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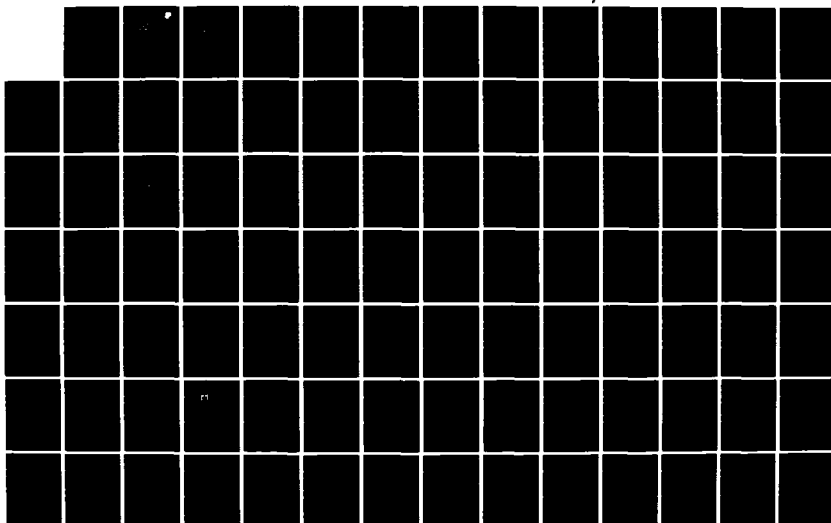
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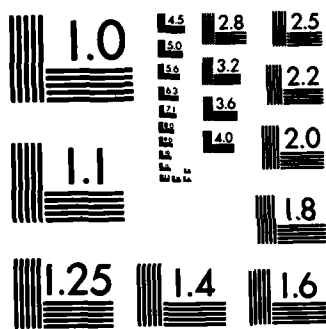
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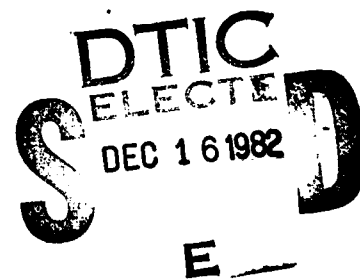


INVESTIGATION OF INTERMODULATION PRODUCTS GENERATED IN COAXIAL CABLES AND CONNECTORS

Georgia Institute of Technology

J. A. Woody and T. G. Shands

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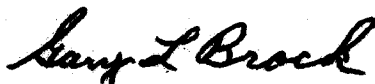
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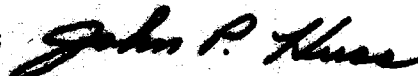
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samples selected to be representative of the coaxial cables and connectors employed on Command, Control, and Communications (C³) platforms. Mathematical models were developed which describe the IM behavior of these cables and connectors as a function of the various parameters investigated. In order to verify the cable-connector model, the IM levels of 21 additional test samples were predicted and then measured. The cable-connector combination model effectively predicts the IM levels within ± 4 dB as a function of each parameter except frequency; it predicts the variation with frequency to within 10 dB over the 20 to 450 MHz frequency range.

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PREFACE

The work described in this report was performed by personnel of the Electronics and Computer Systems Laboratory (ECSL) of the Georgia Tech Engineering Experiment Station. This program was sponsored by the United States Air Force (AFSC), Rome Air Development Center (RADC) as Contract No. F30602-81-C-0059. The program was monitored by Capt. G. L. Brock of RADC. The described work was directed by Mr. J. A. Woody, Project Director, under the technical supervision of Mr. H. W. Denny, Chief of the Electromagnetic Compatibility Division. This report summarizes the objectives, activities, and results of an investigation to develop measurement and modeling techniques for intermodulation products generated in coaxial cables and connectors.

The authors wish to express their appreciation to Mr. J. K. Daher, Mr. H. W. Denny, and Mr. W. B. Warren for their technical assistance and recommendations. Also, the authors wish to thank Mr. G. B. Melson for his assistance in the computer analysis of the data.

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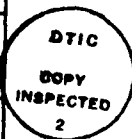


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1.0 INTRODUCTION

1.1 Background

Intermodulation (IM) products and harmonics are spurious frequency signals generated by nonlinear components and devices. Particularly in multiple signal environments like those encountered on Command, Control, and Communications (C³) aircraft, nonlinearities may seriously degrade system performance through interference. The extent of system degradation from nonlinearly-generated spurious signals is related to the properties of the nonlinearities, the amplitude of the applied signals, and the relative susceptibility (sensitivity) of potential receptors. The magnitude and frequency of the IM products and harmonics are related to the voltage transfer characteristic of the particular component exposed to the multiple signals.

The transfer characteristic between the input voltage, e_i , and the output voltage, e_o , for a component is typically expressed as:

$$e_o = A_1 e_i + \sum_{n=2}^{\infty} A_n e_i^n \quad (1)$$

where the A's are constants whose values are dependent upon the properties of the components. The first term of Equation (1) expresses the linear (desired) transfer function of the component. The subsequent series of terms defines the degree to which the network deviates from ideal. These "nonlinear" terms provide a measure of the interference-producing properties of the component. They indicate the degree to which intermodulation and spurious response products may be produced, the degree to which distortion and saturation may occur, the degree to which cross modulation may result, etc.

For example, consider the case where the input signal consists of two frequency components such as

$$e_i = V_1 \cos \omega_1 t + V_2 \cos \omega_2 t \quad (2)$$

From Equation (1), the output signal will be

$$e_o = A_1 V_1 \cos \omega_1 t + A_1 V_2 \cos \omega_2 t + \sum_{n=2}^{\infty} A_n \left[V_1 \cos \omega_1 t + V_2 \cos \omega_2 t \right]^n \quad (3)$$

Expansion of the infinite summation term indicates that spurious IM signals are generated at frequencies described by the IM equation:

$$\omega_{mn} = \pm m \omega_1 \pm n \omega_2 \quad (4)$$

where m and n are positive integers which denote the various harmonics of ω_1 and ω_2 and the sum $m + n$ defines the order of the IM product.

Comprehensive research has been conducted on the nonlinear characteristics of active devices such as transistors, diodes, integrated circuit, and other semiconductor PN junctions [1], [2], [3]. For such devices, it has been shown analytically and experimentally that the power relationship between the level of the extraneous IM products generated and the levels of the two fundamental input signals is

$$P_{mn} = m P_1 + n P_2 + K_{mn} \quad (5)$$

where P_1 = power in dBm of the input signal at ω_1 ,

P_2 = power in dBm of the input signal at ω_2 ,

P_{mn} = power in dBm of the IM output signal at ω_{mn}
(see Equation (4)), and

K_{mn} = a constant in dBm associated with the particular IM products and the properties of the component producing the IM product.

In operational situations where high power sources coexist with sensitive receivers, even seemingly inefficient, i.e., weak, IM product generators may lead to serious interference problems. In fact, recent evidence indicates that "passive" components may exhibit sufficiently nonlinear behavior to produce IM interference [4] - [13]. Examples of passive components that are potential IM interference generators include coaxial cables and connectors [14], [15].

The generation of IM products in passive devices arises from the fact that most metals in air intrinsically possess a thin layer of insulation. (This insulation results from oxidation or from the presence of foreign impurities on the metal.) When two metallic bodies are joined (as in the case of cable braid or contacting connector surfaces), a metal-insulator-metal interface is produced. Before contact, the insulating material serves as a dielectric. Under very light contact, however, the oxidation/impurity layer becomes a semiconductor junction capable of generating IM products. Under increased pressure of contact, the layer is penetrated with

successive decreases in IM product level. Thus, it may be expected that not only will IM products be generated in coaxial cables and connectors, but also that the product levels will be influenced by the types of materials (metals) involved; the metal's surface state, e.g., presence of coatings or platings, roughness, pressure (i.e., torque); physical configuration (bends, kinks, flexure, etc.) which will serve to vary the contacting area and pressure; environmental factors (temperature and humidity) and applied power level (as illustrated by Equation (5)). Other factors shown to influence the levels of IM products are braid type, length, type of center conductor, braid density, braid discontinuities, and the frequency of the applied signals [15].

The IM product levels resulting from these various causative parameters and the relationship between the IM product levels and the parameters have not been previously determined for typical cable-connector combinations employed on C³ aircraft. As more and more sensitive receivers and high power transmitters are placed on the same C³ platforms, the potential for nonlinear interference becomes more pronounced and harder to avoid. Therefore, to permit prediction and analysis of IM interference resulting from nonlinearities in coaxial cables and connectors on C³ aircraft, more accurate definitions of the potential IM product levels and their relation to the various cable and connectors parameters are required. This program was conducted to investigate these relationships.

1.2 Program Scope and Objectives

The scope of this program involved the investigation of parameters that may affect the generation of nonlinear IM interference within typical coaxial cables and connectors.

The objectives of this effort were to: (1) develop a measurement scheme capable of measuring very low level IM interference products; (2) perform measurements on a selected set of coaxial cable types and connector types to determine the level of IM product generation; and (3) develop equations and mathematical models which describe the IM behavior of coaxial cables and connectors.

1.3 Program Approach

To accomplish the above objectives, a 12-month measurement and analysis program was conducted. This technical program consisted of the following major tasks:

- Develop measurement scheme
- Formulate test procedures

- Perform IM tests
- Develop models
- Formulate verification procedures
- Verify and assess models

Thus, a repeatable, accurate, and sensitive measurement scheme to gather data which characterizes the third-order IM product* generated in coaxial cables and connectors was developed. From the resulting data, models were derived which can be used to predict the IM levels in these passive components. Finally, tests were performed to verify the resulting models, and the applicability of the models to actual operational situations was assessed.

*It has been indicated that the third-order ($m + n = 3$) IM product is the strongest odd-order IM interference source [16]. Hence, the third-order IM product was primarily emphasized. In the remainder of this report, when an IM product is discussed, it is assumed to be the third-order IM product.

2.0 MEASUREMENTS

2.1 IM Products

Initial efforts consisted of the development of a measurement scheme to be used to collect data on low level IM products generated in coaxial cables and connectors as a function of various identified parameters. The general procedure utilized was to (1) define the parameters to be considered, (2) develop appropriate test setups, (3) evaluate the test setups, (4) formulate test procedures, and (5) perform the IM tests.

Since the level of the IM product generated in coaxial cables and connectors is related to a large variety of parameters, it was necessary to restrict the number to those of most critical importance. The parameters considered to be of major concern are those related to the physical and material properties of the cables and connectors and those related to the amplitude and frequency of the applied signals. The parameters selected to represent typical physical, material, and signal properties are as follows:

- connector type
- connector plating
- cable type
- cable length
- frequency
- input power level

The effects of the first four parameters were determined via the appropriate selection of the tests samples. A total of 83 test samples (which are identified in Appendix A) were chosen to be evaluated. The behavior with frequency was established by measuring one HF and four different UHF IM test frequencies. These IM frequencies and the associated frequencies of the fundamental input signals are given in Table 1. The nominal HF frequency separation is 2 MHz while the UHF frequency separation is 25 MHz. The rationale for selecting these frequencies and separations is discussed in Appendices B and C.

From Equation (5), the final causative parameter considered to be of major concern was input (applied) power. Its effect was evaluated by performing measurements at several different input power levels at the test sample.* Most of

* The input power level is defined as the linear sum of the power levels of the two equal amplitude fundamental signals at the input of the test sample.

TABLE 1
IM TEST FREQUENCIES

IM Frequency	Input Signal Frequencies	
	f_1	f_2
f_{IM} (MHz)	(MHz)	(MHz)
21.9*	19.89*	17.88*
200	250	225
275	250	225
350	400	375
425	400	375

* These specific frequencies were selected because of the availability of HF filters. The nominal value for these frequencies are $f_{IM} = 22$ MHz, $f_1 = 20$ MHz, and $f_2 = 18$ MHz.

the measurements were performed at each test frequency from the lowest input power level at which IM products could be reliably detected up to +44 dBm (25 W). However, a few tests were performed at input power levels up to +51 dBm (126 W) at 22 MHz and +50.6 dBm (115 W) at 350 MHz.

To perform the measurements, appropriate test setups were developed. These test setups were patterned after those reported in the literature [14], [15], [16]. Figure 1 illustrates the basic measurement setup. Note that the two input signals are amplified, fed through high-Q bandpass filters, and combined in a transmission line hybrid. From the hybrid, the two combined signals are applied to the test component (cable, connector, or combination) through a directional coupler. This first directional coupler supplies a reference from which input power levels are determined. Following the test component is a second directional coupler which provides a sample of the generated IM product. The filter between this second coupler and the spectrum analyzer is to prevent the much higher level fundamental signals from producing IM products inside the spectrum analyzer and obscuring those generated by the test component. A highly linear load terminates the signal path for the fundamentals and the intermodulation products. The specific components of the HF test setup were slightly different than those of the UHF test setup. Detailed descriptions of the block diagrams and detailed descriptions of the resulting HF and UHF test setups are given in Appendix B.

The developed test setups were then calibrated and evaluated to assure accuracy and repeatability. The calibration procedure is described in Appendix D. The evaluation of the test setups was performed by determining their sensitivities, inherent (residual) IM levels, and measurement repeatability. The maximum sensitivity (noise floor) of the HF test setup at the output of the test sample* was -88 dBm which, for an input power level of +44 dBm, is 132 dB below the input. The equivalent maximum sensitivity of the UHF test setup was -126 dBm or 170 dB below an input power level of +44 dBm. The UHF setup is more sensitive because of the lower insertion loss of the test setup components at UHF and because a low noise figure, high gain preamplifier could be employed to improve the noise figure of the spectrum analyzer (see Appendix B).

Since the various components of the test setup are coaxial in nature and include several sections of cables and numerous connectors, they can be expected to produce

* The power levels given in this report for sensitivity and IM products are the values at the output of the test sample.

