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NRL Report 5067

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A STUDY OF MARK X IFF AND TACAN

[UNCLASSIFIED TITLE]

H. M. Suski

Security Systems and Avigation Branch
Electronics Division

March 14, 1958

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NAVAL RESEARCH LABORATORY
Washington, D.C.

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A STUDY OF MARK X IFF AND TACAN

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A METHOD FOR PREDICTING TACAN CHANNELS WHICH CAUSE INTERFERENCE TO THE MARK X IFF SYSTEM

~~[SECRET TITLE]~~

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ABSTRACT

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A method is presented for predicting Tacan channels which can be expected to cause interference to IFF systems. While the method is general and can be applied to either system, this report only treats the case of interference by Tacan system equipments to IFF equipments.

The effects of interference are treated by considering nine simple links between the source and the equipment affected by the interference. Sets of curves have been constructed to approximate the overall frequency response to be expected from the various kinds of IFF equipments (e.g., interrogator-responsors and transponders) using Tacan equipments as signal generators. These overall response curves, which include expected production and service operating variations, have been constructed with the aid of data taken by the Naval Air Test Center (NANEP), Patuxent River, Maryland. When the overall response curves are used with line-of-sight propagation curves, a graphical means is provided for determining the Tacan frequency channels which will cause interference on specific links. By choosing a number of distances (i.e., separations between the interference source and the equipment affected) together with the calculated duty cycle of the source (Tacan equipment) a plot of the interfering channels is obtained for each link. Sets of results for half-wave dipole receiving antennas are given, and means are provided to correct for the effects of using directive, rotating interrogator-responsor antennas.

Predicted results, obtained using the method of this report, compare favorably with NANEP flight test data. Further use is made of the nine simple links to demonstrate that any practical operational situation can be resolved into these links for analysis of the entire interference situation. It is shown that any practical case can be represented as one of two pairs of general cases. A schematic representation is used together with limit equations for duty cycle to provide a systematic means of analyzing practical interference situations and determining the total interference (duty cycle) to be expected. As an example of the use of the complete method, the results of tests performed by the Operational Development Force at Atlantic City, New Jersey, during October 1955, are analyzed. There is favorable comparison of the actual and predicted results.

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PROBLEM STATUS

This is an interim report; work on the problems is continuing.

AUTHORIZATION

NRL Problem R03-01
Projects NR 415-000, Task NR 415-001, NE 041-215-1,
and NA 441-001
BuShips No. S-1234X-S

NRL Problem R03-02
Project NE 041-215-23.3
BuShips No. S-1813

NRL Problem R95-01
Project NA 441-001
BuAer No. EL-8A-376

Manuscript submitted November 15, 1957

UNCLASSIFIED

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A METHOD FOR PREDICTING TACAN CHANNELS WHICH CAUSE INTERFERENCE TO THE MARK X IFF SYSTEM

[Secret Title]

INTRODUCTION

Because the Tacan and IFF Mk X systems have been developed to operate in the same frequency band, they are subject to mutual interference effects. Such effects have been studied and analyzed qualitatively, explored experimentally, and tested operationally (1-5).

There are many effects of mutual interference. The interference to be considered in this report is only that which is propagated as the regular authorized transmission of specific equipments.* It is assumed that final production equipments will have satisfactorily passed radiated and conducted noise tests. Both systems use interrogator-responsors and transponders or beacons. Although the Tacan system includes only an airborne interrogator-responsor and a surface or ground beacon, the IFF system uses both airborne and surface transponders as well as airborne and surface or ground interrogator-responsors. Various combinations of equipments which can create mutual interference are possible; a number of combinations are shown schematically in Fig. 1 as vectors to indicate both the source and the affected equipments for each link.

Even though the interference problems are mutual, and detrimental effects can be caused by both systems, this report considers only effects of interference on the IFF system caused by the Tacan system: the A links of Fig. 1. The process of evaluating the effects of interference is quite general, however; and, given similar performance data, the method developed here can be applied to the other half of the problem: the B links of Fig. 1.

The interference links are either simple or compound. Nine of the simple links (Fig. 1) are to be considered and are described briefly in Table 1. It is shown that compound situations can be described in terms of these simple links.

IFF SYSTEM RESPONSE CURVES

To evaluate the effect of interference on the performance of a system, measurements are made on individual equipments and then related to production lots of the equipments involved. Since this report considers system effects, data on the performance of IFF equipments have been analyzed. A set of overall or system tolerances has been obtained for four parameters which are necessary in predicting frequency regions where interference is expected (see Appendix B). These four parameters are (a) responsor sensitivity or transponder minimum triggering level (MTL), (b) receiver center frequency, (c) receiver overall bandwidth, and (d) transmitter power output. The system tolerances† given in Table 2 are estimates based on the combination of production and operational variations.

*See Appendix A for a more detailed discussion of mutual interference problems.

†These tolerances were obtained by methods described in Appendixes B, C, and D. The production variations (see Appendix C) were obtained from a sample of production test data on a single type of interrogator-responsor (AN/TPX-17) equivalent to AN/UPX-1 type equipments). The operational variations (see Appendix D) were obtained from acceptability test data for a single type of interrogator-responsor (AN/UPX-1A) and a [redacted] of transponder (AN/UPX-5).

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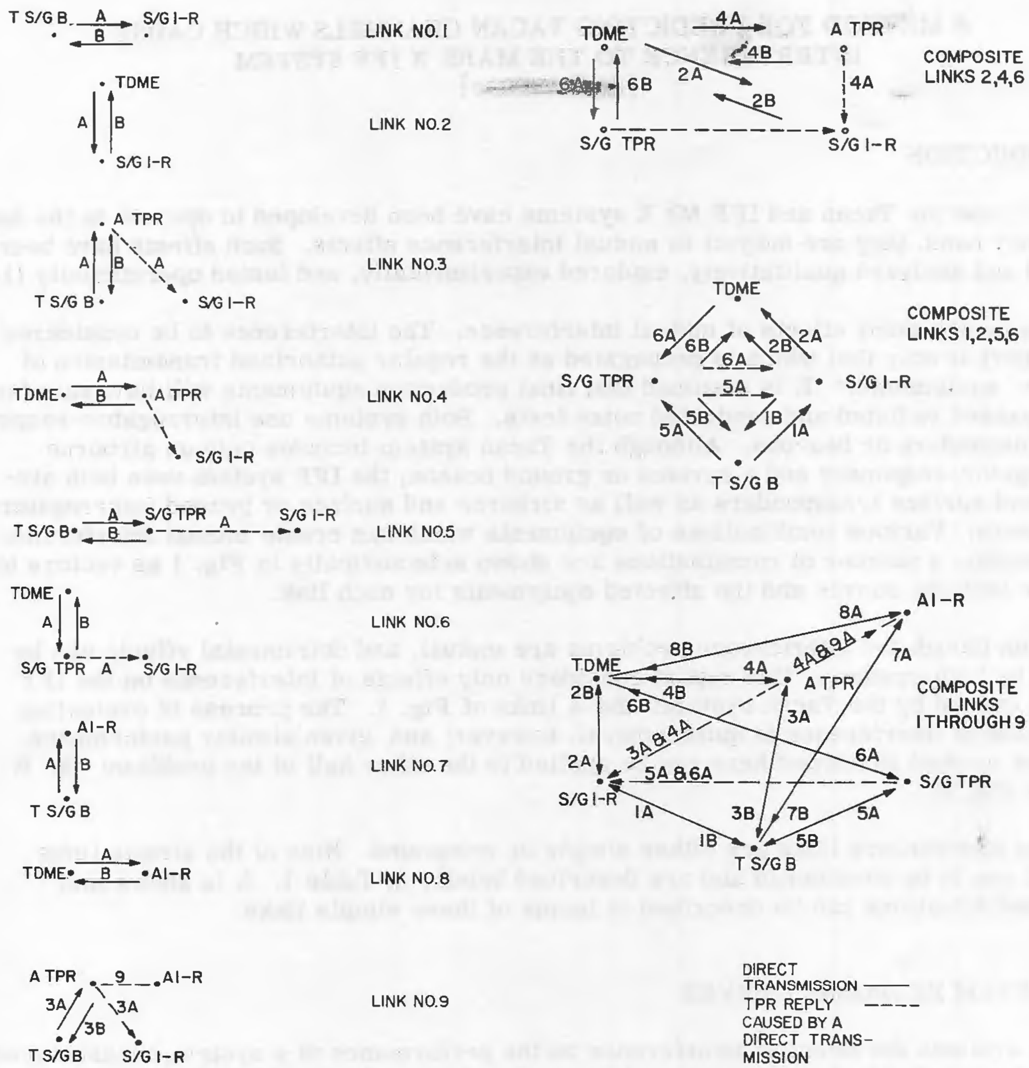

Fig. 1 - Some Tacan-IFF mutual interference links. The notation is based on that used by NANEP (4). The abbreviations used in the figure and throughout the report signify:

A TPR	-	airborne transponder (AN/APX-6, -25, -30)
A I-R	-	airborne interrogator-responsor (AN/APX-7)
S/G I-R	-	surface/ground interrogator-transponder (AN/UPX-1, -6)
S/G TPR	-	surface/ground transponder (AN/UPX-5)
TDME	-	Tacan airborne interrogator-responsor used as distance-measuring equipment (AN/ARN-21)
T S/G B	-	Tacan surface/ground beacon (AN/URN-3)

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TABLE 1
Summary of Simple Links of IFF Interference from Tacan System Sources

Link	Equipment Affected (Receptor)	Source	Interference Duty Cycle (%)*	Effects, if there is interference
1A	S/G I-R	T S/G B	2.5	possible reduction in responsor sensitivity (reduced service area)
2A		TDME	0.02 to 0.10	possible garbling of transponder replies (code rejection or wrong code acceptance) increased fruit rate (unsynchronized replies)
3A	A TPR and/or S/G I-R	T S/G B	2.5	possible reduction in minimum triggering level (reduced service area)
4A		TDME	0.02 to 0.10	possible garbling of interrogations with a possible reduction in replies which can be displayed
5A	S/G TPR and/or S/G I-R	T S/G B	2.5	possible triggering (reduces traffic capacity) with effect on responsor same as in links 1A and 2A
6A		TDME	0.02 to 0.10	
7A	A I-R	T S/G B	2.5	See links 1A and 2A
8A		TDME	0.02 to 0.10	
9A	A TPR and/or S/G I-R and/or A I-R	T S/G B	2.5	See links 3A and 4A
		TDME	0.02 to 0.10	

* Values given are based on interference by a single equipment

[redacted]

TABLE 2
Estimated Overall Tolerances of
IFF Mk X Equipments
(The 3σ values were obtained as a statistical sum of component variations; the maximum values, as an arithmetic sum. See Appendixes B, C, and D.)

Parameter	Overall Tolerance			
	Interrogator-Responsor		Transponder	
	3σ	MAX	3σ	MAX
Receiver Sensitivity or Minimum Triggering Level (db)	±9.5	±13.1	±9.9	±13.5
Receiver Center Frequency (Mc)	±7.5	±10.3	±7.5	±10.3
Receiver Overall Bandwidth (Mc)	±4.8	±6.7	±4.8	±6.7
Transmitter Power Output (db)	±4.7	±6.5	±4.7	±6.5

Use is made of the three receiver system tolerances (see Appendixes E and F) in connection with experimental data to obtain the system response curves. Figure 2-4 show the response of transponders and responsors to Tacan transmitted signals. Each response curve consists of a pair of curves which signify two limit conditions. The lower limit (solid line) represents a response of reasonable expectation; and the upper limit (dashed line), the response which is possible upon combination of extreme conditions. Thus, between these limits approximately 50 percent of the system receivers should be found. The response curves for transponders (Figs. 2 and 3) include both the response causing (Tacan) signals to appear in the receiver output and the response causing the transponders to reply (or to be triggered). There are separate response curves for airborne and surface transponders because of the difference in image rejection.

Since it is expected that a rather large number of Tacan airborne equipment (TDME) will unavoidably contain spurious transmitted signals, the effect of these equipments on the interference problem must be considered. The overall response curves for transponders when spurious signals are present are shown in Fig. 3.

The responsor overall response curves (see Appendix E) are shown in Fig. 4 as a single set which have been drawn for two image rejection values, 35 and 60 db. The receivers for the latter case are those in the IFF system which are crystal controlled. Since no performance data were available for the smaller receiver center-frequency variation to be expected in crystal-controlled receivers, it was decided to show the lower image response alone. The results obtained in determining regions of interference for crystal-controlled responsors, therefore, will be somewhat pessimistic. The effect on responsors of the presence of TDME spurious transmitted signals is also shown in Fig. 4.

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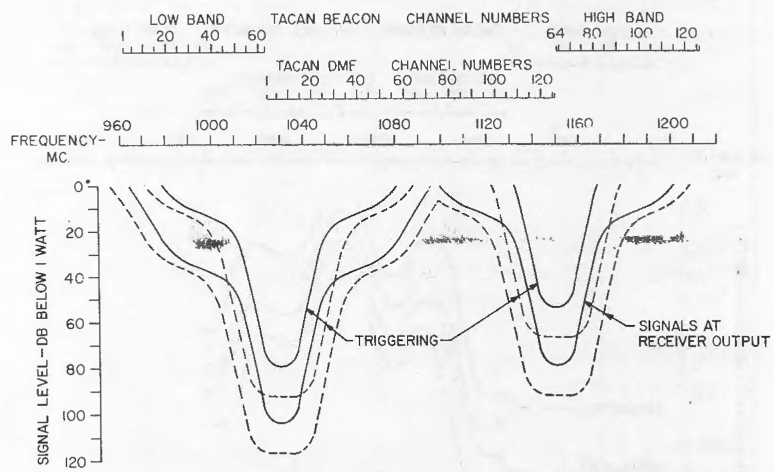
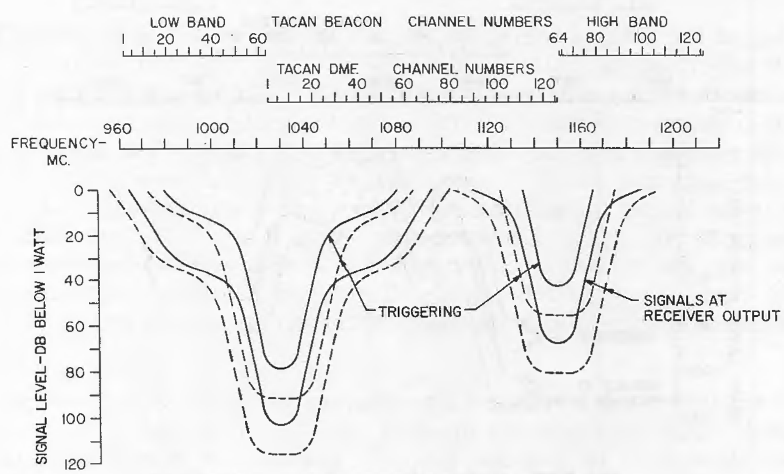


(a) - IFF airborne transponders



(b) IFF surface/ground transponders

Fig. 2 - Overall response of transponders to Tacan transmitted signals, no spurious signals present

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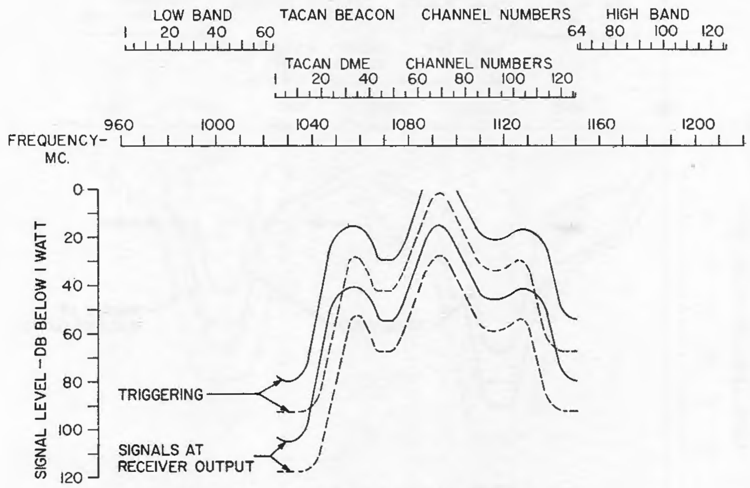
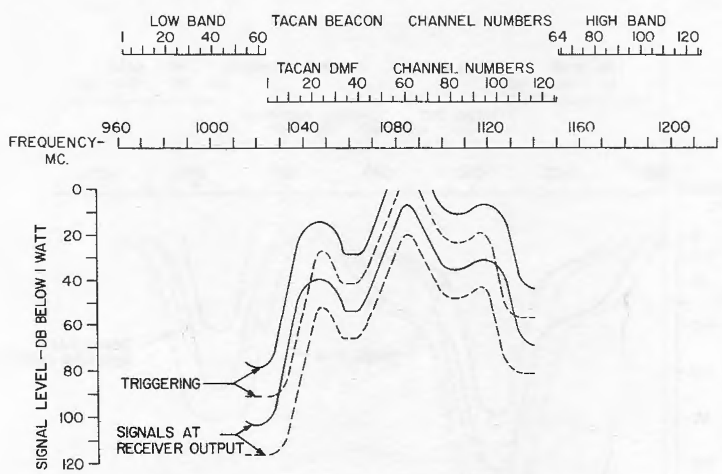


(a) IFF airborne transponders



(b) IFF surface/ground transponders

Fig. 3 - Overall response of transponders to Tacan transmitted signals, spurious signals present

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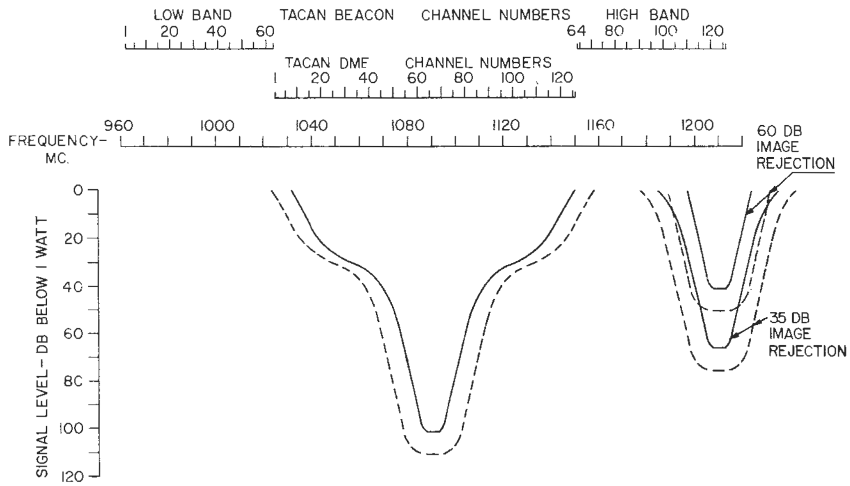
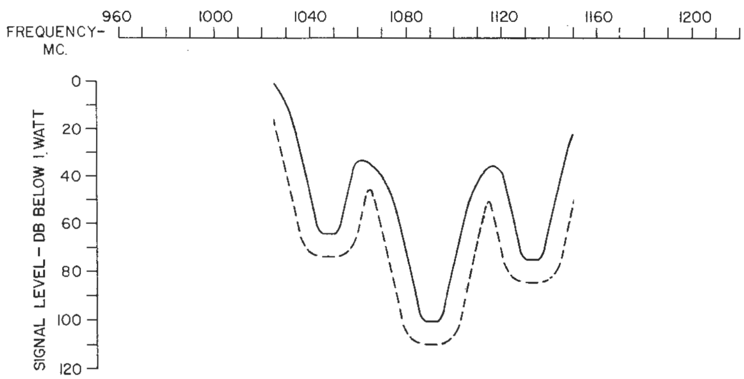


(a) No spurious signals present



(b) Spurious signals present

Fig. 4 - Overall response of IFF responsors to Tacan transmitted signals

GRAPHICAL METHOD OF DETERMINING REGIONS OF INTERFERENCE

To evaluate the effects of interference, the simple links are investigated individually. The system response curves are used together with free-space propagation curves (Fig. 5) to obtain a prediction of the Tacan frequency channels which will cause interference at various ranges (corresponding to the separation between antennas of the equipments involved).

The free-space propagation curves are based on results given by Bullington (6) for the conditions of 1 watt radiated between half-wave dipoles, designated as the reference line in Fig. 4. Curves appropriate to various Tacan transmitters are drawn parallel to the reference line through points obtained by adding the antenna gain over a half-wave

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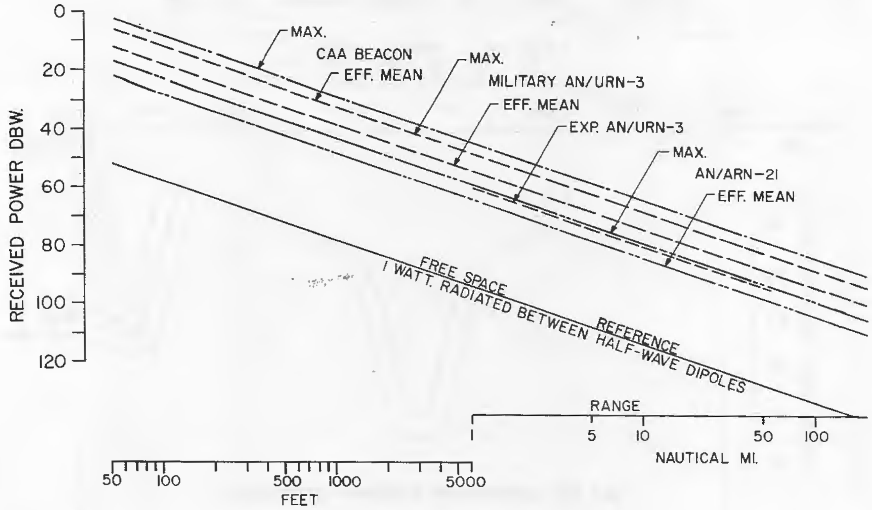

Fig. 5 - Free-space propagation curves for various interference links

	TDME	MIL T S/G B	CAA T S/G B
power output (dbw)	30	39	43
antenna gain (db)	0	5	5
feeder loss (db)	1	4	4
tolerances (db)	6	6	6

dipole (db) and the power output (dbw), and subtracting the feeder loss (db). Using the duty cycle data given in Table 1, it is possible to plot, for each link and at specific equipment separations, the Tacan channels most likely to cause interference. In addition, the maximum possible number of channels which can be expected to cause interference can be plotted. Thus, by graphical means, the extent of interference caused by single equipments can be determined. That such results give a reasonably good estimate of the expected interference is shown in Appendix G.

