A STABILIZED LOCAL-OSCILLATOR PERFORMANCE EVALUATOR

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SUMMARY

Evaluation of the performance of surveillance-radar moving-target-indicator (MTI) equipment is extremely difficult unless all of the characteristics of the radar system, including the indicator device, are accurately known. Residual system instabilities may be considered as one of the major causes of poor over-all performance when tests, theoretical analyses, and examination indicate good performance capabilities. One of the most critical units of the radar MTI system, insofar as stability is concerned, is the stabilized local oscillator (STALO).

An instrument designed to provide accurate quantitative data on the stability and performance characteristics of microwave oscillators is described in this report. The application of the instrument and the interpretation of the data yielded are discussed in detail. Correlation of these data with those obtained on other units of the MTI system, using other test equipment referenced herein, indicates which part of the system limits the performance and to what relative degree. Performance limitations imposed by STALO instabilities are determined with much greater accuracy than heretofore.

The instrument is also useful in determining the effects of line-voltage variations, transients, long-term frequency drift, and automatic-frequency-control (AFC) operation. Peak-to-peak frequency deviation, jitter rate, and drift in kilocycles are directly indicated with good accuracy.

INTRODUCTION

The performance of surveillance-radar equipment with MTI can be roughly assessed by prolonged observation of the plan position indicator (PPI). If the equipment is adjusted for optimum performance, the display may be examined for uncancelled residue from fixed-target signals. This uncancelled residue is that portion of one or more fixed-target signals that is not completely cancelled by the cancellation circuitry because of slight target motion, signal fluctuations caused by excessive antenna scan rates, and residual electrical instabilities in the radar equipment. The residual instabilities of the radar equipment are those pulse-to-pulse variations of frequency, amplitude, and timing which exist in varying degrees in critical circuits of the radar and which effectively limit the cancellation of fixed targets and, under certain conditions, the visibility of moving targets. If no residue is observed, one may conclude that the cancellation is probably satisfactory. Good subclutter visibility is indicated when aircraft of various types flying at random speeds and in random directions over heavy ground clutter consistently display strong signals with only an occasional fade or miss. These conditions, however, do not indicate how good or bad the performance is compared with any standard. For example, uncancelled residue may be seen for various reasons such as excessive antenna scan rates, fixed-target fluctuations, and the combined effects of residual system instabilities. Uncancelled residue may not be seen, and yet poor subclutter visibility can exist to cause aircraft flying over ground clutter to be displayed weakly or not at all under certain conditions. A large number of conditions can exist which individually or in combination result in poor system performance.

The factors involved in contributing to specific results and performance are too numerous to mention here and are beyond the scope of this report. It is appropriate to emphasize, however, that optimum performance for a given system may be obtained only by careful adjustment of the various units through the use of techniques and test equipment capable of indicating the optimum operating conditions. Experience has shown that optimum adjustment of most of the units comprising an MTI system cannot be made with test equipment generally available. Further, it has been determined that performance may be degraded as a result of the existence of small-amplitude power-supply ripple voltages or of random transient-signal voltages appearing at critical points in the system. Such signals are extremely detrimental when they result in frequency changes of the STALO or of the coherent oscillator (COHO), because these frequency changes in turn cause phase changes of the received echo signal with respect to the transmitted radio-frequency pulse. The STALO, in particular, is extremely sensitive to power-supply ripple, voltage variations, and transient conditions, each of which factors cause momentary frequency deviations. The magnitude of these changes varies greatly, depending upon their amplitude and the design and type of local oscillator.

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Recognition of the importance of maintaining proper operating conditions and of providing means for the detection and localization of causes of malfunctioning that commonly available equipment would not reveal led to the placement of a contract with Airborne Instruments Laboratory for the development of special MTI test instruments One instrument, MTI Evaluator TS-677/UP, measures the complete performance characteristics of the MTI system, beginning with the signal and COHO intermediate-frequency preamplifiers on through the system to the final indicator. Simulated fixed- and moving-target signals are provided, along with control of the radial velocity of the latter.

A second instrument, STALO Evaluator Test Set TS-697 (XW-2/U), provides information on the short-term stability of the stabilized local oscillators operating from approximately 900 Mc to 3200 Mc. This instrument, in conjunction with a standard oscilloscope, provides information on the relative stability of local oscillators and can be used with fair accuracy to determine the peak-to-peak frequency deviation and the resultant phase change at any given distance. It has been found, however, that all information required for computing the effect on cancellation and subclutter visibility cannot be directly derived from the instrument with sufficient accuracy. This information includes peak-to-peak frequency deviation, jitter rate (repetitive rate at which the excursion occurs), and instantaneous rate of frequency change (waveform). These factors must all be known with a high degree of accuracy if one wishes to determine, for example, the effect of STALO instabilities on subclutter visibility at a given distance. This latter information is important, especially when tests on the remainder of the MTI system indicate that operation is normal and satisfactory and poor response to aircraft flying over clutter is obtained. It must be emphasized that poor STALO performance is not the only reason for poor cancellation or for subclutter visibility. The required stability for good performance is not always attained, however, it may well be the limiting factor in an otherwise good system. It is the purpose of this report to show the effects of poor STALO performance and to describe the evaluator equipment which supplies the desired information with high accuracy.

THEORY

A simplified functional block diagram of a typical radar MTI system is shown in Fig. 1. A brief review of the fundamental functions of each unit will facilitate an understanding of the stability requirements of an MTI system. It is not within the scope of this paper to describe completely the MTI theory or to establish all of the effects of varied parameters and operating conditions. However, sufficient theory is included to show the effect of STALO instabilities on the ability of the MTI system to discriminate between fixed- and moving-target signals and, further, to show how cancellation and subclutter visibility are affected by the instabilities.

The illustrated type of MTI measures, on a pulse-to-pulse basis, the phase relationship of the received target-echo signals with respect to a reference-phase signal supplied by the coherent oscillator. To simplify visualization of the functions of the various units of the system it will be assumed that all fixed targets within the beam of the radar antenna are motionless, that the radar antenna is not rotating, and that there are no instabilities in the radar and in the MTI system.

The STALO supplies a continuous carrier at a frequency difference of 30 Mc from that of the magnetron mean frequency. When the magnetron is fired by a pulse from the modulator, the resultant r-f pulse is radiated by the radar antenna. Some of this radiated energy strikes various fixed objects on the ground at various distances. Each of these objects reflects or reradiates a small amount of this energy back to the radar antenna. This energy arrives at the radar antenna at a time (with respect to the start of the transmitted pulse) determined by the distance from the antenna to the target and back. This time interval is 10.75 microseconds per statute mile.

As the echo signals arrive at the signal mixer, they are heterodyned with the STALO signal to produce an intermediate frequency of 30 Mc. These signals then pass through the signal preamplifier and into a limiting amplifier, the primary purpose of which is to amplify weak signals and to limit the amplitude of strong signals to a specific level. When the magnetron fires, a sample of the r-f pulse is also delivered to the coherent-oscillator signal mixer, where it is heterodyned with the STALO carrier to produce a 30-Mc intermediate frequency. This 30-Mc pulse passes through the COHO preamplifier and, after further amplification, is used as a locking pulse to start the coherent oscillator. The importance of this locking pulse can be appreciated when it is recognized that the magnetron starts oscillating in random phase from pulse to pulse. For example, the oscillatory wave may start off in a