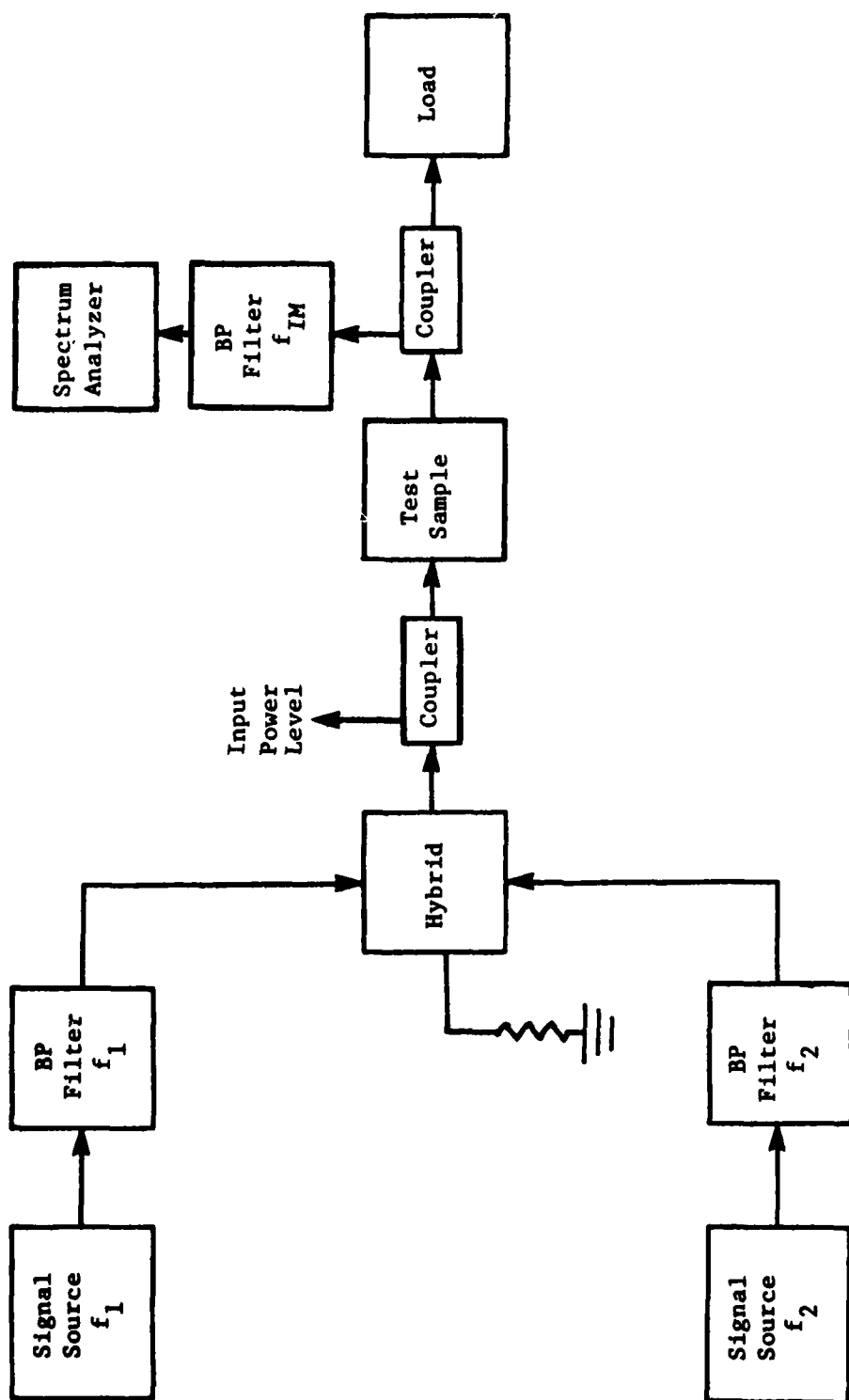


Figure 1. Basic Measurement Setup

IM products of the same orders of magnitude as the samples to be tested. Indeed, the test setups did exhibit characteristic residual levels of IM products. Before proceeding with the evaluation of the test samples, it was necessary to quantify these levels and reduce them where necessary. Thus, the residual (inherent) IM product levels of the test setups were measured without a test sample present at various IM frequencies and input power levels. These measurements were performed both with and without the cancellation schemes described in Appendix B. The inherent IM levels are summarized in Table 2; these levels vary with both frequency and input power. Without the cancellation scheme, the inherent IM level of the test setup was of the same order of magnitude as that of the test samples. With the cancellation scheme, the inherent IM level could be typically reduced to approximately the noise floor at the spectrum analyzer. Therefore, the cancellation scheme was employed to permit the IM level generated in the test sample to be distinguished from the inherent IM level of the test setup. Specifically, the cancellation scheme lowered the inherent IM level of the test setup at the test sample to a value significantly lower than the measured IM level of the test sample. In general, a goal of 10 dB or more difference in these two IM levels was achieved unless the test sample IM level was within 10 dB of the noise floor.

Measurement repeatability was evaluated by performing measurements on representative test samples more than once (consecutively and day-to-day) and by measuring "identical" test samples (i.e., the same connector type and plating and the same cable length and type). These repeatability evaluations were made with regularity throughout the measurements. Over 90% of the IM measurements were found to be repeatable within 3 dB. Over 80% were repeatable within 2 dB and over half were repeatable within 1 dB. The most significant exception was obtained when certain test setup components had to be changed from one manufacturer to another and the physical arrangements had to be changed (because of component connector orientation) to accommodate input powers higher than +44 dBm. Repeatability tests performed before and after these modifications to the test setups indicated differences in the measured IM levels as much as 21 dB and as much as 17 dB in the inherent IM levels of the test setup (see Appendix D). Explanations for these changes in the measured IM levels were not found.

TABLE 2
INHERENT IM PRODUCT LEVELS OF TEST SETUPS

Nominal IM Frequency (MHz)	Input Power (dBm)	Inherent IM Level	
		Without Cancellation (dBm)	With Cancellation (dBm)
22	43	-78	-88
	44*	-69	-88
	46*	-65	-87
	48*	-60	-86
	49*	-56	-78
	51*	-50	-68
	53*	-44	**
200	31	-118	-122
	33	-113	-122
	36	-105	-122
	38	-100	-122
	41	-92	-122
	43	-85	-115
275	43	-101	-120
350	44	-88	-126
	44*	-71	-90
	47*	-65	-80
	50*	-54	-75
	51*	-58	-75
425	29	-92	-126
	32	-100	-126
	36	-87	-126
	40	-82	-119
	44	-82	-114

*At these input power levels, test setup components had to be changed to accommodate the higher powers. As discussed later, this change in the test setup resulted in an unexplained discontinuity in the measured IM levels as a function of input power.

**Inherent IM level not measured.

The test setups were utilized to measure the selected test samples in accordance with the test procedures that are presented in Appendix C. The test samples included cables (without connectors), connectors* (without cables), and cable-connector combinations. Special test jigs for the cables and for the connectors were built such that these test samples could be easily mounted in the test setup. These test jigs as well as the techniques utilized to construct the cable-connector combinations are described in Appendix A. During the initial IM product measurements, it was noted that for the large diameter cable test samples the use of silver-plated Type N connectors yielded more reliable and repeatable results and exhibited lower IM levels than the use of the cable test jig. Conversely, the test jig appeared to provide better results for the small diameter cables. For this reason, silver-plated Type N connectors were used, in general, on the large diameter cable test samples and the test jig was used on the small diameter cables.

During the development, calibration, and evaluation of the test setups as well as during the conduct of the measurements on the test samples, several measurement precautions and considerations were noted. These observations revealed the various factors that must be taken into account when measuring IM levels, and, hence, which will affect the prediction and minimization of the IM levels that may be generated on operational C³ platforms. For example, it was shown that

- Vibration of equipment or connections can cause increases in IM levels as much as 40 dB. Therefore, equipment and interconnections should be rigidly mounted.
- Threaded connectors are especially important. When incorrectly screwed together IM levels can increase 40 dB or more. Therefore, connectors should be carefully threaded and tightened with a wrench.
- Oxidized or dirty surfaces between connections can cause increases in IM levels. Hence connectors should be cleaned regularly.
- Seemingly identical components or pieces of equipment can have significantly different IM product generation characteristics. Several units of each piece of equipment should be tested for the lowest IM generation.

(Thus it is expected that the nature of the results reported herein is representative of field conditions -- field conditions may even be somewhat more variable). These as well as other observed precautions and considerations are discussed in detail in Appendix E.

* The connector test samples consisted of both a male and a female connector of the same type (see Appendix A).

2.2 Harmonics

Third-order harmonics generated by a limited number of test samples were also measured. These measurements were performed at a single harmonic frequency of 675 MHz (i.e., a 225-MHz fundamental frequency).

3.0 MODEL DEVELOPMENT

3.1 Introduction

The data resulting from the IM product and harmonic measurements are presented in Appendices E and F. This measured data are grouped by frequency, connector type, connector plating, cable type, cable length, and power. The model development process began with an analysis of the measured data to define significant trends between IM^{*} levels and particular parameters. This analysis indicated that definitive and consistent trends existed for the IM product level as a function of each parameter. The process outlined in Figure 2 was used to determine the relationship between the measured IM data and the major causative parameters. To implement this process, the variations of the IM level were evaluated for one parameter at a time. A first approximation to a relationship between the IM level and one of the causative parameters was defined. The measured data were next normalized with respect to the evaluated parameter and the variation with the next one was approximated. This process was continued until all of the causative parameters had been analyzed. The functional relationships identified for each parameter were then combined into initial models of the IM levels as functions of all parameters. Finally, these IM models were improved by iterating various steps in the modeling procedure.

The data used in the analysis and model development efforts were restricted to the measured IM levels which were greater than or equal to 3 dB above the cancelled, inherent IM level of the test setup. A goal of cancelling the inherent IM level of the setup at least 10 dB below the measured IM level of the test sample was achieved for the majority of the measurements. However, the IM levels of a few test samples were within 10 dB of the measurement sensitivity and, hence, the 10 dB difference goal could not be achieved. Since the inherent IM or noise floor of the test setup can affect the measured level for the test sample, valid IM levels were defined as those being at least 3 dB above the noise floor.

The results of the repeatability tests indicated that the majority of the data were repeatable within 1 dB. Therefore, to simplify the data analysis and model development efforts, the IM repeatability data for each test sample were averaged to obtain a single IM data point.

* The harmonic data were also analyzed by comparing the measured level to the IM level for the test samples with the same parameter values. This analysis was performed to determine if a relation exists such that the IM level produced in coaxial cables and connectors could be predicted from measured harmonic levels. Such a relation was not found.

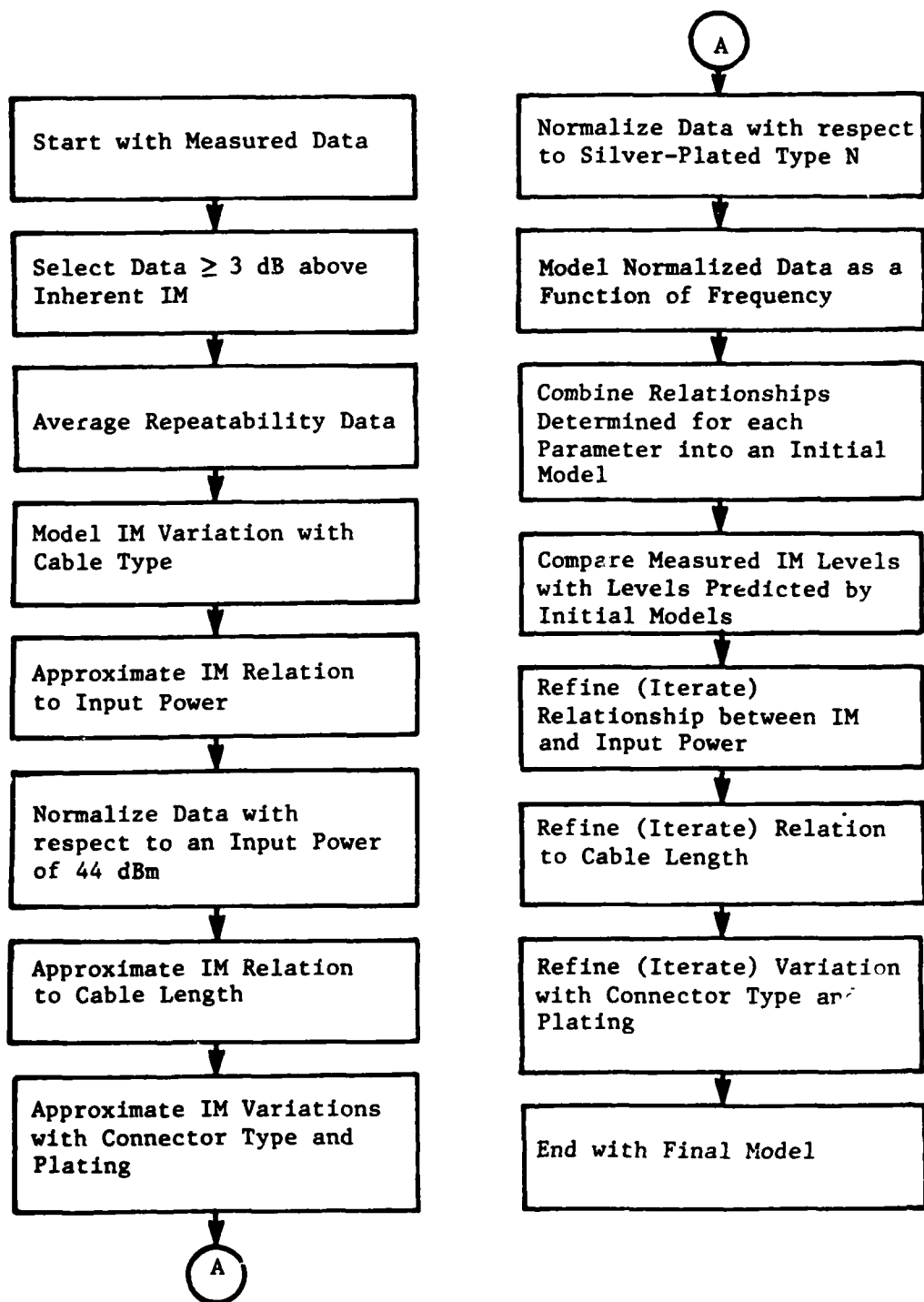


Figure 2. Flow Chart of Modeling Procedure

3.2 Data Analysis

The analysis of the measured data consisted of the formulation of a first approximation to the relationship between each of the following causative parameters and the IM levels generated by the test samples.

