TELEMETRY-SCORING RECEIVERS

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Summary In order to provide high accuracy telemetry and miss distance data in the 2200-2290 MHz band, improved receiver sensitivity and exceptional frequency stability are required. The higher receiver sensitivity is required due to extended range requirements with an antenna as small as possible. The exceptionally high frequency stability arises from the fact that typical deviations in center frequency during an intercept is in the order of a few KHz out of 2250 MHz. If the frequency stability problem is not handled properly, this information can be distorted to the point of uselessness. Another problem area that arises as a by-product of stability is phase noise in the local oscillators that degrade the output SNR of a quieted receiver. The solutions to such problems are described in the following sections along with the compromises required for operation on board ship.

Introduction This paper describes a miss distance indicator (MDI).

The MDI is one subsystem in the complete surface-to-air missile performance evaluation program of the U. S. Navy. The evaluation requires three types of information: (1) telemetry, (2) cooperative doppler, and (3) video doppler (or doppler roll-off). The MDI provides this information.

The telemetry is transmitted by the missile in the frequency range 2200-2290 MHz. The telemetry is received at the shipboard or surface station and at the target transponder. The transponder retransmits the complete telemetry signal and the doppler shift due to the closing velocity of the missile and target.

Therefore, the signals received at the ship occupy two different bands. One band is the 2200-2290 MHz mentioned above. The other band corresponds to the transponder output. This band is called the scoring band and is the range 1760-1850 MHz.

The antenna bandwidth is sufficient to handle the two bands of frequencies. The down-converter has two separate channels to process the two bands. The down-converted telemetry band is 240-330 MHz. The down-converted scoring band is 110-200 MHz.

The local oscillator frequencies for the MDI have been selected to give a telemetry channel IF frequency of 27.7 MHz and a scoring channel IF frequency of 27.824 MHz. This means that when the missile and target relative velocity is zero (no doppler shift), the output of these two IF strips is mixed together to obtain 124 KHz. This 124 KHz signal is processed in a channel G subcarrier discriminator to obtain the cooperative doppler information.

The above description nearly fits the system already in use by the Navy. A significant difference is that the video doppler is being transmitted on a separate carrier from the telemetry. In the new system, the video doppler is translated to the baseband region of 200-350 KHz and placed on the telemetry transmitter. The other major difference is that the old telemetry is FM/FM and the new format is PAM/FM.

The above description of the differences between old and new indicate the need for a new MDI is two-fold: (1) improved receiver performance, and (2) extended frequency coverage. Improved receiver performance is required due to the UHF telemetry conversion and the new modulation format. The performance of the limiter-discriminator had to be improved and expanded. The IF ampf if ier bandwidth had to be increased. Since high power radars will be operating on frequencies near both the UHF and down-converted UHF bands, good immunity to pulse-type interference is required. Another feature that had to be added is the coherent relationship of the local oscillator frequencies of the receiver and down converter. This requirement must be satisfied due to the double conversion of both the scoring and telemetry signals. The small frequency differences that arise in a non-coherent system would invalidate the recovered cooperative doppler information. Since frequencies in the 2 GHz region are involved, stability of the local oscillator signals with time and environmental conditions must be quite good.

The extended frequency coverage arose from the allotment of two 90 MHz bands. One of the bands is for the telemetry from the missile while the other band is for the transponded signal from the target. Channel assignments with information bandwidths of 1-5 MHz can be made in these 90 MHz bands.

MDI-Basic Description The MDI is composed of three basic sections; (1) receivers, (2) frequency synthesizer, and (3) test signal generator.

Unit 2 is shown in Figure 2. This drawer contains a telemetry-scoring receiver that permits scoring one missile against two targets. The telemetry signals at the receiver input occupy the frequency range of 240-330 MHz. The transponded scoring signals at the receiver input occupy the frequency range of 110-200 MHz. The block diagram of Unit 2 is shown in Figure 1 .

