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MTI PERFORMANCE OF THE ASR-1 AND ASR-2 RADARS

Measurements Made At
Willow Run Air Terminal,
Ypsilanti, Michigan, and
Chicago Midway Airport

<u>FOR LIMITED DISTRIBUTION</u>

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Acting on a request from the Office of Federal Airways, engineers from this Center traveled to Willow Run Air Terminal, Ypsilanti, Michigan, and to Chicago Midway Airport, Chicago, Illinois, to perform MTI measurements on the ASR-2 and ASR-1 radars, respectively. These tests were performed on the ASR-2 radar from May 4 to May 14, 1952; and from May 26 to May 28, 1952, tests were performed on the ASR-1 radar.

Test equipment taken to conduct these tests consisted of a stalo stability tester, MTI evaluator, Tektronix 511 AD synchroscope, Tektronix 121 preamplifier, and a DuMont 241 oscilloscope. Before starting the tests, target ranges were selected which would allow comparative checks with other radars. The ranges selected were 10, 30, 45, and 60 miles. These ranges were selected for the following reasons: ten miles represents the average ground clutter radius for normal operation; 30 miles represents the most used operational range; 45 miles represents the maximum MTI evaluator range; and 60 miles represents the maximum range for the ASR-2.

To achieve maximum performance of any MTI radar system, it is necessary that various units of the system are operating at peak efficiency. Neglecting scanning losses and target movement, system instabilities in the equipment limit the ability of the equipment to cancel any specific target. Therefore, it is necessary to know the frequency stability, jitter rate, and rate of change of the stalo and coherent oscillators, the stability of the transmitted pulse regarding pulse-to-pulse time jitter, and variation in pulse length. The equipment available at this time would not permit direct quantitative measurement of all of these parameters; however, it can be shown that adequate information is available to provide accurate and realistic performance data:

Measurements performed on the ASR-1 and ASR-2 radars were:

1. Subclutter visibility ratios
2. Cancellation ratio
3. System trigger jitter
4. Coho stability
5. Stalo stability
6. Magnetron pulse jitter

Measurements 1, 2, and 4 were made at the 30-Mc intermediate frequency of the system and exclude the effects of scanning, stalo, or radio-frequency transmitter instabilities. Measurements 3 and 6 were made at video frequencies. Measurement 5 was made at the fundamental radio frequency. Overall system performance of the MTI system is determined through mathematical correlation of the above measurements. The methods used in determining subclutter visibility ratios, and other data, are described below:

The MTI evaluator provides three signal pulses to the radar equipment:

1. A 30-Mc locking pulse to the coho of the radar pulse width, and variable in amplitude.
2. A 30-Mc fixed target pulse, three times the radar pulse width, movable in range, and variable in amplitude, which is fed to the input of the MTI receiver.
3. A moving target pulse of the radar pulse width, movable in range, and variable in amplitude, also fed to the input of the MTI receiver. Adjustment is provided to vary the moving target speed from 0 to 3000 mph, divided by the radar frequency in Kmc.

Interchangeable delay lines in the MTI evaluator test set provide for moving target and coho locking pulses equal in duration to the pulse width of the radar and fixed target pulses three times the radar pulse width. Measurements are read directly in decibels from three precision variable attenuators which attenuate the locking, moving and fixed target pulses independently and provide for attenuation of the moving target with respect to the fixed target.

1. <u>Subclutter Visibility Measurements:</u> It is important that subclutter visibility ratios be determined for the most favorable and least favorable phase conditions; and, since phase detectors are usually not perfectly balanced, it is desirable to make measurements at four different phase conditions. For reference purposes, these phase conditions are:

Phase A
Phase B
Phase C
Phase D

The procedure is to feed a coho locking pulse, and equal-amplitude, moving and fixed target pulses to the MTI receiver with the moving target adjusted for optimum velocity (maximum response). The target pulses are adjusted to the range at which it is desired to make the measurement and the coho adjusted to display three or four cycles within the MTI gate. Output is observed on a synchroscope having high "Y" axis gain and connected to observe MTI video. The coherent oscillator is readjusted slightly to place the target pulses at the center of the phase detector curve as shown above for phase A. The radar MTI is adjusted for maximum cancellation of the fixed target. The moving target must not be at the same range as the fixed target for this adjustment. After adjusting the cancellation, the moving target is again centered over the fixed target pulse and the amplitude of the moving target is reduced to the point where the amplitude of the moving target equals that of the uncanceled residue of the fixed target. The subclutter visibility ratio for this optimum target speed, phase condition, and range is read directly from the attenuator dial setting. The procedure is then repeated for the same target ranges and each of the other target phase conditions. Measurement at other target ranges is accomplished by repeating the above procedure at the selected target ranges. Measurements are made at 1:1 voltage ratio points. A wide band synchroscope providing high display brightness is necessary for accurate measurements.