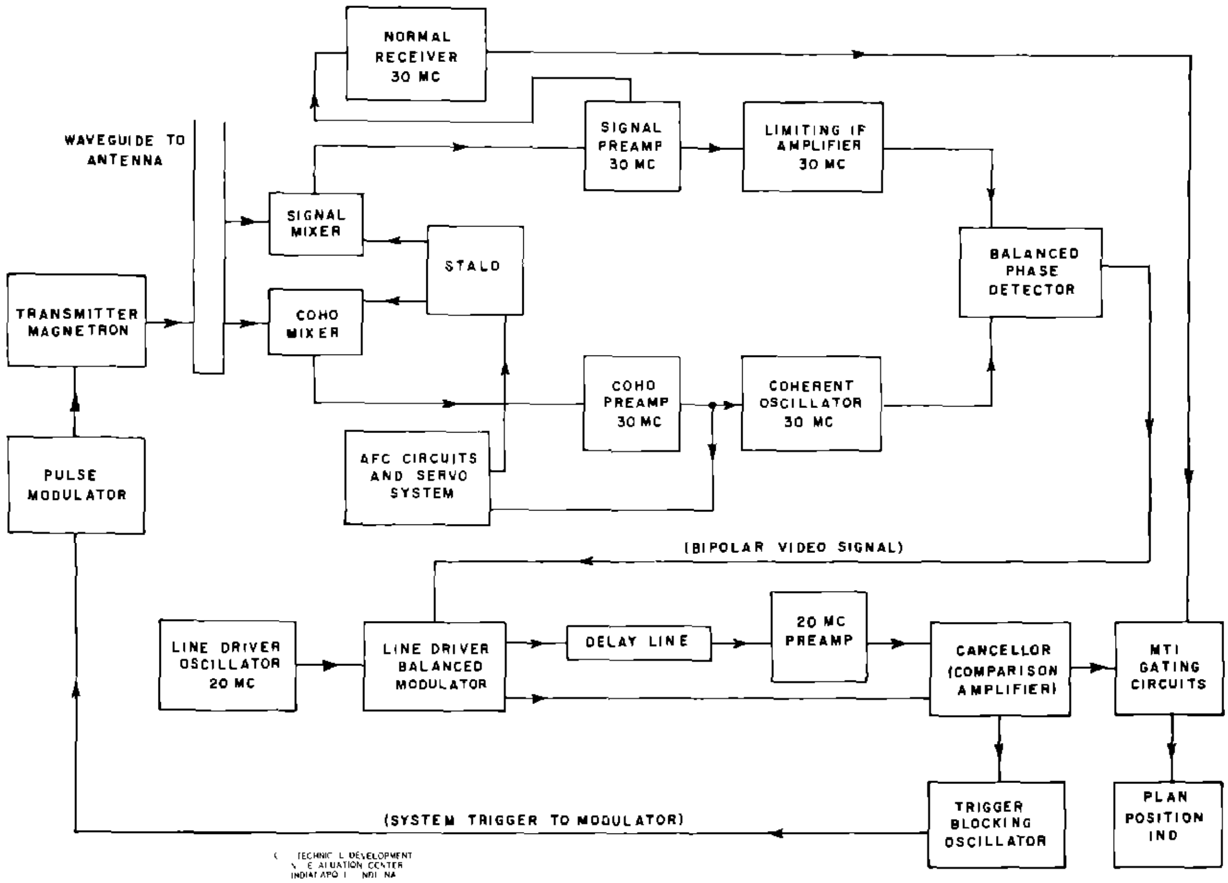

Fig. 1 Functional Block Diagram of a Typical Surveillance-Radar MTI System

positive direction for one pulse and in a negative direction for the following pulse. The phase of the intermediate-frequency echo signal from a fixed target depends upon the starting phase of the transmitted r-f pulse, the starting phase of the STALO, and the fixed-target range. The target range determines the number of cycles executed by the STALO while the transmitted pulse travels to the target and back. Since the phase relationship for fixed targets must be preserved from pulse to pulse for cancellation, a reference signal is provided by an intermediate-frequency coherent oscillator, the phase of which also depends on the starting phase of the transmitted r-f pulse and of the STALO, and on the fixed-target range which in turn determines the number of cycles executed by the COHO during the echo time. Thus, the phase of the reference coherent oscillator is matched to that of the transmitter at each transmitted pulse.

The 30-Mc echo signal from the limiting amplifier is supplied to one input of a balanced-phase detector, while the COHO reference intermediate-frequency signal is supplied to another input. This detector is designed to be phase-sensitive and to convert echo-signal phase variations into amplitude variations. In actual operation of MTI equipment, some signal-amplitude variations appear at the input to the limiting amplifier because of slight target motion, scanning losses, and residual system instabilities. These variations will change from pulse to pulse and thus will produce phase changes unless eliminated. A second purpose of the limiting amplifier is therefore to eliminate amplitude fluctuations from the input of the phase detector and to provide, as nearly as possible, a fixed input level.

It can be seen from the preceding that fixed-target signals, by virtue of the coherence established on a pulse-to-pulse basis, will have a constant phase relationship at the phase-detector output. Moving targets, however, with a radial velocity with respect to the radar

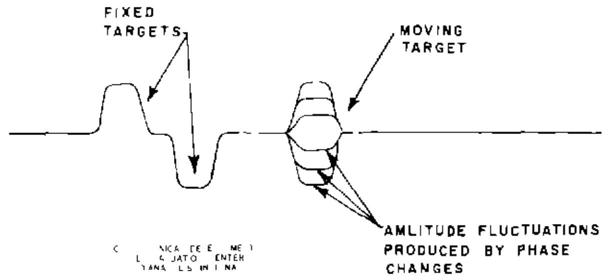

Fig. 2 Bipolar Video Signal at Output of Phase Detector

antenna, have a continuously changing phase since the distance to the moving target is changing from pulse to pulse. These phase variations are converted to uniform amplitude variations by the phase detector. The bipolar video appearing at the output of the phase detector resembles that illustrated in Fig. 2. The moving-target signal fluctuates in both amplitude and phase because of its changing distance. The performance under blind-speed conditions is not dealt with here because it has no direct bearing on system stabilities It is desirable to point out, however, that the phase detector should have a linear characteristic so that output-amplitude variations are directly proportional to input-phase variations.

Cancellation of fixed-target signals is accomplished by the comparison of the resultant signal amplitudes on a pulse-to-pulse basis. This is effected by storing or delaying the phase-detector output signals from each transmitted pulse and by comparing them with those created by the next transmitted pulse. Bipolar video from the phase detector is amplified and is used to modulate the amplitude of the output of a high-frequency oscillator, the frequency of which is usually between 10. and 20. Mc. This modulator is balanced to preserve the waveform of the bipolar video signal. The modulated carrier is divided into two channels. A portion of the output is passed through a delay line, which has a delay of precisely one pulse-repetition interval. This delayed-output signal is amplified to compensate for the losses in the delay line and is then fed to a subtraction circuit. This signal path is referred to as the delayed channel. An undelayed channel receives a portion of the modulated carrier output,which in turn is passed through a variable-gain amplifier and on to the subtraction circuit. These amplifiers are designed to pass the bipolar-pulse signals without distortion so that subtraction of the delayed signal from the undelayed signal results in as near zero output from fixed targets as the system instabilities will permit. The amplitude of the undelayed-channel signals must be adjusted initially to match the amplitude of the delayed-channel signals and thereby effect optimum cancellation.

In practice, circuitry is provided to balance the signal levels automatically and, further, to control the pulse-repetition interval very closely by amplifying the trigger video pulse after it has passed through the delayed channel, using it to synchronize a blocking oscillator-system trigger generator as shown in Fig. 1. It is usually referred to as a circulating trigger.

Moving targets, since they change in both time and phase from pulse to pulse, do not subtract to give zero output from the subtraction circuit. The resultant bipolar video is amplified and rectified to provide a video signal for application to the PPI. Modern MTI systems provide variable gating circuits which, by electronic switching, cause MTI video to be displayed to any desired range, depending on the terrain and the maximum distance that fixed targets are detected at a given location. Normal video is displayed beyond that range, thus maximum sensitivity to weak moving-target signals is attained by elimination of the MTI and blind-speed losses.

The degree to which fixed-target signals are cancelled is referred to as cancellation ratio. In the absence of any absolute standards of measurement, the cancellation is usually expressed as a ratio in decibels representing the reduction in amplitude below a limiting signal level which the radar and MTI system affords.

Subclutter visibility refers to the ratio of the amplitude of the echo signals of the moving target to fixed target for a given video-output level. This latter level is usually defined as the level at which the amplitude of a moving target which has a pulse width equal to that of the radar and which moves at optimum radial velocity equals the amplitude of the uncancelled residue of a fixed target which has a pulse duration of approximately three times the width of the radar pulse. Therefore, it is an expression of that number of decibels below a fixed-target signal level at which a moving target may be detected under specific conditions This measurement is made with an A-scope for observation of the signals and does not represent the visibility on a PPI[1]. Subclutter visibility measurements are usually made at the most favorable and the least favorable target-phase conditions to further indicate the phase-detector performance. It has been shown that the target-signal phase changes with target distance, therefore, it is desirable that subclutter visibility measurements be made at specific target distances.

In summary

1. The phase of the intermediate-frequency echo signal depends on the starting phase of the transmitted pulse, the starting phase of the STALO, and the target range.
2. Maximum cancellation of fixed targets may be obtained only when the phase-detector input for those targets remains the same on a pulse-to-pulse basis.
3. Any phase change from a target signal from pulse to pulse, other than at a blind speed, will result in the display of the target signal to a degree largely proportional to the magnitude of the phase variations.
4. Residual instabilities of the radar MTI system, primarily variations of the pulse-to-pulse interval, variations of COHO frequency, and variations of the STALO frequency, will cause target-signal phase variations and will result in reduced cancellation and subclutter visibility because the phase detector reacts to these variations as though they were moving targets.