Unit 2, also, contains the frequency synthesizer that provides the local oscillator signals for the telemetry and two scoring channels and the L0 for the Telemetr Converter CV-2138/UK. The converter L0 as supplied by the synthesizer is 490 MHz. The receiver L0’s are a function of the S -band telemetry channel of operation.

Unit 2 contains the MDI discriminator which is a Data Control Systems GFD-13. This discriminator is used to demodulate the cooperative doppler channel. It is a phase-locked loop discriminator with an adjustable loop noise bandwidth. This feature permits selection of the lowest loop bandwidth that can be used to lock onto the signal and provide the highest possible output signal-to-noise ratio. This feature is used in conjunction with playback of the recorded cooperative doppler channel .

Unit 2 contains two signal processors that prepare the demodulated information for application to the decommutator (Unit 12 of the AN/SKQ-2) and the tape recorder.

Unit 3 contains a telemetry-only receiver which provides the same function and outputs as the telemetry channel of the Unit 2 receiver. One additional module identical to one of the frequency synthesizer modules is used to provide the local oscillator for this receiver.

Unit 3 contains the test signal generator. This unit contains an analog-digital section and an RF section. This generator provides an RF signal that simulates the cooperative doppler signal received from the missile-target combination with the exception that there is no telemetry modulation. A CW telemetry signal is available by itself for zeroing the 27.7 MHz demodulator portion of the receivers in both Units 2 and 3. The doppler simulation has two forms: (1) straight line approximations of trajectory curves, and (2) a step calibrator (9 steps). The digital section provides the timing information for the curve generation.

Receivers The receivers are of modular construction. The modules were devised on a function basis; i.e., RF amplifier module, IF amplifier module, distribution amplifier module, and 27.7 MHz demodulator module. A detailed description of the modules is given in the following paragraphs.

a. RF Amplifier - This module provides preselection and amplification. Low noise NPN Si transistors are used. FET’s were not used because there were no military qualified units available when this module was designed. Also, the upper limit ot the telemetry band (UHF) exceeds the recommended operating frequencies of existing FET’s.

This module is fixed-tuned and contains two stages of amplification with a double-tuned input and output. The -3 db bandwidth is approximately 5 MHz. The -60 db bandwidth of a typical unit in the telemetry band is 60 MHz while the -60 db bandwidth of a typical unit in the scoring band is 45 MHz. The minimum gain is 20 db.

b. IF Amplifier - This module contains not only the IF band-shaping amplifier but also the hot carrier diode double-balanced mixer and a 2-stage hard limiter.

The amplifier contains three stages of amplification and four double tuned filter sections used for interstage coupling as well as band shaping.

The -3 db bandwidth of the IF amplifier is approximately 1 MHz and the -60 db bandwidth is approximately 5.7 MHz. Minimum gain is 58 db.

The selectivity was allowed to roll off slowly to achieve the linear phase response in the pass band. The normalized phase response of the amplifier is shown in Figure 3. The data points have been plotted along with the 10/6 best straight line.

The amplifier has no AGC which is not impractical for an FM only type receiver. In fact, this tends to improve the capture ratio at certain signal levels. The problem that must be overcome, however, is intermodulation distortion at high signal levels. The problem was partially solved by using a hot carrier diode mixer. A transistor mixer was designed and tested. Without some form of AGC, however, the intermodulation distortion is too high.

The appropriate combination of fast silicon and hot carrier diodes used as amplitude limiters solved the remainder of the intermodulation problem.

c. Distribution Amplifier - This module contains the distribution network that provides two 27.7 MHz (IF) signals to the demodulator and one 27.7 MHz signal to a test point on the receiver sub-chassis.

This module, also, contains the transistor mixer that combines the 27.7 MHz telemetry IF signal and the 27.824 MHz scoring IF signal to obtain the cooperative doppler signal. This 124 KHz cooperative doppler signal is amplified and the high frequencies are filtered out in the output stage of the distribution amplifier.

d. 27.7 MHz Demodulator - The demodulator contains a phase-locked loop discriminator, a modified Foster-Seeley discriminator, 50 KHz active low-pass filter, 200 KHz high-pass filter with a 12.5 KHz notch filter, loss-of-lock indicator, and a tuning meter.