Subclutter visibility ratios (at intermediate frequency with targets at optimum velocity) for the ASR-1 radar at Chicago, Illinois, are:

Miles:	10 (db)	30 (db)	45 (db)
Phase A	27	27.5	26.4
Phase B	27.7	27.9	27.1
Phase C	20.1	20.3	18.4
Phase D	18	17.9	19

(All figures are the averages of several readings. Variations in readings for each phase condition are due to reading errors.)

Subclutter visibility ratios (at intermediate frequency with targets at optimum velocity) for ASR-2 radar at Detroit, Michigan, are:

	Channel A			Channel B		
Miles:	10 (db)	30 (db)	45 (db)	10 (db)	30 (db)	45 (db)
Phase A	32.72	31.11	32	29	28	28.4
Phase B	29.5	31.3	30	30	27	29
Phase C	13.25	20	19.9	18	17	17.8
Phase D	12	18	20	15	19.9	18.8

2. Video Cancellation Ratio: ASR-1 radar, Chicago, Illinois; ASR-2, Detroit, Michigan.

The MTI evaluator is used for the measurement of cancellation ratio provided by the cancellation circuits. The moving and fixed target pulses are fed into the intermediate frequency amplifier of the evaluator where they are amplified and detected. Precautions are observed to avoid limiting and nonlinearity. The output video signal is delivered to the input of the MTI line modulator. A synchroscope connected at the output of the delay line driver is observed to determine modulation percentage. The intermediate-frequency gain control of the evaluator is then adjusted to supply the rated modulation of the carrier. Then the moving target is centered over the fixed target. The synchroscope is then connected to observe canceled video with the moving target adjusted for optimum velocity. The moving target is then attenuated until it is of the same amplitude as the canceled fixed target residue (1·1 ratio). The cancellation ratio is then read from the moving target attenuator dial. Cancellation ratio at ten miles for ASR-1 radar: 27 db; ASR-2 radar: Channel A - 24 db, Channel B - 27 db.

3. System Trigger Jitter.

Jitter is measured by a jitter tester which is a part of the evaluator. A high-intensity post-acceleration cathode-ray tube is built into the MTI evaluator for observation of jitter. A free-running sine wave oscillator provides the horizontal time base. The system trigger, or other pulse in question, is displayed vertically on the cathode-ray tube. The frequency of the time base is adjusted manually until the displayed pulse is essentially stationary. Jitter can then be observed by the spreading of the trace or fuzziness of the leading edge of the pulse. The amount of time jitter can then be read on a scale on the face of the cathode-ray tube which is calibrated in 0.1-microsecond intervals. This measurement represents the over-all time jitter of the pulse and not the pulse-to-pulse jitter. However, the radar pulse jitter cannot exceed the long term jitter.

System trigger jitter (over-all term jitter) on ASR-1: 0.08 microsecond.

System trigger jitter (over-all term jitter) on ASR-2 radar with prf tracker on: Channel A - 0.08 microsecond; Channel B - 0.07 microsecond.

4. Coho Stability.

This is determined with the MTI evaluator. A 30-Mc CW carrier is provided by the evaluator which is fed to the MTI receiver. A coho locking pulse from the evaluator is provided to lock the 30-Mc coherent oscillator. The output of the coherent oscillator is compared to the output of the 30-Mc reference CW carrier by the phase detector. The waveform displayed on the synchroscope is the phase detector response curve. By adjusting the frequency of the coherent oscillator, it is possible to vary the number of displayed cycles. If the coherent oscillator frequency jitters, it will be evidenced by widening of the trace which becomes worse as the range increases.

Coho stability - ASR-1 radar: Jitter or drift not perceptible.