3.2.1 Cable Types

An observation regularly made during the gathering of the data was that there did not appear to be any significant or consistent variation with cable type. Analyses of all the measured data supported this observation. For example, note that the measured IM levels for various cable types which are presented in Figures 3 and 4 for each IM test frequency show no definite differences between the various types of cables measured. Also note that the measured IM level versus input power, plotted for two different cable types in Figure 5, show similar behaviors. (As discussed in Section 2.1 and Appendix A, the most reliable results were obtained by using silver-plated Type N connectors on the large diameter cables (Figures 3 and 5) and by using the cable test jig on small diameter cables (Figure 4)). The IM levels given in these figures are approximately 20 dB higher than the levels previously reported for comparable cable lengths and at comparable frequencies [16]. However, that investigation used especially selected, state-of-the-art, low-IM generating connectors. In contrast, the test samples on this program were selected, and the cable-connector combinations were constructed in accordance with standard procedures [17], in order to represent typical installations on actual C³ platforms. Hence, it is expected that the measured levels in Figures 3, 4, and 5 are primarily due to the connectors or test jig and are not the result of the cable itself.

These data indicate that in actual installations utilizing typical construction practices the IM product level will be determined by the connectors. Therefore, the type of coaxial cable employed in typical installations on C³ platforms is not expected to affect the level of the IM product generated. For this reason it was decided that the effects of cable type should not be included in the final models.

3.2.2 Power

A review of the measured data indicated that evaluation of the effects of cable length, connector type, connector plating, and frequency would be greatly facilitated by first normalizing all measured IM data to a common input power level. In order to perform this normalization, it was necessary to establish the relation-

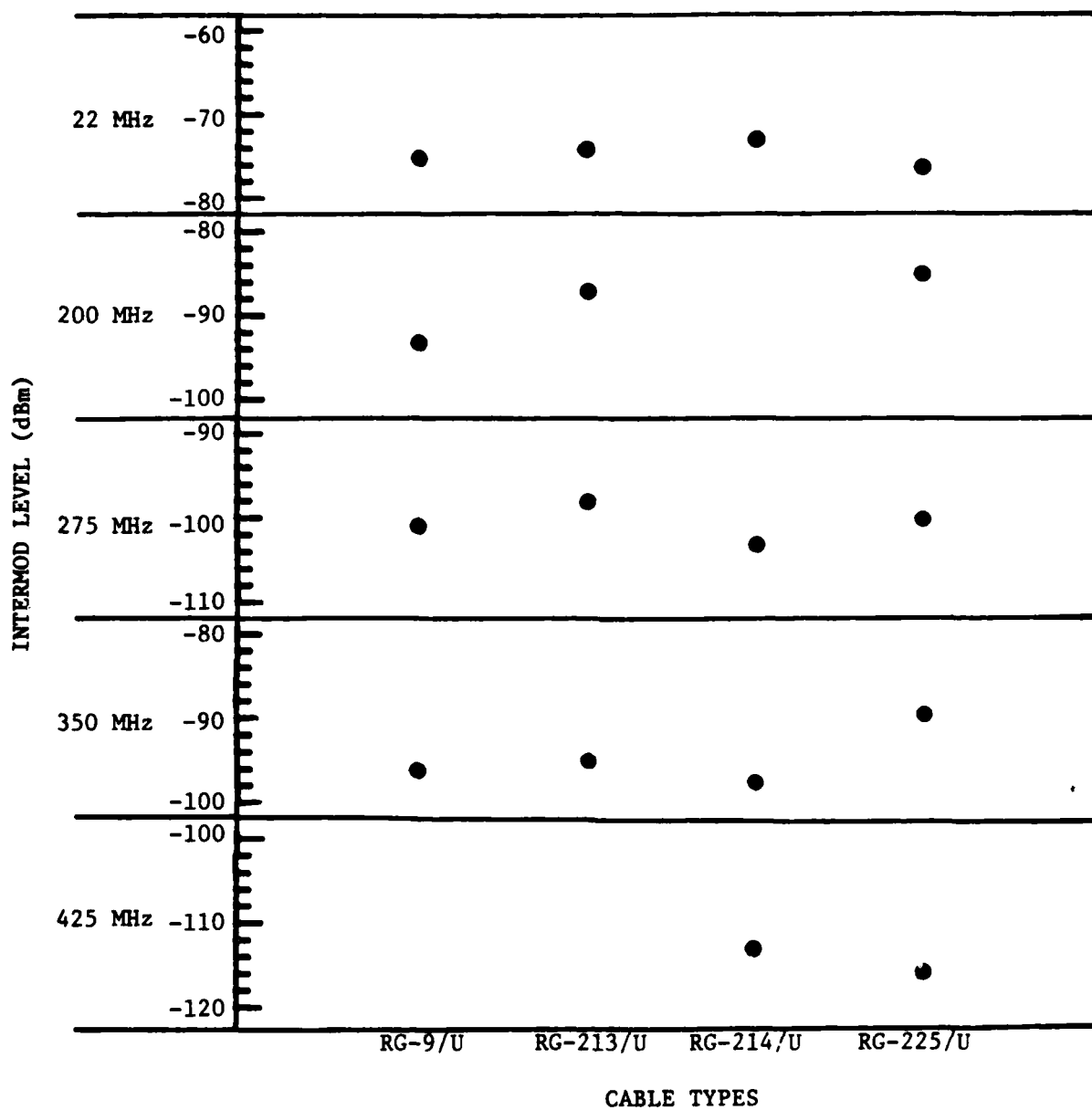


Figure 3. IM Level as a Function of Cable Types for Large Diameter Cables 4.5-ft Long with Silver-Plated Type N Connectors

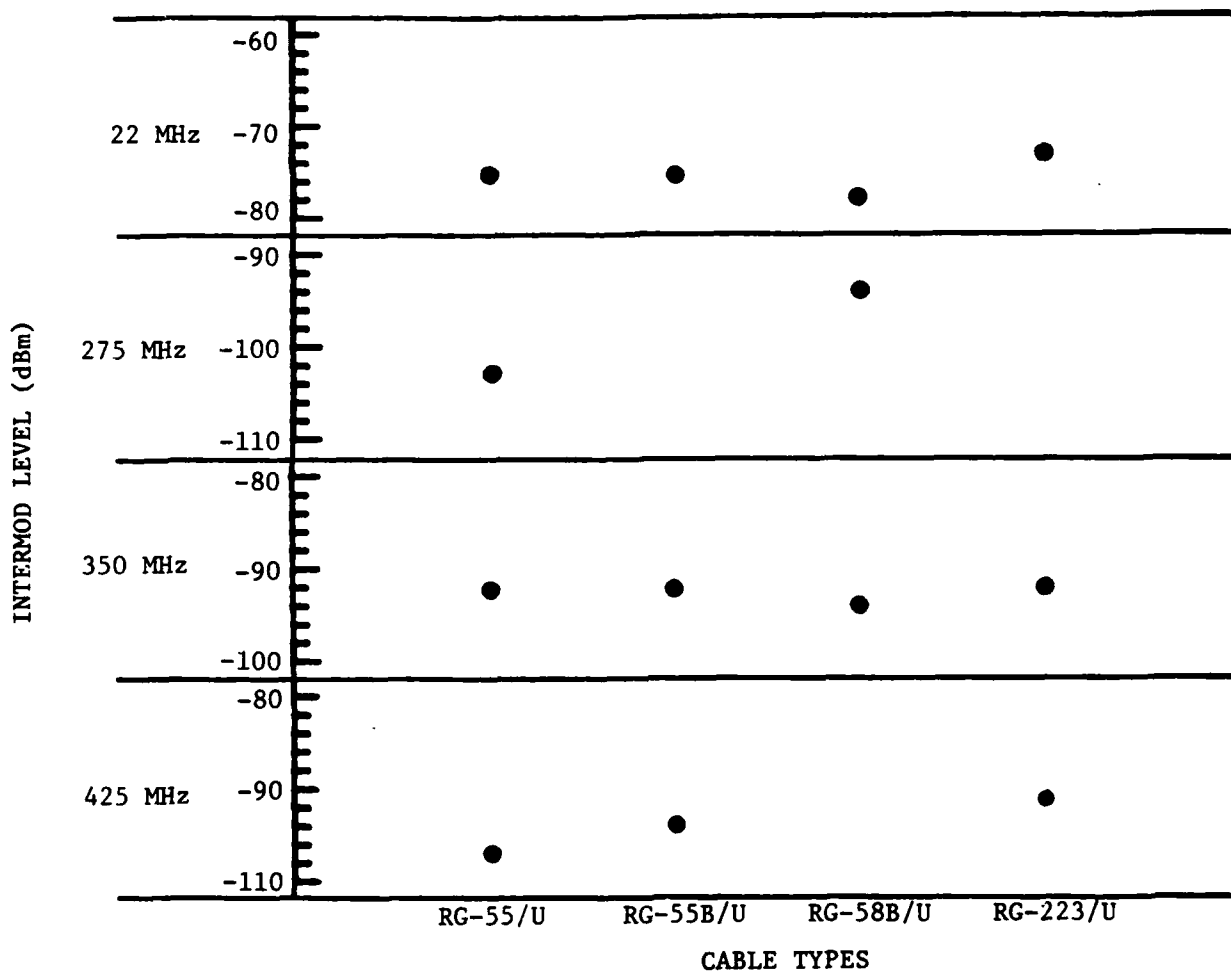


Figure 4. IM Level as a Function of Cable Type for Small Diameter Cables 5-ft Long in the Test Jig.

CONNECTOR TYPE - N
CONNECTOR PLATING - SILVER

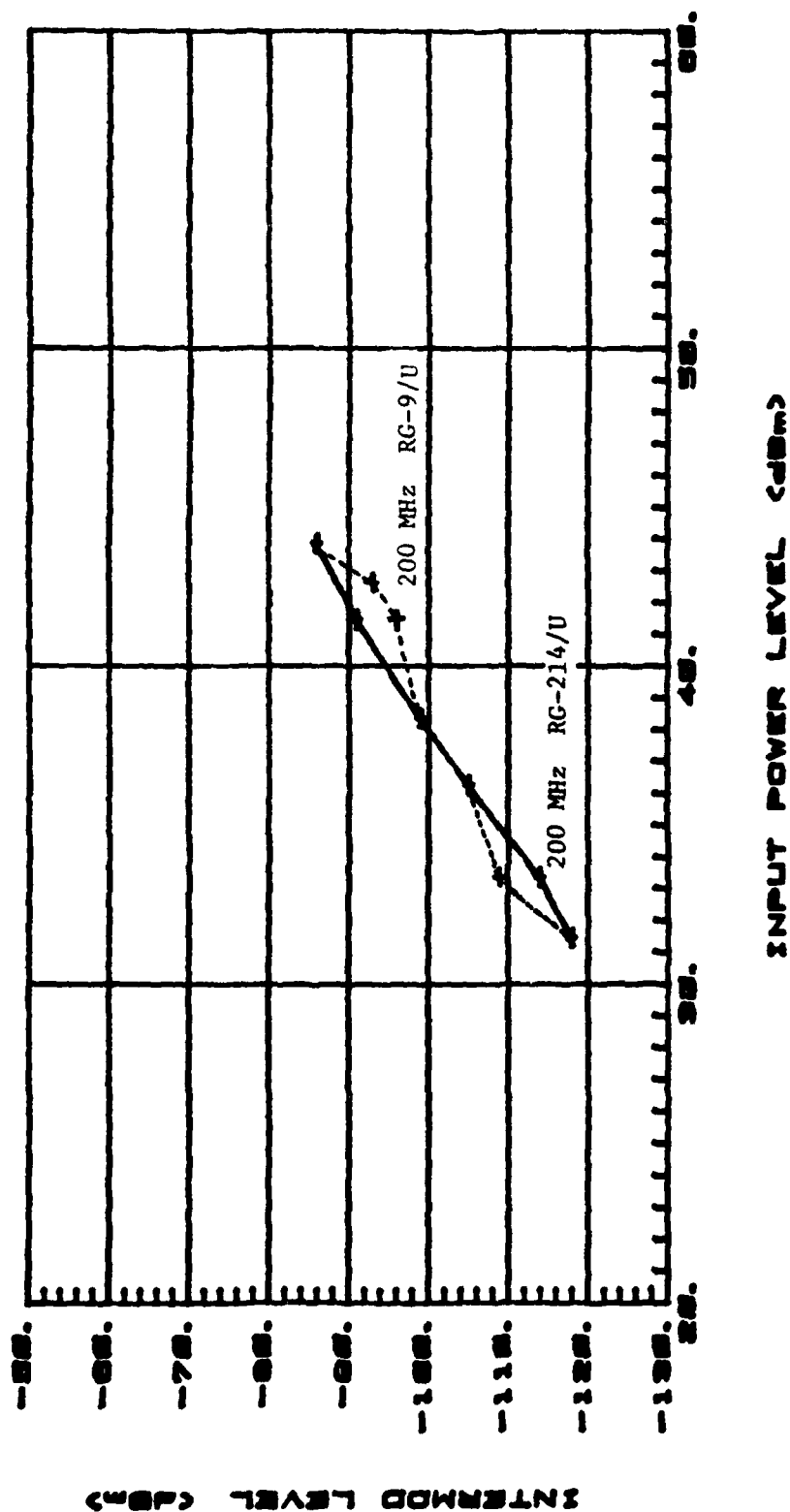


Figure 5. Comparison of Two Cable Types in Terms of IM Level Versus Input Power at 200 MHz; both Cables are 4.5-ft Long and have Type N Silver-Plated Connectors.

ship, if any, existing between the IM levels and input power at all measured frequencies and for all cables, connectors, and cable-connector combinations. Another important reason for examining this relationship was to see if Equation (5), which has been derived for active devices, also holds for passive devices. If so, confidence in the normalization process is enhanced. Therefore, the functional relationship between IM level and input power was evaluated next. The measured IM levels were plotted versus input power for each connector type, connector plating, and frequency. A typical graph is given in Figure 6. All of the graphs of IM level versus input power are presented in Appendix G.