The PLL discriminator was selected to extend the FM demodulation threshold. Laboratory tests indicated the PLL discriminator had at least a 3 db advantage over the modified Foster-Seeley discriminator. At the time these tests were made, the range-transmitter power-antenna problem was such that the advantage was sufficient. Another advantage of the PLL discriminator was its performance during simulated fades or nulls in the antenna pattern. This performance advantage is in conjunction with the operational characteristics of the decommutator used in this system. It was of interest to determine the dynamic performance of the PLL as a function of input carrier power. The two loop parameters which were measured are hold-in range and lock-on range. In this case, hold-in range is taken to mean the amount that the loop can be pulled after initially being locked up. The lock-on range is the difference in frequency between the VCO free-running frequency and an input carrier to the demodulator which results in the loop acquiring the input signal. The results of these measurements are shown in Figure 4. These curves apply to measurements made above the VCO free-running frequency. The results are not symmetric about its center frequency. This asymmetry is produced by the characteristic of the varactor used in the VCO.

The VCO for the PLL is in a proportional oven to improve the stability vs. temperature change and provide the accuracy required.

The PLL discriminator is used to recover the PAM telemetry transmitted from the missile. The modified Foster-Seeley is used to recover the translated video doppler. The translated video doppler covers the baseband from 200 KHz to 350 KHz. The Foster-Seeley discriminator, also, is used to provide a wideband output that can be used for low deviation FM/FM.

The demodulated video doppler is fed to a separate PC board that contains a 12.5 KHz notch filter and a 7-pole Tschebyscheff passive filter. The notch filter is used to attenuate the sampling frequency of the PAM beyond that of the 7-pole filter. Simulated video doppler tests indicate that the phase distortion near band-edge of the 7-pole filter is not a problem.

The loss-of-lock indicator and tuning meter electronics are located on the same PC plug-in card. The loss-of-lock indicator gives an indication when the PLL discriminator loses lock, but not when the receiver loses the signal or RF carrier. This feature has been used in troubleshooting Units 2 and 3 and checking transmitters. The primary purpose of the tuning meter is to provide a visual indication when zeroing the VCO in the PLL discriminator. The accuracy of the tuning meter permits setting the VCO to within ±5 KHz of 27.7 MHz.

e. Signal Processors - There are two signal processors in the receiver drawer or Unit 2. These are plug-in modules. One portion of the signal processor contains a dc restoration circuit. The purpose of this circuit is to compensate for any offset in the missile transmitter frequency and the doppler shift between the ship and missile. The input to this circuit is either the PAM or Wideband out of the 27.7 MHz demodulator. The output of the dc restorer drives both the FM electronics of the tape recorder and the decommutator.

The remaining portion.of the signal processor is a 3-input combiner circuit. This circuit linearly combines three signals separated in the frequency domain in order to put them on one channel of the tape recorder. The inputs to the combiner portion are video doppler, cooperative doppler, and voice or time signals. The outputs of the signal processor are matched to 75 ohms.

f. MDI - Receiver Performance - This section contains the description of the overall performance of the receiver as a system composed of the units described in the previous paragraphs.

The sensitivity of the receiving system has been measured and is approximately -99 dbm with a 1 MHz predetection bandwidth.