Coho stability - ASR-2 radar: Channel A - Jitter or drift not perceptible; Channel B - Jitter or drift not perceptible.

5. Stalo Stability.

Performance data were obtained through the use of the stalo stability tester. The output of the stalo under test beats with harmonics of a crystal oscillator which is designed for very high short-term stability. The output of the stalo is combined with a harmonic from the crystal oscillator in a mixer. The output of the mixer is then amplified by a narrow band 10.7-Mc amplifier. The output of this amplifier is followed by a detector that heterodynes the 10.7-Mc signal with the output of a 10.7-Mc, crystal-controlled beat frequency oscillator. The resulting audio frequency beat varies in frequency by the same number of cycles as the frequency of the stalo under test. The displayed cycles can be used to observe drift and jitter. Drift or a slow change in stalo frequency will be noticed as a change in the number of beat cycles displayed by the synchroscope. This value may be read directly by use of an audio frequency meter. Jitter is observed on the scope as a widening of the audio beat trace, which increases in value with range provided that the scope sweep speed is greater than any rate of jitter. For purposes of computation, the width of the trace at a known range is measured and recorded as a ratio to the width of one beat cycle. This ratio represents frequency deviation of the stalo which has the effect of causing fixed targets to appear as moving targets. If the rate of jitter is unknown, an approximation of subclutter visibility may be calculated, using the above measurement as a voltage ratio. If the jitter is sinusoidal and relatively low in frequency, the sweep speed frequency of the oscilloscope can be reduced to the point where one or more complete cycles of the jitter modulation can be observed. Using known sweep speeds, the rate of modulation may be determined. Peak-to-peak frequency deviation can be determined by measuring the trace ratio, which is a frequency ratio at a given sweep distance and dividing the ratio by the given sweep figure. If one knows that the cause of jitter is sinusoidal at a radian frequency, the frequency deviation may be differentiated with respect to time to obtain the rate of frequency change. Considering the maximum phase change as 180 degrees, the above frequency ratio times pi will give the maximum phase change that can be expected at the predetermined range. The data obtained on the ASR-1 radar stalo are given. All figures shown are averages of several readings.

	Miles:	10	30	45	60
Peak-to-peak frequency deviation:	Cycles/sec:	398	224	233	236
Jitter rate: 60 cycles/sec.					
Maximum rate of change:	Cycles/sec.^{2}:	75,000	42,250	43,900	44,500
Maximum phase change:	Degrees:	6.7	13	20.1	27.4
Maximum subclutter visibility ratio:	Miles:	10	30	45*	60*
(obtainable neglecting scan losses)	DB:	27.16	21.52	17.76	15.04
Maximum cancellation:	Miles:	10	30	45*	60*
(obtainable neglecting scan fluctuations)	DB:	27.16	21.52	17.76	15.04

(*) Assumes ground clutter at these ranges.

ASR-2 Radar Stalo Measurements

Due to interaction between stalos, when both were operated simultaneously, measurements were taken with stand-by channel inoperative.

Stalo stability - <u>Channel A:</u>	Miles :	10	30	45	60
Peak-to-peak frequency deviation	Cycles/sec :	420	523	390	390
Jitter rate: 60 cycles/sec.					

Maximum rate of change:	Cycles/sec^2:	158,000	148,400	73,300	73,600
Maximum phase change:	Degrees:	14.2	29.5	32.5	43.4
	Miles:	10	30	45*	60*
Maximum subclutter visibility ratio: (obtainable neglecting scan losses)	DB :	23.4	16.06	14.8	12.3
Maximum cancellation: (obtainable neglecting scan losses)	DB :	23.4	16.06	14.8	12.3

(*) Assumes ground clutter at these ranges.

ASR-2 Radar Stalo Measurements

Stalo stability - Channel B:	Miles :	10	30	45	60
Peak-to-peak frequency deviation:	Cycles/sec:	434	530	438	402
Jitter rate: 60 cycles/sec.					
Maximum rate of change:	Cycles/sec^2:	144,467	99,967	85,567	77,100
Maximum phase change:	Degrees:	15.1	31	38	48
	Miles:	10	30	45*	60*
Maximum subclutter visibility ratio: (obtainable neglecting scan losses)	DB :	22.8	15.8	14	12.1
Maximum cancellation:	DB :	22.8	15.8	14	12.1

(*) Assumes ground clutter at these ranges.