Except for the discontinuities* at an input power level of +44 dBm, the graphs of IM level (in dBm) versus input power (in dBm) are approximately straight lines. Such a linear relationship with input power indeed agrees with previous experience on active devices [1], [2], [3]. A linear regression analysis that utilizes the method of least squares was performed on the data for each test sample to obtain the "best-fit" straight line for each graph. The slopes for connectors and for cable-connector combinations are given in Tables 3 and 4, respectively. From Equation (5), it would be expected that the third order ($m + n = 3$) IM product should increase 3 dB for each 1 dB increase in the levels of each applied signal. Thus the slope of an ideal third order IM curve should be 3 dB/dB. Analysis of the data indicates that the slopes for the connectors are generally greater than the slopes for cable-connector combinations; the majority of the connector slopes are slightly less than 3 dB/dB while the cable-connector combination slopes are approximately 2 dB/dB.

Since there was not sufficient data to absolutely define the power slopes for each connector type, connector plating, cable-connector combination and frequency, it was decided that the best approach was to use only two slopes: one for connectors and one for cable-connector combinations. As a first approximation, a slope for connectors of 2.7 dB/dB and a slope for cable-connector combinations of 2.2 dB/dB were obtained by averaging the numbers in Tables 3 and 4, respectively.

The two average slopes of the straight-line approximations to the variation of IM level with input power were then used to extrapolate all the measured IM data to equivalent IM levels for input powers of +44 dBm. These extrapolated data were then used in the evaluation of the remaining causative parameters.

* These discontinuities are not related to the input power level; they are due to required changes of test setup components (see Section 2.1 and Appendix D for further discussions of these discontinuities). The relation between IM level and input power above and below the discontinuities are approximately the same. In other words, the relative variation with input power is the same for all power levels considered.

CONNECTOR TYPE - N
CONNECTOR PLATING - NICKEL

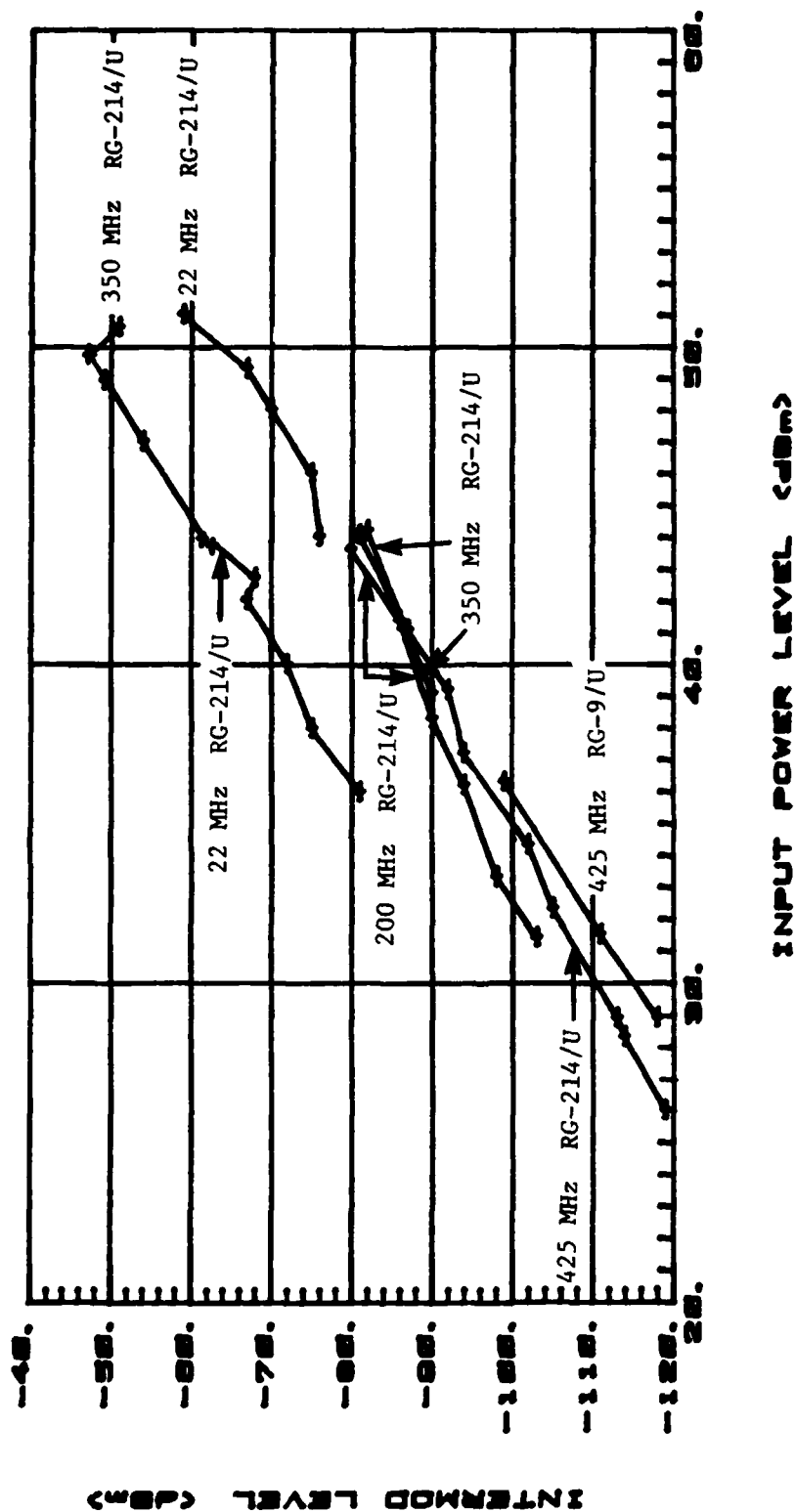


Figure 6. Typical IM Level as a Function of Input Power for Cable-Conductor Combinations.

TABLE 3
IM LEVELS VERSUS
INPUT POWER SLOPES OF CONNECTORS

Connector		Frequency (MHz)	IM vs Power Slope (dB/dB)
Type	Plating		
N	silver	200	2.7
		350	2.8
	beryllium- copper silver	350	2.9
		425	2.8
	gold	350	2.6
		425	2.9
	nickel	22	1.7
		425	3.1
HN	silver	425	2.5
TNC	silver	350	2.9
		425	2.9
	gold	425	2.8

TABLE 4
IM LEVELS VERSUS
INPUT POWER SLOPES OF CABLE-CONNECTOR COMBINATIONS

Connector		Frequency (MHz)	Cable Type (RG- /U)	IM vs Power Slope (dB/dB)
Type	Plating			
N	silver	22	214	3.5
		200	9	2.2
			214	2.7
		275	9	1.8
		350	9	2.3
	gold	22	214	2.5
		425	213	2.5
	nickel	22	214	2.2
		200	214	1.8
		350	214	1.6
		425	9	2.6
			214	2.1
HN	silver	425	9	1.9
TNC	gold	425	55	1.3
			223	1.5

3.2.3 Cable Length

Even though it was determined that cable type is not likely to affect the IM level generated in typical installations, the effect of cable length must still be considered in cable-connector combinations. Therefore, cable length was the next causative parameter evaluated for three different cable types (RG-55/U, RG-214/U, and RG-225/U). The variation of IM level with cable length in terms of cable attenuation is presented in Figures 7, 8, and 9. As can be seen from these graphs, there does not appear to be any consistent, significant relation to cable length. Therefore, as a first approximation the IM level was assumed to be constant with cable length.

3.2.4 Connector Type and Plating

The relationships between IM level and connector types and platings were analyzed at the same time. The measured IM levels extrapolated to an input power of +44 dBm were plotted for each connector type and plating at each test frequency. A typical plot for cable-connector combinations is illustrated in Figure 10; all of the plots are given in Appendix H. A preliminary assessment of the data indicated that silver-plated Type N connectors exhibited the most consistent behavior. Therefore, it was decided to relate the performance of all other connectors to these. Using silver-plated Type N connectors as the reference, the differences in IM levels due to connector type and plating were approximated as given in Tables 5 and 6. These differences were then used to normalize the IM data to silver-plated Type N connectors (or cable-connector combinations, as appropriate) such that the frequency variation could be evaluated.

3.2.5 Frequency

The final causative parameter evaluated during the data analysis phase was frequency. Following the final normalization step, the IM data were plotted versus IM test frequency for both connectors and cable-connector combinations as shown in Figures 11 and 12, respectively. A mathematical relationship between IM level and IM frequency was determined by performing a regression analysis which utilizes the method of least squares on each set of data. For both connectors and cable-connector combinations, the resulting "best-fit" curve was a cubic function of frequency. The cubic frequency equation for connectors is

$$P_{IM}(\text{normalized}) = -81 + 0.28f - 2.2 \times 10^{-3}f^2 + 3.6 \times 10^{-6}f^3 \quad (6)$$

CABLE TYPE - RG-55/U CONNECTOR TYPE - J10

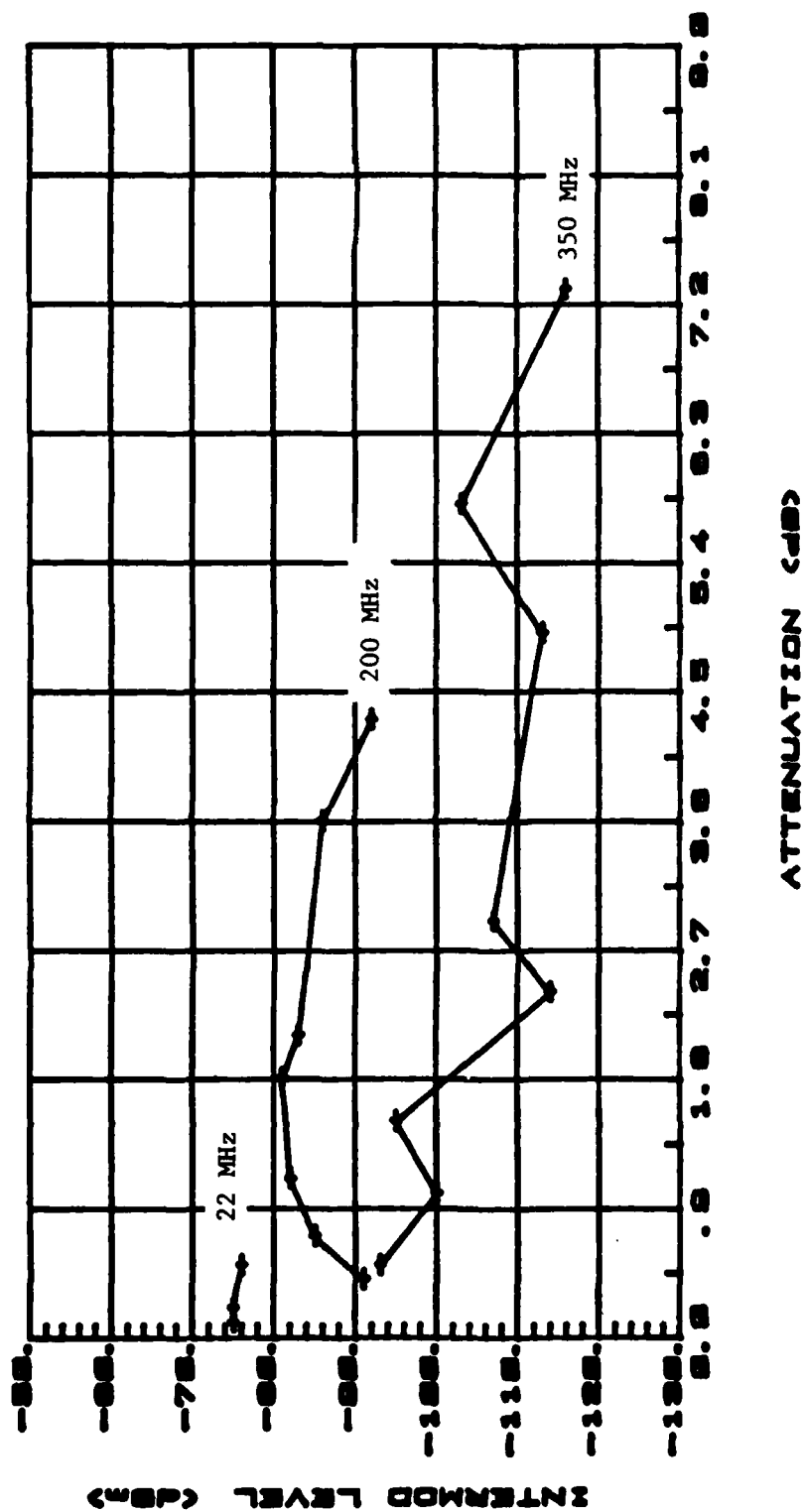


Figure 7. Variation of IM Level of RG-55/U with Cable Length in Terms of Cable Attenuation.