The next area described is the dynamic performance of the 27.7 MHz demodulator. The tests were made using a 20 KHz sine wave to drive the PLL discriminator so that the output could be checked with a S ierra Wave Analyzer Model 121A. This 20 KHz sine wave was combined with a 275 KHz sine representing the middle of the video doppler spectrum. The 20 KHz signal deviated a Boonton 202J Telemetry Signal Generator 125 KHz and the 275 KHz was allotted 87.5 KHz of deviation. The measurements were made at 25° C with an input power to the RF plug-in module of -85 dbm. An additional phase of this test was to determine how the outputs varied as the center frequency of the signal generator was varied ± 100 KHz to simulate the offset in the transmitter frequency. The harmonic distortion of the PAM output varied from 1% at a center frequency in the IF strip of 27.7 MHz to 2% when the offset reached +100 KHz. The distortion decreased to 1% at a generator frequency offset -100 KHz. The level of the 275 KHz video doppler signal remained 50 db below the 20 KHz signal in the PAM output over the range of center frequency ± 100 KHz. The harmonic distortion in the wideband output with respect to the 20 KHz signal was 3% for +100 KHz offset of the signal generator and 2% for -100 KHz offset and no offset. The wideband harmonic distortion with respect to the 275 KHz signal was in the range of 1% to 2%. The harmonic distortion in the video doppler filter output was comparable to that for the wideband output with respect to the 275 KHz signal.

Another area of interest with respect to the entire system is capture ratio. A widely used definition was applied in this case. Two FM signal generators were set to the center frequency of the receiver (292.5 MHz). Both were deviated equal amounts (± 125 KHz). The desired signal was selected as a modulating frequency of 20 KHz and generator power of -74 dbm. The undesired signal was selected as a modulating frequency of 30 KHz. The definition states that capture ratio is the ratio of the desired signal RF power to the undesired signal RF power which yields the undesired modulating frequency 30 db below the desired modulating frequency. For the PLL discriminator the capture ratio was 2 db and 3.5 db for the modified FosterSeeley discriminator.

The remaining area to be discussed is that of adjacent channel interference. During these tests the receiver was operated at threshold without the decommutator. Sine wave modulation of two telemetry generators was used to identify the demodulated outputs. At threshold the output SNR was approximately 13-14 db with no apparent “clics” or “pops”. An interfering signal 1 MHz below the desired channel could be 30 db stronger than the desired without producing any distortion of the desired output. At a channel spacing of 2.4 MHz the interfering signal can be 60 db stronger than the desired without producing distortion in the output.

Frequency Synthesizer The synthesizer consists of three plug-in modules:

(1) T/M L0 (telemetry local oscillator), (2) 5 MHz coherent source, and (3) 49-490 MHz frequency multiplier.

a. T/M L0 - The T/M L0 module along with the RF amplifier module provides the channel selection capabilities of the receiver.

The T/M L0 contains a times 100 multiplier chain that multiplies the frequency of a high stability $2X10^{2}$/day) crystal oscillator by 100. The output of this multiplier chain is fed to three different other circuits. Two of these are triple tuned filters. The outputs of these filters are fed to the 5 MHz coherent source. The third output is filtered further and amplified to provide the proper power level (4 mw) for the mixer in the telemetry channel IF amplifier module.

b. 5 MHz Coherent Source - This module uses one 5 MHz high stability ($2X10^{-9}$/ day) crystal oscillator to produce three outputs frequencies: (1) 79 MHz, (2) 84 MHz and, (3) 49 MHz.

The 49 MHz is produced by dividing the 5 MHz down to 1 MHz and multiplying by 49 (two times 7 chains). The output is fed to the 49-490 MHz frequency multiplier module.

The 79 MHz and 84 MHz signals are produced by mixing the 49 MHz signal with the sixth and seventh harmonics of the 5 MHz crystal oscillator.

The 79 MHz and 84 MHz signals are mixed with the two T/M L0 outputs to produce the local oscillator signals for the scoring channels. These L0 signals are amplified and filtered in the T/M L0 module. By placing the scoring amplifiers and filters in the T/M L0, all the tuned circuits for a particular channel are in a single module.

c. 49-490 MHz Frequency Module - This module contains a times 10 frequency multiplier and power amplifier at 490 MHz. The power amplifier is required to overcome the cable losses that might exist between the console location and the downconverter. The down-converter requires 5 mw of 490 MHz.