It is evident that system instabilities must be kept to the lowest level consistent with the state of the science and the intended application. It can be shown that the intermediate-frequency portion of the MTI system, which includes the COHO, places definite restrictions on the cancellation and subclutter-visibility ratios that can be realized in practical equipments. In this part of the system, the prime factors determining the attainable cancellation are the variations in pulse-to-pulse timing, amplitude and frequency variations of the coherent-oscillator output, and the dynamic range of the phase-detector and cancellation circuits. Power-supply ripple, tube microphonics, and vibration are among the most common causes of instabilities in this section of the system. The TS-677 (XW-2)/UP MTI Evaluator Test Set is an excellent instrument for accurately determining the performance of this part of the system. Phase-detector characteristics, COHO stability, cancellation and subclutter-visibility ratios, and pulse-to-pulse jitter are among the important measurements which can be made with this instrument. Blind-speed characteristic curves may also be determined.

It is apparent that the stability of the STALO is an extremely important factor in determining the cancellation and subclutter-visibility performance of the system. It is of utmost importance that the stability of the STALO be sufficiently high so that it places no limitation on the performance of the entire system with regard to cancellation and subclutter visibility. For example, if the intermediate-frequency portion of the MTI system will provide cancellation of 38 db and the subclutter-visibility ratio for a target at optimum radial velocity and in the most favorable phase condition is 30 db, the STALO stability should be high enough so that these ratios are not reduced. Similarly, the scan rate of the radar antenna should not be so high that scan fluctuations produced by rotation of the antenna reduce these figures to values lower than the remainder of the system permits[2].

DESCRIPTION OF OPERATION

The TDEC test set, shown in Fig. 3, was designed primarily for use in the field to permit maintenance personnel to readily detect changes in the STALO performance and to determine the effect of the measured instability on cancellation and subclutter visibility. Other uses of the instrument will be subsequently described.

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[1] Ruby Payne-Scott, "The Visibility of Small Echoes on Radar PPI Displays," Proceedings of the I. R. E., Vol. 36, pp. 180-196, February 1948.

[2] A. G. Emslie and R. A. McConnell, "Moving-Target Indication," in Louis N. Ridenour, ed., Radar System Engineering (Massachusetts Institute of Technology Radiation Laboratory Series, Vol. 1, Section 16.10, McGraw-Hill Book Company, Inc., 1947).

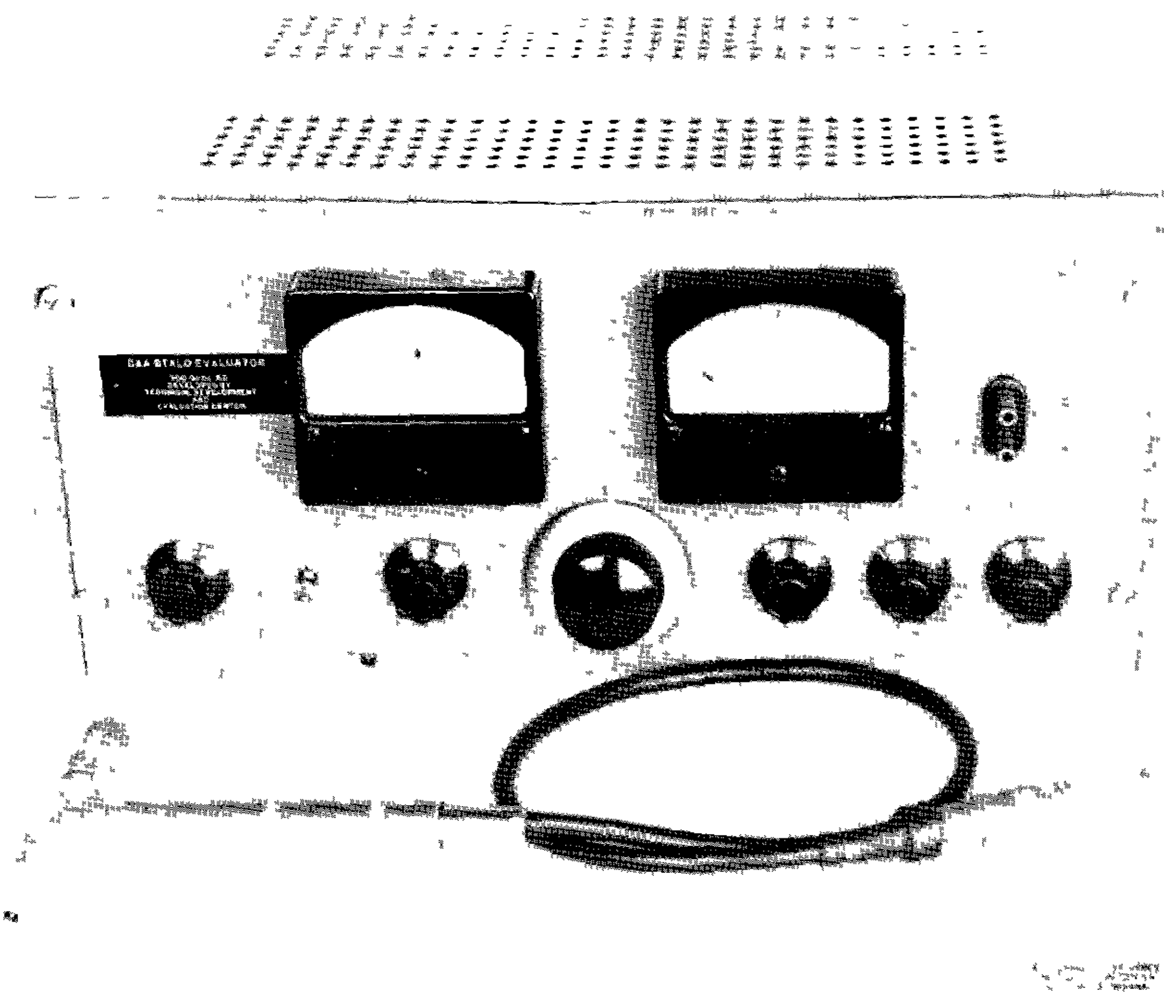

Fig 3 CAA STALO Evaluator

The determination of the effect of frequency instability on subclutter visibility at a specific target range requires that the following information be known

a The peak-to-peak deviation from a mean frequency, in kilocycles
b The rate at which this excursion occurs (jitter or repetitive interference frequency), in cps
c The rate at which the frequency changes, in cycles per second per second
d The pulse-repetition rate of the radar, in pulses per second
e The distance at which the subclutter-visibility ratio is desired, in microseconds