CABLE TYPE - RG-214/U CONNECTOR TYPE - N
CONNECTOR PLATING - SILVER

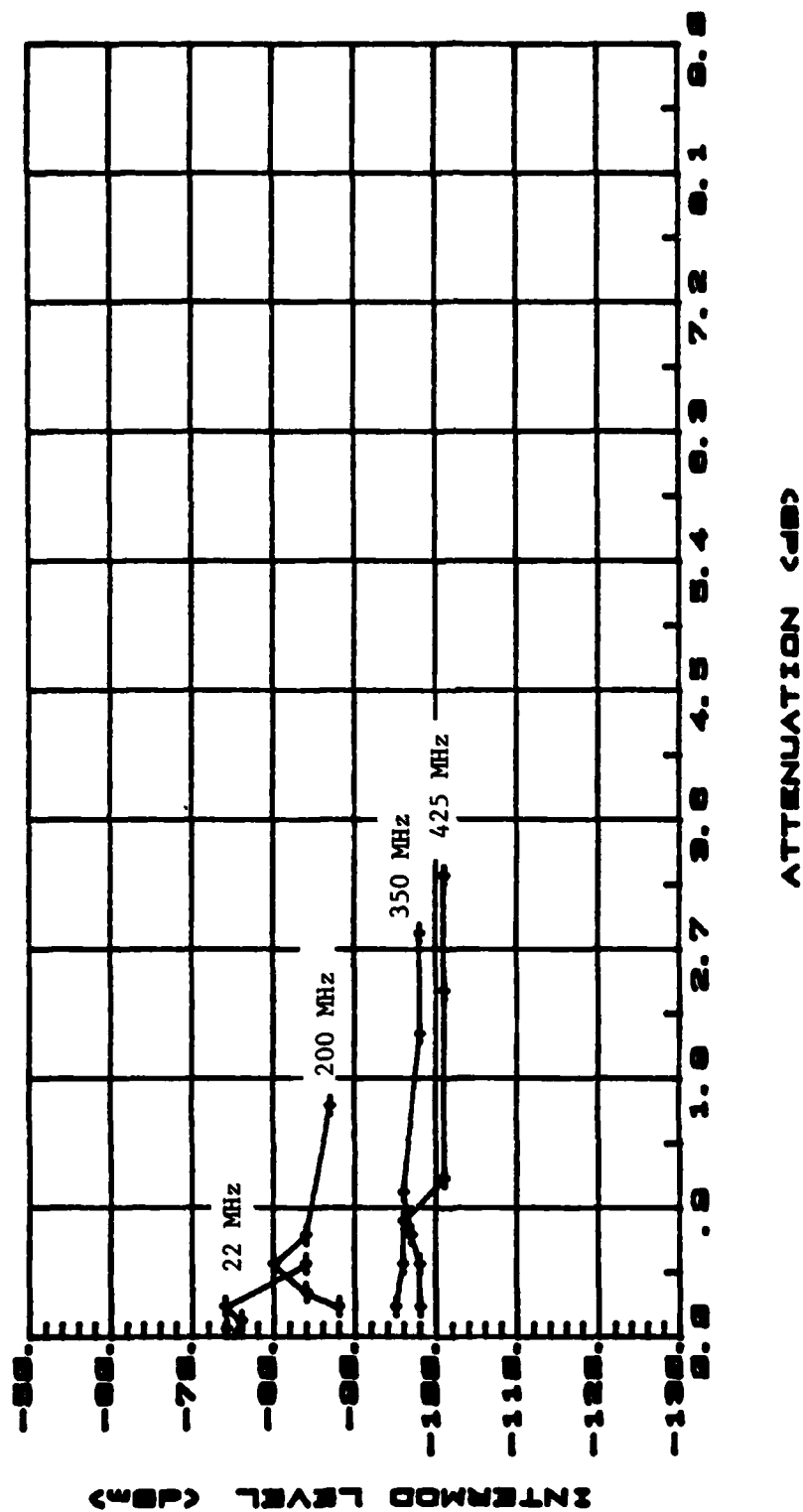


Figure 8. Variation of IM Level of RG-214/U with Cable Length in Terms of Cable Attenuation.

CABLE TYPE - RG-225/U CONNECTOR TYPE - N
CONNECTOR PLATING - SILVER

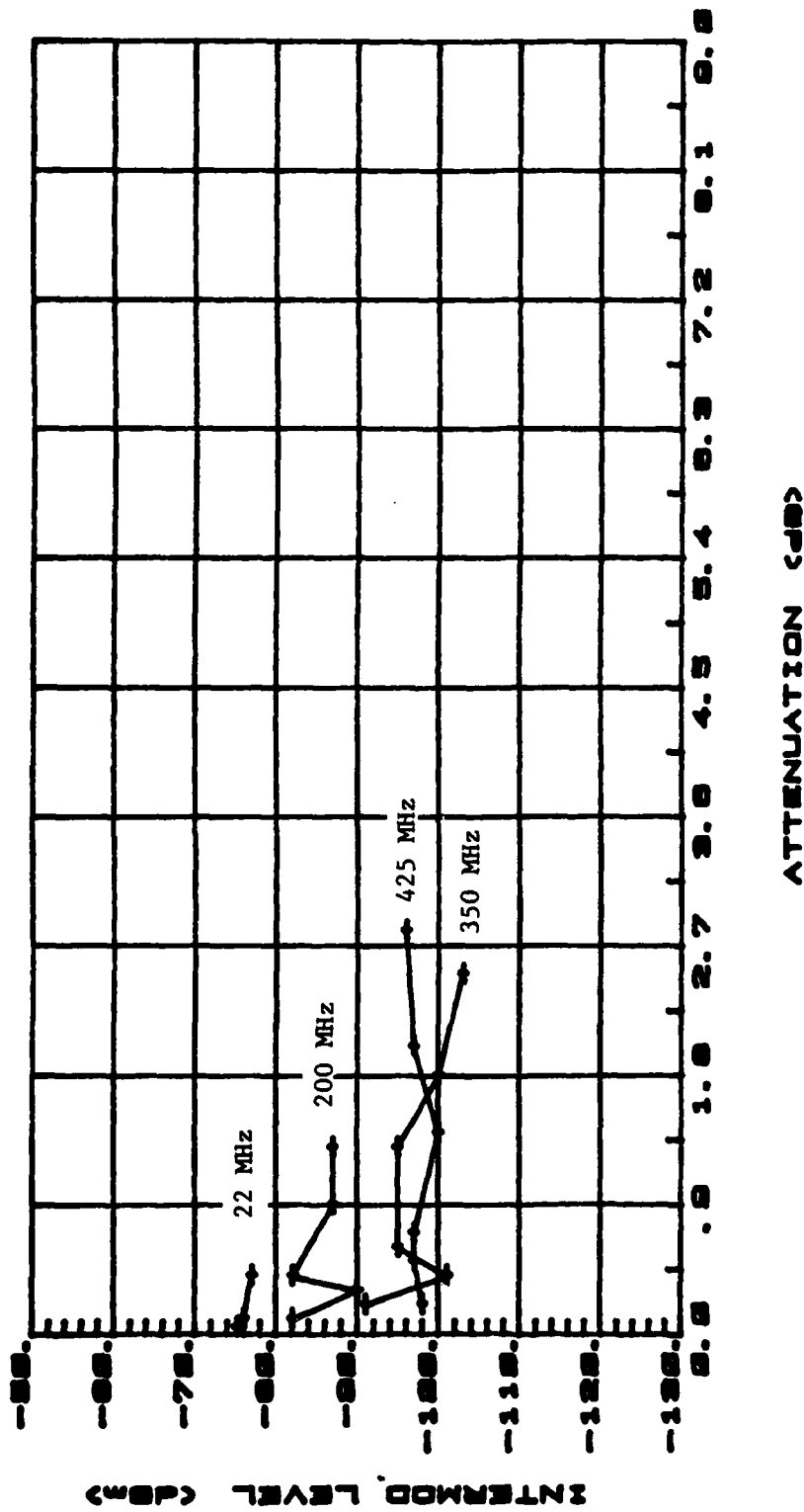


Figure 9. Variation of IM Level of RG-225/U with Cable Length in Terms of Cable Attenuation.

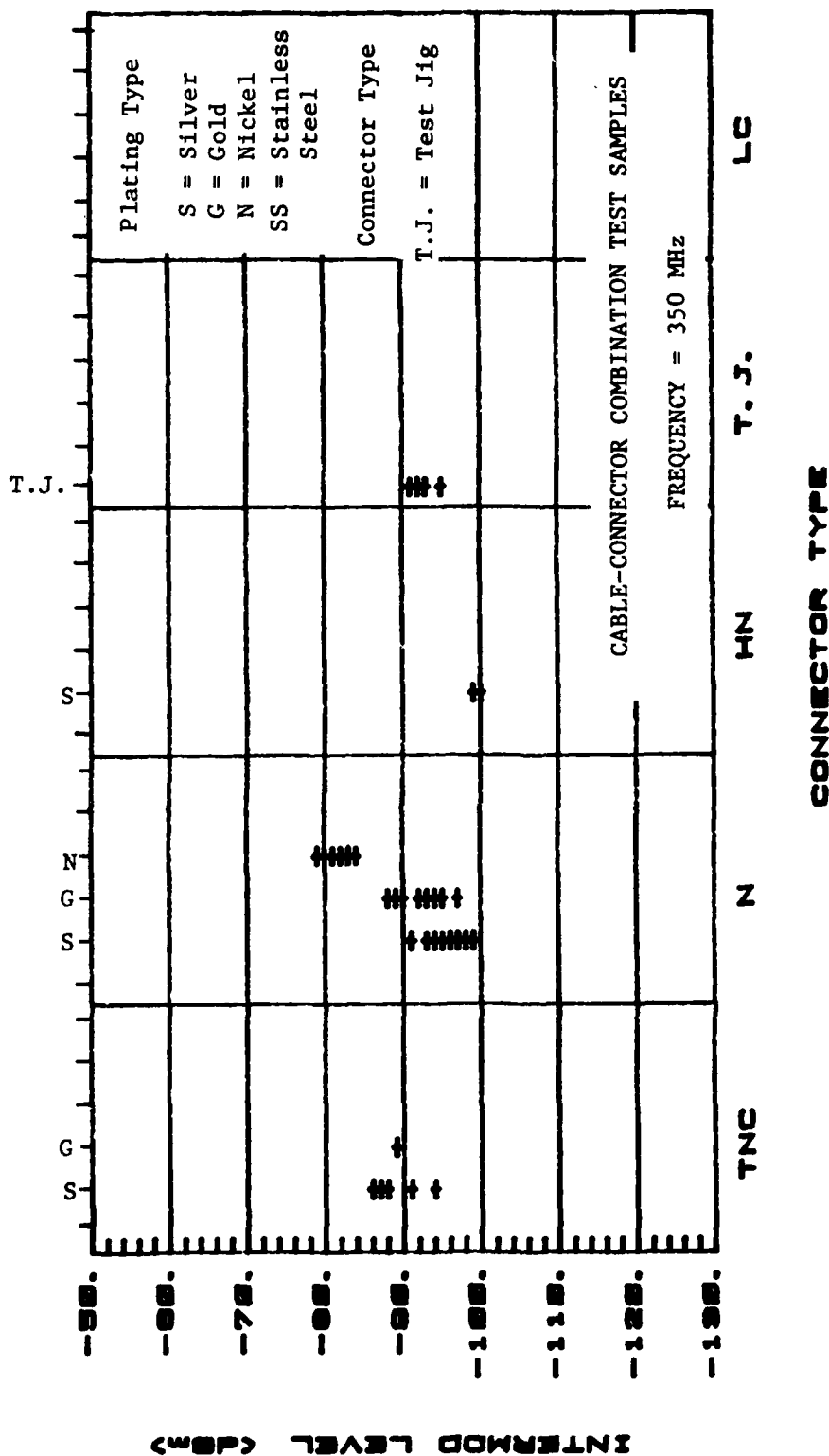


Figure 10. Variation of IM Level (Normalized to +44 dBm) with Connector Type and Plating for Cable-Connector Combinations at 350 MHz (See Appendix H for other similar plots).

TABLE 5

INITIAL APPROXIMATION TO
VARIATION OF IM LEVEL WITH CONNECTOR TYPE

Connector Type	Relative Differences in IM Level When Compared with Type N	
	Connectors (dB)	Cable-Connector Combinations (dB)
N	0	0
HN	-2	-2
TNC	+5	0
LC	-3	*

* Data not measured.

TABLE 6

INITIAL APPROXIMATION TO VARIATION
OF IM LEVEL WITH CONNECTOR PLATING

Connector Type	Relative Differences in IM Level When Compared with Type N	
	Connectors (dB)	Cable-Connector Combinations (dB)
silver	0	0
beryllium- copper silver	0	0
gold	1	2
nickel	6	12
stainless steel	4	*

* Data not measured.