It should be noted that in each case the equipment separation used is determined on the basis of a receiver with a half-wave dipole antenna. The results are quite general and can be applied readily to any practical situation, even to the case of responsors having directional antennas by applying the appropriate corrections for antenna gain.

Separations of 50, 200, and 1000 feet as well as 1, 5, 10, 50, and 100 nautical miles, as appropriate for each link, have been chosen. By graphical construction, results for the nine simple links have been obtained; the results for links 1A, 2A, and 3A apply respectively to links 7A, 8A, and 9A. Typical results, for links 1A (7A) and 2A (8A) are shown in Figs. 6 and 7, which give the interference to single responsor equipments from Tacan transmitters for both military and civil situations for the types of responsors likely to be encountered. In Fig. 7, both the cases, with and without spurious transmitted signals, are given.

The results for the remaining simple links, taken in pairs, are given in Figs. 8 and 9 (interference to IFF airborne transponders) and in Figs. 10 and 11 (interference to IFF surface-ground transponders).

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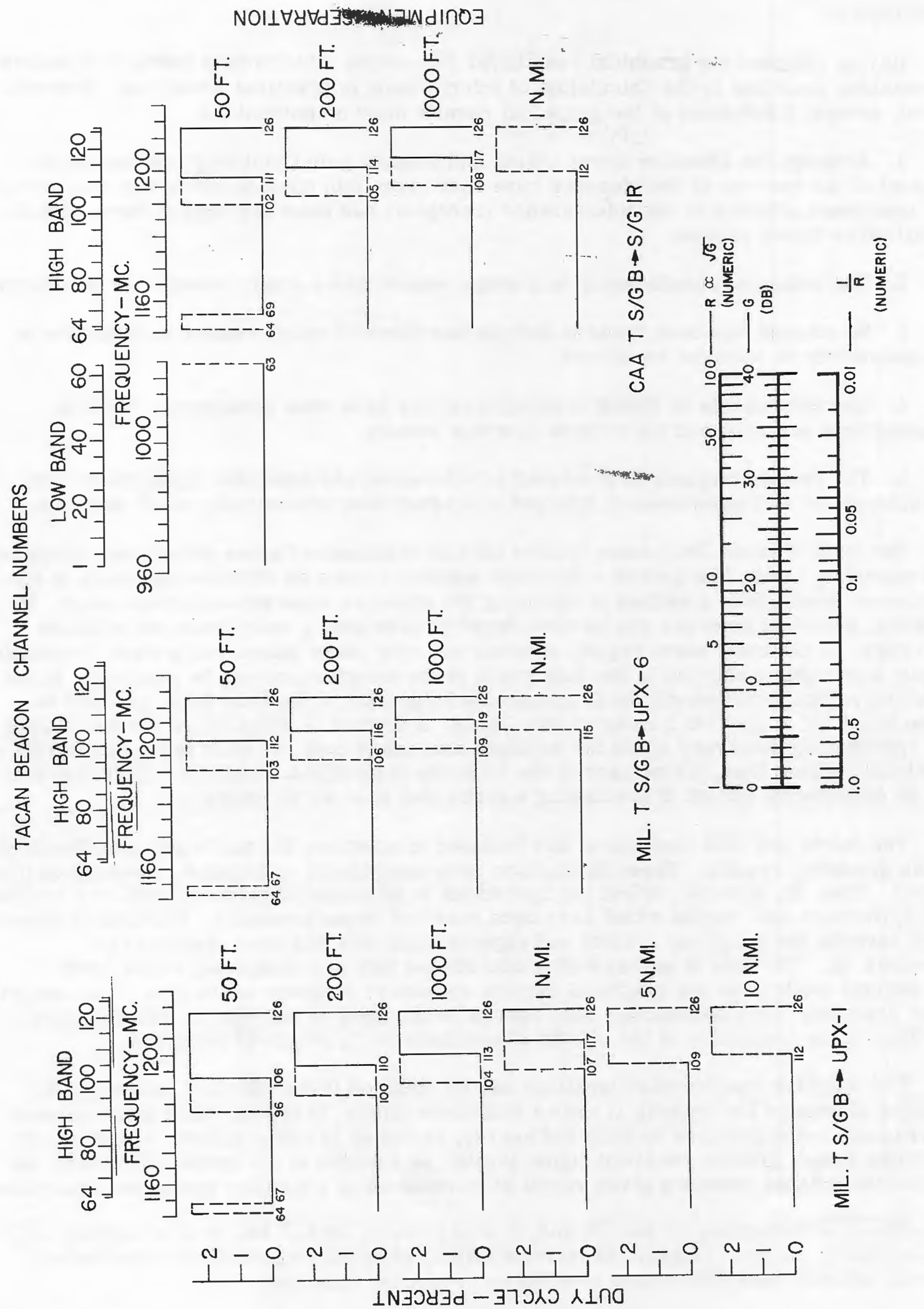

6 - Tacan channels on which interference is expected from the Tacan surface/ground beacon to IFF responsors — links 1A and 7A

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DISCUSSION

Having obtained the graphical results for the simple interference links, it is necessary to consider their use in the calculation of interference in practical situations. However, to do so, several limitations of the graphical results must be pointed out.

1. Although the effective power output and antenna gain (including representative losses) of the sources of interference have been taken into consideration, the receiver of the equipment affected by the interference (receptor) has been assumed to have, thus far, a half-wave dipole antenna.

2. The indicated results apply to a single source and a single receptor of interference.

3. No attempt has been made to include interference which results in reduction in the sensitivity of receptor receivers.

4. Spurious effects in TDME transmitters only have been considered; T S/G B transmitters are assumed not to have spurious effects.

5. The results (regions of predicted interference) are dependent upon theoretical considerations and experimental data and somewhat upon statistically small samples.

The first of these limitations applies only to responsors* since directional antennas are generally used. The gain of a directive antenna causes an effective decrease in the equipment separation; a method of obtaining the effective separation is given below. In addition, practical antennas can be considered to have both a main beam and sidelobe coverage. In the main beam region, sources can only cause interference when illuminated; hence, a possible reduction in the duty cycle of the interference can be expected. In the sidelobe region, sources will be illuminated a large part of the total time, and will be considered not to provide a reduced duty cycle. A method is given below for calculating the approximate total duty cycle for multiple sources in both the main beam (directive) and sidelobe regions, thus, taking care of the first two limitations. The third limitation will not be considered, except in discussing a particular case as an example.

The fourth and fifth limitations are included to complete the applicable qualifications of the graphical results. These limitations have been stated or implied elsewhere in this report. They do, however, affect the agreement to be expected between predicted regions of interference and results which have been obtained experimentally. Reasonable agreement between the graphical results and experimental data has been obtained (see Appendix G). The data of an OpDevFor operational test are compared, below, with predictions made from the graphical results as further evidence of the type of agreement to be expected. This comparison also serves the purpose of introducing other factors involved in the evaluation of the effects of interference in practical situations.

The effective equipment separations can be obtained if the effective antenna gain (making allowance for losses), G over a half-wave dipole, is known. Gain in an antenna increases the effective area to received energy, resulting in either greater range or, for the same range, greater received signal levels. In relation to the graphical results, the gain of the antenna causes a given result to be obtained at a smaller equipment separation.

*Limitation affects links 1A and 2A and, in some cases, 7A and 8A. It also applies, as shown below, to other links as an indirect effect, when the triggering of transponders results in fruit (unsynchronized replies) on responsor displays.

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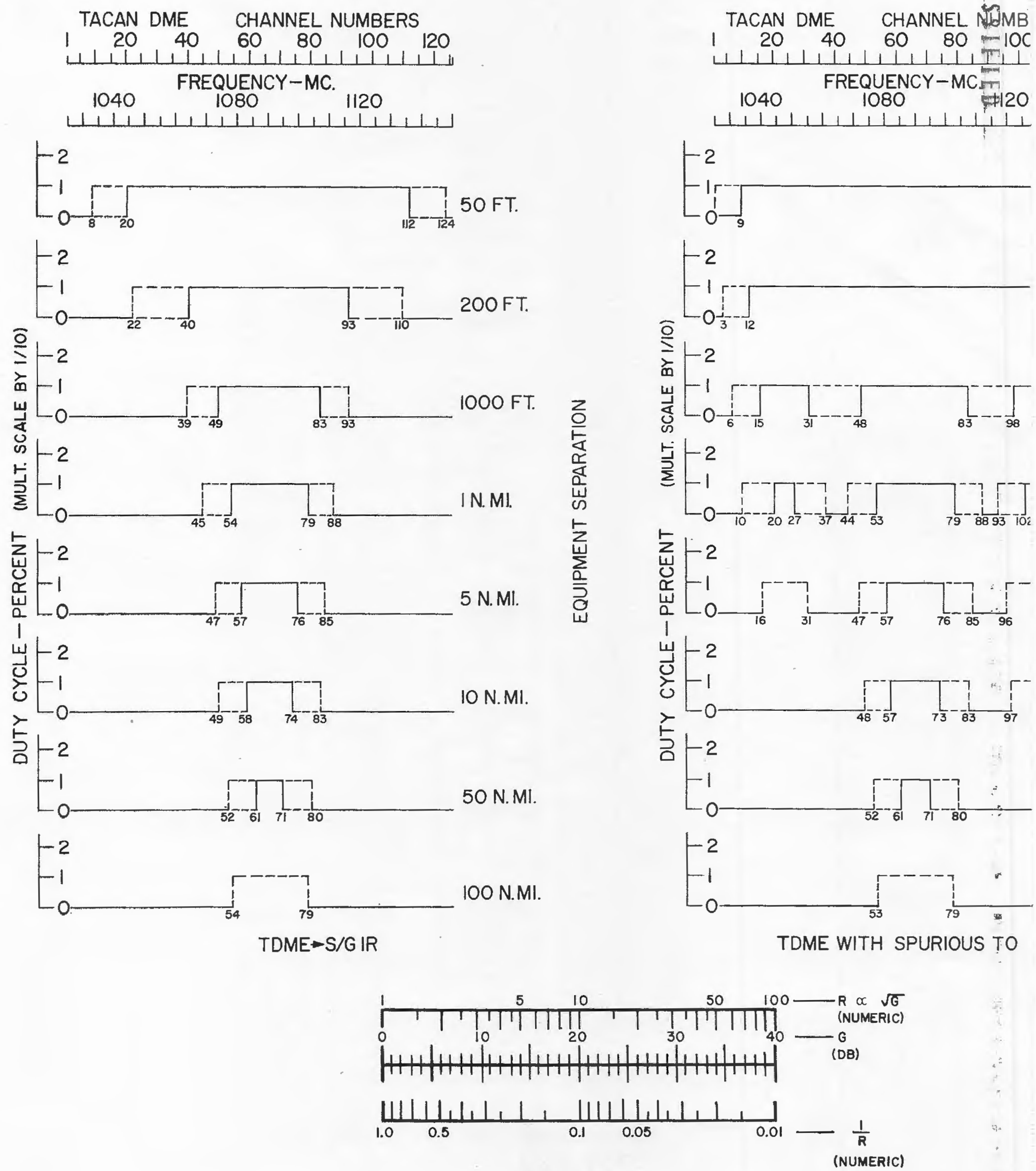

Fig. 7 - Tacan channels on which interference is expected from Tacan airborne equi[p]
to IFF responsors — links 2A and 8A

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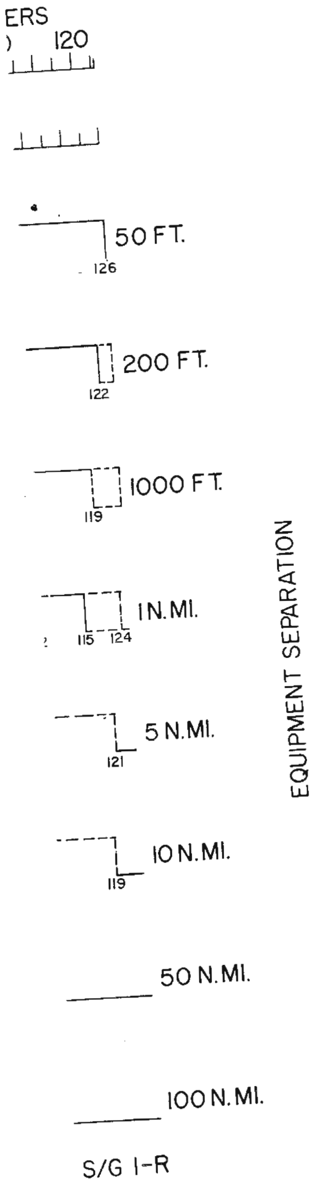
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EQUIPMENT SEPARATION
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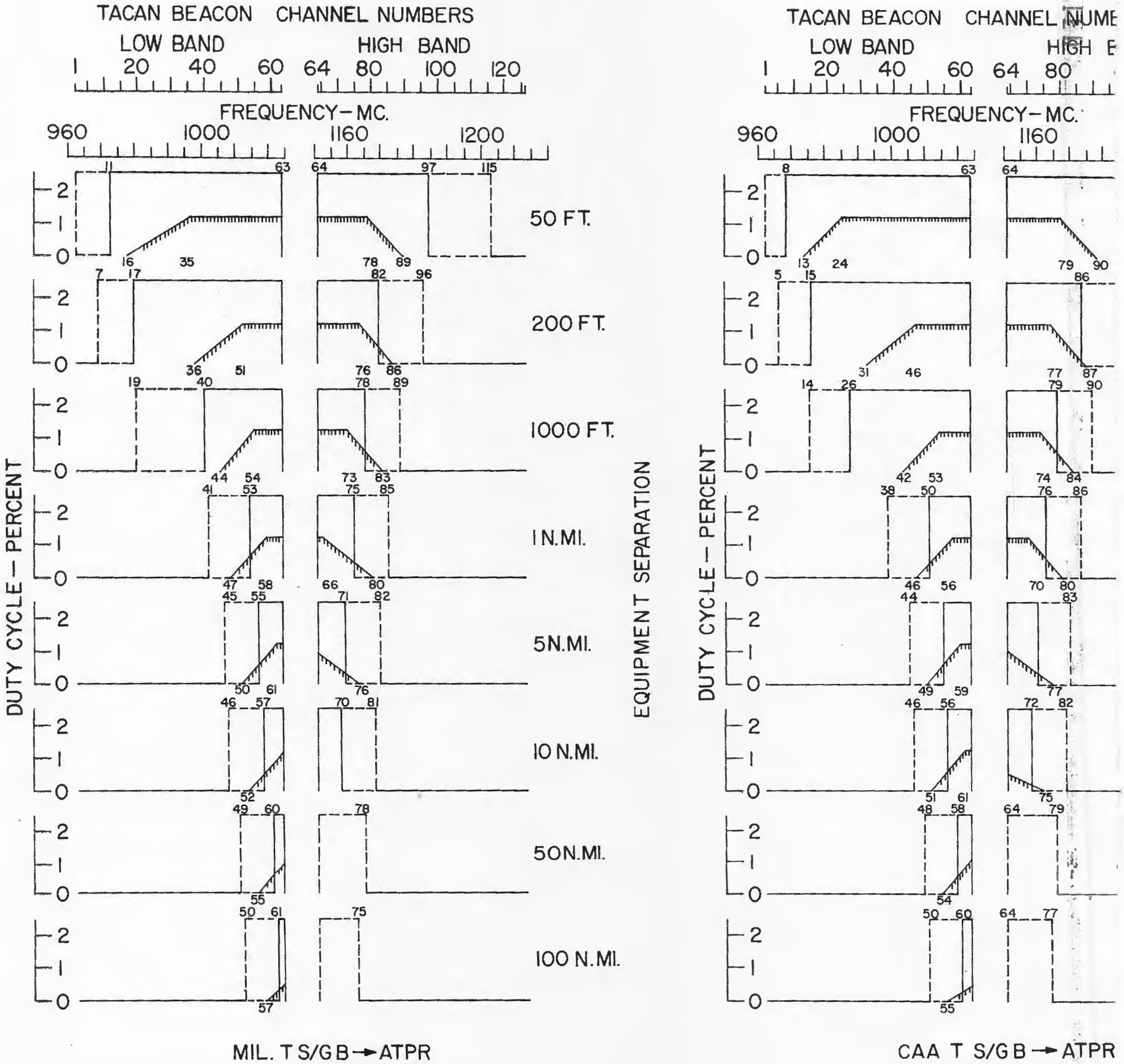
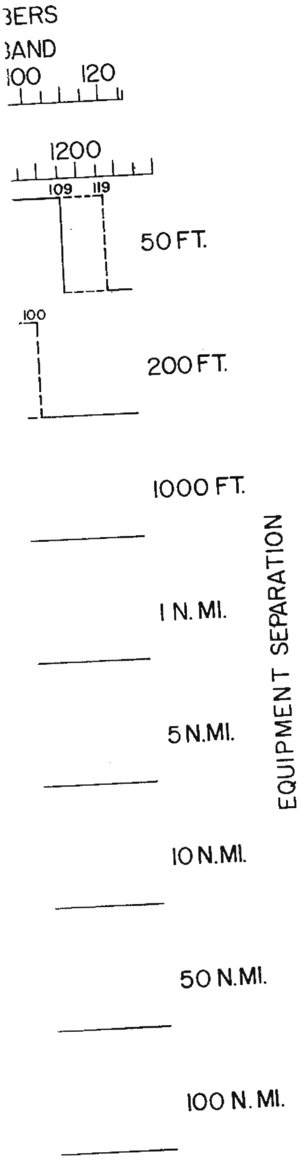


Fig. 8 - Tacan channels on which interference is expected from Tacan surface/gr beacons to IFF airborne transponders — links 3A and 9A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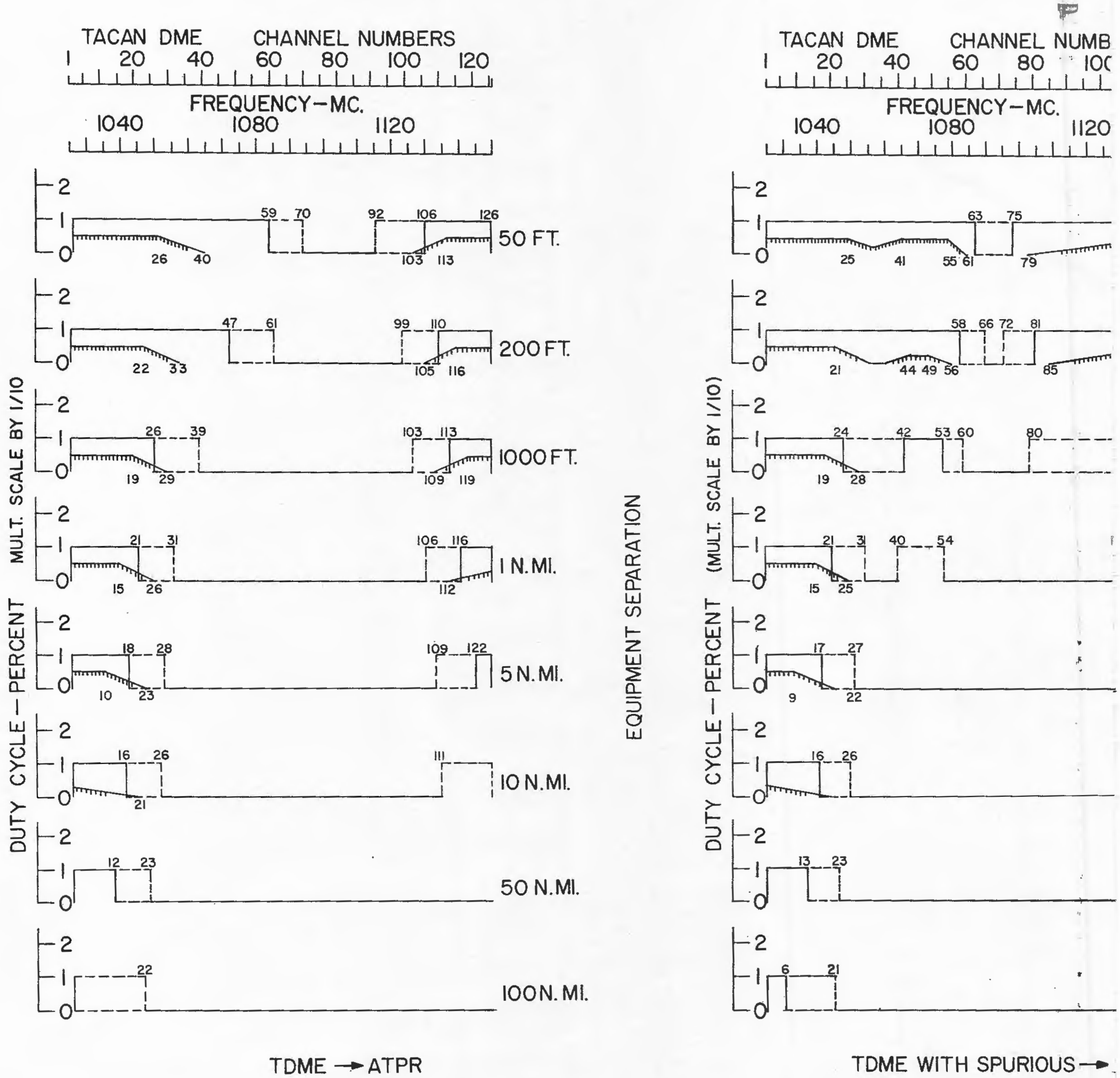

Fig. 9 - Tacan channels on which interference is expected from Tacan airborne equ
to IFF airborne transponders -- link 4A

