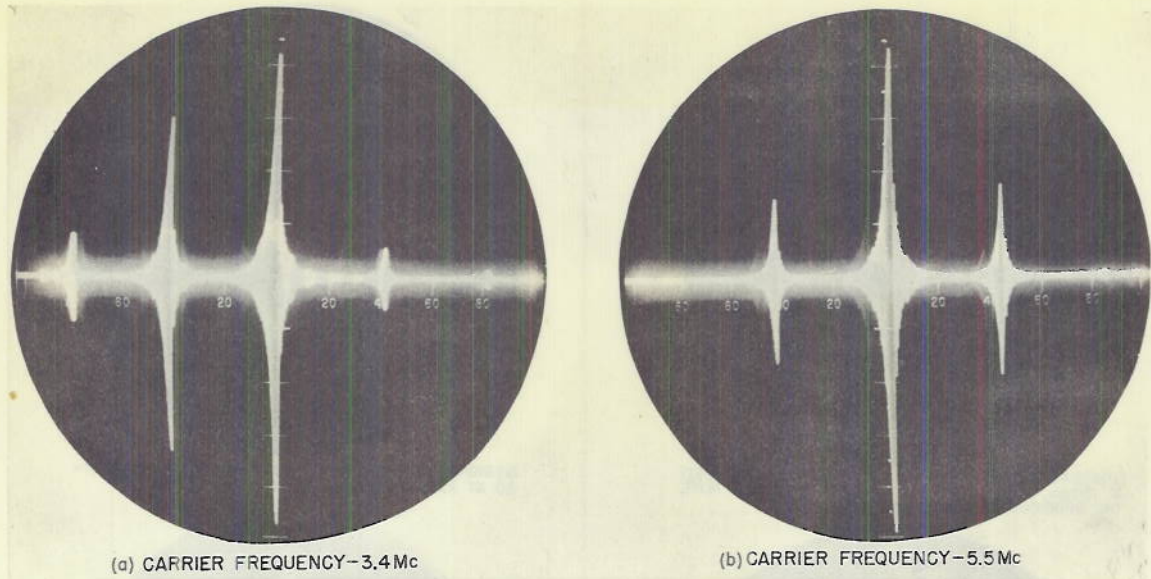


Figure 21 - Signal generator C, 50% sinusoidally amplitude modulated at 400 cps

and qualitative analyses with other types of modulation present, satisfies the most essential requirements of instrumentation in this field.

The R-F Wave Analyzer meets all the original requirements as stated in regard to resolutions, accuracy, stability and accurately adjustable sweep width. Some temperature compensation should be employed on the first two local oscillators in order to hold the picture steady on the lowest sweep positions, where oscillator stability becomes critical. There are a few spurious responses, but these are identifiable and do not introduce difficulties if the analyzer is properly operated. Additional filtering after the first mixer may be used to eliminate many of the spurious responses.

It is suggested that practicabilities of the technique in the field of signal interception and identification be considered. It is evident that such information as signal frequency, spectrum occupancy, and composition of the complex wave, if furnished by a single instrument, would be of great value.

It is recommended that a very uniform carbon-type potentiometer of 10,000 ohms be developed if or when the use of the R-F Wave Analyzer justifies it; see "Discrete Frequencies Sweep." The use of an R-C filter for smoothing purposes should also be investigated. It should be noted that the sweep uniformity also depends upon the smoothness of the driving source which may require additional development if the ideal sweep is to be achieved.

ACKNOWLEDGMENT

This report would not be complete without acknowledging the helpful suggestions and constructive criticism offered by Messrs. H. F. Hastings, J. P. Leiphart, and W. E. Leavitt. Further credit is due Mr. Hastings for furnishing the concept upon which this technique was based.

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