Test Signal Generator The test signal generator provides three different signals thaf can be used to test the entire shipboard telemetry installation including the antenna, down-converter, receivers, and interconnecting cables. The test signal generator is located in Unit 3. The primary purpose of the test signal generator is to provide an accurate calibration of the oscillograph output to determine the miss distance and intercept velocity on board ship. This can be done by generating any one of 240 doppler curves by simply setting the front panel controls to the desired miss distance an intercept velocity. The curves generated are straight line approximations to the actual trajectory curves. The generator has a step calibrator (9 steps @ 10 KHz/step) to check the MDI discriminator for bandedge-to-bandedge deviation.

The basic mechanism used to generate the curves is to drive a capacitor in the feedback loop of an operational ampl if ier with a constant current source. Comparators, one-shots, and logic gates shape the curve.

The end result is an analog voltage of the correct proportions that deviates an FM transmitter operating at the scoring channel S -band frequency.

The telemetry channel signal is produced by multiplying a crystal oscillator by 100. The crystal oscillator operates at 22.525 MHz. A times 20 frequency multiplier is driven by the crystal oscillator. The times 20 multiplier drives a times 5 varactor multiplier. A two-cavity structure is used to select the correct harmonic of the step recovery diode.

Both the telemetry carrier and the scoring carrier are combined in a diplexer and fed to a test prod on the antenna pedestal.

The telemetry carrier can be supplied without the scoring carrier and used to zero the VCO in the PLL discriminator. The tuning meter and a front panel access potentiometer are used to make the zero adjustment.

Conclusion This paper has been concerned with describing the major elements of a missile performance evaluation program, and the part in this program played by the MDI. The MDI is the fixed-tuned receiver that demodulates the PAM/FM telemetry and video doppler. By having three independent channels of RF-IF amplification and selection, it can mix together the telemetry signal from a missile and the transponded telemetry signal from two targets to obtain cooperative doppler information.

The signal processors form the interface between the demodulator outputs and the display and recording devices in the remainder of the console in which the MDI is located. The distribution amplifier supplies the amplified and filtered cooperative doppler to the MDI discriminator for real time or on-line scoring.