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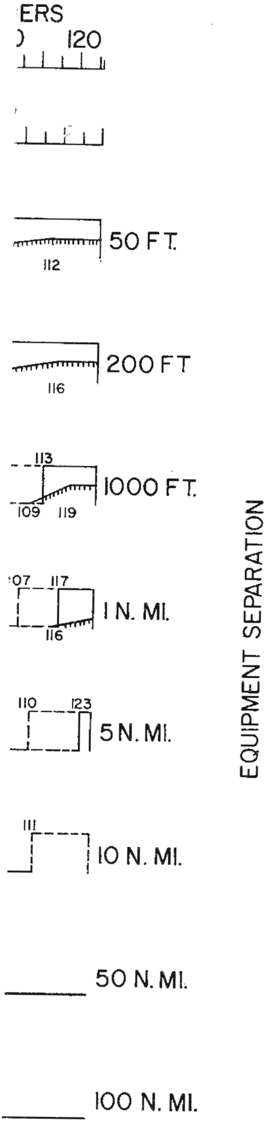
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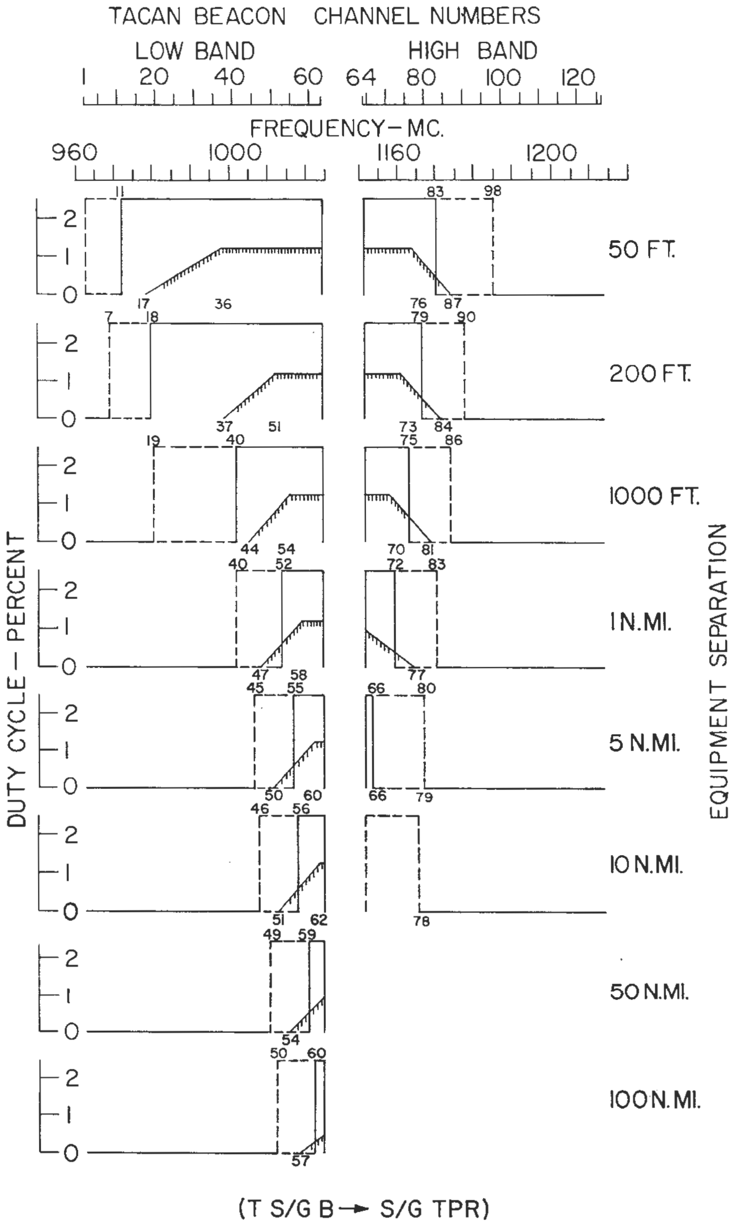

Fig. 10 - Tacan channels on which interference is expected from Tacan surface/ground beacons to IFF surface/ground transponders — link 5A

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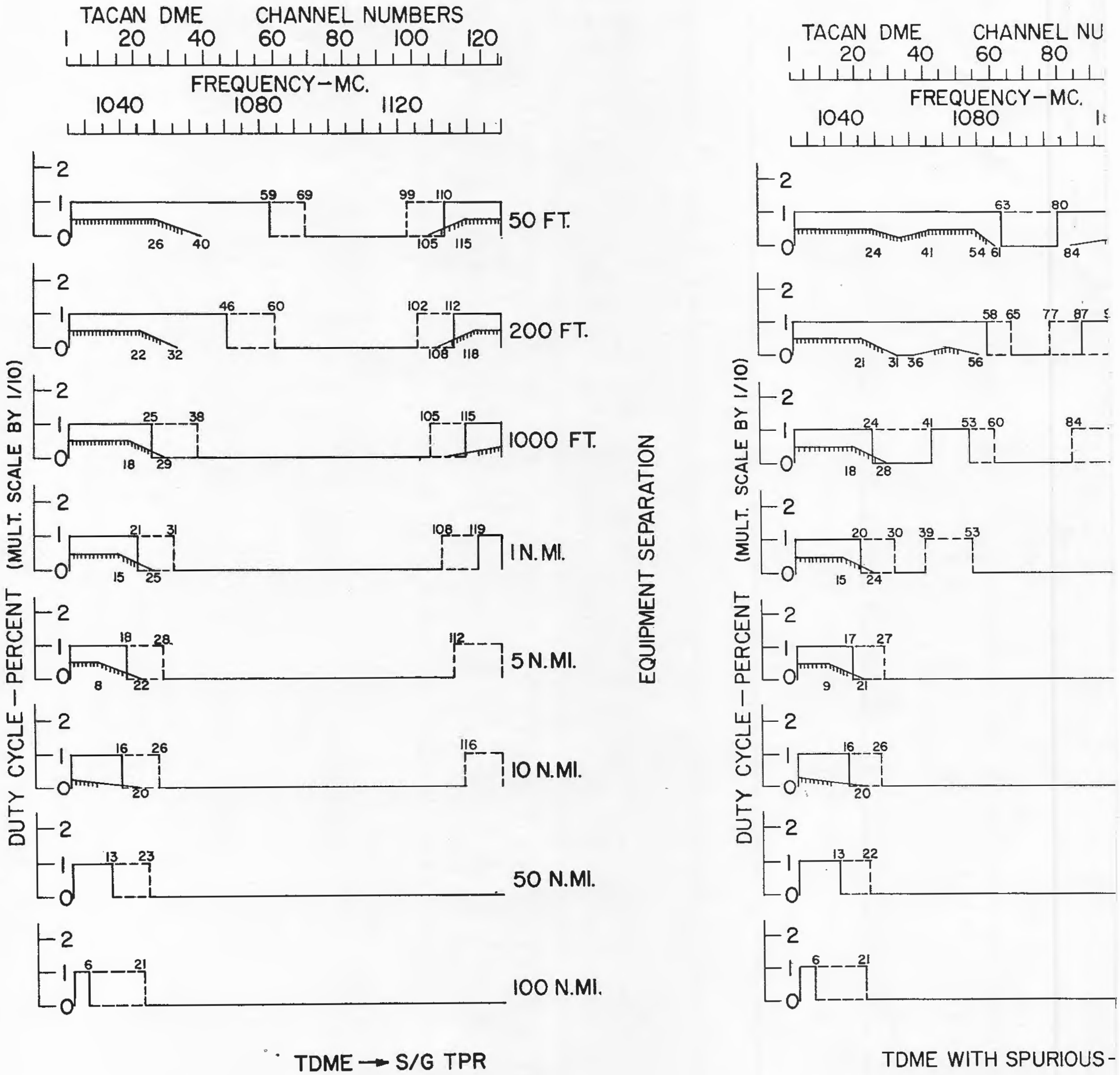

Fig. 11 - Tacan channels on which interference is expected from Tacan airborne e
to IFF surface/ground transponders — link 6A

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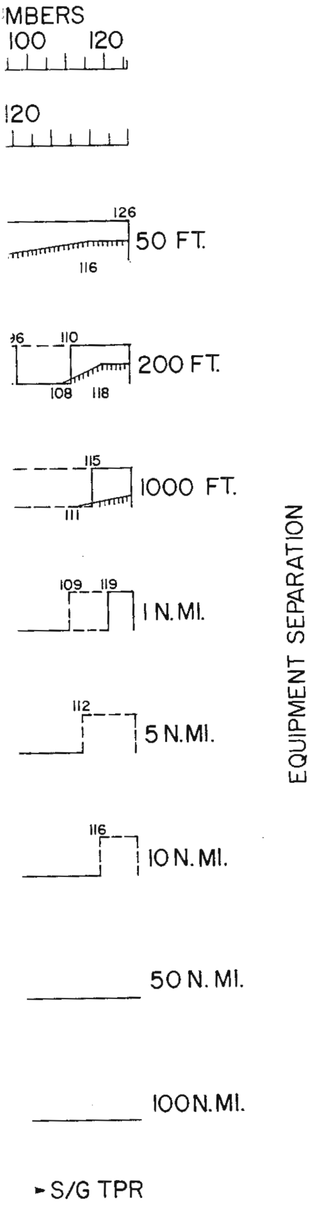
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1 N.MI.
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116
10 N.MI.
50 N.MI.
100 N.MI.
EQUIPMENT SEPARATION
S/G TPR

ıipment

A range correction factor R is taken to be the range ratio, $d_{dir}/d_{\lambda/2}$ where d_{dir} is the range obtained with a directional antenna and $d_{\lambda/2}$ is that obtained with a half-wave dipole. From the beacon range equation, R is proportional to $\sqrt{G}$. Two situations present themselves in which corrections for antenna gain are required: (a) a given physical separation is known and (b) a certain received power level, established by the choice of separations, is given. In the first case, the same power level is received by the antenna with effective gain G at a lesser separation; the correction is 1/R times the physical range. Results for the indicated* range closest to the corrected range can be used, or the results can be interpolated. In the second case, the received power level is obtained at a greater range with the antenna of effective gain G; the correction is R times the indicated* separation. A scale has been provided for the appropriate links for making these corrections (see Figs. 6 and 7).

By dividing the coverage obtained with directional antennas into a directive region and a sidelobe region, the problem of obtaining corrections for the indicated* duty cycle is simplified. The directive region is defined, for simplicity, as being between d_{hor} (the distance to the radio horizon) and d_s (the maximum distance of the sidelobe region). Of course, in duty cycle considerations, time intervals are assumed to be large compared with antenna rotational periods. (For rotation rates greater than 6 rpm, this period is less than 10 seconds.)

In the directive region $(R)_d$ sources will cause interference when they are illuminated by the receptor's directive antenna. The illumination time in each revolution is B/6w seconds, where B is the half-power beamwidth in degrees, and w is the rotational rate in rpm, and the source is illuminated w/60 times per second. Hence, sources in the directive region are illuminated B/360 seconds, each second. However, this is true only for the range at which the half-power beamwidth B occurs. For shorter ranges, the beam is broadened, as shown (approximately) in Fig. 12. In an ideal rectangular antenna it is found (7) that the beamwidth doubles at ranges corresponding to levels between 10 and 20 db below peak. Thus,

$$\frac{B}{360} \leq \begin{array}{c}\text{duty cycle correction}\\ \text{in } (R)_d\end{array} \leq \frac{2B}{360} \quad (d_{hor} \leq d \leq d_s)$$

may be used to approximate the effect of variation in beamwidth with range in the directive region.

In the sidelobe region $(R)_s$ of antenna coverage, sources will be illuminated almost continuously; hence, the indicated duty cycle need not be corrected.

The range correction factor R must be applied in both regions, $(R)_d$ and $(R)_s$, to obtain the effective equipment separation. In $(R)_d$, the effective gain G is the nominal gain with respect to a half-wave dipole G′, reduced by 3 db for adjustment of the pattern to cause B to occur at d_{hor} (see Fig. 12), and reduced by representative losses L (e.g., feeder) or

$$G = G' - 3 - L,$$

*That value given in the graphical results.

[redacted]

 [redacted]

where all quantities are expressed in db. The sidelobe level S is usually given with reference to G′, the peak of the main beam; or in a practical system, with reference to G′ - L. Hence the sidelobe maximum G_S occurs at a level G ± 3 - S or

$$G_S = G - (S - 3).$$

The range ratio for region $(R)_d$ can be written as

$$R = \frac{d_{hor}}{d_{\lambda/2}}$$

for effective gain G, where $d_{\lambda/2}$ is the indicated separation; and for region $(R)_S$ as

$$R = \frac{d_S}{d_{\lambda/2}}$$

for effective gain G_S.

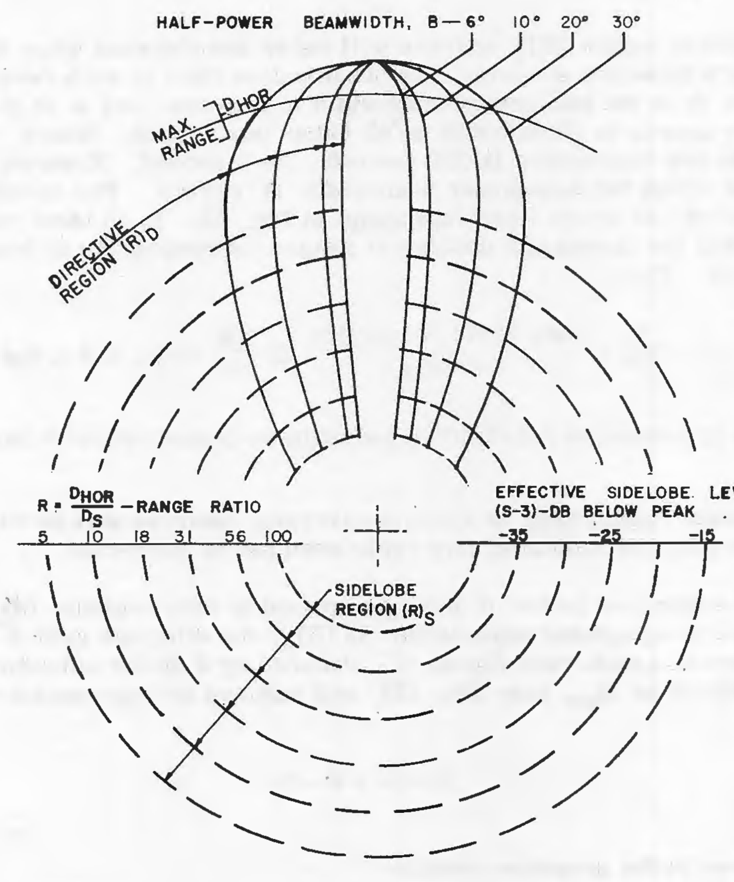

Fig. 12 - Approximate coverage for various beamwidths and sidelobe levels

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The relative relationship of the two antenna regions is shown in Fig. 12. The regions $(R)_d$ and $(R)_s$ can be related quantitatively if it is assumed that the half-power beamwidth occurs at the radio horizon, d_{hor}. If the antenna sidelobe level with respect to the maximum of the main beam is S(db), the sidelobe coverage distance d_s can be determined in terms of the distance ratio, d_{hor}/d_s,

$$(S-3) \text{ db} = -20 \log \left(\frac{d_{hor}}{d_s}\right)^2 .$$

The effect of various sidelobe levels (S - 3) is shown in Fig. 12. Values of d_s are given in Table 3 for various values of both d_{hor} and (S - 3) considered likely in the operation of the IFF system. Included in Table 3 are values of d_s for each of the individual interference links.

Thus, effective equipment separations are obtained by making corrections for the effective gain. In $(R)_d$, G is used, and in $(R)_s$, G_s is used.

In applying the above corrections for duty cycle and the equipment separation, the duty cycle to be corrected must be known. To obtain the duty cycle the specific situation must be analyzed into the links which are expected to contribute interference. The schematic representation of Fig. 1 provides a basis for systematically determining the interference contributed on each of the simple links and for general cases, the effects to be expected when there are multiple sources and multiple receptors of interference. The nine simple links can be represented by two pairs of general cases; one pair has the T S/G B as a source, and the other, the TDME. In Fig. 13 the four general cases are shown. One pair applies to the case of interference between multiple Tacan sources and multiple responsors; the other pair to interference between multiple transpondors and responsors.

The first pair of general cases (links 1A and 7A and links 2A and 8A, Fig. 13) indicates the division of the responsor coverage into the directive and sidelobe regions. In this pair, which depicts the situation expected at the i^{th} interrogator-responsor, the number of sources simultaneously in the beam, in the directive region, is designated as n_{di} (for T S/G B sources) or n'_{di} (for TDME sources). The locations of sources are shown by an X; and, of receptors, by an O. For simplicity only a single X is shown in each of the two coverage regions of the responsor antenna. In the sidelobe region, the number of sources is designated as n_{si} (for T S/G B sources) and n'_{si} (for TDME sources). An attempt has been made to indicate the relative differences in magnitudes of the duty cycle contributed in each region by the thickness of the arrow. The approximate values of the total interference in each region are given. On either link, the total duty cycle is given in terms of two limiting values: (a) the lower limit, which is determined from the number of sources within the sidelobe region (it is expected that there may be some areas in the directive region in which there are no sources), and (b) the upper limit, which approximately is given by the sum of the effects: those in the sidelobe region and those in the directive region having the greatest density of sources. The interference level should fluctuate between these two limits as the responsor antenna rotates.

In the second pair of general cases, links 3A, 5A, 9A involve T S/G B sources, and links 4A, 6A involve TDME sources. In these cases, however, two distinct effects are possible: a direct and an indirect effect. First of all, the primary or direct receptor of the interference is a transponder (either A TPR or S/G TPR). The affected transponders may be receiving interfering signals only, or they be triggered by the interference. In the

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TABLE 3
Distances to Radio Horizon and to Maximum Range of Sidelobe Coverage

Antenna Height (feet)		Radio Horizon d_{hor}* (naut mi)	Maximum Sidelobe Coverage Distance d_s (naut mi) at Sidelobe Levels of				Applicable Interference Link	Remarks
			20db	25db	30db	35db		
			corresponding to Range Ratios of†					
h_1	h_2		10.0	17.7	31.6	56.2		
10	10	7.7	0.8	0.4	0.2	0.1	1	surface/ground by
33	33	14.1	1.4	0.8	0.4	0.3		surface ground
150	150	30.1	3.0	1.7	0.9	0.5	5	
150	300	36.3	3.6	2.0	1.1	0.7		
300	300	42.5	4.3	2.3	1.3	0.8		
10	1,000	42.6	4.2	2.4	1.3	0.8		
	5,000	90.6	9.0	5.1	2.8	1.6	2	air by surface/ground
	10,000	126.5	12.7	7.0	3.9	2.3	3	
	50,000	278.2	27.8	15.6	8.6	5.0	6	or
33	1,000	42.8	4.2	2.4	1.3	0.8	7	
	5,000	93.8	9.3	5.3	2.9	1.6	9	surface/ground by air
	10,000	129.7	13.0	7.2	4.0	2.3		
	50,000	281.4	28.1	15.8	8.7	5.1		
150	1,000	53.8	5.3	3.0	1.7	0.9		
	5,000	101.8	10.1	5.7	3.2	1.8		
	10,000	137.7	13.8	7.7	4.2	2.5		
	50,000	289.4	28.9	16.2	9.0	5.2		
300	1,000	60.1	6.0	3.4	1.8	1.0		
	5,000	108.0	10.8	6.0	3.3	1.9		
	10,000	144.0	14.4	8.0	4.4	2.6		
	50,000	295.6	29.5	16.6	9.1	5.3		
1,000	1,000	77.6	7.7	4.3	2.4	1.4		
	5,000	125.5	12.6	7.0	3.9	2.3	4	air by air
	10,000	161.5	16.2	9.0	5.0	2.9	8	
	50,000	131.1	31.3	17.5	9.7	5.6		
5,000	5,000	173.5	17.4	9.7	5.4	3.1		
	10,000	209.4	20.9	11.7	6.5	3.8		
	50,000	361.1	36.1	20.2	11.2	6.5		
10,000	10,000	245.1	24.5	13.7	7.6	4.4		
	50,000	397.0	39.7	22.2	12.3	7.1		
50,000	50,000	548.7	54.9	30.7	17.0	9.9		

*d_{hor} (n mi) = $1.227 \left(\sqrt{h_1(\text{ft})} + \sqrt{h_2(\text{ft})}\right)$

†Range ratio = $\dfrac{\text{maximum range}}{\text{sidelobe range}} = \dfrac{d_{hor}}{d_s}$

or $d_s = \dfrac{d_{hor}}{\text{range ratio}}$

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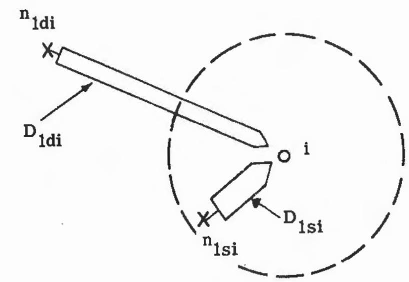
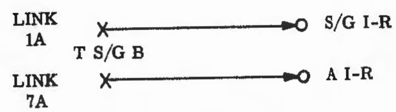
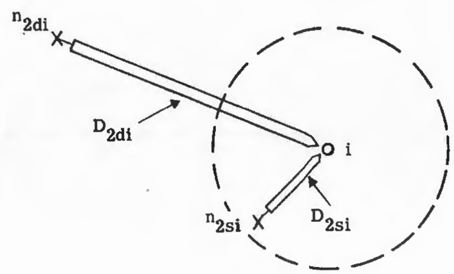