6. Magnetron Radio Frequency Pulse Jitter:

Magnetron pulse jitter measurements are obtained with the use of the jitter tester, using the same method as described for taking system trigger jitter.

ASR-1 magnetron radio-frequency pulse jitter: 0.08 microsecond.
ASR-2 magnetron radio-frequency pulse jitter:

Channel A	Channel B
0.08 microsecond tracker off	0.07 microsecond tracker off
0.15 microsecond tracker on	0.07 microsecond tracker on

Coherent Oscillator Locking Pulse Amplitude:

The coherent oscillator of the ASR-1 radar locks in with a locking pulse amplitude of -37 db below one milliwatt at Jack J-117. To insure proper locking of the coherent oscillator, the locking pulse amplitude should be increased by approximately 15 db. This gives a locking pulse amplitude of -22 db below one milliwatt.

CONCLUSIONS

The MTI performance data taken of the ASR-1 and ASR-2 radars were obtained with test equipment now available for that purpose. Scanning losses were neglected as it is impossible to compute these losses accurately. No data were obtained on magnetron frequency stability as test equipment was not available at the time these measurements were made. PRF jitter effects have been included in all tabulated data where applicable.

Analyzing data obtained on the ASR-1, it is concluded that a locking pulse amplitude of -22 dbm will properly lock the coherent oscillator. The locking pulse amplitude, necessary to lock the coherent oscillator, will vary somewhat with various radars.

The known limiting factors for MTI performance of the ASR-1 and ASR-2 radars will be stability of the stalo, MTI intermediate frequency and cancellation circuits, coherent oscillator and system trigger jitter. From tabulated data shown herein, performance limitations of the MTI system may be ascertained. As an example, for the ASR-1 radar at Chicago, using the MTI evaluator, the subclutter visibility ratio measurement for ten miles shows that for Phase B (optimum phase) a 27.7 db reading was obtained. For Phase D (least favorable phase) a reading of 18 db was obtained. The maximum subclutter visibility which the stalo will allow is 27.16 db. These figures show that for the Phase B condition the performance limiting factor is the stalo. For the Phase D condition the phase detector characteristic is the limiting factor.

Subclutter visibility ratios taken at 30 miles show; for Phase B (optimum phase) 27.9 db and for Phase D (least favorable phase) 17.9 db. The maximum subclutter visibility which the stalo will allow is 21.52 db. For the Phase B condition the limiting factor would be the stalo performance but not for the Phase D condition.

From data obtained on stalo performance, the maximum subclutter visibility allowed by the stalo drops rapidly with increasing range. This limitation is not a serious factor in over-all MTI performance since the maximum MTI gate is 30 miles, and ground clutter beyond 30 miles is seldom encountered. The video cancellation ratio taken with the MTI evaluator was 27 db at 10 miles for the ASR-1. Stalo performance will be a limiting factor in over-all cancellation ratio beyond approximately ten miles. The limiting factors are shown in the tabulated data.

Coherent oscillator drift and jitter for the ASR-1 and ASR-2 radars is not a limiting factor for over-all MTI performance since there was no drift or jitter. For the ASR-2 radar at Willow Run Air Terminal, the known limiting factors may be ascertained in the same manner by checking the tabulated data. A comparison of the over-all MTI performance of the ASR-1 and ASR-2 radars also may be made from the tabulated data.

For a comparison between the ASR-1 and ASR-2 radars the tabulated data will show that for subclutter visibility ratios the difference between the two radar equipments is negligible. Cancellation ratios of the ASR-1 and ASR-2 radars are about the same. From the tabulated data, the figures show that the performance of the ASR-1 stalo is superior to that of the ASR-2 stalos. A definite improvement is needed in the performance of the ASR-2 stalo. Scanning losses may be the limiting factor for good over-all MTI performance for the ASR-1 and ASR-2 radars now in service. These losses will vary from site to site.

Further development of stalo oscillators to reduce instabilities is desirable for improved MTI performance. Crystal control of the stalo frequency would be advantageous.

Magnetron frequency control is also a desirable feature. Development of a crystal-controlled radar transmitter should be helpful in minimizing this stabilization problem.