These factors are arranged into the equation

$$S = 20 \log \frac{2F_d}{P} \sin \pi Pt \sin \pi PT \qquad (1)$$

where

S = Subclutter visibility, in db

$2F_d$ = peak-to-peak frequency deviation

P = Interference frequency

T = PRF interval, in microseconds

t = Time, in microseconds, to point of measurement

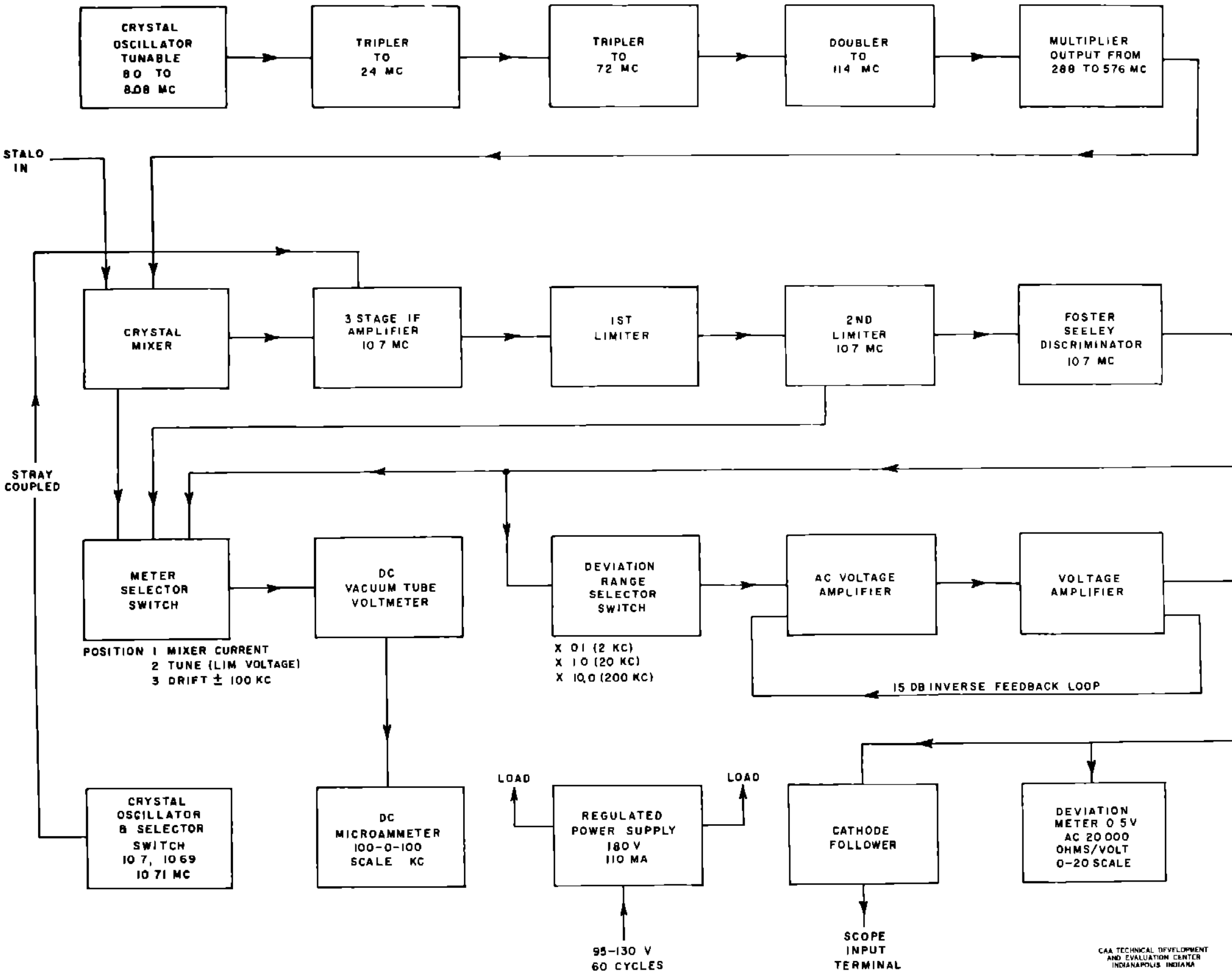

Fig 4 Functional Block Diagram of STALO Evaluator

The instrument directly indicates the peak-to-peak frequency deviation, and, by the use of an ordinary oscilloscope or of an electronic frequency meter, the interference frequency may be determined

The TDEC STALO evaluator makes use of the basic principle that the STALO output is frequency-modulated at a rate determined by the interference frequency and that the peak-to-peak frequency deviation from the mean frequency is determined by the amplitude of the modulating frequency As indicated in Fig 4, the evaluator consists basically of a tunable superheterodyne receiver in which a discriminator is used to recover the audio-frequency interference signal. At low modulation indexes, the output of the discriminator is proportional to the peak-to-peak frequency deviation [3] This value is measured by a stable vacuum-tube voltmeter which is calibrated in terms of peak-to-peak deviation A sample of the interference voltage is available at terminals on the front panel for connection to an oscilloscope in order to determine the frequency and waveform

The technique referred to uses a crystal oscillator with a fundamental frequency of approximately 8 Mc, which provides high short-term stability In the schematic diagram, Fig 5, the oscillator V-1A is tunable over a frequency range of approximately 0.5 per cent. A total of 16 crystals are provided, each one separated in frequency by 2 5 kc One of these crystals is selected by the coarse-frequency selector For purposes of discussion, let us assume a coarse frequency of 8 Mc The output of the oscillator feeds a multiplier chain consisting of tripler V-1B, tripler V-2A, doubler V-3, and doubler V-2B. This chain will therefore provide output frequencies of 24, 72, 144, and 288 Mc, respectively, at each successive stage The design of the multiplier stages is such that high harmonic output is obtained by the choice of circuitry and by the deliberate introduction of crosstalk in the multiplier chain V-2B functions as a harmonic generator and may be considered as receiving, at its grid, very narrow pulses at a repetition rate of 8 and 24 Mc The output of this stage therefore feeds harmonics 8 Mc apart to the mixer An adjustable hairpin tuner on the mixer makes it possible to emphasize the level of the desired harmonic

The mixer consists of a circuit in which the signal from the STALO being tested is coupled through a 1-mmfd capacitor into a 1N21B crystal. One side of the mixer crystal is connected to the intermediate-frequency amplifier through a conductor about one inch long, which is approximately one-quarter wavelength at S-band frequencies This conductor is terminated by a section of low-impedance coaxial cable which functions as a by-pass capacitor This arrangement presents a high impedance to the signal frequencies, especially at S-band The other side of the crystal is tuned over a wide frequency range by the mixer tuning control, which in turn actuates a sliding contact on the hairpin tuner and presents a relatively low impedance to the signal frequencies.

By choosing one of the 16 crystals and tuning the oscillator, it is always possible to find a setting that will give a 10 7-Mc beat between the STALO being tested and the output of the multiplier chain L-6 is tuned to 10 7 Mc and functions as an impedance-matching transformer from the mixer output to the grid of the first intermediate-frequency amplifier V-4, V-5, and V-6 are intermediate-frequency amplifiers centered on 10 7 Mc Capacitors in parallel with the primary and secondary of each intermediate-frequency transformer minimize any detuning effects caused by variation of tube capacities, Miller effect, and temperature Tubes V-7 and V-8 function as cascaded limiters Both grid and plate-limiting are provided by the circuitry shown and by the application of low plate voltages to these stages This limiting action eliminates noise and amplitude-modulation products from the signal voltage applied to the discriminator It also provides a constant output level over a bandwidth of approximately 200 kc, as indicated by the selectivity curves of Fig 6, when the input signal is of such a level that full limiting is attained. A balanced discriminator follows the second limiter and uses a 6AL5 tube V-9. The secondary of the discriminator transformer is tuned for zero d-c output when a 10 7-Mc unmodulated signal is applied to the input of the intermediate-frequency amplifier.

It can be seen that when the proper crystal is selected and the crystal oscillator is properly tuned to give a 10 7-Mc beat with the frequency of the STALO under test, the frequency shift from the STALO will produce an output voltage from the discriminator and proportional to the deviation from the mean frequency The discriminator-response curve is linear over a range of plus or minus 100 kc The output of the discriminator, therefore, accurately reproduces the STALO modulating waveform

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[3] J. G Chaffee, "The Detection of Frequency Modulated Waves," Proceedings of the I R E , Vol 23, No. 5, pp 517-540, May 1935

The signal voltage from the discriminator is fed to a low-pass filter having a time constant of 1,000 microseconds The attenuation for frequencies above 1,000 cps is approximately 6 db per octave This filter serves to further reduce the amplitude of noise components or of other transients which in some cases might give erroneous meter readings STALO interference frequencies are not attenuated since they are below this transition frequency The interference-signal voltage appearing at the output of the low-pass filter, which consists of R-29 and C-34, is amplified by a low-noise and hum pentode V-10 and is further amplified by triode V-11 This amplifier output is applied to a rectifier-type voltmeter whose scale is calibrated from 0 to 20 kc The meter has a full-scale sensitivity of 50 microamperes and, in combination with multiplier resistor R-54, indicates 5 volts at full scale Approximately 15 db of inverse feedback is used in the amplifier circuit from its output to the cathode of the input tube Thus, aging of tubes or replacement thereof will not significantly affect the calibration It should be noted, however, that since the indicating instrument is of the rectifier type the value of the indicated voltage is subject to waveform errors The magnitude of these errors is roughly equivalent to the percentage of departure from a sine wave In practice, it is found that audio-frequency envelopes have essentially a random distribution of harmonics whereby the actual error introduced by deviation from true sine waves is relatively small, and the instrument is eminently satisfactory for this application This will be discussed further under the section entitled "Interpretation of Data"

A cathode-follower stage V-12 samples the modulating voltage and waveform Its output is available at terminals on the front panel for connection to an oscilloscope to facilitate the determination of the waveform and its frequency. The frequency may easily be determined by initially setting the oscilloscope sweep to display one cycle of a 60-cps voltage Application of the output signal from the STALO Evaluator to the Y-axis input of the scope, in place of the 60-cps test voltage, will result in the display of the interference frequency when internal synchronization of the scope is used This interference frequency is nearly always 60 cps or a multiple thereof, since the interference is usually due to the presence of a power-frequency component at the local-oscillator tube In those cases where mechanical vibration is responsible for the major portion of the disturbance, the oscilloscope sweep frequency may be readjusted to determine the predominant frequency or an electronic frequency meter may be used A deviation-range selector switch at the input to the audio-frequency vacuum-tube voltmeter provides full-scale peak-to-peak deviation ranges of 2, 20, and 200 kc in accordance with the attenuator factor selected This range embraces the deviation to be expected from the most stable local oscillators to very poor ones The lowest scale mark on the 2-kc range corresponds to a 50-cycle peak-to-peak deviation The total of the residual noise and hum components of the test set, when full limiting is attained, is at least 20 db below the equivalent voltage required to indicate a peak-to-peak deviation of 50 cycles.