LOWER LIMIT	UPPER LIMIT
${}_1D_i = D_{si}$	${}_1D_i = D_{si} + D_{di}$

$$D_{si} \cong n_{si} D_a$$

$$D_{di} \cong n_{di} \frac{B_i D_a}{360}$$

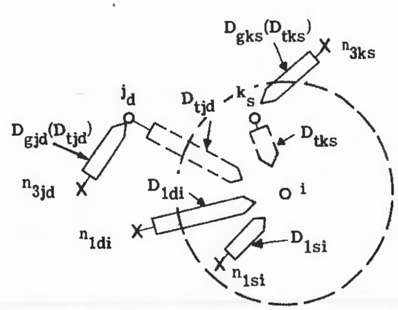




LOWER LIMIT	UPPER LIMIT
${}_2D_i = D'_{si}$	${}_2D_i = D'_{si} + D'_{di}$

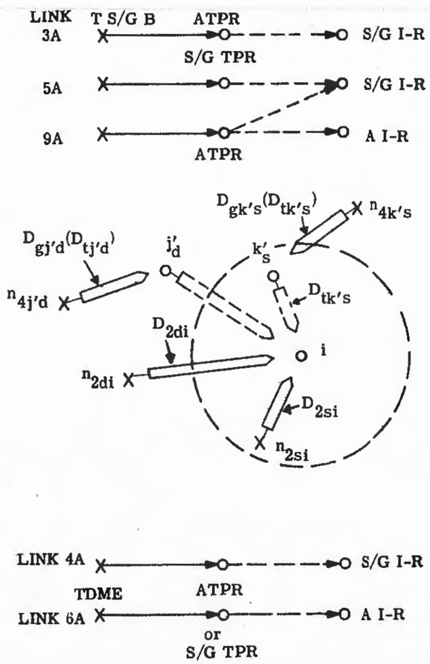
$$D'_{si} \cong n'_{si} D_b$$

$$D'_{di} \cong n'_{di} \frac{B_i D_b}{360}$$



LOWER LIMIT	UPPER LIMIT
garbling (received signals)	
$D_{gjd} = 0$	$D_{gjd} \cong n_{jd} D_a$
$D_{gks} = 0$	$D_{gks} \cong n_{ks} D_a$
${}_3D_i = D_{si}$	${}_3D_i = D_{si} + D_{di} = {}_1D_i$
fruit and reduced traffic capacity (TPR triggering)	
$D_{tjd} = 0$	$D_{tjdi} \lesssim jdi\ D_a$
$D_{tks} = 0$	$D_{tksi} \lesssim ksi\ D_a$
${}_3D_i = D_{si}$	${}_3D_i = D_{si} + D_{di}$

[redacted]



$$+ \frac{B_i D_a}{360} \sum_{j=1}^{md} jdi + D_a \sum_{k=1}^{ms} ksi$$

$$_3D_i = {_1D_i} + \left(M_{si} + \frac{B_i M_{di}}{360}\right) D_a$$

LOWER LIMIT	UPPER LIMIT
garbling (received signals)	
$D_{gj'd} = 0$	$D_{gj'd} = n_{j'd} D_b$
$D_{gk's} = 0$	$D_{gk's} = n_{k's} D_b$
$_4D_i = D'_{si}$	$_4D_i = D'_{si} + D'_{di} = {_2D_i}$
fruit and reduced traffic capacity (TPR triggering)	
$D_{tj'd} = 0$	$D_{tj'd} - n_{j'd} D_b$
$D_{tk's} = 0$	$D_{tk's} \lesssim n_{k's} D_b$
$_iD_4 = D'_{si}$	$_4D_i = D'_{si} + D'_{di}$

$$+ D_b \sum_{k'_s=1}^{m'_s} k'_{si} + \frac{B_i D_b}{360} \sum_{j'_d=1}^{m'_d} j'_{di}$$

$$= {_2D_i} + \left(M'_{si} + \frac{B_i M'_{di}}{360}\right) D_b$$

Fig. 13 - Effects on total duty cycle of multiple sources of interference and multiple affected equipments -- summary of limit values for general cases

former event, only the transponder operation is affected; whereas, in the latter event, the responsors in the area also may be affected. Thus, this pair of general cases involves not only the number of sources and transponders, but also the number of responsors; in fact, the first pair of general cases must be considered as the secondary or indirect effect. In Fig. 13, the situation in which the transponders only are affected is described briefly as "garbling" of interrogations; and the situation in which transponders are triggered is described as "fruit and reduced traffic capacity." The approximate expressions for the total duty cycle (lower and upper limits) are given in Fig. 13 for both situations. For this pair of general cases, it is necessary to determine the number of transponders either garbled or triggered. Those which are garbled affect the overall responsor situation somewhat differently from those which are triggered; the numbers may be different in both cases. In any event, the total effects are dependent upon both the density of sources and the density of transponders.

To obtain quantitative results, Fig. 14 has been drawn as an aid in calculating duty cycle. The determination of any component duty cycle (a component represents one of the four general cases shown in Fig. 13) requires only that ① the responsor beamwidth (B) and ② the density of sources be known in order to obtain ③ the approximate total duty cycle - the numbers refer to the procedural key given in Fig. 14. It is considered that for the range of values of duty cycle D shown in Fig. 14, the actual values will not differ appreciably from the approximate values.

ANALYSIS OF AN ACTUAL INTERFERENCE SITUATION

To illustrate the method of analysis in a relatively simple, actual situation, use is made of data given in Ref. 3. Since the results obtained using the Atlantic City test data (3) are essentially qualitative, no quantative comparison can be made in terms of predicted duty cycle. Instead, the areas of agreement, and disagreement, regarding the interference regions (i.e., channels affected) will be discussed. The geographic test situation is shown in Fig. 15. The results available from Ref. 3 are given only for the responsors located at Atlantic City. The data was taken by means of systematic switching of equipment; the sketches shown in Fig. 16 show the applicable conditions in terms of the nomenclature of Fig. 13. In Fig. 16, a geographic and a vector schematic are given for each applicable interference link: links 1A through 6A. The geographic schematic shows the equipments involved in the interference for each link. In cases involving flights of aircraft, two distinct situations can be expected: (a) the aircraft are either on or over the station and it is assumed that the climb to the operating altitude (30,000 feet) takes place within $(R)_S$* and (b) the aircraft are in flight (four aircraft in close formation) at the operating altitude. The schematic vector diagrams have been drawn to indicate, by the thickness of the arrows, the relative magnitudes of the duty cycle for each component contributing to the total interference on each link.

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*While two S/G I-R were involved, the geographic situation for only one is shown, the interference for the other is not expected to be much different.

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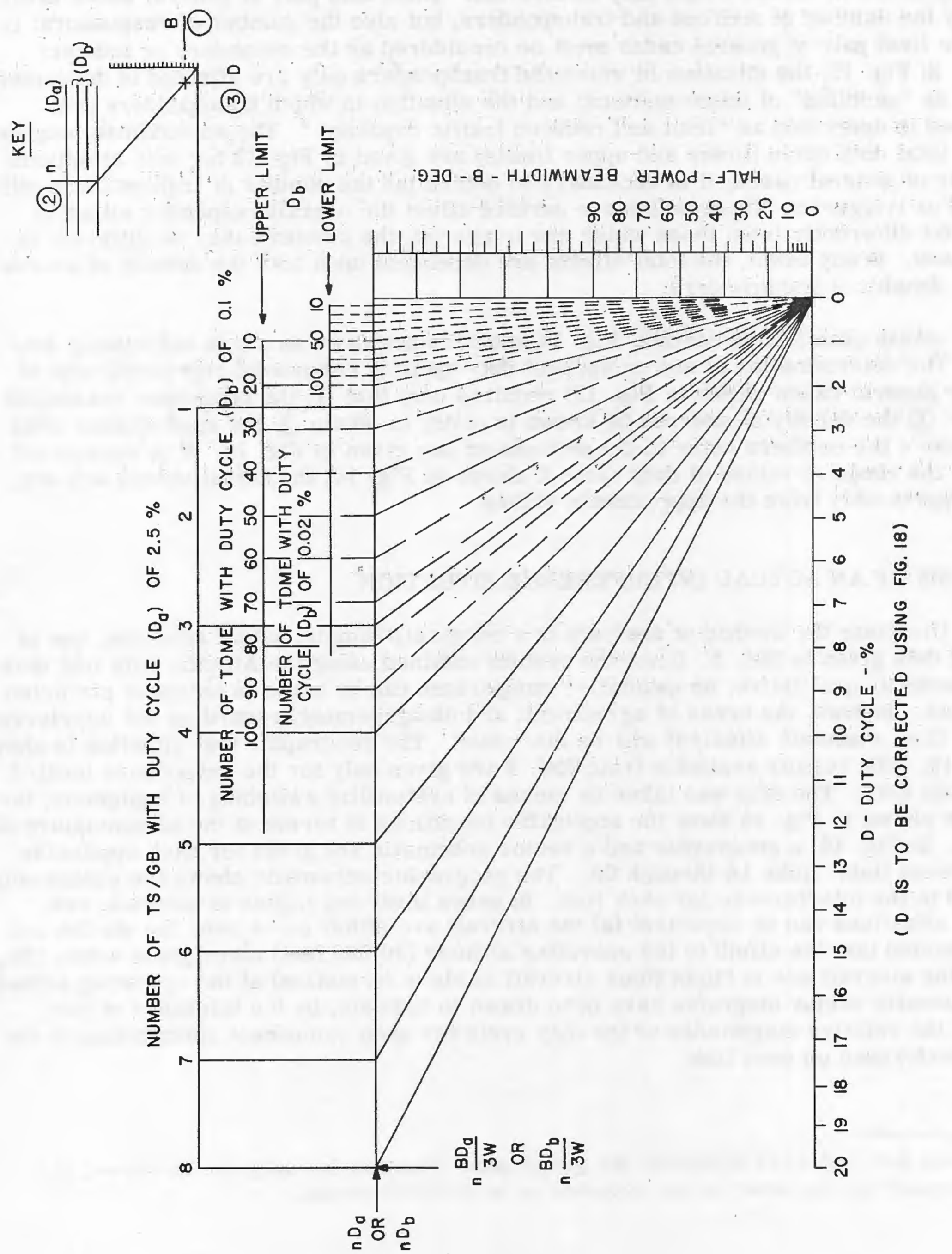

Fig. 14 - Graphical method for calculating interference duty cycle component values

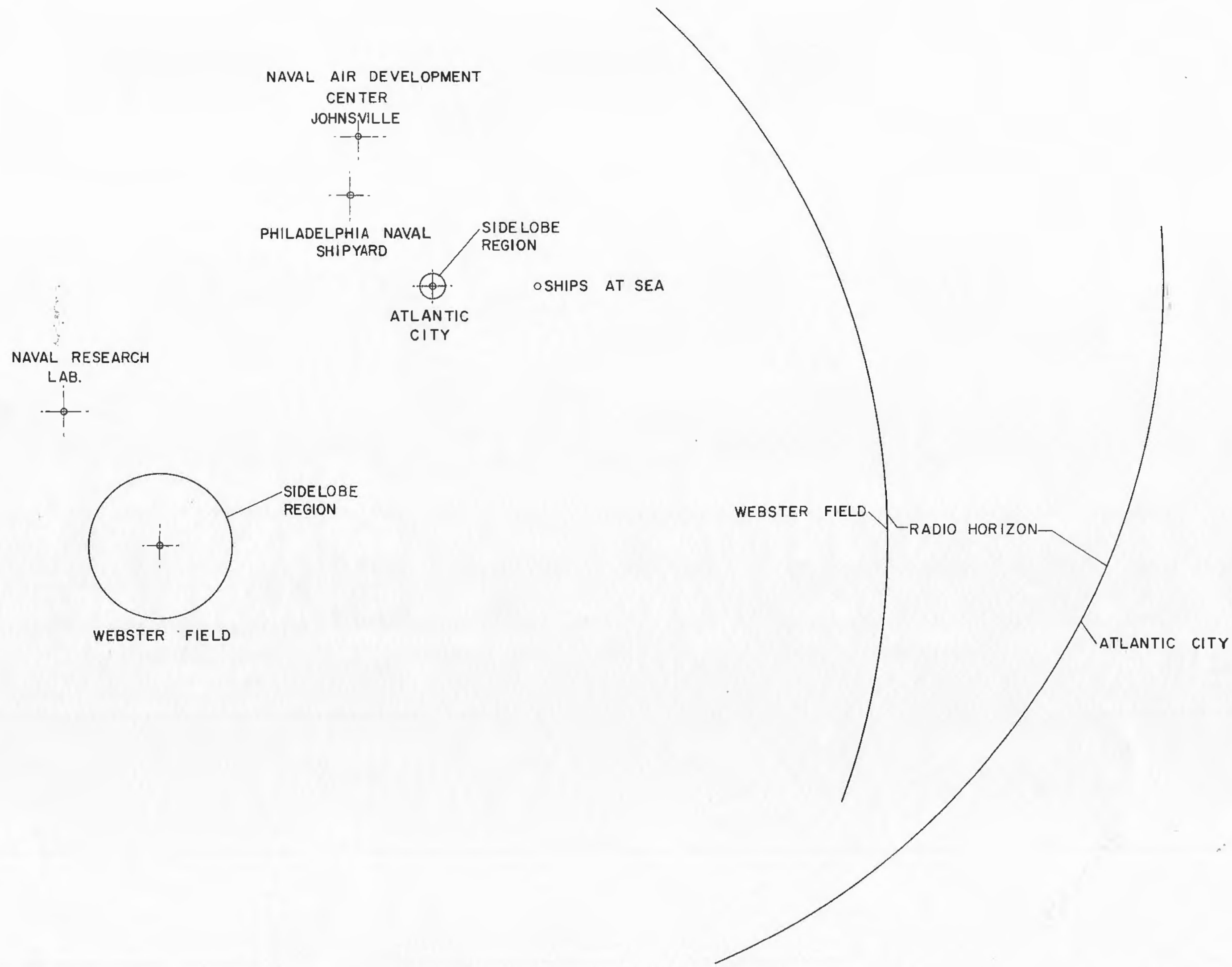

Fig. 15 - Geographic situation -- Atlantic City tests, October 1955. Key S/G I-R installations are shown. T S/G B installations were located at Atlantic City and Webster Field; reported measurements were those taken at Atlantic City. The appropriate I-R sidelobe and directive regions for Webster Field and the best antenna pattern at Atlantic City are indicated.

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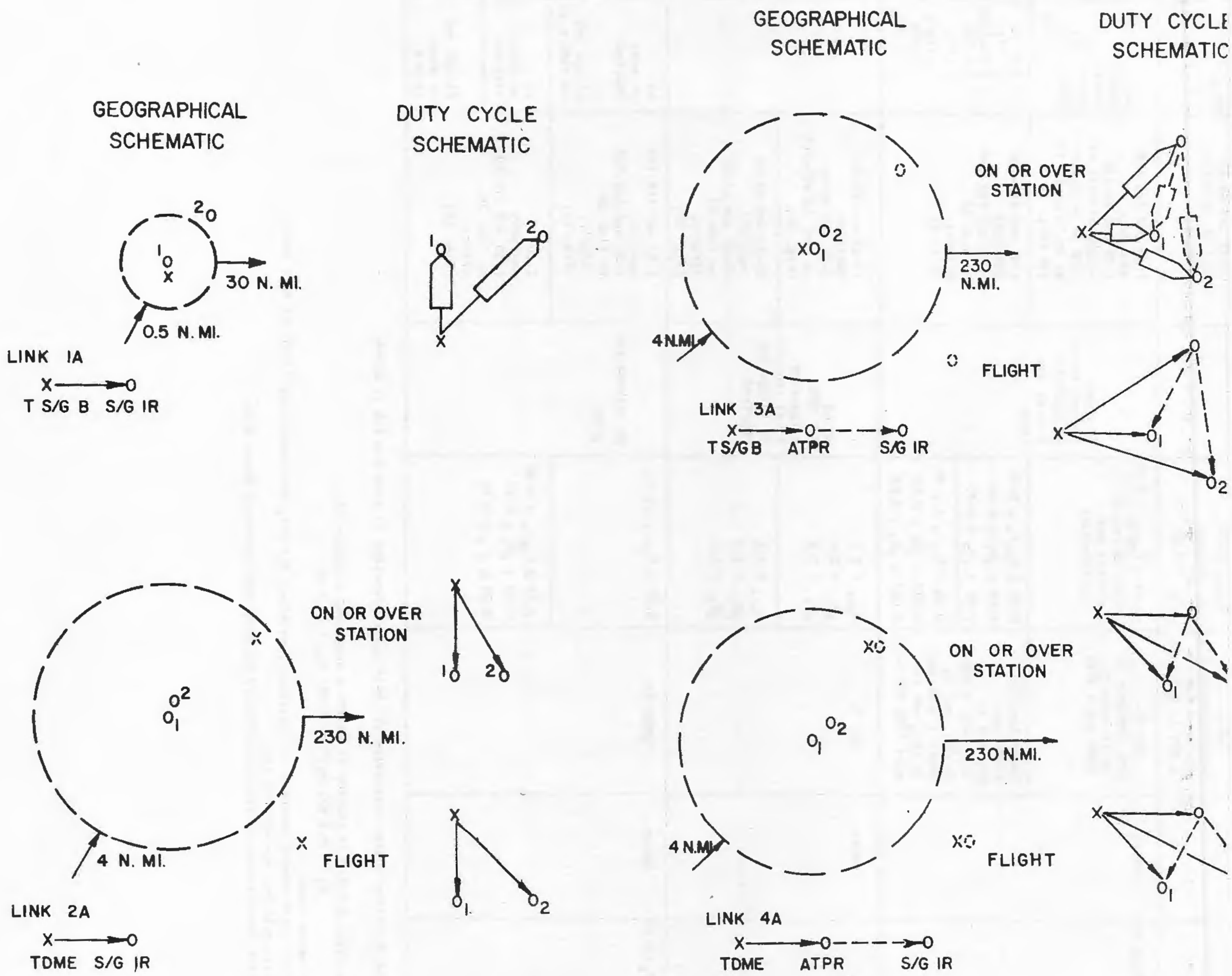

Fig. 16 - Schematic representation of interference links — Atlant

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						230 n mi (separation nearly the same for A TPR to S/G I-R)	$D_{tjd_2} = 0.04$ $_3D_1 = 0.08$ $_3D_2 = 0.04$		50-63 and 64-76 no link 1A effects (Fig. 8)	$(R)_d$	
4A	4 TDME	4 A TPR in either $(R)_s$ or $(R)_d$ of 2 S/G I-R	—	$0.02 \leq D_b \leq 0.10$	Unity	>50 ft (one instance of 10 ft between TDME and A TPR)	$0.08 \leq D_{gk}$'s ≤ 0.90 (link 2A and 4A effects are synchronous)	No inter ference found on channels 1-18 at any range.	1-59 and 106-126 possibly 1-70 and 92-126 slight effects of link 2A possible: 54 to 79 or 22 to 110 (Fig. 9)	only close forma-tions flown	Garbling (affects only A TPR
			(1) 6 (2) 3			Range between A TPR and S/G I-R is involved. A TPR in $(R)_s$ out to about 1 n mi and in $(R)_d$ out to more than 100 n mi	$0.08 \leq D_{tk}$'s ≤ 0.40 $0.08 \leq {}_4D_1 \leq 0.40$ $0.08 \leq {}_4D_2 \leq 0.40$ $0.08 \leq D_{tj'd} \leq 0.40$ $0.010 \leq {}_4D_1 \leq 0.05$ $0.005 \leq {}_4D_2 \leq 0.03$		1-26 and 113-126 possibly 1-40 and 103-126 no link 2A effects. (Fig. 9)	on or over station A TPR $(R)_s$ Flight A TPR in $(R)_d$	Triggering (traffic capacity reduced, S/G I-R fruit increased)
5A	1 T S/G B	1 S/G TPR in $(R)_s$ of 2 S/G I-R	—	$D_s = 2.5$	Unity	<50 ft	$D_{gks} = 2.5$ $_5D_1 = 2.5$ $_5D_2 = 2.5$	52-63 S/G TPR triggering level reduced. No triggering observed.	11-63 and 64-83 possibly 1-63 and 64-98 no link 1A effects (Fig. 10)		Garbling (affects only S/G TPR)
							$D_{tks} = 2.5$ $_5D_1 = 2.5$ $_5D_2 = 2.5$		36-63 and 64-76 possibly 17-63 and 64-87 no link 1A effects. (Fig. 10)		Triggering (traffic capacity reduced S/G I-R fruit increased)
6A	4 TDME	1 S/G TPR in $(R)_s$ of 2 S/G I-R	—	$0.02 \leq D_b \leq 0.10$	Unity	>1000 ft	$0.08 \leq D_{gk}$'s ≤ 0.40	No information given	1-25 and 115-126 possibly 1-38 and 105-126 no link 2A effects. (Fig. 11)	on or over station on Flight out to >100 n mi	Garbling (affects only S/G TPR)
							$0.08 \leq D_{tk}$'s ≤ 0.40 $0.08 \leq {}_6D_1 \leq 0.40$ $0.08 \leq {}_6\ {}_1 \leq 0.40$		1-18 possibly 1-29 and 110-126 no link 2A effects. (Fig. 11)	on or over station Flight out to about 10 n mi	Triggering (traffic capacity reduced, S/G I-R fruit increased.)

*( ) indicates no. assigned to source in $(R)_d$, the directive region, otherwise the half-power beamwidth of each S/G I-R is given.

NOTES:

S/G I-R #1 located at GC1 site, NAS Atlantic City; S/G I-R #2 located at AN/FPS-8 site, NAS Atlantic City.
G_1 = 16 db; S_1 = 35 db; G_{s1} = −16 db G_2 = 24.3 db; S_2 = 30.0 db; G_{s2} = −2.7 db

Predictions made only for S/G I-R #1, except where noted.

Predictions were made as follows - (a) Definite interference expected at effective separation for $(R)_s$ obtained using "mean or full curve in Figs.,6-11 for appropriate link
(b) Possible interference on channels obtained by using MAX curves of Figs. 6-11.

Corrections per Fig. 18 should be applied.