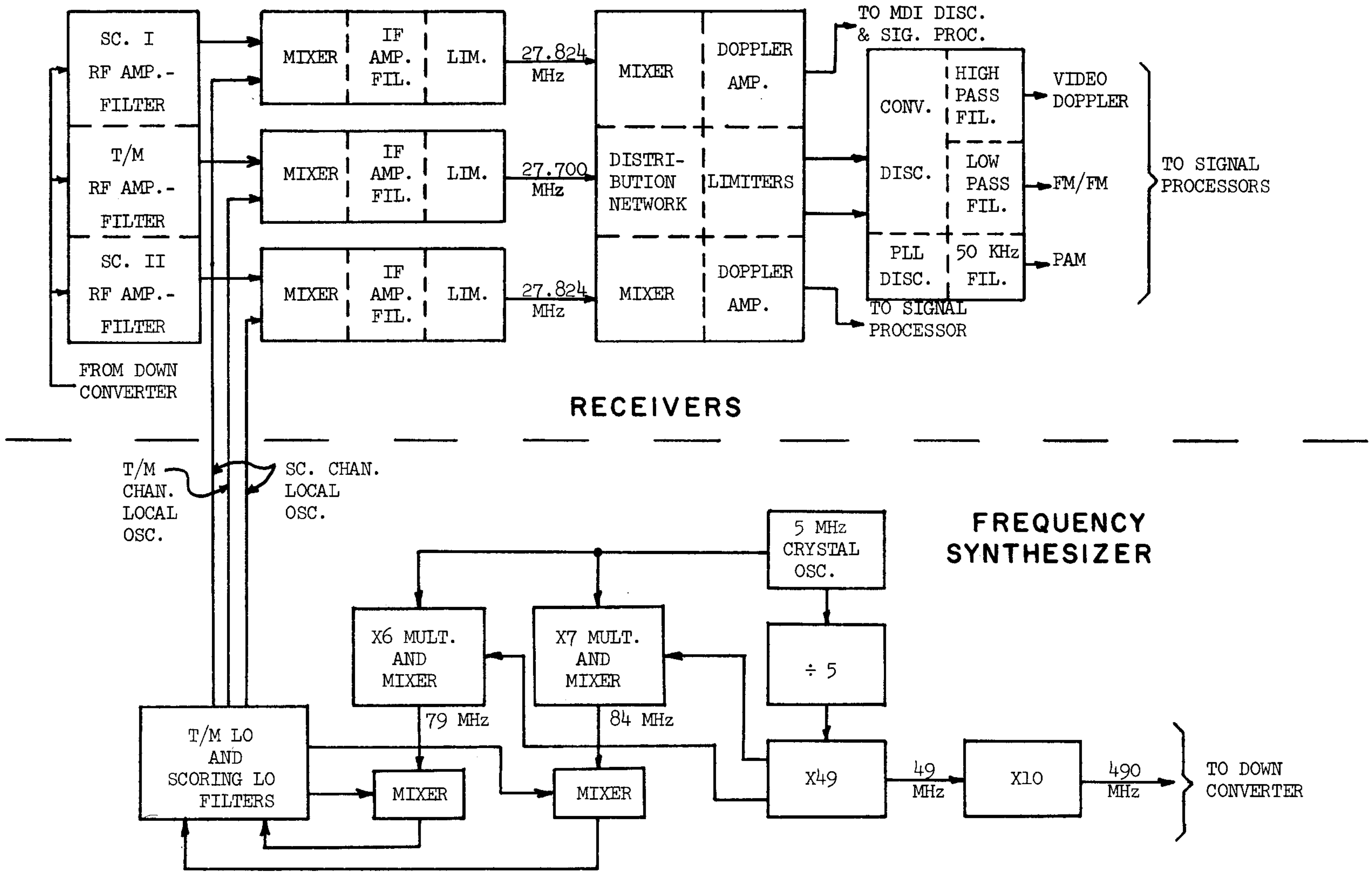

Figure 1. Block Diagram of Unit 2

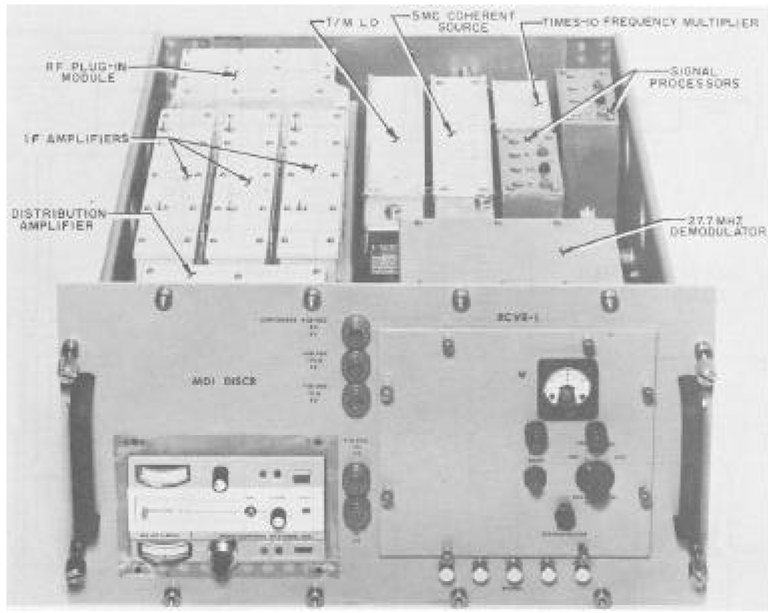

Figure 2. Front View of Unit 2 of AN/SKQ-2(XAN-1)