It will be noted that a d-c vacuum-tube voltmeter, comprised of the tubes V-13, V-14, V-15, and their associated circuitry, is provided The indicating meter associated with this voltmeter is a d-c microammeter with a sensitivity of 100 microamperes, a center zero position, and a scale calibrated to indicate -100, 0, and +100 kc at the left, center, and right-hand scale-limit positions, respectively The meter-selector switch, S-2, permits connection of the voltmeter to the discriminator output in order to measure the d-c voltage change from the zero-output (10 7-Mc) point Adjustment of R-28 permits setting the sensitivity so that a frequency change of 100 kc produces full-scale deflection With the selector switch in this position, STALO drift may be measured over a range of plus or minus 100 kc. A second position of the meter-selector switch connects the voltmeter to the grid circuit of the second limiter This TUNE position facilitates selection of the correct crystal and tuning point in the oscillator-multiplier chain It further facilitates adjustment of the mixer tuning by indicating when maximum output is obtained and by verifying that sufficient signal is available to effect full limiting The scale units are arbitrary in this case Full limiting is obtained when the meter indicates more than 75 divisions The third position of the switch causes crystal-mixer current to be indicated by measuring the voltage drop across R-78 The meter may be calibrated to indicate a full-scale value of one milliampere by adjustment of this potentiometer Mixer-crystal current will vary, depending upon the mixer tuning and the crystal-oscillator tuning The condition of the oscillator-multiplier chain may readily be checked periodically by ascertaining that the mixer-crystal current exceeds 50 microamperes for any combination of coarse-frequency, fine-tuning, and mixer-tuning adjustments. This current will normally maximize at more than 250 microamperes.

The STALO evaluator was designed to be very stable and to retain its accuracy over long periods of time with a minimum effect due to line-voltage variations. In recognition of field-servicing problems, maximum effort was made to simplify the procedures and to

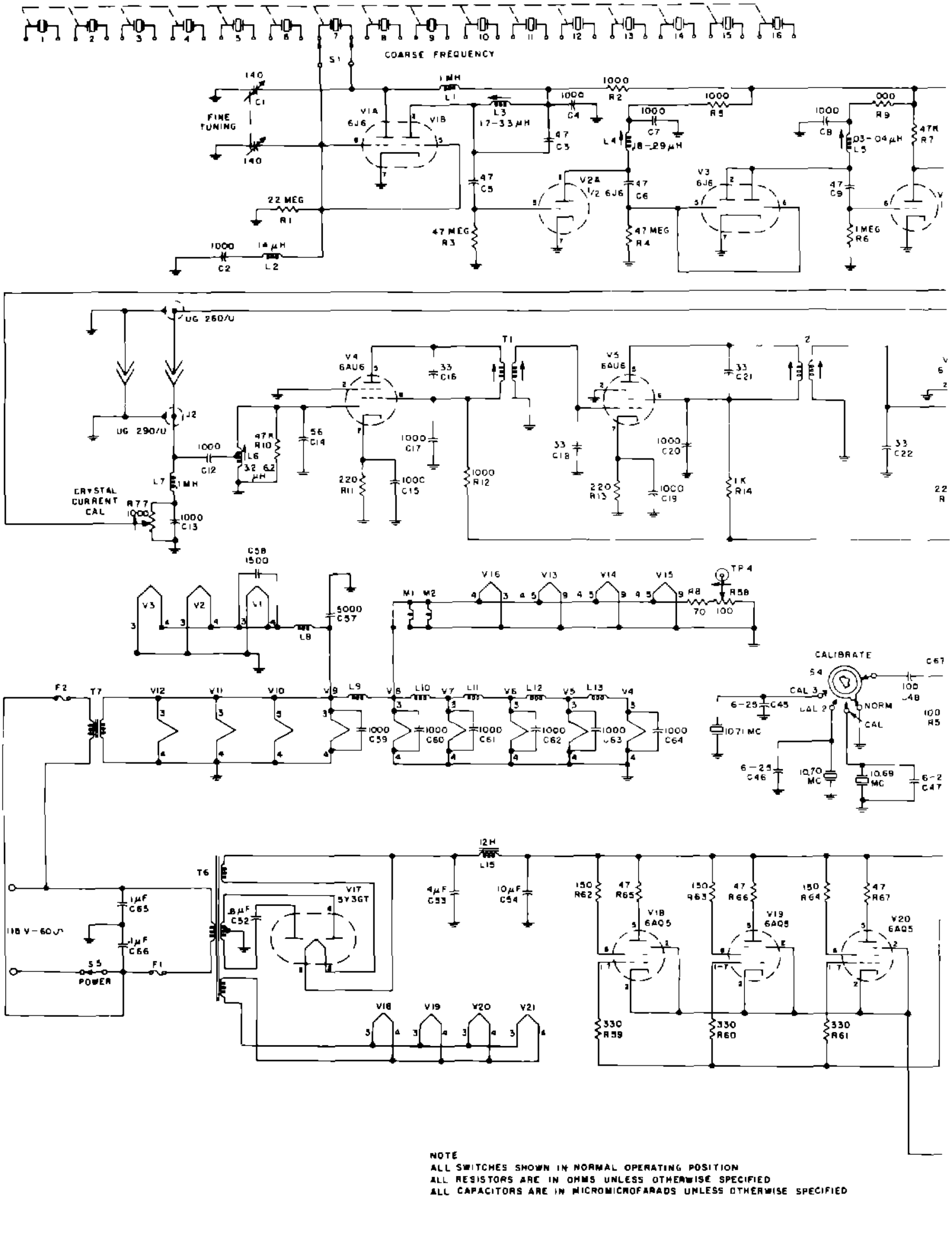
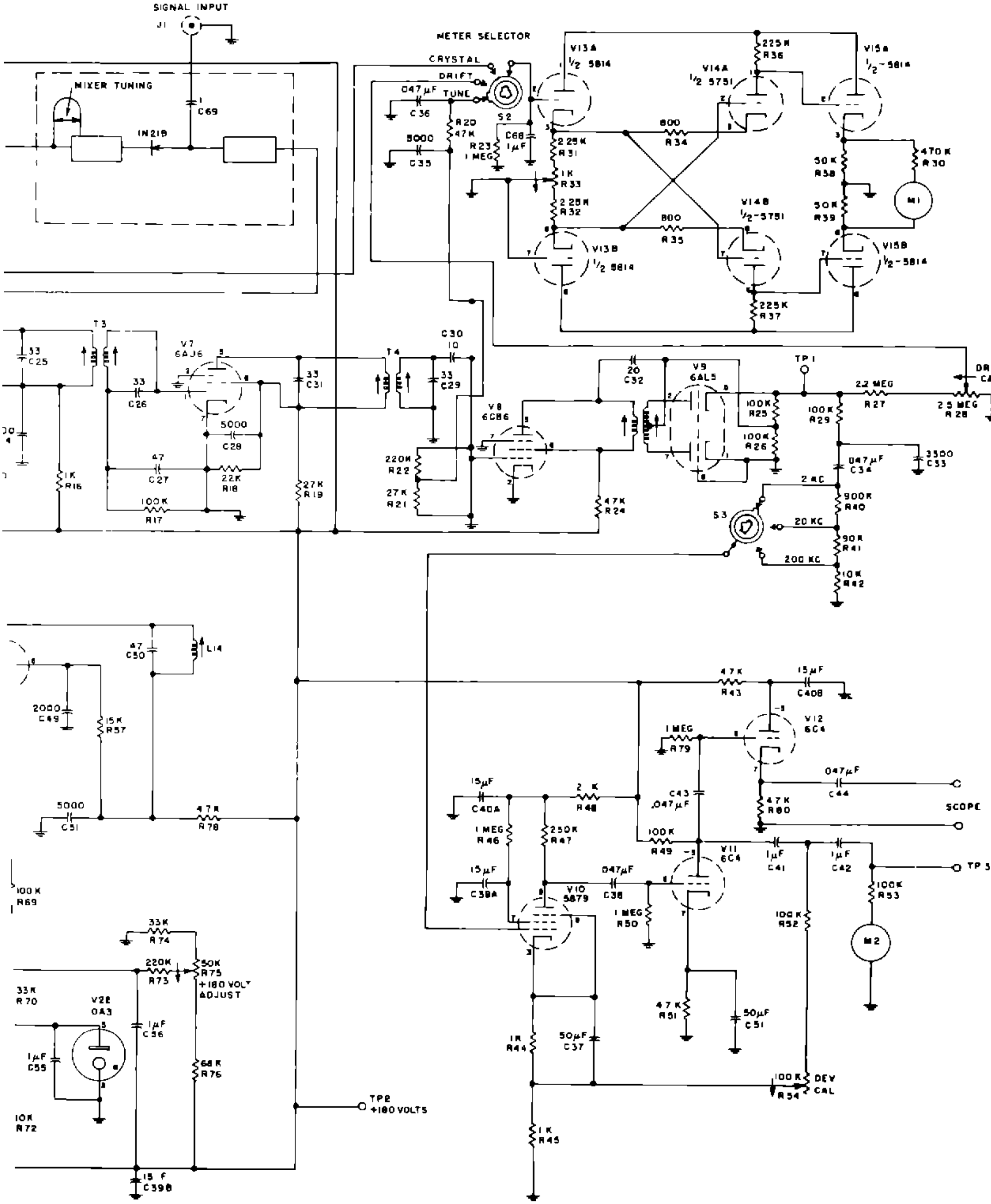