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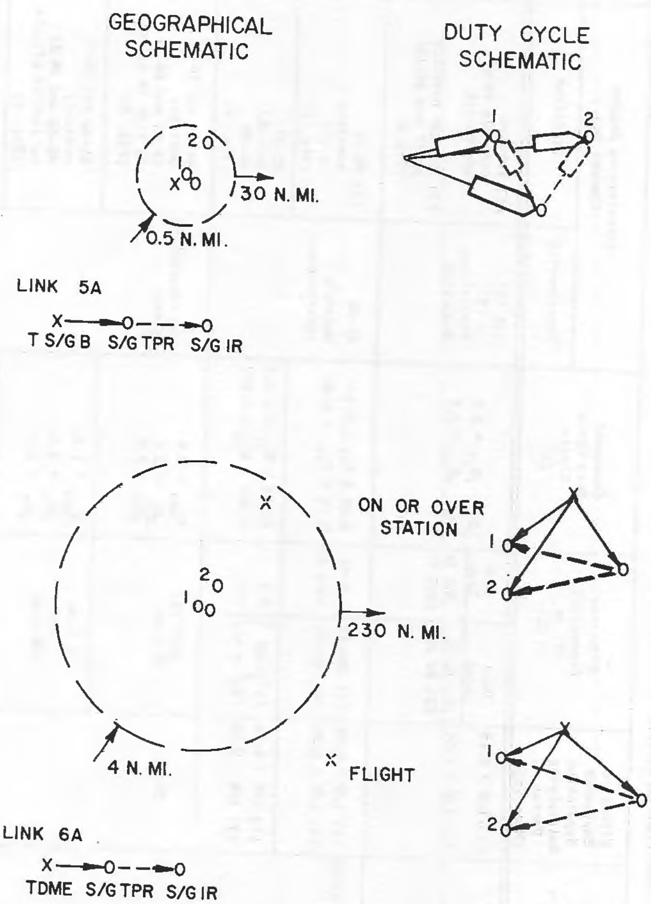

tic City tests, October 1955

TABLE 4

Summary of Conditions on Affected Interference Links and Comparison of Experimental and Predicted Results

Link (No.)	Source (No.)	Receptor (No.)	B* (Deg)	Nominal Source Duty Cycle (%)	Effective Equipment Separation Multiplying Factor (Numeric)	Effective Separation (Ft or N Mi): Main Beam	Effective Separation (Ft or N Mi): Side Lobe	Component Duty Cycle Limits (%)	Interference Region (Channel Nos.): Experimental	Interference Region (Channel Nos.): Predicted	Remarks	
1A	1 T S/G B	2 S/G I-R	(1) - (2) -	$D_s = 2.5$	(1) 1/R = 0.16 (2) 1/R = 0.06	(1) 50 ft (2) 50 ft	200 ft 1000 ft	${}_1D_1 = {}_1D_{s1} = 2.5$ ${}_1D_2 \quad {}_1D_{s2} = 2.5$	115-126 in $(R)_s$; Sensitivity Reduction	(1) 110-126 possibly 64-67 and 96-126 (2) 113-126 possibly 64-67 and 96-126. (Fig.6)		
2A	4 TDME	2 S/G I-R	(1) - (2) -	$0.02 \leq D_b \leq 0.10$	(1) 1/R = 0.16 (2) 1/R = 0.06	(1) 200 ft (2) 50 ft	1 n mi 1000 ft	$0.08 \leq D'_{s1} \leq 0.40$ $0.08 \leq D'_{s2} \leq 0.40$	63-69 moderate interference	(1) 54-79 possibly 22-110 (Fig. 7)	On or over station or sidelobe region $(R)_s$	
			(1) 6 (2) 3		(1) 1/R = 0.16 (2) 1/R = 0.06	(1), (2) >100 n mi	> 1 n mi	$0.003 \leq D'_{d1} \leq 0.013$ $0.001 \leq D'_{d2} \leq 0.007$		61-71 possibly 45-88 (Fig. 7)	Flight, or directive region $(R)_d$	
3A	1 T S/G B	1 A TPR in either $(R)_s$ or $(R)_d$ of 2 S/G I-R		$D_s = 2.5$	Unity	1000 ft <5 n mi		$D_{gks} = 2.5$ ${}_3D_1 = 2.5$ ${}_3D_2 = 2.5$	No information given	40-63 and 64-75 possibly 19-63 and 64-89 no link 1A effects (Fig. 8)	on or over station $(R)_s$	Garbling (affects only A TPR)
						5 n mi to 230 n mi		$D_{gjd} = 2.5$ ${}_3D_1 = 2.5$ ${}_3D_2 = 2.5$		55-63 and 64-71 possibly 45-63 and 64-82 no link 1A effects (Fig. 8)	Flight $(R)_d$	
			(1) 6 (2) 3		Unity (since basic effect is between A TPR and T S/G B)	1000 ft <5 n mi (separation nearly the same for A TPR to S/G I-R)		$D_{tks} = 2.5$ ${}_3D_1 = 2.5$ ${}_3D_2 = 2.5$		54-63 and 64-73 possibly 44-63 and 64-83 no link 1A effects (Fig. 8)	on or over station $(R)_s$	Triggering (traffic capacity reduced, S/G I-R fruit increased)
						5 n mi to ...		$D_{tjd} = 0.08$ D ...		61-63 possibly ...	Flight	

[redacted]

Following is a comparison of reported results (3) and predicted results. The OpDevFor results† (qualitative), quoted verbatim, have been separated as they apply to each of the links, as far as it is possible to do so. No attempt was made to include the effects of the Webster Field installation in the predictions. For ease of comparison, the six links are considered separately. It should be noted that in these OpDevFor tests, "...the primary purpose of Task SIX was to determine operational characteristics. For this purpose the two main criteria were the appearance of interference to the IFF equipment as shown on the PPI picture and any interference to the IFF system causing loss of IFF response (3)." Furthermore, spurious responses should have been minimized by the location of the Tacan and IFF antennas on the aircraft (5). Table 4 and Fig. 17 are included to summarize the comparison.

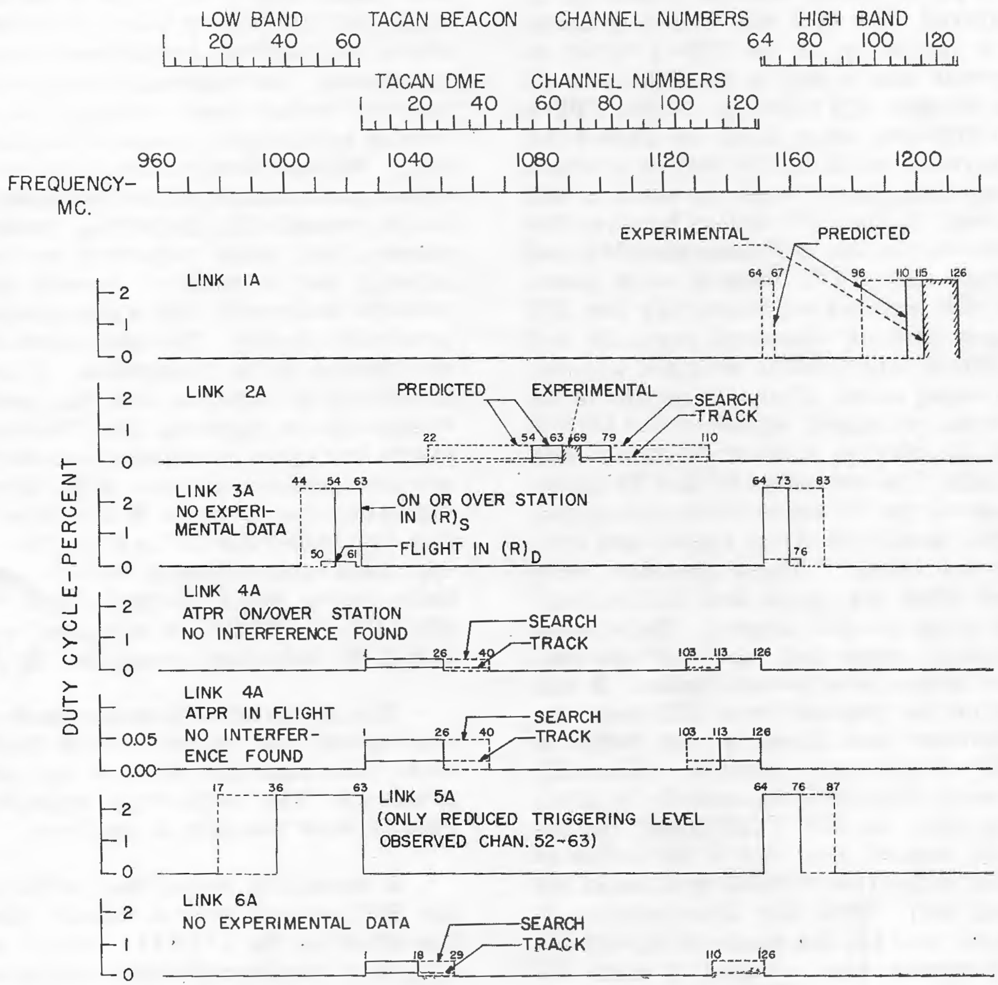

Fig. 17 - Summary of experimental and predicted results -- Atlantic City tests, October 1955

†Tests were performed using the following Tacan channels: 1-18, 23, 46, 49, 52, 54, 56-76, 80, 83, 86, 107, 110, 112, 117, 120, 122-124, 126.

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LINK 1A: T S/G B - S/G I-R
(See Figs. 6 and 16 and Table 4)

Experimental Results of OpDevFor (3)

"In the area of Tacan channels 115 to 126 the URN-3 signals fed into the receiver image passband of the UPX-1. In the GCI station the signals were received equally as well with the UPX-1 antenna disconnected and a dummy antenna installed. It is believed that this was due in a large part to the pickup of the URN-3 signal on the power cables and in the UPX-1 itself in the wooden GCI building. On the FPS-8 located 850 feet away from the URN-3 the interference was noted for 360° on channel 122 but disappeared when the antenna was removed. In the GCI station however the interference to the IFF completely blocked the scope and no IFF targets were seen. When SIF was used however the SIF equipped aircraft appeared normally and the URN-3 interference did not appear. When using codes 10 and 14 on any mode the north reference pulses of the URN-3 signal decoded as a string of eleven dots in a radial line covering a total of 28 miles. On code 41 the 40 degree reference pulses decoded as strings of ten radial dots covering ten miles. These decodes were spaced about the scope and did not generally mask the SIF targets. There were some other codes that "decoded" the reference pulses to a lesser degree. It was noted that on channels near 122 where the interference was strongest the range of the SIF targets was reduced. Normally they were received dependably to about 160 miles on SIF ("DECODE" on the UPA-24 control box) and to 210 miles on raw IFF video (the "CODE" position of the control box). With this interference on channels near 122 the range of dependable SIF response was reduced to about 100 miles. In the final week of ground tests a notch filter designed by BROWN & SHARP for the Bureau of Ships was tested. This filter effectively eliminated the URN-3 interference to the UPX-1 at the FPS-8 site 850 feet away. When the URN-3 was moved away from the GCI site this filter eliminated the interference at the GCI site also. The filter did not seem to reduce the range of the IFF-SIF materially.

Predicted Results

There is general agreement, as shown in Table 4, between the experimental and predicted results. It is to be expected that the predicted region should yield a region of greater effect; the effective power output of T S/G B (see Fig. 5, EXP. AN/URN-3) is lower than that for which the graphical results were obtained. In addition, the responsor sensitivity was reported to have been reduced. These two effects account for a part of the discrepancy. Without detailed information on the actual performance of the responsor (e.g., actual sensitivity, bandwidth, center frequency, and image rejection) no further attempt can be made to resolve the difference between the experimental and predicted results. The agreement obtained appears to be reasonable. It should, therefore, be inferred that the predicted results can be expected when Tacan equipments having the assumed characteristics are produced and as more S/G I-R equipments become involved. It should be noted that the OpDevFor Atlantic City tests represent measurements involving essentially twelve AN/APX-6B (ATPR), twelve AN/ARN-21 (TDME), a single beacon (T S/G B), and a single responsor (S/G I-R).

The predicted values are made on the assumption that radiated and conducted noise (see Appendix A) are not serious problems. The reported experimental results show that this is not true.

It should be noted that, while use of the SIF decoder gave a "clean" picture, the effect of the interference on the decorder's ability to decode in the presence of interference was not measured quantitatively. Such a (theoretical) determination of the effect of interference on decoder efficiency, while necessary, is beyond the scope of this report.

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LINK 2A: TDME - S/G I-R
(See Figs. 7 and 16 and Table 4)

"In the area of TACAN channels 63-69, where the ARN-21 interrogating pulses would be expected to be received directly into the receiver channel of the UPX-1, interference was found. The interference was of nearly equal intensity on TACAN channels 65, 66, and 67. When the aircraft were over the field or on the field the ARN-21 pulse pairs produced moderate interference all around the scope. When they were out on a bearing the interference produced was restricted to a small sector. In all cases the ARN-21 interference was so light compared with the random IFF responses of the same aircraft triggered by other IFF interrogators that the TACAN interference could not be seen unless the APX-6B's in the aircraft were turned off. As a further measure of this interference, the MRN-16/URN-3 was set up on channel 65 and this TACAN channel was used for the operational tests run during the final week of flights.

There is general agreement between the experimental and predicted results. No specific information is available on the minimum equipment separation (between TDME and S/G I-R) which occurred during the flight tests. Had such data been available, a better check would have been possible. The predicted region of interference for this link is based on the assumption that a separation of 1000 feet is the closest approach of aircraft (TDME) on either takeoff or landing to the responsor antenna. Such interference occurs within the responsor sidelobe region and its determination is dependent upon the antenna characteristics. A comparison of the magnitude of the component duty cycle for this link and for link 1A shows that it is to be expected that the interference should have been "moderate."

By comparison, the interference to have been expected from the aircraft (TDME) in "flight," i.e., in the directive region, should have been much less than that observed when the aircraft were "on or over the station," i.e., in the sidelobe region. The presence of interference in the directive region might easily have gone undetected. Perhaps, the reported interference in the directive region was actually observed on the fringes of the sidelobe region. The presence of interference (experimentally) on this link may be considered a measure of the "sensitivity" of the IFF system to Tacan interference (as measured in terms of duty cycle); see also the discussion of link 4A, below.

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LINK 3A: T S/G B - ATPR - S/G I-R
(See Figs. 8 and 16 and Table 4)

There is no mention in the experimental results of interference having been observed on this link; perhaps the switching system used did not allow for specific tests on this link (but this is not definitely known). It was not possible during the OpDevFor tests to determine if signals were being received by the ATPR, since this could only have been measured using a recorder.

Had there occurred interference on this link which caused triggering of the ATPR (from a single T S/G B), there should have been a noticeable increase in the interference as the close formation of aircraft was opened. Such a change in formation should have increased the number of interference pulses present and, hence, should have caused somewhat more obscurity of the display (PPI). The effects of interference on this link are a function of range (separation) and the greatest effects in terms of the number of channels causing interference should have been observed while the aircraft were close to the station.

While, in Fig. 16, it is indicated that the effects on link 1A can be expected to occur simultaneously with effects on link 3A, this merely serves as a warning in case such effects can occur on the channels for link 3A. A comparison of Table 4 entries for the predicted regions of links 1A and 3A indicates that these two effects should not be expected to occur simultaneously, for the experimental situation being considered.

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LINK 4A: TDME - ATPR - S/G I-R
(See Figs. 9 and 16 and Table 4)

"In the area of TACAN channels 1-18, and especially on channel 6, where the ARN-21 radio frequency energy present at a continuous level could be expected to cause partial blocking of the APX-6B receiver, no interference was found even at a range of 230 miles. A check flight was run on channel 6 where the aircraft were flown in pairs so that the IFF antenna of one was approximately ten feet from the TACAN antenna of the other. No effect was noted. Additional flights were run on channels 6 and 23 with the suppressor connections from the ARN-21 to the APX-6B disconnected. No change in the triggering rate of the APX-6 was noted nor was the range reduced. It should be noted however that the antenna installation of the F9F-8 is nearly the optimum to keep the ARN-21 from interfering with the APX-6.

The magnitude of the duty cycle as seen from Table 4 suggests that it might have been difficult to detect the presence of interference on this link. Only an increase in the number of aircraft flown in the same close formation could have been counted upon to improve the detectability. Of course, the interference on this link might be less than that predicted because of shielding of the aircraft structures; this may not be the case for aircraft with other types of antenna installations. Certainly it is not surprising that the interference caused by a single TDME (even for D_b = 0.10%) was not detected.

Note that from Table 4, the direct link (2A) between the TDME and the S/G I-R should have introduced no interference (which could have been observed in the experiment) in the region of the channels on which interference is actually predicted for link 4A.

LINK 5A: T S/G B - S/G TPR - S/G I-R
(See Figs. 10 and 16 and Table 4)

"In the area of TACAN channels 52-63, where the URN-3 might be expected to trigger or block the UPX-5 IFF ground transponder, the only effect noted was a reduction of the UPX-5 receiver sensitivity. Representative values were: down 6 db on channel 63, 3.3 db on 59, 1 db on 52, and none on 49. The UPX-5 was not triggered by the URN-3."

The predicted region did not include consideration of the effect of a reduction in transponder triggering level. Of course, the proximity of the T S/G B and the S/G TPR antennas and their relative locations should have placed the path of the transmitted energy below the path of maximum energy. Naturally, a reduction of interference effects by such installation means are desirable, and it would be advantageous to design installations on this basis.

Evidence is available from the operating fleet (8) which establishes that S/G TPR equipments are being triggered by T S/G B. The particular experience (8) revealed that triggering occurred with the T S/G B set on channel 55 and that a 16-Mc separation (i.e., to channel 39) was required to prevent triggering. Without details regarding the state of equipment performance or the antenna installations, this experience confirms the predicted interference region.

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LINK 6A: TDME - S/G TPR - S/G I-R
(See Figs. 11 and 16 and Table 4)

This situation is somewhat comparable with that of link 4A except that in this case the interference should have been observable, i.e., at the same level as link 2A. As in the case of link 4A, the predicted region of interference is dependent upon the equipment separation, which is not known. It is possible that the duty cycle of predicted interference is too great by virtue of possible shielding of some of the sources as a result of close formation flying. When on or over the station, shielding of the antennas may have occurred as a result of maneuvers of the aircraft during climb, descent, or bank. Such shielding effects might have reduced both the number of sources seen by the S/G TPR and the time during which the interference was observable. Other TDME antenna installations might have produced quite different results.

SUMMARY

The foregoing example illustrates an approach which leads to a systematic analysis of the effects of interference in a particular situation; there is fair agreement between predicted and actual results. The approach is general and can be used to evaluate the effects in any actual situation. However, in the above example, only effects on individual links were considered; this completed the analysis because of the switching procedure used in obtaining the data. In general, although actual situations will be complex, they can be described in terms of the links involved. The effect of interference, then, will be obtained by considering all effects which can be expected to occur simultaneously (see, for example, the compound links shown in Fig. 1).

In any specific situation to be investigated, a map geographically locating the equipments involved (similar to Fig. 15) should be drawn. From such a map, geographical and duty cycle schematics should be constructed (Fig. 16). In the geographical schematics it should be possible to replace individual sources of interference by a density of a type of sources; the duty cycle schematic is then based on the density of sources expected, and the duty cycle (vector width) is obtained with the aid of Fig. 14. The results obtained for each simultaneously active link can be presented together (Fig. 17), from which overall effects can be derived by combining effects on the individual links. In combining the duty cycle of signals present on the simultaneously active links, it is permissible to use values obtained directly from Fig. 14 for each link; these values can be added arithmetically to obtain a total duty cycle for specific channels. After the total duty cycle is obtained, a correction factor can be applied to the result (from Fig. 18) to account for signals which overlap, and which, therefore, do not contributed independently to the duty cycle.*

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*Figure 18 was obtained by considering the signals causing the interference to occur at random at the receptor input. Thus, the law of repeated trials can be applied to calculate the percentage of time signals are present. An effective number of signals is obtained by dividing the time during which signals are present by the duration of an interfering signal (all Tacan signals have the same duration). The ratio of the effective number of signals to the total number of signals is the correction factor.

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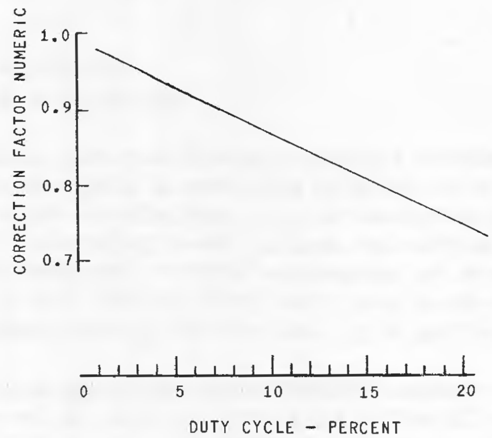

Fig. 18 - Total duty cycle correction factor

ACKNOWLEDGMENT

The suggestions made by Mr. C. V. Parker of the Security Systems and Avigation Branch at various stages of this analysis are gratefully acknowledged.

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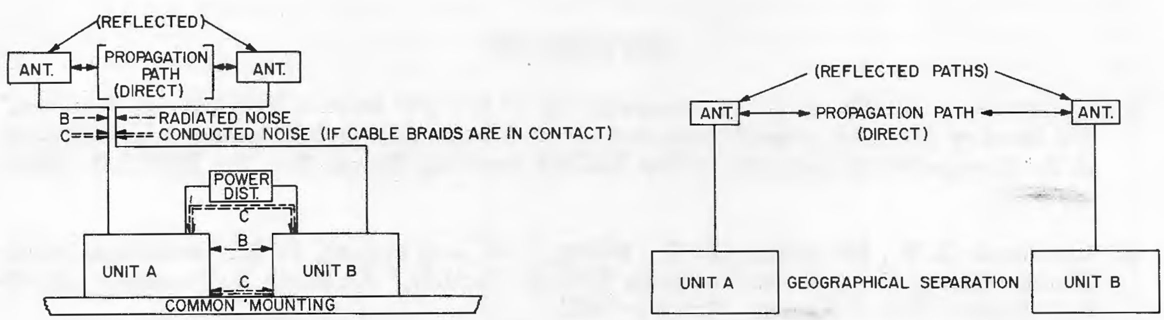
APPENDIX A
Interference Problems

Electronic equipment used in aircraft, shipboard, and surface installations must be capable of operating in proximity to other electronic equipment. Under such conditions of operation mutual interference between equipments may exist. In general, the causes of such interference are:(a) direct propagation (and reflections thereof) between the antennas of the equipments involved, (b) direct radiation of energy between equipments installed physically in the same locality, and (c) conduction through common interconnecting cabling (e.g., power leads, ground leads).

The source of interference may be an equipment operated either close to or widely separated from the equipment affected. In the general case of equipments which must be installed and operated in close proximity, all three causes of interference may be found to exist to some extent (Fig. A1a). In the case where equipments are isolated geographically, interference should be expected only from the normal transmissions of particular equipments, reflections thereof, and spurious signals which cannot be suppressed (Fig. A1B).



(a) - A general case of equipments in close proximity

(b) - A general case of equipments isolated geographically

Fig. A1 - Some possible sources of mutual interference between units or equipments

Since the problem of mutual interference between equipments is very general, for the specific case of interference between equipments which are part of the Mark X IFF and Tacan systems, a division can be made on the basis of the system function of equipments into interrogator-responsors (I-R) and transponders (TPR) of either system as sources and/or receptors of interference. Furthermore it is necessary to consider that direct-path propagated interference can occur on the following paths or links between the affected equipment or receptor (listed first) and the source or cause of interference (listed second):

1. surface/ground by surface/ground,
2. surface/ground by air,
3. air by surface/ground,
4. air by air.