1

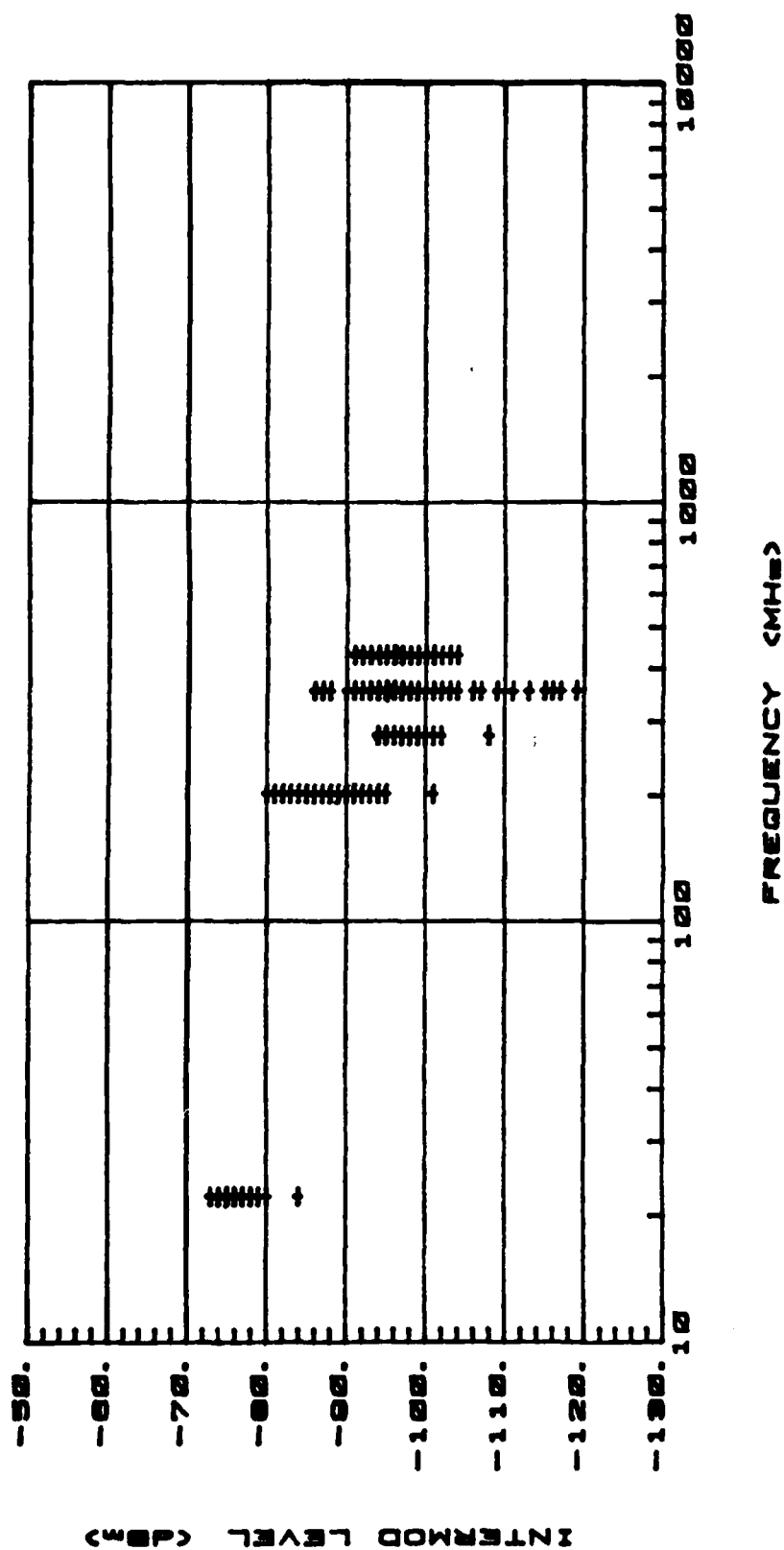


Figure 12. Initial Variation of IM Data with Frequency for Cable-Conductor Combinations (Normalized to 4.5-ft Cables with Silver-plated Type N Connectors at +44 dBm Input Power).

where $P_{IM}(\text{normalized})$ is the IM level, in dBm, normalized to an input power level of +44 dBm and to Type N, silver-plated connectors and f is the IM frequency in MHz. The predicted IM levels produced by this equation when compared to the measured data, results in a standard deviation of $\sigma = 4$ dB. The equivalent equation for cable-conductor combinations is

$$P_{IM}(\text{normalized}) = -73 - 5.1 \times 10^{-2}f - 2.7 \times 10^{-4}f^2 + 6.6 \times 10^{-7}f^3 \quad (7)$$

which fits the measured data with a standard deviation of $\sigma = 5$ dB. The curves of these two equations are presented in Figures 13 and 14 superimposed over the normalized measured data.

3.3 Initial IM Models

As a result of the data analysis, a first approximation to the functional relationship between IM level and each causative parameter was determined. Initial models for the IM levels generated in coaxial connectors and in coaxial cable-conductor combinations were obtained by combining these functional relationships for each parameter into two models. The initial connector model is given by the following equation:

$$P_{IM} = 2.7P_{IN} + (k_{\text{conn}} + k_{\text{plt}} - 201) + 0.28f - 2.2 \times 10^{-3}f^2 + 3.6 \times 10^{-6}f^3 \quad (8)$$

where

- P_{IM} = IM level in dBm generated in the connector;
- P_{IN} = total input power in dBm to the connector, i.e., linear sum of the two equal fundamental input powers;
- k_{conn} = constant related to connector type,
 - = 0 dB for Types N and LC,
 - = -2 dB for Type HN, and
 - = 5 dB for Type TNC;
- k_{plt} = constant related to connector plating,
 - = 0 dB for silver and beryllium-copper silver,
 - = 1 dB for gold,

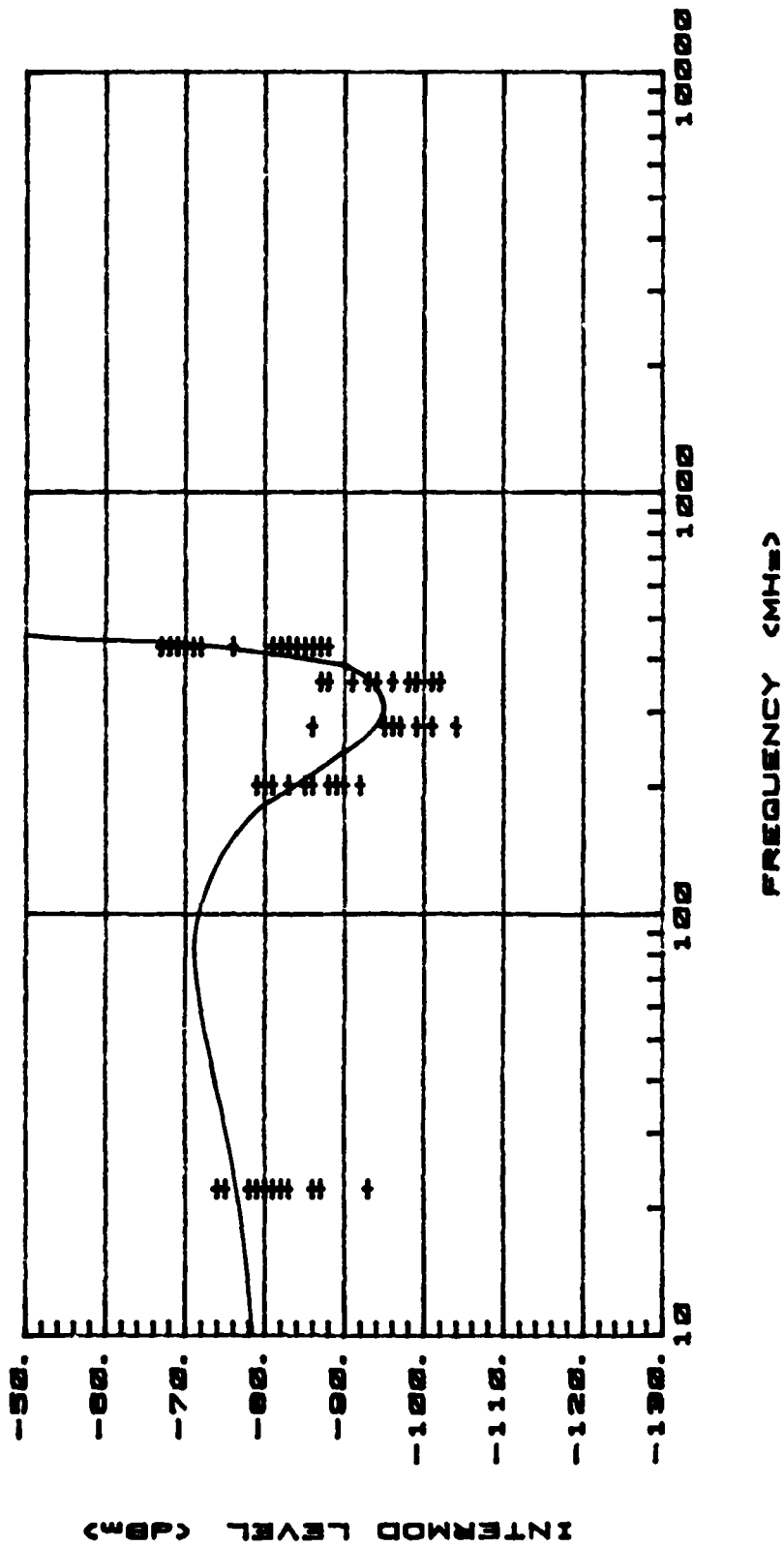


Figure 13. Connector Frequency Model Plotted on IM Data of Figure 11 (Normalized to Silver-plated, Type N Connectors at +44 dBm Input Power).

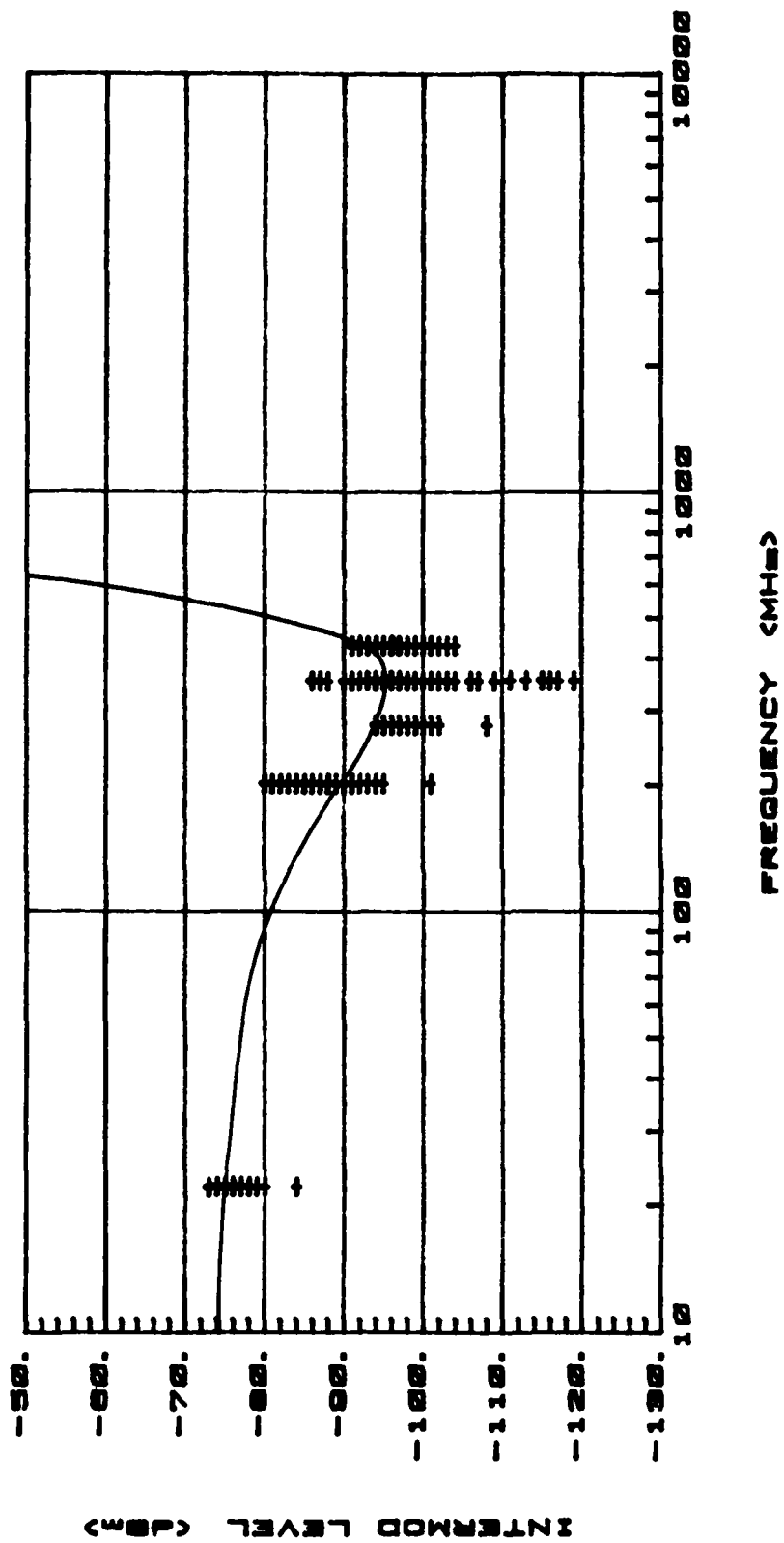


Figure 14. Cable-Connector Combination Frequency Model Plotted on IM Data of Figure 12 (Normalized to 4.5-ft Cables with Silver-plated, Type N Connectors at +44 dBm Input Power).

= 4 dB for stainless steel, and
 = 6 dB for nickel; and
 f = IM frequency in MHz for f between 20 and 450 MHz.