Fig. 5 Schematic Di



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STALO Evaluator

minimize the requirements for auxiliary equipment for such maintenance To this end and to provide a simple method of checking calibration on a periodic basis, a crystal oscillator is provided which will supply an unmodulated 10 7-Mc carrier to the intermediate-frequency amplifier and discriminator through stray-coupling This oscillator consists of V-16 and its associated components and circuitry Switch S-4 permits selection of one of three quartz crystals providing frequencies of 10 690, 10 700, or 10 710 Mc Each of these crystals is tuned by a small capacitor to permit adjustment of the output to the exact frequency specified When the drift meter is correctly calibrated, it will indicate -10, 0, and +10 kc when the crystal switch is correspondingly positioned

Similarly, the audio-frequency voltmeter section contains calibrating facilities Potentiometer R-59 in parallel with the 6 3-volt filament supply provides a means of obtaining a low-voltage sine-wave signal The rotor of this potentiometer is terminated at test point TP-4 An external a-c voltmeter is required for connection to this point for calibration purposes only The only instruments required for calibration or maintenance, other than replacement components, are a d-c vacuum-tube voltmeter and an a-c voltmeter having a scale on which 1 0 volt may be read accurately These meters are of a type normally available at field radar facilities

The power-supply section of the STALO evaluator supplies 180 volts d-c at a normal load of 100 milliamperes Filament voltages for the tubes are supplied from transformers T-6 and T-7, as indicated on the schematic diagram The power transformers are of the regulating type and thereby hold all filament and plate-supply voltages within 3 per cent for line voltages varying from 95 to 130 volts Design on the basis of varying line voltages was considered important since the supply voltage at most field sites varies over wide limits Through the regulation provided, the accuracy of the evaluator is not adversely affected within the foregoing voltage limits. V-17 is a conventional, full-wave rectifier supplying approximately 380 volts to a capacitor-input filter consisting of C-54, L-15, and C-55 Tubes V-18, V-19, and V-20 are d-c cathode followers functioning as regulator tubes in parallel Tube V-21 functions as the tube controlling the bias on the cathode followers Potentiometer R-76 sets the bias on

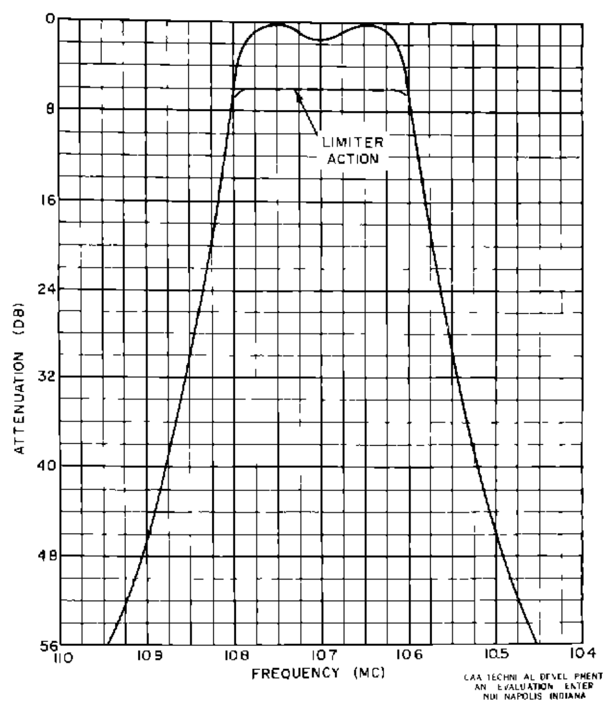


Fig 6 STALO-Evaluator Intermediate-Frequency-Amplifier Selectivity Curve

the control tube and thereby determines the plate-supply output voltage V-22 is a voltage-regulator tube used to maintain the cathode of V-21 at a fixed potential above ground The maximum ripple content of the plate supply is about 10 millivolts

MEASUREMENTS AND PROCEDURES

Operation of the instrument is straightforward and consists essentially of a tuning procedure and the indexing of selector switches to obtain the desired measurements. Accurate measurements of deviation may be made immediately after the set is turned on, however, it will be found that frequent retuning of the oscillator will be required until the oscillator circuits and components reach the maximum operating temperature. The output of the STALO or other signal source to be measured is connected to the input connector through a length of 50-ohm coaxial cable. A suitable attentuator is used when the output of the STALO exceeds approximately -40 dbw. The Y-axis terminals of a conventional oscilloscope are normally connected to the output terminals at the right side of the panel to facilitate determination of the modulation frequency and of the waveform.

The oscillator-multiplier chain of the test set is tuned to obtain a 10.7-Mc intermediate-frequency signal by initially setting the coarse-frequency switch to position No. 1 and then turning the fine-tuning dial until a signal is obtained, as evidenced by a left-hand deflection of the drift meter. This meter indicates limiter voltage when the meter-selector switch is in the tune position. If no response is obtained throughout the range of the fine-tuning control with the coarse-frequency selector in position No. 1, the procedure is repeated with the coarse-frequency selector in sucessive positions until there is obtained an intermediate-frequency signal which results in a meter deflection of 80 divisions or more. Several indications of an intermediate-frequency signal may be obtained throughout the range of the oscillator-multiplier chain, and it makes no difference which tuning point is used, provided that the tuning meter indication is in excess of about 80 divisions. Maximum sensitivity to low-level signals (approximately 40 to 45 db below one milliwatt) is obtained after tuning by adjusting the mixer tuning control for maximum limiter voltage.

The deviation-range switch is normally indexed to the 200-kc position because noise or other signals derived in the process of tuning may instantaneously cause off-scale deflection Similarly, if the peak-to-peak deviation of the STALO being tested is not known to be very low, physical damage to the pointer of the meter may result from off-scale deflection. Protection against electrical overload and burnout is provided by the circuitry.

After the evaluator is properly tuned, the deviation-range selector may be indexed to a lower range if the indication is less than 10 per cent of the full-scale value. The peak-to-peak deviation is then read directly from the deviation meter. The indicated deviation is correct for waveforms approximating a sine wave. The oscilloscope connected to the test-set output will, when synchronized, indicate the waveform of the interfering signal. The frequency of the signal may be determined by methods previously described.

The evaluator may be used for measuring drift by tuning as described and then indexing the meter-selector switch to the drift position. The fine-tuning control may be adjusted so that the drift meter indicates zero to establish a reference frequency Since, after temperature stabilization of the test set is reached, essentially all frequency change indicated will be from the STALO being tested, the drift or change may be read directly from the meter and the time for a given change may be measured. The performance of AFC circuits may be studied in part and adjustment may be facilitated by observation of the drift meter while various adjustments are made. For example, the deviation of the STALO frequency before AFC circuits effect correction, and the degree of correction may be easily determined. Likewise, AFC servo-hunting present in some types of AFC circuits may be detected, since the meter will closely follow these low-frequency excursions. Magnetron frequency-pulling, caused by variation of coupling or of the standing-wave ratio, with rotation of the radar antenna, may be detected by observation of the deviation meter when the AFC circuits are operating, because the AFC circuits will tend to follow and to correct the STALO frequency. The results of line-stretcher adjustment to minimize frequency pulling may also be observed. In addition, the evaluator may be used to determine the optimum reflector voltage for the klystron local-oscillator tube by the correlation of the reflector voltage with the peak-to-peak frequency deviation indicated. Similarly, the optimum adjustment of the feedback circuits may be determined.

INTERPRETATION OF DATA

The STALO performance data obtained by the evaluator must be interpreted with maximum care. In the design of STALOS, the engineer goes to a great amount of trouble to shock-mount the oscillator assembly properly and to regulate and filter associated power supplies adequately. In some cases the assembly, including the cavities, is temperature-controlled to minimize drift. In spite of these precautions certain residual ripple voltages, transients, vibrations, thermal effects, and microphonics exist to cause some deviation of the oscillator frequency. The magnitude of the effect of these disturbances on frequency stability is largely determined by the type of oscillator and in some cases by the operational mode. It is apparent then that the interference or modulating waveform will include components from these sources. Thermal effects and microphonics are usually the least considered of the foregoing sources because any deviation caused by them is ordinarily negligible compared to power-supply ripple and vibration.