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In addition, since the problem concerns mutual interference between two systems each having interrogator-responsors and transponders or beacons, an equipment of either kind in one system may be a source which affects equipment of either kind in the other system. Some possible interference links are shown in Fig. 1, which identifies the links by numbers and the specific equipments involved by each system. In each link, interference shown by line A represents the case in which a Tacan equipment is the source; and line B, the case in which an IFF equipment is the source.

Link 1A represents interference to the IFF surface/ground interrogator-responsor (S/G I-R) caused by the Tacan surface/ground beacon (T S/G B); link 1B, the interference to the T S/G B by the IFF S/G I-R. On link 1A, for an interference duty cycle of 2.5% (for single equipments), responsor sensitivity may be reduced with the consequence of a reduced service area, transponder reply codes may be garbled to the extent that proper codes are rejected and wrong codes accepted, and the fruit or unsynchronized reply rate may be increased to reduce the readability of IFF and radar displays. On link 1B, for an interference duty cycle (for single equipments) of up to 0.08%, in addition to possible reduction in service area (caused by a reduction in receiver sensitivity) interrogations for distance measurement may be garbled, thereby reducing the beacon replies available for display by the responsor; the distance indication may be affected and the interrogator caused to be in the SEARCH mode more often.

Link 2A represents interference to the IFF S/G I-R from the Tacan airborne interrogator-responsor (TDME) used as distance measurement equipment and for receiving Tacan beacon transmissions for continuous bearing data; link 2B represents interference to the TDME by the S/G I-R. The effects of interference in link 2A are the same as those on link 1A except that the interference duty cycle (of single equipments) will be between 0.02 and 0.1%. Interference on link 2B, at a duty cycle (for single equipments) of up to 0.08%, in addition to possible reduction in receiver sensitivity (service area), may result in a loss of azimuth and/or range information or errors in either or both.

Link 3A represents interference to the IFF airborne transponder (A TPR) from the T S/G B; link 3B represents interference to the T S/G B from the A TPR. Interference on link 3A, at a duty cycle (for single equipments) of 2.5%, will introduce extraneous signals which may (a) reduce the minimum triggering level (service area), (b) cause garbling of interrogations, and/or (c) cause the A TPR to reply. Effect (b), to the IFF system, causes a reduction in the number of replies from a given A TPR thus degrading the responsor display; and effect (c) causes a reduction in traffic capacity, introducing fruit (unsynchronized replies) into the responsor display. Interference on link 3B, at a duty cycle (for single equipments) of up to 0.3% or, in emergencies, as much as 0.6%,* should cause effects similar to those of link 1B.

Link 4A represents interference to the IFF A TPR from TDME; link 4B, interference to the TDME from the IFF A TPR. Interference on link 4A is expected to be similar to that on link 3A but at a duty cycle (for single equipments) between 0.02% and 0.1%. Interference on link 4B is expected to be similar to that on link 2B, but at a duty cycle (for single equipments) up to 0.3%, or, in emergencies, as much as 0.6%.*

*For situations in which the IFF system is being used at its greatest capabilities.

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The four links which have just been described qualitatively indicate the effects to be expected. However, these four links are not the only ones. Other simple linkages are possible involving the IFF surface/ground transponder (S/G TPR) and the IFF airborne interrogator-responsor (A I-R) equipments. These additional simple mutual situations are shown as links 6 through 8 in Fig. 1. Link 9 (Fig. 1) is a combination of links, an additional possibility which can occur when link 3 exists. Other composite linkages are possible (Fig. 1): (a) the links likely to be involved when Tacan airborne equipment (TDME) is transmitting in the environment of both airborne and surface/ground IFF equipments, (b) the links involved when both airborne and surface/ground Tacan equipments are transmitting and only IFF surface/ground equipments are involved, (c) the case involving all simple linkages and all types of equipments of both systems. In each case, the total effects of the interference can be deduced from the descriptions given for the first four links.

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APPENDIX B
Estimate of the Overall Tolerances for Parameters of the Mark X IFF System

The parameters required in evaluating the extent to which the Mark X IFF system is affected by interference from the Tacan system are: receiver (responsor) sensitivity or transponder minimum triggering level (MTL), receiver center frequency, receiver overall bandwidth, and transmitter power output. Each parameter is subject to variations which occur either in production or while the equipments operate under changing ambient conditions. The variations in each parameter obtained from a sample of production test data of an S/G I-R (AN/TPX-17)* are given in Appendix C. An estimate of the operational variations likely to be encountered in using the equipments of the IFF system was obtained by analyzing acceptability test data for an S/G I-R (AN/UPX-1A) and an S/G TPR (AN/UPX-5) (Appendix D). The results of Appendixes C and D are summarized in Table B1

TABLE B1
Summary of Estimated Tolerances, Mark X IFF System

Equipment	Type of Tolerance	Receiver Sensitivity (db)	Receiver Center Frequency (Mc)	Receiver Overall Bandwidth (Mc)	Transmitter Power Output (db)
Interrogator-Responsor	Production	±5.0	±6.5	±3.7	±3.9
	Operational	±8.1	-	-	±2.6
Transponder	Production	-	-	-	-
	Operational	±8.5	±3.8	±3.0	±2.7

To obtain the overall tolerances, production and operational effects must be combined. Since the data do not include both effects for S/G I-R and S/G TPR equipments, estimates are made by assuming that the data available for one type of equipment (e.g., I-R) are applicable as an order of magnitude to the other type of equipment (i.e., TPR). The production and operational effects can be combined in many ways, but two limiting values are obtained if the two effects are considered on the one hand to be independent, and, on the other hand, dependent. In the former case, the resultant is obtained as a statistical sum; in the latter, as an arithmetic sum. The overall tolerance will be between these two limiting values. Both limits are given in Table 2; the lower limit is obtained from the statistical sum (tabulated as $\pm 3\sigma$), and the upper limit, from the arithmetic sum of the two effects. The relation between the two limits is shown in Fig. B1 where the lower limit is represented by the extremities ($\pm 3\sigma$) of the normal curve and the upper limit is represented by the ends of the rectangular distribution (indicated as MAX).

*The AN/TPX-17 is a specially packaged AN/UPX-1 type of equipment.

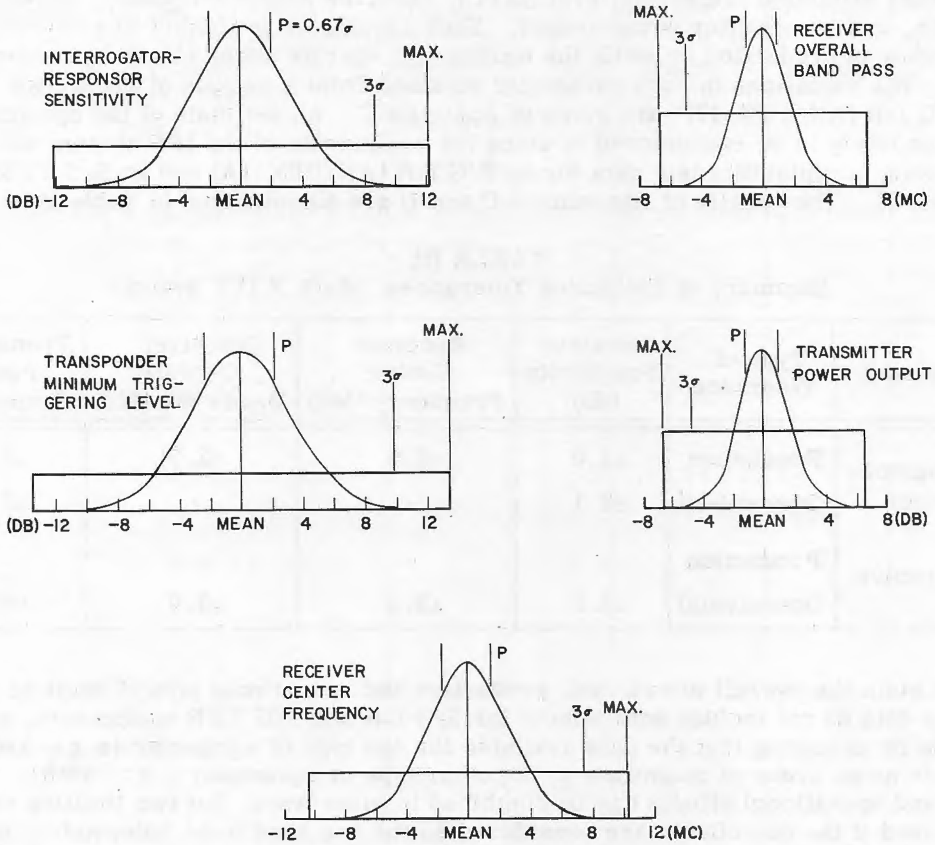


Fig. B1 - The relation between the probable range (±p = 0.67 σ about the mean), the statistical range (±3σ about the mean), and the maximum range. The rectangular distribution represents the same area contained between the limits ±3σ under the normal curve.

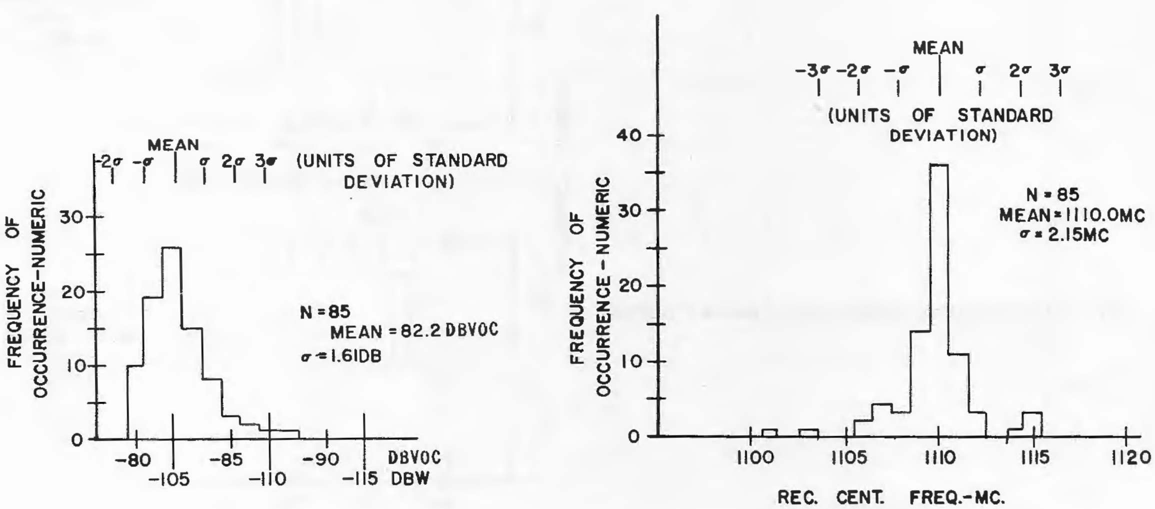
* * *

APPENDIX C
Calculation of Production Tolerances

The production tolerances of several parameters must be known, or it must be possible to approximate them, in order to estimate magnitudes of the overall system tolerances for each parameter. For the IFF system, the results of tests made during a production run of AN/TPX-17 equipments (data obtained for BuShips Contract NObsr 57496) were analyzed. Pertinent results (sample of a production lot) are summarized in the histograms shown in Fig. C1 for receiver sensitivity, receiver center frequency, receiver bandwidths (-6 db and -40 db with respect to peak response), and transmitter power output. For each histogram both the average and standard deviation have been calculated; for convenience the range of each variation is given in units of the standard deviation (σ scale at top).

From the histograms it can be seen that nearly all values for each parameter are included between the limits $\pm3\sigma$ about the average value. Hence, the limits $\pm3\sigma$ are used to represent the production variation for each parameter. The following values derived from the production data are used in this report as estimates of the production variations for IFF system equipments.

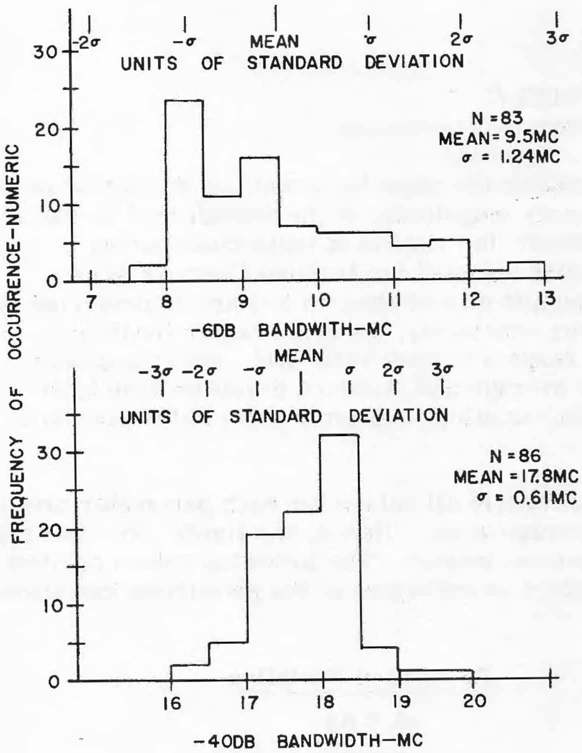
Parameter	Production Variation
receiver sensitivity	±4.8 db
receiver center frequency	±6.5 Mc
receiver overall bandwidth	±1.8 to ±3.7 db
transmitter power output	±2.7 to ±3.9 db



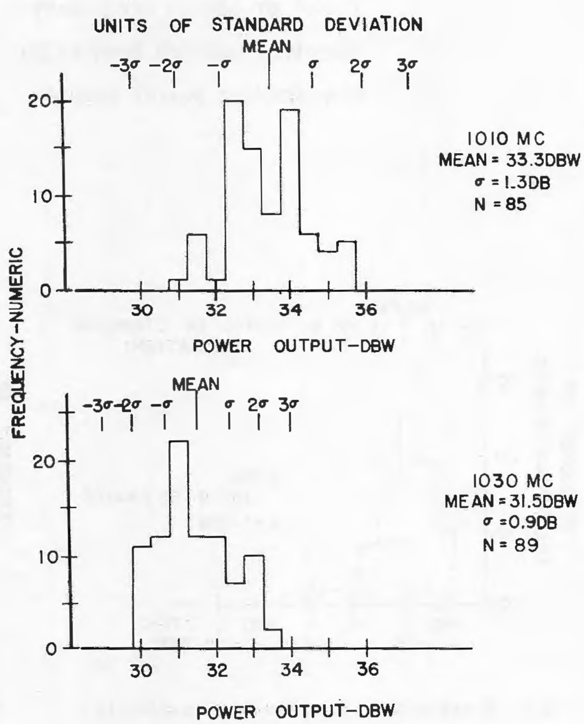
(a) - Responsor (receiver sensitivity)

(b) - Responsor (receiver) center frequency

Fig. C1 - Histograms of production test data



(c) - Responsor (receiver) overall bandwidth



(d) - Interrogator transmitter power output

Fig. C1 - Histograms of production test data (continued)

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APPENDIX D
Determination of Operational Variations

To determine the tolerance to be assigned for the operational variation of the pertinent parameters, two sets of available acceptance test data (for AN/UPX-1A, S/G I-R, and AN/UPX-5, S/G TPR, equipments) have been analyzed. The discussion of the data follows for each of these equipments.

SURFACE/GROUND INTERROGATOR-RESPONSOR (S/G I-R)

Responsor Sensitivity

Using the test results for a single equipment* given in Fig. D1, the causes of operational variation and their magnitudes are found to be:

Cause of Variation	Range of Variation ($2b_i$) (db)	Variation about Mean ($\pm b_i$) (db)	Standard Deviation ($\sigma_{xi} = b_i / \sqrt{3}$) (db)
Temperature (-50° to +65°C) and Humidity (to 100% relative)	6	±3.0	1.73
Shock and Vibration	5	±2.5	1.44
Drift (24-hour test)	1	±0.5	0.29
Line Voltage and Frequency	5	±2.5	1.44

If each of the foregoing distributions is assumed to be rectangular having limits of $\pm b_i$, then the range of total variation is represented by $2b_i$, or b_i is the half range. Following Schwartz† the variance becomes

$$\sigma_{xi}^2 = \frac{b_i^2}{3}$$

from which σ_{xi} may be determined.

Upon combination, the overall variation should be approximately normally distributed. The statistical combination of these variations by the method of Schwartz results in a value of σ_y = 2.7 db. It is estimated that 99.7% of the responsors in operation should have sensitivities which fall within limits ±8.1 db (3σ) about the mean sensitivity.

*The results of part of the preproduction type test of radar recognition set AN/UPX-1A, obtained during July and August 1952 for Bureau of Ships contract NObsr 57039. Power output was measured using AN/UPM-6B equipment.

†L. S. Schwartz, "Statistical Methods in the Design and Development of Electronic Systems," NRL Report 3111 (Unclassified), July 1947, p. 25, Eq. (52)

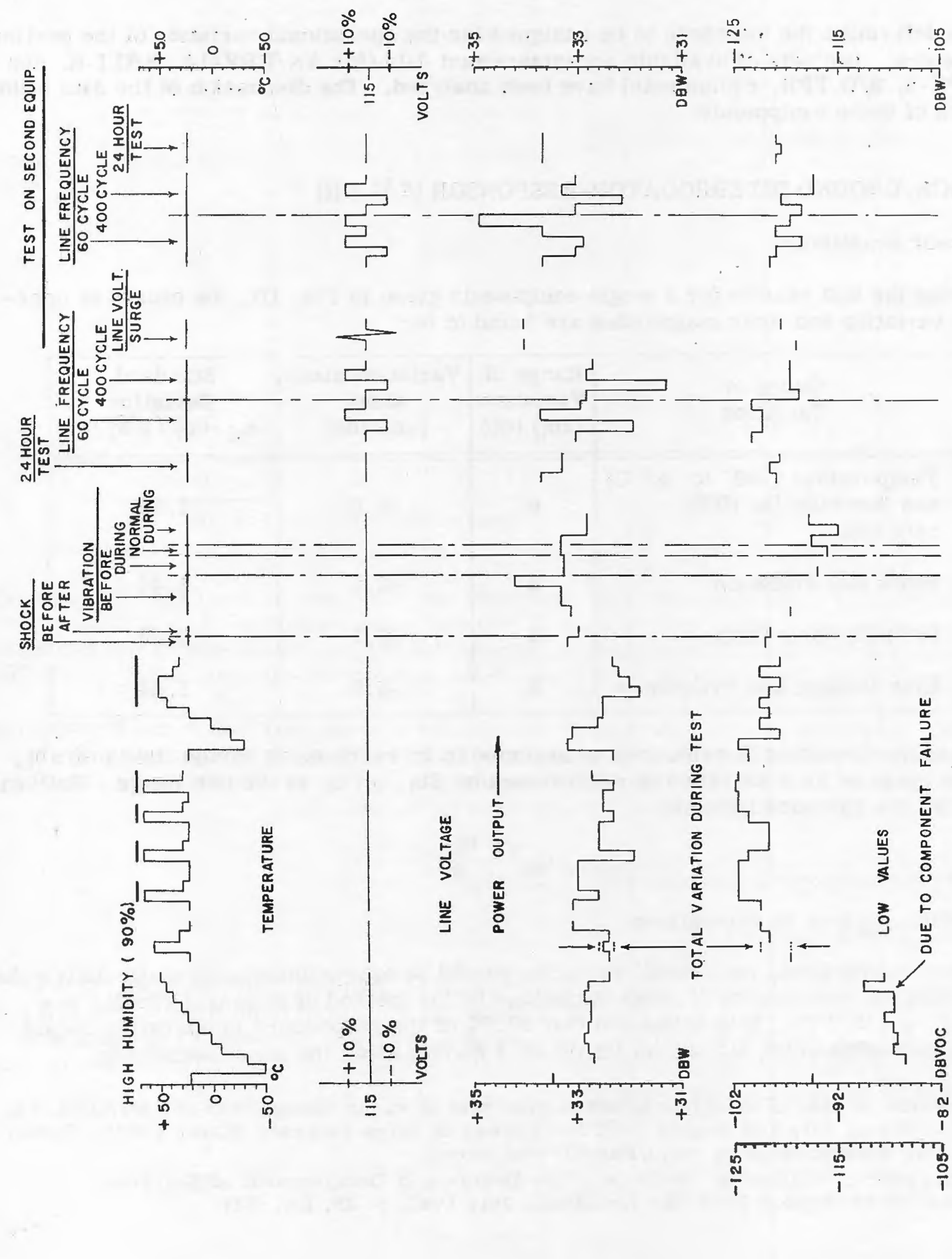

Fig. D1 - Summary of acceptability test results – AN/UPX-1A

Power Output

On the basis of acceptability test results on a single equipment (Fig. D1) the following causes of variation in output power and their magnitudes were obtained:

Cause of Variation	Range of Variation ($2b_i$) (db)	Variation about Mean ($\pm b_i$) (db)	Standard Deviation ($\sigma_{xi} = b_i/\sqrt{3}$) (db)
Temperature (-50° to +65°C) and Humidity (to 100% relative)	1.7	0.85	0.49
Vibration	1.4	0.70	0.40
Shock	0.2	0.10	0.05
Drift (24-hour operation)	0	-	-
Voltage (1) 60 cps	1.9*	0.95	0.55
(2) 400 cps	1.3*	0.65	0.37
Duty Cycle	0.7*	0.35	0.20

*Average based on 2 equipments — range obtained from Fig. D1

Two distinct types of operation of equipment are possible. In one case 60-cps power supplies will be used and in the other case, 400-cps power supplies. Calculations have been made for both cases, from which it is found that the statistical sum of the individual variations is: for 60-cps operation, $\sigma_y = 0.86$ db, and for 400-cps operation, $\sigma_y = 0.76$ db.

Upon combination of the independent causes, the overall distribution can be expected to be nearly normal. Therefore, it is estimated that 99.7% of the equipments may be expected to operate within the transmitter power limits of $\pm 3\sigma_y$. These limits are, for 60-cps operation, ±2.6 db and, for 400-cps operation, ±2.3 db.