The equivalent equation for the initial cable-connector combination model is

$$\begin{aligned}
 P_{IM} = & 2.2P_{IN} + (k_{conn} + k_{plt} - 171) \\
 & - 5.1 \times 10^{-2}f - 2.7 \times 10^{-4}f^2 + 6.6 \times 10^{-7}f^3 \quad (9)
 \end{aligned}$$

where

P_{IM} = IM level in dBm generated in the cable-connector combination;
 P_{IN} = total input power in dBm to the cable-connector combination, i.e.,
 linear sum of the two equal fundamental input powers;
 k_{conn} = constant related to connector type,
 = 0 dB for Types N and TNC, and
 = -2 dB for Type HN;
 k_{plt} = constant related to connector plating,
 = 0 dB for silver and beryllium-copper silver,
 = 2 dB for gold, and
 = 12 dB for nickel; and
 f = IM frequency in MHz for f between 20 and 450 MHz.

The next step of the model development process was to refine these two initial models.

3.4 IM Model Refinement

The initial connector and cable-connector combination models were refined by re-evaluating the relationships between the causative parameters and the generated IM level. First, Equations (8) and (9) were used to calculate the IM levels for the various test samples. Next, the calculated IM levels were compared to the actual measured values. Considering one parameter at a time, the relationship between that parameter and the IM level was then varied until the differences between the calculated and measured values were minimized.

The input power relationship was refined by varying the slopes of the straight lines for IM level versus input power to minimize the differences in the calculated and measured values. These slopes were iterated above and below 2.7 dB/dB for connectors and above and below 2.2 dB/dB for cable-connector combinations until the best match was obtained. The final power slopes were 2.6 dB/dB for connectors and 1.9 dB/dB for cable-connector combinations.

The relationships between IM level and length (attenuation) were re-evaluated next. Since connectors are the predominate sources of IM products in cable-connector combinations, the measured IM level should be inversely proportional to the cable attenuation. Therefore, the variation of IM level with attenuation was assumed to be linear with a slope of -1 dB/dB. The differences between the calculated and measured IM levels were determined and the value of this slope was iterated until these differences were minimized. The final slope of the IM level versus attenuation was -2.5 dB/dB.

Finally, the values of the connector type and plating constants in Equations (8) and (9) were alternately varied until the differences in the calculated and measured IM levels were minimized. The resulting values of these constants either did not change or changed by only 1 dB.

Using these improved relationships for the causative parameters, the measured data were again normalized with respect to silver-plated, Type N connectors at an input power of +44 dBm (and 4.5-ft lengths for cable-connector combinations). The normalized connector data points as well as the cubic frequency curve are given in Figure 15 while the equivalent cable-connector combination data and curve are given in Figure 16. A comparison of these figures with Figures 13 and 14 reveals that the model refinement has indeed reduced the spread in the normalized data points at each frequency. Thus, the refined model including these improved parameter relationships more accurately predicts the measured data, i.e., the standard deviation of the model is lower.

The refined equation for the connector model is

$$P_{IM} = 2.6P_{IN} + (k_{conn} + k_{plt} - 196) + 0.28f - 2.2 \times 10^{-3}f^2 + 3.6 \times 10^{-6}f^3 \quad (10)$$



Figure 15.

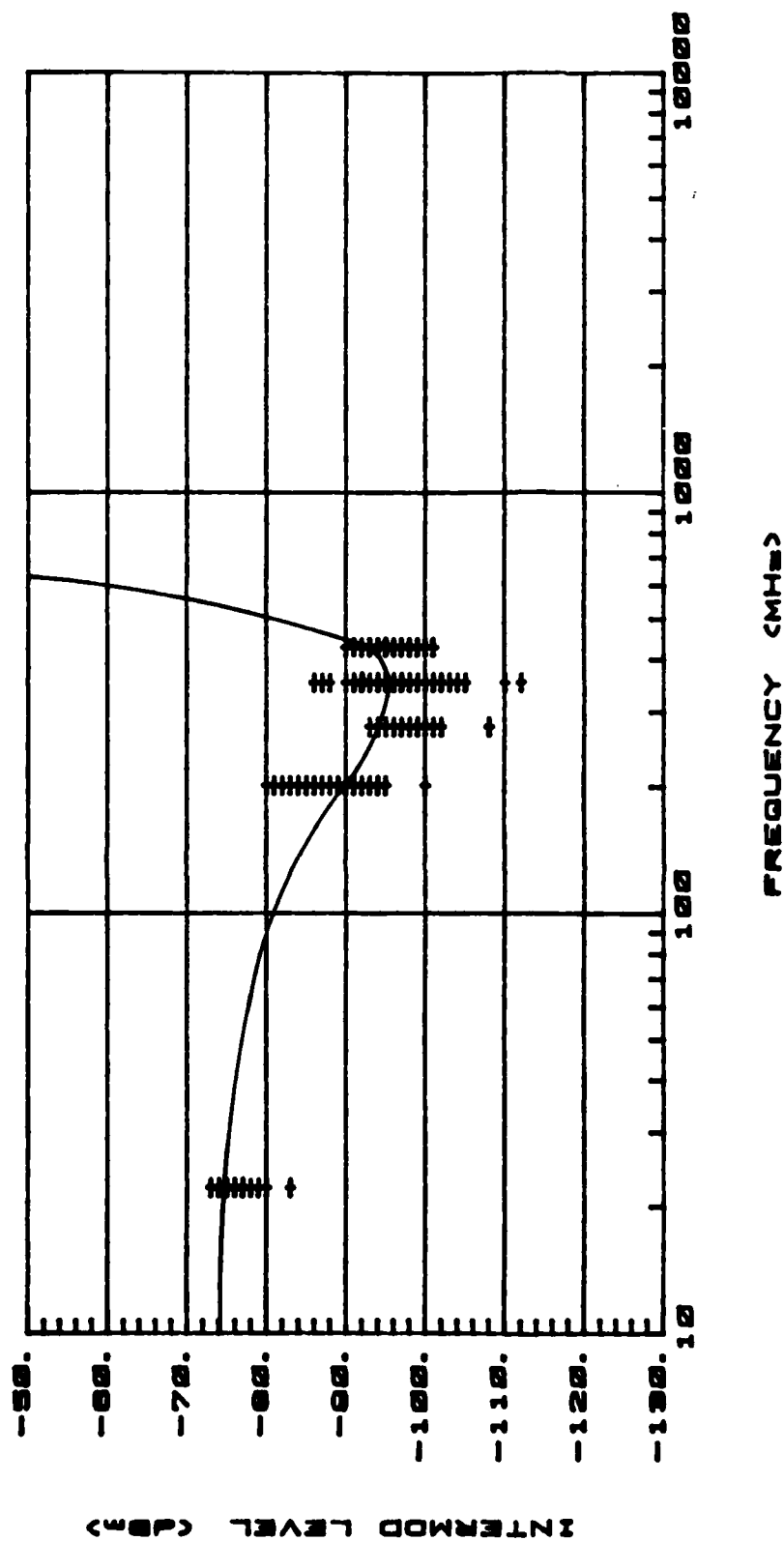


Figure 16. Cable-Connector Combination Frequency Model Plotted on Refined IM Data (Normalized to 4.5-ft Cables with Silver-plated, Type N Connectors at +44 dBm Input Power).

where

- P_{IM} = IM level in dBm generated in the connector;
 P_{IN} = total input power in dBm to the connector, i.e., linear sum of the two equal fundamental powers;
 k_{conn} = constant related to connector type,
= 0 dB for Type N,
= -2 dB for Type HN,
= -3 dB for Type LC, and
= 6 dB for Type TNC;
 k_{plt} = constant related to connector plating,
= 0 dB for silver, gold, and beryllium-copper silver,
= 5 dB for stainless steel, and
= 7 dB for nickel; and
 f = IM frequency in MHz for f between 20 and 450 MHz.

When compared with the actual measured data, this equation gives a standard deviation of $\sigma = 4$ dB. The equivalent refined equation for the cable-connector combination model with a standard deviation of $\sigma = 4$ dB is

$$P_{IM} = 1.9P_{IN} - 2.5\alpha l + (k_{conn} + k_{plt} + 11.2\alpha - 158) - 5.1 \times 10^{-2}f - 2.7 \times 10^{-4}f^2 + 6.6 \times 10^{-7}f^3 \quad (11)$$

where

- P_{IM} = IM level in dBm generated in the cable-connector combination;
 P_{IN} = total input power in dBm to the cable-connector combination, i.e., linear sum of the two equal fundamental input powers;
 α = cable attenuation in dB/ft;
 l = cable length in ft;
 k_{conn} = constant related to connector type,
= 0 dB for Type N and TNC and
= -2 dB for Type HN;
 k_{plt} = constant related to connector plating,
= 0 dB for silver and beryllium-copper silver,

- = 2 dB for gold, and
- = 11 dB for nickel; and
- f = IM frequency in MHz for f between 20 and 450 MHz.

4.0 MODEL VERIFICATION

A model, Equation (11), was developed from the measured data which predicts the levels of IM products generated in cable-connector combinations as a function of several parameters. In order to verify the model, 21 cable-connector combinations were chosen and constructed as outlined in Appendix A. These verification test samples included 20 "new" combinations (i.e., cable-connector combinations that had not been previously measured) and one RG-58B/U with silver-plated Type TNC connectors, which had been measured previously. The IM level of each verification test sample was predicted with the model. Measurements were then made, as outlined in Appendix C, and the predicted and measured values compared.

Table 7 lists each verification test sample, its parameters, and the IM levels predicted by Equation (11). Cable-connector combinations were chosen as verification test samples to represent "real world" situations. The specific combinations in Table 7 were selected to permit validation of the model's ability to predict the effect of the various parameters within a predicted accuracy. (The large amount of original data taken was sufficient to establish a good statistical sample. Therefore, it was predicted that 68% of any future measurements would fall within the standard deviation calculated for Equations (10) and (11) when compared to the original data measured in Appendix E. The predicted accuracy was arbitrarily chosen as 1σ (one standard deviation)). Test samples were selected so as to allow one parameter to be examined separately from others. For example, Test Sample #8 varies only cable type when compared with Test Sample #9. Likewise, Test Sample #8 varies only frequency when compared to Test Sample #17. In this manner, all of the parameters included in the model were verified independently.

The results of the verification effort are given in Tables 8 - 15. Table 8 shows that one-half of the verification measurements fall within the predicted accuracy of 4 dB and that all of the measurements are within 9 dB of the predicted values. Furthermore, the standard deviation obtained by comparing Equation (11) to the verification data is ± 5 dB. Table 9 shows that 10 out of 12 of the measured IM levels were repeatable within 2 dB. For each of the repeatedly measured test samples, the average of the IM levels are used in the remaining tables.

In Tables 10 - 15 the verification results for each parameter contained in the model are shown. The first column in each table indicates the test samples compared. The second column shows for these test samples the corresponding specific values of the parameters which were varied. Furthermore, for all comparisons in the following

TABLE 7
VERIFICATION TEST SAMPLES
AND PREDICTED INTERMODULATION LEVELS

TEST SAMPLE #	CABLE Type	CABLE Length (ft)	I.D.# [*]	CONNECTOR Type	Plating	I.D.# [*]	INPUT POWER LEVEL (dBm)	FREQUENCY (kHz)	PREDICTED INTERMODULATION LEVEL (dBm)	PREDICTED ACCURACY + 1 (dB)
1	9	4.5	63	N	S	64/65	44.0	350	-96	+4
2	9	4.5	63	HN	S	66/67	44.0	350	-98	+4
3	214	4.5	70	N	N	68/69	44.0	350	-85	+4
4	225	4.5	75	N	G	73/74	44.0	350	-106	+4
5	213	4.5	76	N	G	73/74	44.0	350	-94	+4
6	214	10.0	71	N	N	68/69	44.0	350	-86	+4
7	214	15.0	72	N	N	68/69	44.0	350	-87	+4
8	55	4.5	81	TMC	S	77/78	44.0	350	-96	+4
9	223	4.5	82	TMC	S	77/78	44.0	350	-96	+4
10	55	4.5	81	TMC	G	79/80	44.0	350	-94	+4
11	223	4.5	82	TMC	G	79/80	44.0	350	-94	+4
12	213	4.5	87	N	S	83/84	44.0	22	-75	+4
13	213	4.5	87	HN	S	85/86	44.0	22	-77	+4
14	213	4.5	87	N	N	88/89	44.0	22	-64	+4
15	214	4.5	70	N	N	88/89	44.0	22	-64	+4
16	9	4.5	63	HN	S	85/86	44.0	22	-77	+4
17	55	4.5	81	TMC	S	90/91	44.0	22	-75	+4
18	223	4.5	82	TMC	S	90/91	44.0	22	-75	+4
19	55	4.5	81	TMC	G	92/93	44.0	22	-73	+4
20	223	4.5	82	TMC	G	92/93	44.0	22	-73	+4
21	58B	4.5	32	TMC	S	90/91	44.0	350	-96	+4

* I.D. # - is an - identification number used to distinguish between identical test samples

TABLE 8
MODEL VERIFICATION RESULTS

Test Sample #	Frequency (MHz)	Input Power (dBm)	Predicted IM Level (dBm)	Measured IM Level (dBm)	Difference Between Prediction and Measurement (dB)
1	350	44.0	-96	-92	-4
		38.0	-108	-113	5
2	350	44.0	-98	-91	-7
3	350	44.0	-85	-83	-2
		44.0	-85	-83	-2
		44.0	-85	-79	-6
		44.0	-85	-88	3
		41.0	-91	-96	5
		38.0	-97	-103	6
		35.0	-102	-110	8
4	350	44.0	-94	-93	-1
		38.0	-106	-105	-1
5	350	44.0	-94	-90	-4
		38.0	-94	-92	-2
6	350	44.0	-86	-85	-1
7	350	44.0	-87	-82	-5
8	350	44.0	-96	-92	-4
9	350	44.0	-96	-89	-7
10	350	44.0	-94	-88	-6
11	350	44.0	-94	-85	-9
12	22	44.0	-75	-74	-1
13	22	44.0	-77	-75	-2
14	22	44.0	-64	-68	4