Transients frequently appear in the interference waveform. Some of these are caused by rapid load changes on the power line. These random transients seldom detract from or limit cancellation or subclutter-visibility ratios because their duration is very short and approximates two or three prf intervals. If they occur at high repetition rates not synchronous with the radar pulse rate, they may become objectionable. Other transients may appear at a 60-cps or 120-cps rate which may seriously limit the cancellation. These latter types are similar to those caused by defective gaseous voltage-regulator tubes and generally resemble a sawtooth. Still other transients may appear which are synchronous with the radar prf but which do not adversely affect cancellation or subclutter visibility since they are repetitive on a pulse-to-pulse basis and cause the same frequency deviation for each pulse period. If, however, there is a variation in time between successive pulses of 0.01 microsecond, a 30-cps change will occur at STALO frequency of 3,000 Mc, or a 10-cps change at 1,000 Mc. It is evident, therefore, that cancellation can be reduced if this time variation is very large.

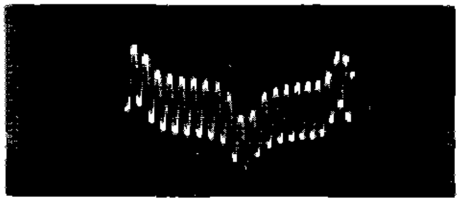
Experience with the testing of radar STALOS shows that sometimes the modulating waveform is not sinusoidal. For this reason, certain considerations are necessary. The operator of the instrument must first determine whether

1. The waveform is essentially sinusoidal with low-amplitude harmonics present, and all repetitive transients are synchronous with the radar pulse-repetition frequency.
2. The waveform is complex and has high-order harmonics of relatively high amplitude, with or without transients synchronous with the radar prf.

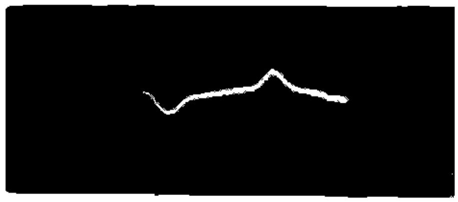
In category 1, the amplitude of the repetitive transients may greatly exceed the amplitude of any sinusoidal voltage present If this condition exists, the deviation meter will read high by an amount determined by the transient amplitude, the duration, the repetition rate, and the ballistics of the meter To obtain an accurate reading, the magnetron should be turned off, and, in some cases where transients from the trigger generator are radiated or coupled into the STALO power supply by crosstalk in cabinet cabling or through power transformers, the blocking oscillator tube should be removed or disabled. The low-pass filter within the test set will attenuate these high-frequency disturbances but will not eliminate them. With these transients eliminated, the rate of frequency change is essentially sinusoidal and may be computed from Equation (1). Similarly, the limitation on cancellation or subclutter visibility may be computed.

In the event that the waveform displayed fits the description of category 2, the frequency change is not strictly at a sinusoidal rate and the phase change is very difficult to compute. From a practical point of view, it is usually adequate to assume that the change is at a sinusoidal rate. The interference frequency must be determined, however, and may be taken as the basic or lowest frequency evident since it usually has the greatest amplitude. The error caused by this assumption will increase approximately in proportion to the deviation from a sine wave. The waveforms usually encountered are sufficiently sinusoidal to preclude the possibility of large errors in subclutter-visibility ratios.

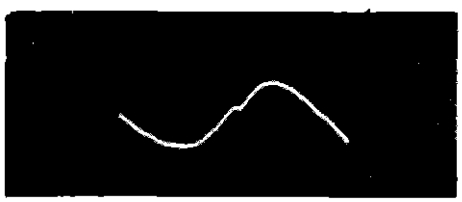
Figs. 7a, 7b, and 7c show oscilloscope traces of the interference waveforms for the ASR-2 S-band radar and the TDEC L-band radar STALOS and are representative of the waveforms frequently encountered. Fig. 7a shows the waveform of the ASR-2 radar with the blocking-oscillator functioning and indicates the presence of repetitive transients synchronous with the radar prf. Fig. 7b illustrates the interference pattern with the blocking oscillator disabled. The excellent stability of the L-band radar STALO is indicated in Fig. 7c. This latter STALO has a peak-to-peak frequency deviation of about 120 cps and an interference



(A) ASR 2 WITH BLOCKING OSCILLATOR ON
1800 CYCLES PEAK-TO-PEAK DEVIATION



(B) ASR 2 WITH BLOCKING OSCILLATOR DISABLED
350 CYCLES PEAK-TO-PEAK DEVIATION



(C) L BAND RADAR NORMAL OPERATION
120 CYCLES PEAK-TO-PEAK DEVIATION

Fig. 7

frequency of 60 cps, and it permits cancellation and subclutter-visibility ratios of 38 db at 30 miles. At 20 miles the limitation is 41 db, and at 10 miles this stability permits a subclutter-visibility ratio of 47 db. The intermediate-frequency portion of the system limits the subclutter visibility to about 33 db for targets at optimum velocity and phase conditions. It may be conservatively stated that the large majority of waveforms encountered are essentially sinusoidal in character. Elimination of transient signals at the radar prf by disabling the magnetron and the trigger generator will usually result in the display of a low-frequency wave of 60, 120, or 180 cps. It has been found that unbalance of the rectifiers in the STALO power supply frequently causes 180-cps components to appear. It is therefore advisable to check the condition of these rectifiers and of any gaseous voltage-regulator tubes in the power supply before concluding that the calculated subclutter-visibility limitation is typical or normal for the system.

The determination of the limitation on either cancellation or subclutter-visibility ratios imposed by the STALO at specific distances is accomplished by substituting measured data in the following equations

$$S_{db} = 20 \log \frac{2F_d}{P} \sin \pi Pt \sin \pi PT \qquad (2)$$

where

S = subclutter-visibility limitation, in db.

$2F_d$ = peak-to-peak frequency deviation, in kc.

P = interference frequency.

T = prf interval, in microseconds.

t = time, in microseconds, to point of measurement

The derivation of the equation for subclutter visibility follows Let the output of a STALO be frequency-modulated by a sinusoidal signal. This voltage will be

$$e = \sin (\omega t + K \sin \omega_P t) \tag{3}$$

where

$$\omega_P = 2 \pi P$$

$$K = \frac{F_d}{P} = \frac{\omega F_d}{\omega_P}$$

Let the pulse transmitted at time t_0 be

$$u = \sin \omega' (t - t_0) \tag{4}$$

The intermediate beat frequency between the pulse and the STALO has the form of

$$\begin{aligned} e_B &= \cos (\omega t + K \sin \omega_P t - \omega' t + \omega' t_0) \\ &= \cos [(\omega - \omega') t + K \sin \omega_P t + \omega' t_0] \end{aligned} \tag{5}$$

where

$(\omega - \omega') = 2 \pi \times$ intermediate frequency.

The COHO, which is locked by this pulse form, continues to oscillate after the pulse is transmitted and oscillates at a frequency ω_0. Thus

$$e' = \cos (\omega_0 t + K \sin \omega_P t + \omega' t_0) \tag{6}$$

$$\omega_0 = (\omega_I - \omega')$$

When the pulse is returned at time $(t_0 + \tau)$ after striking a target, it has the form

$u' = \sin \omega' (t - t_0 - \tau)$. It is assumed that there is no phase shift, and the voltages at the

phase detector are

$$\begin{aligned} V_{IF} &= \cos [\omega_0 t + K \sin \omega_P t + \omega' (t_0 + \tau)] \\ V_{COHO} &= \cos (\omega_0 t + K \sin \omega_P t_0 + \omega' t_0) \end{aligned} \tag{7}$$

The phase difference at time $t = (t_0 + \tau)$ between the COHO output and the signal is

$$\Delta \phi_1 = K [\sin \omega_P t_0 - \sin \omega_P (t_0 + \tau)] - \omega' \tau \tag{8}$$

After a pulse period T, the phenomenon is repeated and

$$\Delta \phi_2 = -2 K \sin \frac{\omega_P}{2} t \cos \omega_P (t_0 + T + \frac{\tau}{2}) - \omega' \tau \tag{9}$$

The difference ($\Delta \phi_1 - \Delta \phi_2$) measures the cancelled residue U of the return from a fixed target. Then

$$U = \Delta \phi_1 - \Delta \phi_2 \approx 2 K \sin \frac{\omega_P}{2} t \left[-2 \sin \frac{\omega_P}{2} T \sin \omega_P \left(t_0 + \frac{T + \tau}{2} \right) \right] \quad (10)$$

From this equation, the maximum value of U becomes

$$U_{max} = 4 K \sin \frac{\omega_P}{2} \tau \sin \frac{\omega_P}{2} T \quad (11)$$

which represents the maximum phase change during one pulse period.
The uncancelled residue, which is a measure of subclutter visibility, corresponds to a moving-to-fixed-target ratio of

$$S = \frac{U_{max}}{2} = 2 K \sin \frac{\omega_P \tau}{2} \sin \frac{\omega_P}{2} T \quad (12)$$