SURFACE/GROUND TRANSPONDER (S/G TPR)

Minimum Triggering Level (MTL)

Some of the acceptability tests performed on a single preproduction model of the AN/UPX-5* are summarized in Fig. D2. These tests differed from those of the S/G I-R (Fig. D1) in that results of combining several of the variable parameters are available (i.e., temperature and humidity, as well as ±10% voltage variation). The causes of variation may be summarized as follows:

*Partial results of a preproduction type test for a single radar identification set AN/UPX-5, obtained for Bureau of Ships contract NObsr 52038.

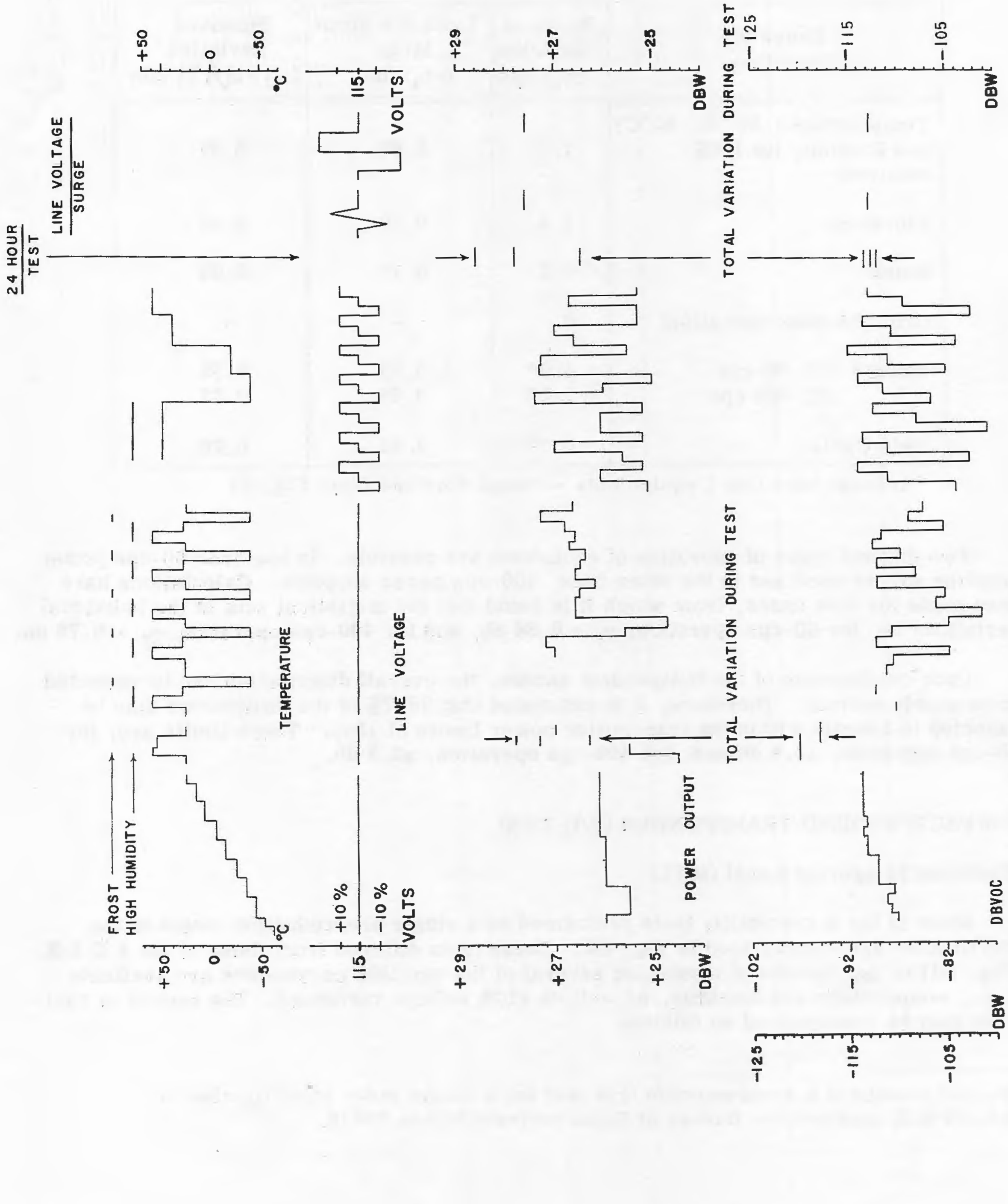

Fig. D2 - Summary of acceptability test results — AN/UPX-5

Cause of Variation	Range of Variation (db)
Temperature (-50° to +65°C) Humidity (to 100% relative) Voltage (±10%)	15
Drift (obtained from approximately 24-hour operation during high-temperature test)	2

By comparison, during the same series of tests, a value for drift of 1.7 db was obtained from a 24-hour test made at room-temperature conditions; this confirms the approximate magnitude of the drift component.

Since only two variations are to be combined, it is appropriate to take as the resultant the arithmetic sum, 17 db (±8.5 db) to be used as the estimated magnitude of the variation in triggering level for transponders operating in the system.

Transponder Receiver Center Frequency

The acceptability test data gives two distinct causes of variation

Cause of Variation	Range of Variation (Mc)
Temperature (-50° to +65°C) Humidity (to 100% relative) Voltage (±10%)	2.5
Drift (obtained from approximately 24 hours of operation during high-temperature test)	1.3

Under these circumstances, the procedure is as just described; the arithmetic sum, 3.8 Mc, is the estimated magnitude of the variation in the overall system receiver frequency to be expected from operational causes.

Transponder Receiver Bandwidth

The acceptability test data give two distinct causes of variation

Cause of Variation	Range of Variation (Mc)
Temperature (-50° to +65°C) Humidity (to 100% relative) Voltage (±10%)	4
Drift (obtained from approximately 24 hours of operation during high-temperature test)	2

The arithmetic sum of the two, 6 Mc, is taken as the estimated magnitude of the variation in bandwidth to be expected operationally in the system.

Transponder Power Output

Examination of the acceptability test results (Fig. D2) shows that data are available for two distinct variations (the combined effects of temperature, humidity, and voltage variations as well as drift — as deduced from the 24-hour test). Further test data give information on two other causes of variation, duty cycle changes and the effect of standing waves on the antenna feeder. These variations are summarized as follows together with calculated values of the standard deviations obtained by the method of Schwartz.

Cause of Variation	Range of Variation ($2b_i$) db	Variation about Mean ($\pm b_i$) db	Standard Deviation ($\sigma_{xi} = b_i/\sqrt{3}$) (db)
Temperature (-50° to +65°C) Humidity (to 100% relative) Voltage (±10%)	2.40	1.20	0.69
Duty Cycle (500 - 3000 pps)	0.5	0.25	0.14
VSWR (0.4 to 3.5 db)	0.8	0.40	0.23
Drift (24-hour test)	1.8	0.90	0.52

Upon combination of these variations, the distribution should be nearly normal. The overall standard deviation which results from the above variations is found to be, σ = 0.91 db. Hence, it is estimated that 99.7% of the transponders in the system will operate within power limits, ±2.7 db, with reference to the mean value.

* * *

APPENDIX E
Calculations of Overall Frequency Response of IFF System Receivers

The construction of overall frequency response curves of IFF system receivers requires a knowledge of responsor sensitivity or transponder triggering level, receiver bandwidth and center frequency, as well as their expected variations. Data are available from equipment specifications for the nominal values and in Appendix B for estimated overall variations for equipments produced for and operating in the IFF system. Furthermore, in Appendix F there is given a method for combining bandwidth and center-frequency tolerances or variations. To include the effect of variations in receiver sensitivity (triggering level), it is to be expected that the condition of the best sensitivity (triggering level) occurs when bandwidth is a minimum; and poorest sensitivity (triggering level), when bandwidth is a maximum. Having described, in Appendix B, each variation statistically in terms of a probable maximum ($\pm 3\sigma$)* and a maximum (MAX)* value, use is made of these values to obtain a pair of limit frequency response curves.

It is desired to use the constructed pair of response curves to denote the frequency range of interference between a condition of reasonable likelihood and some low-probability expectation of occurrence. Such a frequency range is approached if (a) the MAX values of all parameters are used to establish the upper limit or the low-probability expectation, and (b) the lower, or reasonable likelihood, limit is obtained by using the most probable value for each parameter. The value p corresponds to 0.67σ for a normal distribution.† Thus, in constructing the response curves, values associated with the lower limit will be

$$\text{mean} \pm p;$$

and, with the upper limit,

$$\text{mean} \pm \text{MAX}.$$

Values of these tolerances to be used in the calculations are given in Table E1.

TABLE E1
Tolerances Used in Calculation of Overall Frequency Response Curves

Parameter	Tolerances		
	3σ§	p (0.6745σ)‡	MAX§ ‡
(IR) Responsor Sensitivity (db)	9.5	2.1	13.1
(TPR) Minimum Triggering Level (db)	9.9	2.2	13.5
Receiver Center Frequency (Mc)	7.5	1.7	10.3
Receiver Overall Bandpass (Mc)	4.8	1.1	6.7
Transmitter Power Output (db)	4.7	1.1	6.5

§From Table 2
‡Used in calculation of response curves

*The relation between these two maximum limits is shown in Fig. B1.
†Half the population is included between the limits $\pm p$.

 [redacted]

In the actual construction of the response curves, since calculations can only be made for the bandpass at the points 6 db below peak response, use must be made of available experimental data to obtain the remaining portions of the curves.

PROCEDURE FOR CONSTRUCTING TRANSPONDER RESPONSE CURVES

To obtain the upper limit, use is made of the following values:

mean MTL = -103 dbw

feeder loss = 1 db

to give the effective mean value, $\overline{MTL}$ = -102 dbw. Hence, values of MTL are given by $\overline{MTL} + p \leq MTL \leq \overline{MTL} + MAX$, which with the aid of Table E1 gives $-104 \leq MTL \leq -116$ dbw. (The MTL may be specified in several ways, e.g., as -80 db below 1 volt, open circuit. Figure E1 is included as a ready means of conversion from one set of units to any other. This applies as well to responsor sensitivity. The units, dbw, will be used throughout this report.)

The values of bandwidth (-6 db with respect to peak response) to be associated with the above values of MTL are: $B_a - MAX \leq B \leq B_a - p$, where the lower bandwidth limit is associated with the upper limit of MTL, and the upper bandwidth limit with the lower limit of MTL.

The combination of receiver and bandwidth center-frequency variations (by the method of Appenidx F) involves the values $p \leq \Delta f \leq MAX$, since the mean value is zero. The lower limit of Δf is associated with the upper limit of B_a and the upper limit of Δf with the lower limit of B_a.

Using this method, a total frequency variation, Δf (for a = -110 dbw), about the nominal operating frequency of (±) 13 Mc is obtained for the maximum value of MTL (-116 dbw). And the frequency variation Δf is (±) 7 Mc (a = -98 dbw) for the lower MTL limit of -104 dbw. These are points on the overall frequency response curves.

Further construction details of the overall response curves are obtained by using available experimental data,* composites of which have been drawn and are shown as Figs. E2 and E3. The first of these figures gives the response (at a relatively small signal-to-noise ratio) as measured by the presence of interference signals in the transponder receiver. Interfering signals of somewhat greater level (approximately 25 db) cause the transponder to be triggered; Fig. E3 is the composite of experimental response data for three equipments. Since the transponders now in use are known to have small dynamic ranges (between the minimum detectable or just triggering level and saturation or full triggering level), the 25-db difference between the data of Figs. E2 and E3 is attributed to the characteristics of the decoder and its associated protective circuits. Figures E2 and E3 were used to sketch in the upper and lower portions, respectively, of the overall response curves; see Figs. E4 and E5 for a comparison of the derived and experimental results.

*D. T. Latimer, "Investigation of Interference between Mark X IFF and TACAN Equipments," Naval Air Test Center (NANEP) Final Report (~~Secret~~), August 17, 1953

[redacted]

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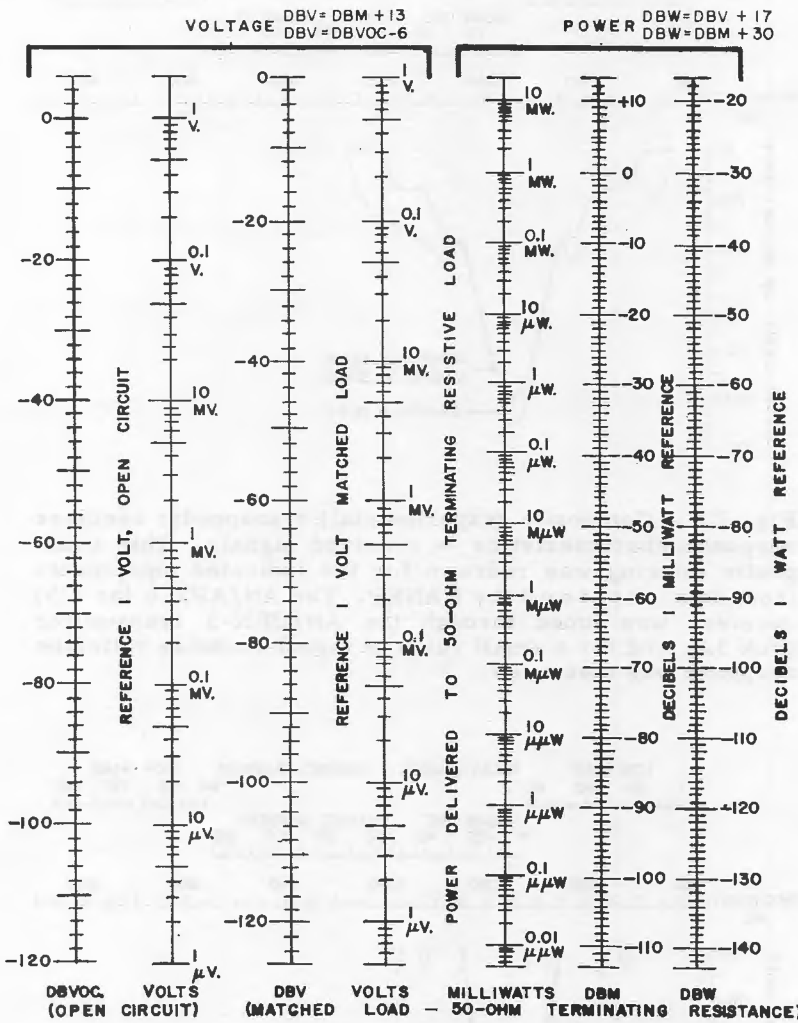

Fig. E1 - Chart of decibel conversions for several reference values. Corrections for matched loads other than 50 ohms may be made as follows:

R (ohms)	Correction (db)
51	0.1
52	0.2
53.5	0.3

The correction should be subtracted if converting from 50 ohms to R; and added if correcting from R to 50 ohms (R > 50 ohms).

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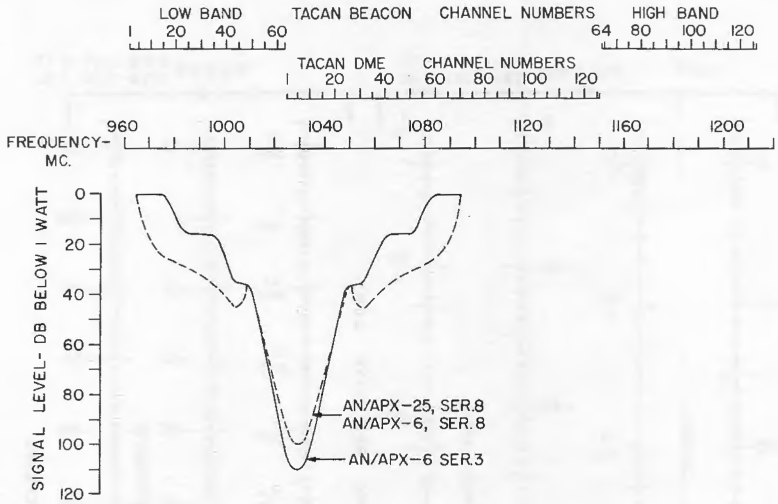

Fig. E2 - Composite (experimental) transponder receiver response characteristics -- received signals. This composite drawing was redrawn for the indicated equipments from data obtained by NANEP. The AN/APX-6 (or -25) receiver was tuned through the AN/URN-3 transmitter (link 3A), and for a small value of signal-to-noise ratio, the response was measured.

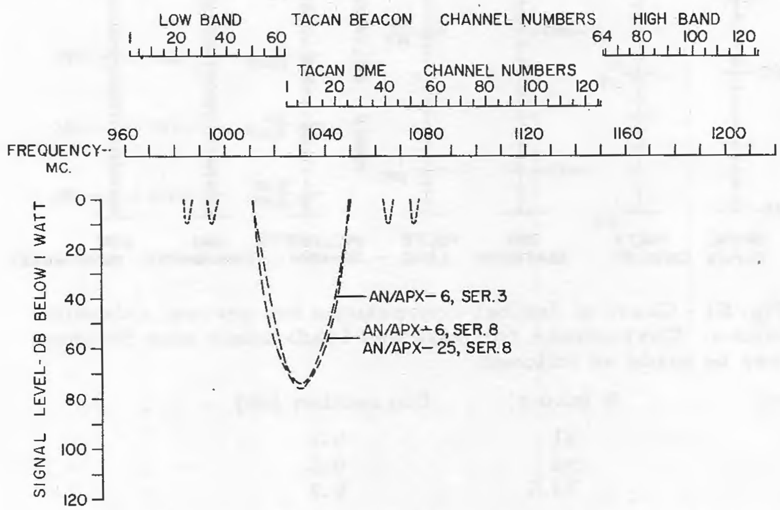

Fig. E3 - Composite (experimental) transponder triggering level response characteristics. This composite drawing was redrawn for the indicated equipments from data obtained by NANEP. The AN/APX-6 (or -25) receiver was tuned through the AN/URN-3 transmitter (link 3A).

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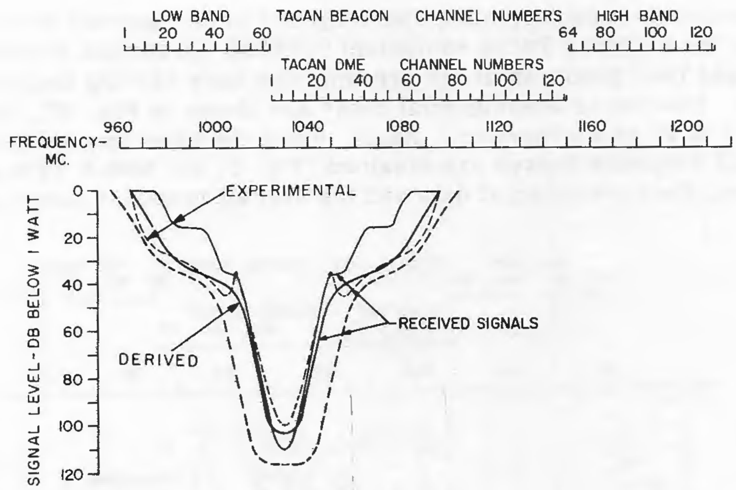

Fig. E4 - Graphical comparison of transponder overall (received signal) response curve with experimental data

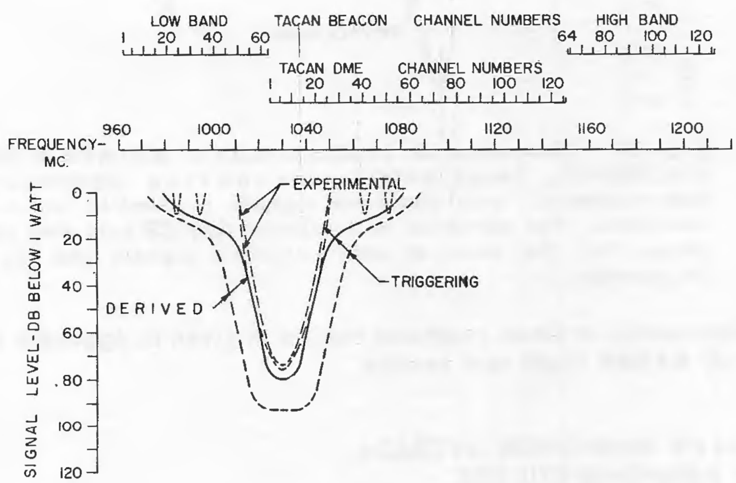

Fig. E5 - Graphical comparison of transponder overall (triggered) response curve with experimental data

To complete the construction, the assumption is made that the image response will be similar to the direct frequency response but reduced by the amount of the image rejection. Thus, the direct frequency responses of the A TPR and the S/G TPR are expected to be the same, but since the image responses are different (25 and 35 db, respectively) the overall responses will differ in this respect.

The final overall response curves for A TPR and S/G TPR are shown in Fig. 2. For each type of transponder, the received signal and triggering cases are shown.

[redacted]

It is necessary to consider, also, the response to be expected when the source of interference is the airborne Tacan equipment (TDME). A certain proportion of the equipments which have been produced at the present time have varying degrees of spurious transmissions. Composite experimental data* are shown in Fig. E6, obtained using the AN/URN-3 (T S/G B) as a generator. Again, using the experimental data as a guide, modified overall response curves are obtained (Fig. 3, for both A TPR and S/G TPR). For comparison, the experimental data and the overall response curve are shown together in Fig. E7.

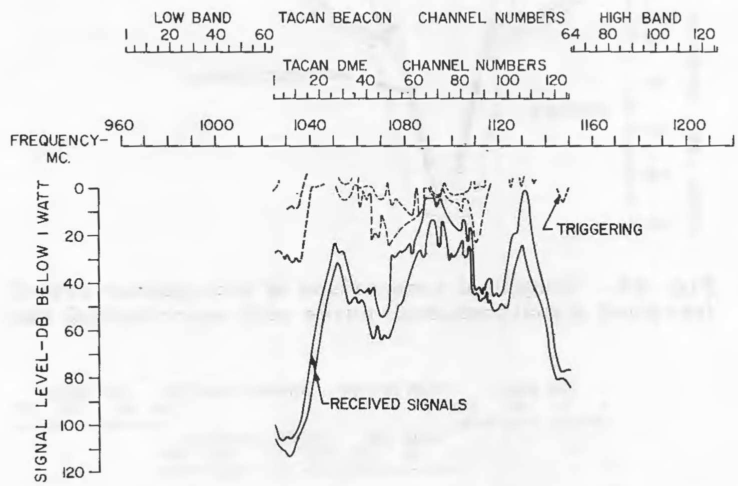

Fig. E6 - Response of transponder AN/APX-6 to AN/ARN-21, Tacan distance measuring equipment (experimental) with spurious signals present in transmissions. The envelope of available NANEP test data is shown for the case of both received signals and for triggering.