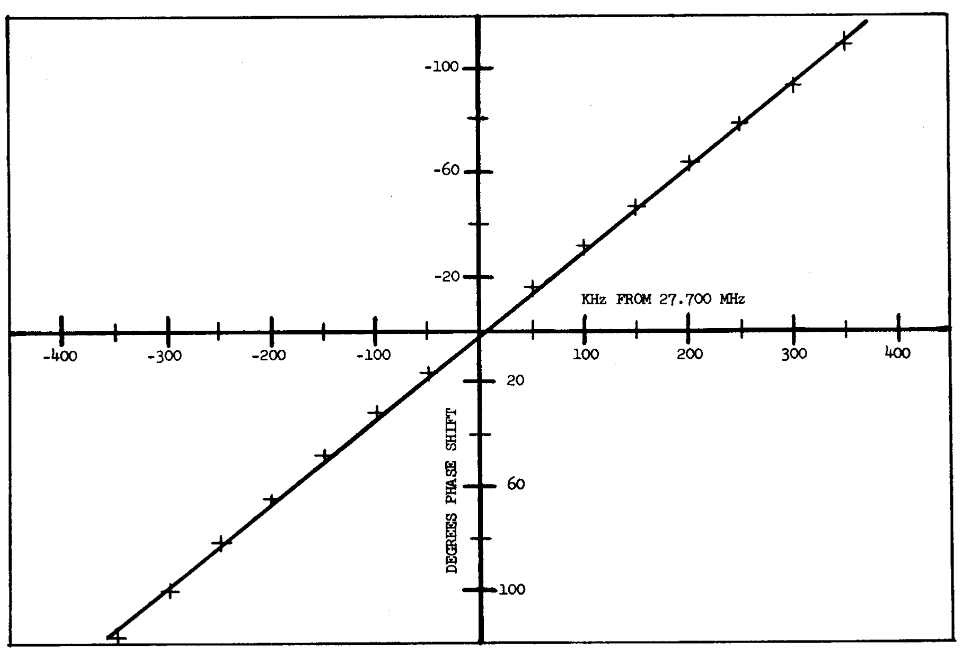

Figure 3. Phase Shift of IF Amplifier

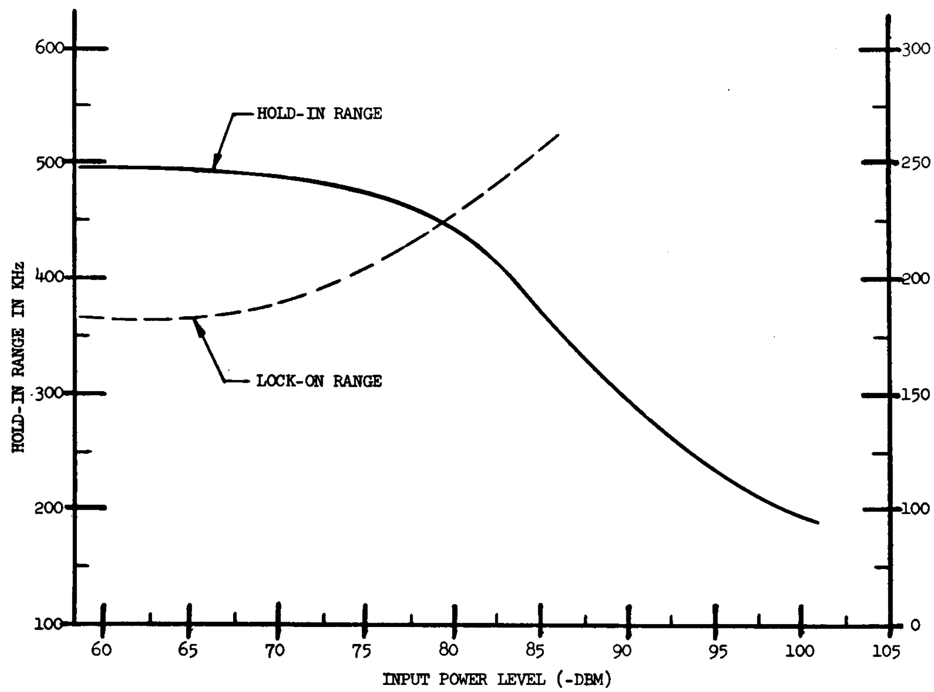

Figure 4. Hold-In Range Variation