From this equation the value, in decibels, of subclutter visibility may be determined by

$$S_{db} = 20 \log \frac{2F_d}{P} \sin \pi Pt \sin \pi PT \quad (13)$$

From Equation (13) for subclutter visibility, it is indicated that phase difference at a specified range is

$$\phi_t = \frac{2F_d}{2} \sin \pi Pt \quad (14)$$

The maximum rate-of-frequency change at a given range can be determined quite easily if the interfering source is sinusoidal, as

$$\frac{df}{dt} = F_d \ \omega_P \quad (15)$$

For example, assume that the radar under test has a prf of 1,400 and that it is desired to find phase change, maximum rate-of-frequency change, and limitation on subclutter visibility, at 30 miles. Measurements obtained with the stability tester show that the peak-to-peak frequency deviation is 600 cps and that the jitter rate is sinusoidal at 60 cps. Rate of change is

$$\frac{df}{dt} = 377 \frac{600}{2} = 113,100 \text{ cycles per second per second} \quad (16)$$

Phase change is

$$\phi_t = \frac{600}{60} \sin \pi Pt = \frac{600}{60} \sin \pi \times 60 \times 342 \times 10^{-6} = 34.4^\circ \quad (17)$$

Subclutter-visibility limitation, in db, is

$$S_{db} = 20 \log \left(\frac{600}{60} \sin \pi\ 60 \times 342 \times 10^{-6} \times \sin \pi\ 60 \times 714 \times 10^{-6}\right) \quad (18)$$

$$S_{db} = 20 \log .078 = 22 \text{ db}$$

The subclutter-visibility limitation in decibels is usually the most frequently required value In the preceding example, the jitter in the STALO makes fixed targets appear like moving targets with a moving-to-fixed-target ratio of 22 db.

In the course of field-testing and maintenance of radar STALO, many conditions of STALO operation may exist because of the causes previously mentioned. Furthermore, it is laborious to solve the equations repeatedly each time a change in performance is noted or an adjustment is made. This situation is alleviated to a large degree by use of the curves of Fig. 8. These curves may be used to determine the subclutter-visibility limitation at 10, 20, 30, 40, 50, or 60 statute miles directly, when the interference source is 60 cps and the waveform is reasonably sinusoidal. This curve is used in the following manner.

1. Locate the peak-to-peak frequency deviation indicated by the STALO evaluator on the vertical axis at the left edge. Project horizontally to the intersection with the curve which represents the distance at which the subclutter limitation is to be determined.

2. Project vertically from this point to the intersection of the straight line representing the radar prf. Then project horizontally to the right edge of the graph and read the subclutter-visibility ratio in decibels.

Step 1 may be used to determine the phase change at a given distance by continuing the projection to the lower edge of the graph and reading the indicated phase change. These curves may also be used to determine the subclutter-visibility limitation for other interference frequencies such as 120, 180, or 240 cps by proceeding as directed in step 1 and projecting to the lower edge of the graph and reading the phase change for a 60-cps interference source. If the interference frequency is 120 cps, the phase change is twice that for 60 cps. Therefore, locate 2ϕ on the lower edge of the graph and project vertically to the intersection of the prf line, then project to the right to read subclutter-visibility ratio as indicated in step 2. In like manner use 3ϕ for 180 cps.

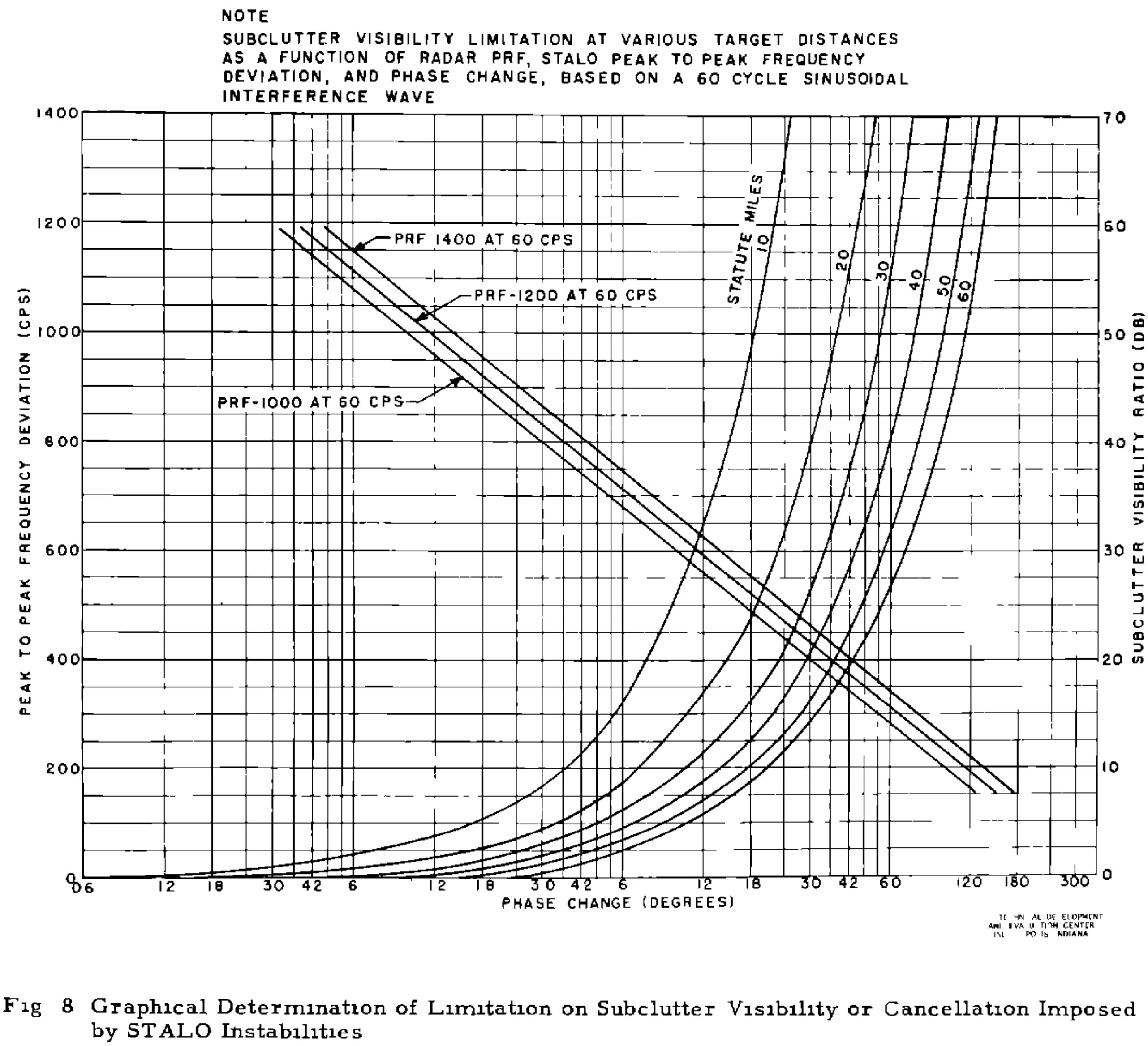


Fig 8 Graphical Determination of Limitation on Subclutter Visibility or Cancellation Imposed by STALO Instabilities

CONCLUSIONS

It has been shown that the STALO evaluator provides very accurate and complete data on the stability of radar local oscillators and, through the use of the charts provided, permits rapid determination of the limitation on cancellation and subclutter visibility. A series of measurements on the ASR-2 radar revealed that, with the radar adjusted for optimum performance according to currently prescribed adjustment criteria, the STALO was limiting the cancellation and subclutter visibility to 18 db. Readjustment of the reflector voltage on the local-oscillator tube improved the stability sufficiently to provide a subclutter visibility of 27.5 db. These ratios are for target distances of 20 miles. At a distance of 10 miles, the ratios are 24 and 33.5 db, respectively. These latter values are commensurate with the capabilities of the intermediate-frequency portion of the MTI system. On the basis of these figures, the STALO of the radar which was tested limits the cancellation and subclutter visibility beyond 10 miles.

The instrument, designed primarily for field use, is equally satisfactory for laboratory use where more complete data on the performance of STALO or other microwave signal generators or transmitters are desired. Use of the evaluator in connection with the maintenance of MTI radars is considered essential, since there is available no other instrument which provides the required accuracy and directly indicates optimum performance of the STALO and its effect on system performance. It is recommended that use of the evaluator be supplemented by use of an intermediate-frequency system evaluator to assure that optimum performance is obtained throughout. Since the STALO is usually the most critical part of the MTI system, the use of a suitable evaluator is strongly recommended.

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