A further discussion of these response curves is given in Appendix G, where they are used to verify NANEP flight test results.

CONSTRUCTION OF RESPONSOR OVERALL FREQUENCY RESPONSE CURVES

The procedure for constructing responsor overall frequency response curves is the same as that used for the transponder curves; appropriate tolerances, from Table E1, are used.

For purposes of calculation, the effective mean usable sensitivity, $\bar{S}$, is found to be

$$\begin{aligned} \text{mean } S &= -103 \text{ dbw} \\ \text{feeder loss} &= \underline{\quad 4 \text{ db}} \\ \bar{S} &= -99 \text{ dbw} \end{aligned}$$

*NANEP test results were obtained by taking the combinations of two each AN/ARN-31 and AN/APX-6.

[redacted]

[redacted]

and

$$\overline{S} + p \leq S \leq \overline{S} + MAX.$$

Therefore,

$$-101 \leq S \leq -111 \text{ dbw},$$

where p = 2 db and MAX = 12 db, from Table E1.

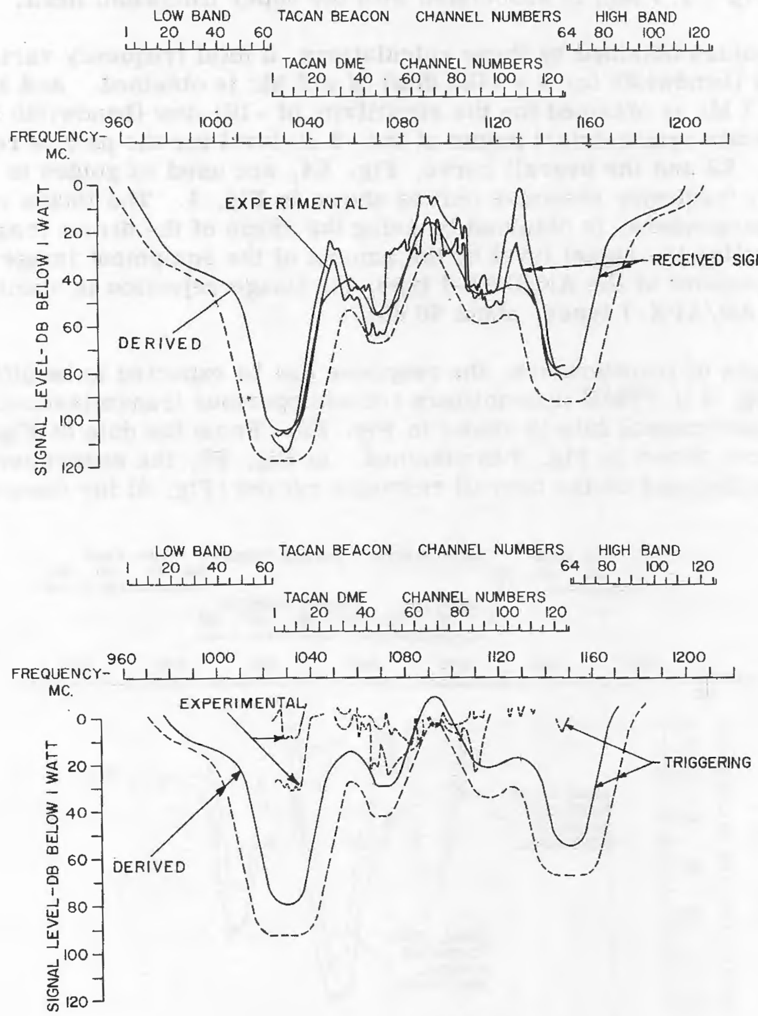

Fig. E7 - Graphical comparison of overall transponder response with experimental data. Data were obtained for AN/APX-6 and AN/APX-25 IFF transponders using experimental AN/ARN-21 equipments as signal generators.

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For a mean bandwidth (B_a) of 9.0 Mc (measured at -6 db with respect to peak response) the bandwidth limits are

$$2.3 \leqq B \leqq 7.9 \text{ Mc},$$

for p = 1.1 Mc and MAX = 6.7 Mc, from Table E1. The lower bandwidth limit is associated with the upper sensitivity limit; and the upper bandwidth limit, with the lower sensitivity limit.

The receiver center-frequency tolerance is obtained from Table E1 and the upper limit (MAX = 10.3 Mc) is associated with the lower bandwidth limit. The lower receiver center-frequency limit (p = 1.7 Mc) is associated with the upper bandwidth limit.

Using the values obtained by these calculations, a total frequency variation at maximum sensitivity (bandwidth for a = -105 dbw) of ±12 Mc is obtained. And a frequency variation of ±5.7 Mc is obtained for the sensitivity of -101 dbw (bandwidth for a = -95 dbw). These values locate symmetrical points at the -6 db level for the pair of response curves. The data of Fig. E2 and the overall curve, Fig. E4, are used as guides to obtain the pair of overall direct frequency response curves shown in Fig. 4. The image response, as in the case for transponders, is obtained by using the shape of the direct frequency response curves and adjusting the signal level by the amount of the equipment image rejection. In the case of responsors of the AN/UPX-1 type, the image rejection is about 35 db; for the AN/UPX-6 and AN/APX-7 types, about 60 db.

As in the case of transponders, the response can be expected to be different from that shown in Fig. 4 if TDME transmitters contain spurious transmissions. An example of composite experimental data is shown in Fig. E8. From the data of Fig. E8 the overall response curve shown in Fig. 4 is obtained. In Fig. E9, the experimental data from Fig. E8 is superimposed on the overall response curves (Fig. 4) for comparison.

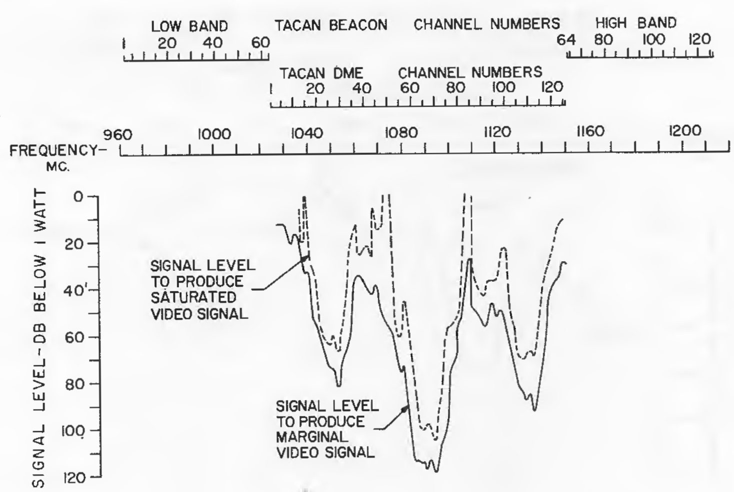

Fig. E8 - IFF responsor composite response to AN/ARN-21 (XN-2) experimental Tacan distance measuring equipment with spurious transmissions. The envelope of NANEP test data obtained using three responsors (one AN/UPX-1 and two AN/UPX-6) and two AN/ARN-21 equipments.

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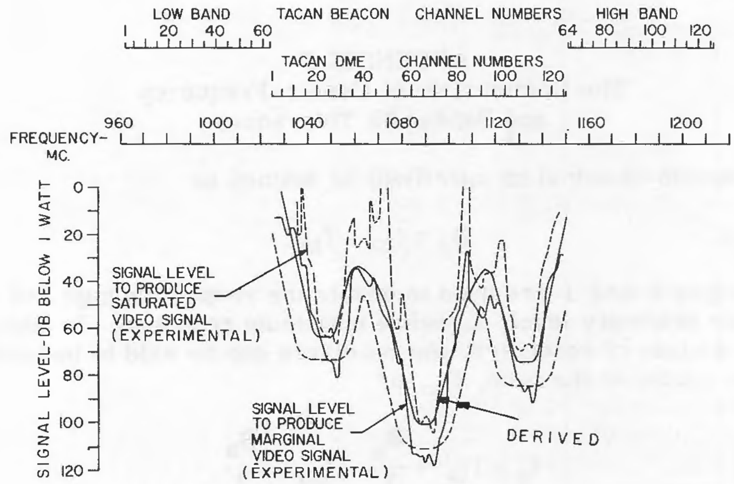

Fig. E9 - Graphical comparison of responsor overall response to spurious Tacan transmitted signals with experimental data

* * *

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APPENDIX F
The Combination of Center-Frequency and Bandwidth Tolerances

Let the bandwidth (nominal or specified) be defined as

$$B_a \equiv f_{ha} - f_{la}, \qquad \text{(F1)}$$

where the subscripts h and l are used to denote the respective high and low frequencies measured at some arbitrary level, a, below maximum response. In addition, if B_a is the bandwidth of a class of receivers, the receivers can be said to be tuned to the frequency (f_c) at the center of the band, B_a, or

$$f_c = f_{la} + \frac{B_a}{2} = f_{ha} - \frac{B_a}{2}. \qquad \text{(F2)}$$

Generally, it is desired to have the receivers tuned within certain total limits (Δf) of a particular frequency f. Thus,

$$f = f_c \pm \Delta f, \qquad \text{(F3)}$$

from which maximum allowable limits for f_c can be obtained, as

$$\left.\begin{aligned} {}_{min}f_c &= f - \Delta f \\ \text{and} \qquad {}_{max}f_c &= f + \Delta f, \end{aligned}\right\} \qquad \text{(F4)}$$

in order that the system continue to operate.

From Eq. (F2) it follows that there must be limits within which f_{ha} and f_{la} can be permitted to occur if Eq. (F4) is to be satisfied. These limits, which are denoted by primed symbols until bandwidth tolerances can be included, from Eqs. (F2) and (F4), are

$$\left.\begin{aligned} {}_{min}f'_{la} &= {}_{min}f_c - \frac{B_a}{2}, \quad {}_{max}f'_{ha} = {}_{max}f_c + \frac{B_a}{2}, \\ {}_{max}f'_{la} &= {}_{max}f_c - \frac{B_a}{2}, \quad {}_{min}f'_{ha} = {}_{min}f_c - \frac{B_a}{2}. \end{aligned}\right\} \qquad \text{(F5)}$$

To account for bandwidth tolerances, let the total or maximum variation be ΔB. Then the limits are

$$\left.\begin{aligned} {}_{max}B_a &= B_a + \Delta B \\ \text{and} \qquad {}_{min}B_a &= B_a - \Delta B. \end{aligned}\right\} \qquad \text{(F6)}$$

It should be expected that the combined frequency and bandwidth tolerances fall within limits given by Eqs. (F12) and (F10), as respective lower and upper limits.

Figure F1 illustrates the results to be expected in using Eqs. (F10) and (F12) and allows a comparison to be made of the differences between the probable maximum and the maximum resultants. The maximum limit was obtained by considering the component variation tolerances to be somehow dependent; the combined tolerance is the arithmetic sum of the components. The probable maximum limit was obtained as the statistical sum of the components which are considered to be independent variations or tolerances.

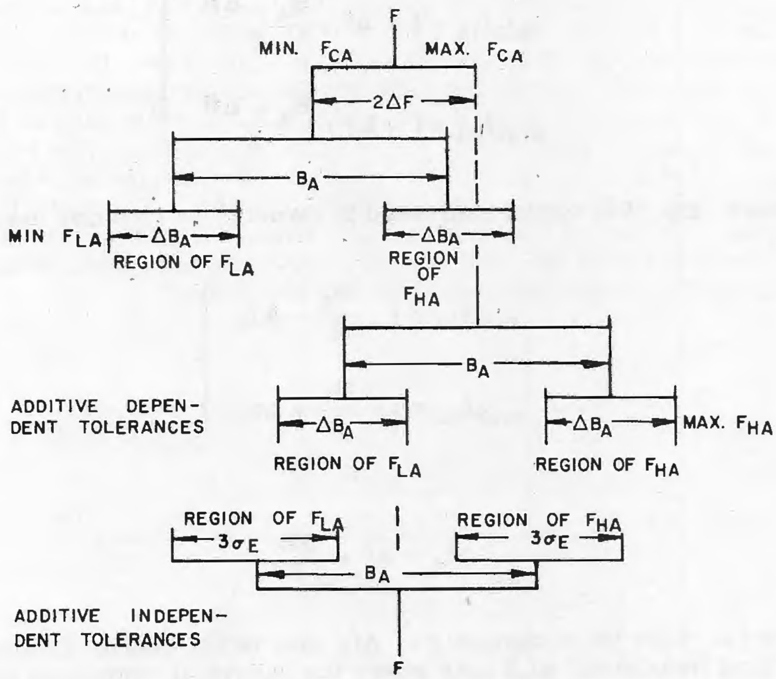

Fig. F1 - The relation between maximum and probable maximum limits obtained in the combination of receiver center-frequency and bandwidth tolerances

* * *

The limit values f_{la} and f_{ha} can be obtained by substituting $_{max}B_a$ from Eq. (F6) in the upper pair of Eq. (F5); thus,

$$\left.\begin{aligned} {}_{min}f_{la} &= {}_{min}f_c - \frac{{}_{max}B_a}{2} \\ \text{and} \qquad & \\ {}_{max}f_{ha} &= {}_{max}f_c + \frac{{}_{max}B_a}{2} \end{aligned}\right\} \tag{F7}$$

from which, using Eq. (F4),

$$\left.\begin{aligned} {}_{min}f_{la} &= f - \Delta f - \frac{B_a + \Delta B}{2} \\ \text{and} \qquad & \\ {}_{max}f_{ha} &= f + \Delta f + \frac{B_a + \Delta B}{2}. \end{aligned}\right\} \tag{F8}$$

For convenience, Eq. (F8) can be expressed in terms of an effective overall tolerance Δf_e, as

$$\left.\begin{aligned} {}_{min}f_{la} &= f - \frac{B_a}{2} - \Delta f_e \\ \text{and} \qquad & \\ {}_{max}f_{ha} &= f + \frac{B_a}{2} + \Delta f_e, \end{aligned}\right\} \tag{F9}$$

where

$$\Delta f_e = \Delta f + \frac{\Delta B}{2}. \tag{F10}$$

There are two ways the components of Δf_e may be combined. Ordinary addition gives the limiting (maximum Δf_e) case where the individual component qualities of Δf and ΔB are somehow dependent. The other limiting (probable maximum Δf_e) case, considering the components of Eq. (F9) to be independent, permits the definition

$$\sigma_f = \frac{1}{3}\Delta f$$

and

$$\sigma_B = \frac{1}{3}\left(\frac{\Delta B}{2}\right) = \frac{\Delta B}{6},$$

or

$$\sigma_e = \sqrt{\sigma_f^2 + \sigma_B^2} = \frac{1}{3}\sqrt{(\Delta f)^2 + \left(\frac{\Delta B}{2}\right)^2}, \tag{F11}$$

and

$$\Delta f_e = 3\sigma_e. \tag{F12}$$

[redacted]

APPENDIX G
Comparison of Some Predicted and Experimental Interference Effects

To compare the predicted results of interference with experimentally obtained data, test results obtained on link 3A (Fig. 1) will be considered. Experimental data* are available resulting from range runs made at several altitudes to investigate the extent of A TPR triggering by the T S/G B. The transmitter power output conditions reported to have existed are shown in Fig. 5 by the line designated as "EXP AN/URN-3." The response curve for the transponder used in the flight tests has been superimposed on the overall response curve in Fig. G1. The flight tests were intended to simulate the effect of interference when the AN/URN-3 is operating on channel 63. By using Figs. G1 and 5, (i.e., assuming free-space propagation) it is predicted that interference should have occurred out to a range of 1.9 nautical miles (this point is designated in Fig. G1 as the experimental check point). However, if an overall error in measuring triggering level and power output of ±3 db is allowed,† it is predicted that triggering of the A TPR should have occurred at least to 1 and possibly to 3 nautical miles. The NANEP results* showed that triggering was obtained from 1 to 5 nautical miles. However, for the test conditions, had A TPR equipments having the best possible sensitivity been used, triggering might have been obtained for ranges out to about 45 nautical miles.

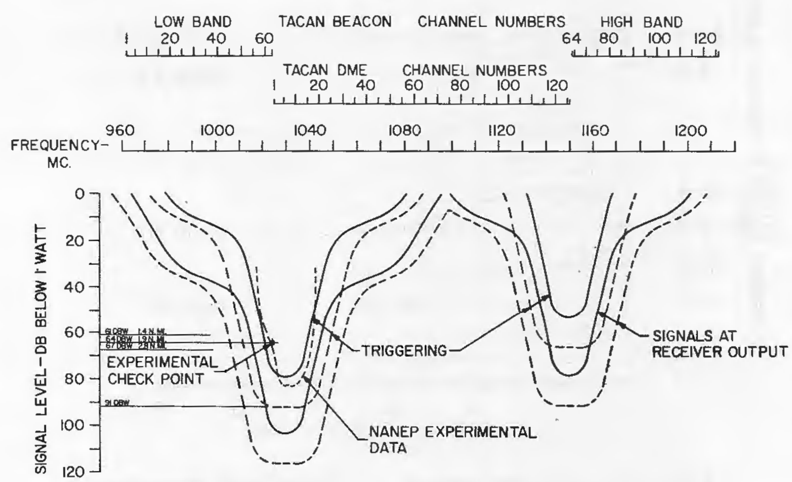

Fig. G1 - Experimental data superimposed on transponder overall response curve

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*D. T. Latimer, "Investigation of Interference between Mark X IFF and TACAN Equipments," Naval Air Test Center (NANEP) Final Report (Secret), August 17, 1953

†Using tolerances of 2 db for triggering level and 1 db for power output

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Figure G2 illustrates better how predicted ranges can be expected to agree with actual flight test data.* The reported NANEP data (essentially for a single A TPR) were superimposed to obtain maximum and minimum envelopes of signals which caused triggering. For comparison, the predicted interference regions should be interpreted as values which are equal to or greater than the percent triggering indicated. In the predicted curves, the reduction in triggering rate between 1.4 and 3 nautical miles is indicated arbitrarily as occurring linearly.

In the NANEP data (Fig. G2) distances were measured along the earth's surface; hence, it is to be expected that the extent of triggering should be reduced as the altitude increases. In Fig. G3 altitude and range are drawn to the same scale and the arcs are loci of points at constant slant range from an antenna located at the origin. The reduction in range expected for the altitudes used in the NANEP tests is shown for altitudes of 2000 and 4000 feet.

The degree of agreement (Fig. G2) between the experimental data and the predicted values is considered adequate to proceed with the use of the method in evaluating the extent of interference on the various links.

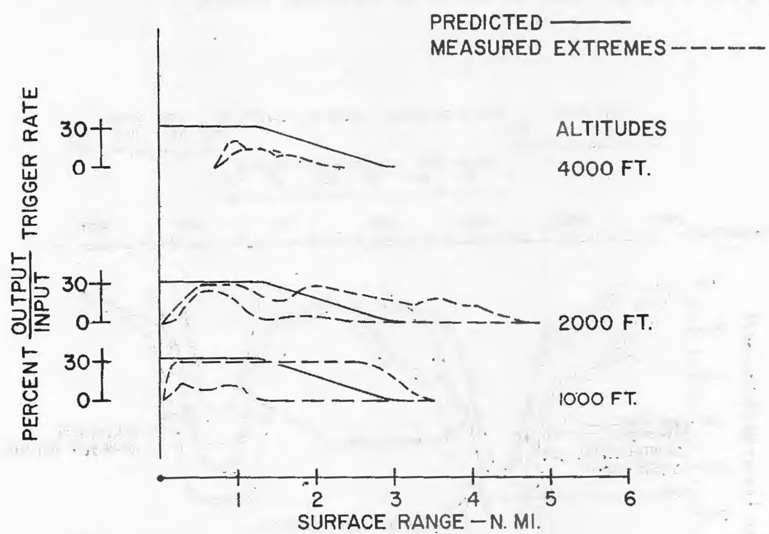

Fig. G2 - Comparison of predicted and measured interference on link 3

*Obtained by counting replies when the interference on link 3A occurred.

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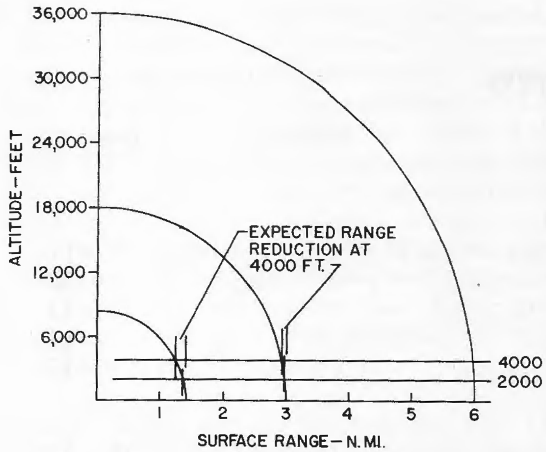

Fig. G3 - Variation of surface range with altitude

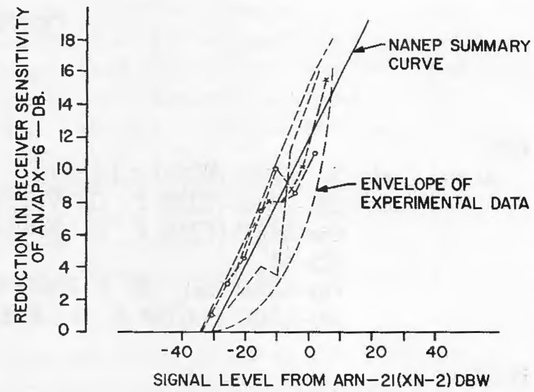

Fig. G4 - The effect of Tacan transmissions on IFF equipment receiver sensitivity

In making the comparison between predicted and experimental results, no attempt has been made to include the possible effects of reduction in receiver sensitivity caused by the presence of interference. An indication of the seriousness of this effect is shown in Fig. G4. The data presented in Fig. G4 summarize the results obtained by NANEP. Their data have been replotted together with the characteristic they used to summarize their data. In addition, envelopes have been drawn to indicate possible limits of extreme values.

* * *