(continued)

TABLE 8 (continued)
MODEL VERIFICATION RESULTS

Test Sample #	Frequency (MHz)	Input Power (dBm)	Predicted IM Level (dBm)	Measured IM Level (dBm)	Difference Between Prediction and Measurement (dB)
15	22	44.0	-64	-69	5
		44.0	-64	-70	6
		44.0	-64	-71	7
		44.0	-64	-70	6
		42.0	-68	-74	6
		41.0	-70	-77	7
		40.0	-72	-79	7
		38.0	-76	-84	8
16	22	44.0	-77	-74	-3
17	22	44.0	-75	-75	0
18	22	44.0	-75	-74	-1
19	22	44.0	-73	-74	1
20	22	44.0	-73	-74	1
		44.0	-73	-74	1
21	350	44.0	-96	-87	-9

TABLE 9
REPEATABILITY VERIFICATION RESULT

<u>Test Sample #</u>	<u>Measured IM Levels (dBm)</u>	<u>Maximum Difference in Measured Levels (dB)</u>	<u>Average IM Level (dBm)</u>
3	-79, -83, -83, -88	9	-83
5	-90, -92	2	-91
15	-69, -70, -70, -71	2	-70
20	-74, -74	0	-74

TABLE 10
CABLE TYPES VERIFICATION RESULTS

<u>Test Samples Compared</u>	<u>Cable Types Compared (RG-#/U & RG-#/U)</u>	<u>Predicted IM Change (dB)</u>	<u>Measured IM Change (dB)</u>	<u>Difference Between Prediction And Measurement (dB)</u>
4 & 5	225 & 213	0	-2	2
8 & 9	55 & 223	0	-3	3
8 & 21	55 & 58B	0	-5	5
9 & 21	223 & 58B	0	-2	2
10 & 11	55 & 223	0	-3	3
13 & 16	213 & 9	0	-1	1
14 & 15	213 & 214	0	2	-2
17 & 18	55 & 223	0	-1	1
19 & 20	55 & 223	0	0	0

TABLE 11
INPUT POWER VERIFICATION RESULTS

<u>Test Sample #</u>	<u>Input Power Levels Compared (dBm & dBm)</u>	<u>Predicted IM Change (dB)</u>	<u>Measured IM Change (dB)</u>	<u>Difference Between Prediction And Measurement (dB)</u>
1	44 & 38	12	21	-9
3	44 & 41	6	13	-7
3	41 & 38	6	7	-1
3	38 & 35	5	7	-2
4	44 & 38	12	12	0
15	44 & 42	4	4	0
15	42 & 41	2	3	-1
15	41 & 40	2	2	0
15	40 & 38	4	5	-1

TABLE 12
CABLE LENGTH VERIFICATION RESULTS

<u>Test Samples Compared</u>	<u>Cable Lengths Compared (ft & ft)</u>	<u>Predicted IM Change (dB)</u>	<u>Measured IM Change (dB)</u>	<u>Difference Between Prediction And Measurement (dB)</u>
3 & 6	4.5 & 10	1	2	-1
6 & 7	10 & 15	1	-3	4

TABLE 13

CONNECTOR PLATING VERIFICATION RESULTS

<u>Test Samples Compared</u>	<u>Connector Platings Compared</u>	<u>Predicted IM Change (dB)</u>	<u>Measured IM Change (dB)</u>	<u>Difference Between Prediction And Measurement (dB)</u>
8 & 10	Silver & Gold	-2	-4	2
9 & 11	Silver & Gold	-2	-4	2
12 & 14	Silver & Nickel	-11	-6	-5
17 & 19	Silver & Gold	-2	-1	-1
18 & 20	Silver & Gold	-2	0	-2

TABLE 14

CONNECTOR TYPE VERIFICATION RESULTS

<u>Test Samples Compared</u>	<u>Connector Types Compared</u>	<u>Predicted IM Change (dB)</u>	<u>Measured IM Change (dB)</u>	<u>Difference Between Prediction And Measurement (dB)</u>
1 & 2	N & HN	2	-1	3
12 & 13	N & HN	2	1	1

TABLE 15

FREQUENCY VERIFICATION RESULTS

<u>Test Samples Compared</u>	<u>IM Frequencies Compared (MHz & MHz)</u>	<u>Predicted IM Change (dB)</u>	<u>Measured IM Change (dB)</u>	<u>Difference Between Prediction And Measurement (dB)</u>
2 & 16	350 & 22	-21	-17	-4
3 & 15	350 & 22	-21	-13	-8
8 & 17	350 & 22	-21	-17	-4
9 & 18	350 & 22	-21	-15	-6
10 & 19	350 & 22	-21	-14	-7
11 & 20	350 & 22	-21	-11	-10

tables, the only variation between the two test samples are those given in this second column. The third column gives the difference between the predicted IM level for the first test sample and the predicted IM level for the second test sample. Similarly, the fourth column gives the difference between the measured IM levels for the two test samples. Comparing columns 3 and 4 in Table 10 shows that the measured differences between cable types are generally within 3 dB of the predicted differences; in fact, only 1 out of 9 is greater than 3 dB. Most of the measured differences for power were within 2 dB of the predicted differences (See Table 11). However, one was 7 dB greater and another was 9 dB greater. For length, the measured differences were within 4 dB of the predicted differences (See Table 12). All except one of the measured differences for connector plating were within 2 dB of the predicted differences. The one exception was 5 dB (see Table 13). Table 14 shows that measured differences between connector types were within 3 dB of the predicted differences. Finally, as shown in Table 15, one-half of the measured differences with frequency are within 6 dB of the predicted differences, and the largest exception is only 10 dB.

In summary, the cable-connector combination model given by Equation (11) was verified by comparing IM levels predicted by it with the IM levels measured for 21 additional test samples. The results show that the model effectively predicts the IM levels within 4 dB as a function of each parameter except frequency. Because of the sparsity of frequency data, the model's functional relationship with frequency is not as accurate. The verification results indicate that the cable-connector combination model predicts the variation with frequency to within 10 dB over the 20 to 450 MHz frequency range.

5.0 DISCUSSION

A connector model and a cable-connector model that represents a "best fit" to the measured data as a function of the various causative parameters has been developed. These models indicate that reliable and repeatable relationships exist between the IM level and power, cable length, connector type, and connector plating. Specifically, the IM level increases 2.6 dB for connectors and 1.9 dB for cable-connector combinations with each dB increase in total input power. For connectors, the IM levels generated by Type HN are 2 dB lower, Type LC are 3 dB lower, and Type TNC are 6 dB higher than those generated by Type N. In contrast, for cable-connector combinations the levels generated by Type TNC are the same as Type N and those in Type HN are 2 dB lower than Type N. For connectors alone, gold and beryllium-copper silver platings produce levels about the same as silver; stainless steel produces levels that are 5 dB higher; and nickel levels are 7 dB higher than silver. On cable-connector combinations, the IM levels characteristic of silver and beryllium-copper silver connector platings are the same while those of gold are 2 dB higher and nickel 11 dB higher. These models also indicate, in general, that for cable-connector combinations the IM level decreases 2.5 dB with each dB increase in cable attenuation. Since in typical cable-connector combinations the connectors are the predominate source of IM products, there is no significant variation in IM level with cable types.

Unfortunately, the relation of the IM level to frequency is not as well defined as the relation to the other causative parameters. The results of this program do indicate that mathematical models with cubic functions of frequency can be derived which will predict the exhibited behavior of IM levels with frequency. However, it is to be cautioned that measurements were performed at only a limited number of IM frequencies on this program. Therefore, the cubic function of frequency should not necessarily be considered as the final, definitive relationship between IM level and frequency.

The changes in IM level obtained when the test setup had to be modified can be larger than the differences between the predicted IM levels and the measured verification data (see Table 15). Also, it is noted that these changes are in different directions (i.e., positive and negative) at different frequencies. Hence, adding or subtracting a single number at all frequencies will not correct for these changes. A definitive explanation for these changes was not identified.

Since the unexplained changes in IM level are test setup dependent and since the test setup consists of the same types of components that are used in typical operational installations, similar variations can be expected between apparently identical installations on actual C³ platforms. For this reason, it may not be cost effective, nor realistic, to rely upon the cubic frequency model to predict the IM levels generated in actual installations. In many instances, it will probably be sufficient and more appropriate to use a simple relationship between IM levels and frequency. Such an approach is to use a piecewise linear model to express the frequency dependence of IM products. For example, the normalized data in Figures 15 and 16 can be modeled in a piecewise linear manner as shown in Figures 17 and 18. Using the piecewise linear frequency representation of Figure 17 in Equation (11), the IM model for connectors is

$$\begin{aligned}
 P_{IM} &= 2.6P_{IN} + (k_{conn} + k_{plt} - 83) && \text{for } f \leq 70 \\
 &= 2.6P_{IN} + (k_{conn} + k_{plt} - 46) - 20 \log f && \text{for } 70 \leq f \leq 275 \\
 &= 2.6P_{IN} + (k_{conn} + k_{plt} - 144) + 20 \log f && \text{for } f \geq 275
 \end{aligned} \tag{12}$$

where

- P_{IM} = IM level in dBm generated in the connector;
- P_{IN} = total input power in dBm to the connector; i.e., linear sum of the two equal fundamental input powers;
- k_{conn} = constant related to connector type,
 - = 0 dB for Type N,
 - = -2 dB for Type HN,
 - = -3 dB for Type LC, and
 - = 6 dB for Type TNC;
- k_{plt} = constant related to connector plating,
 - = 0 dB for silver, gold, and beryllium-copper silver,
 - = 5 dB for stainless steel, and
 - = 7 dB for nickel; and
- f = IM frequency in MHz for f between 20 and 450 MHz.

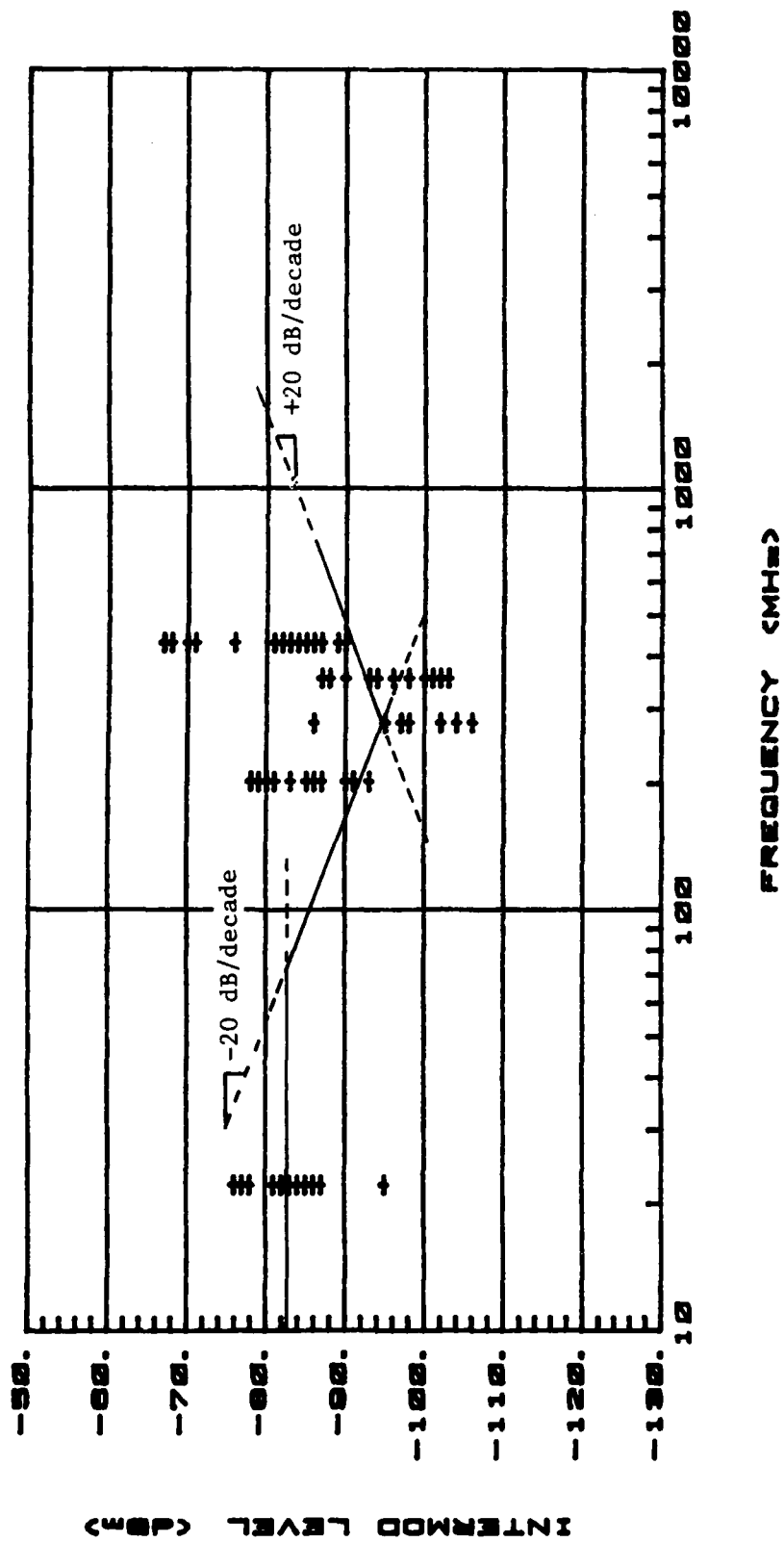


Figure 17. Piecewise Linear Frequency Model for Connectors Plotted on Refined IM Data (Normalized to Silver-plated, Type N Connectors at +44 dBm Input Power).

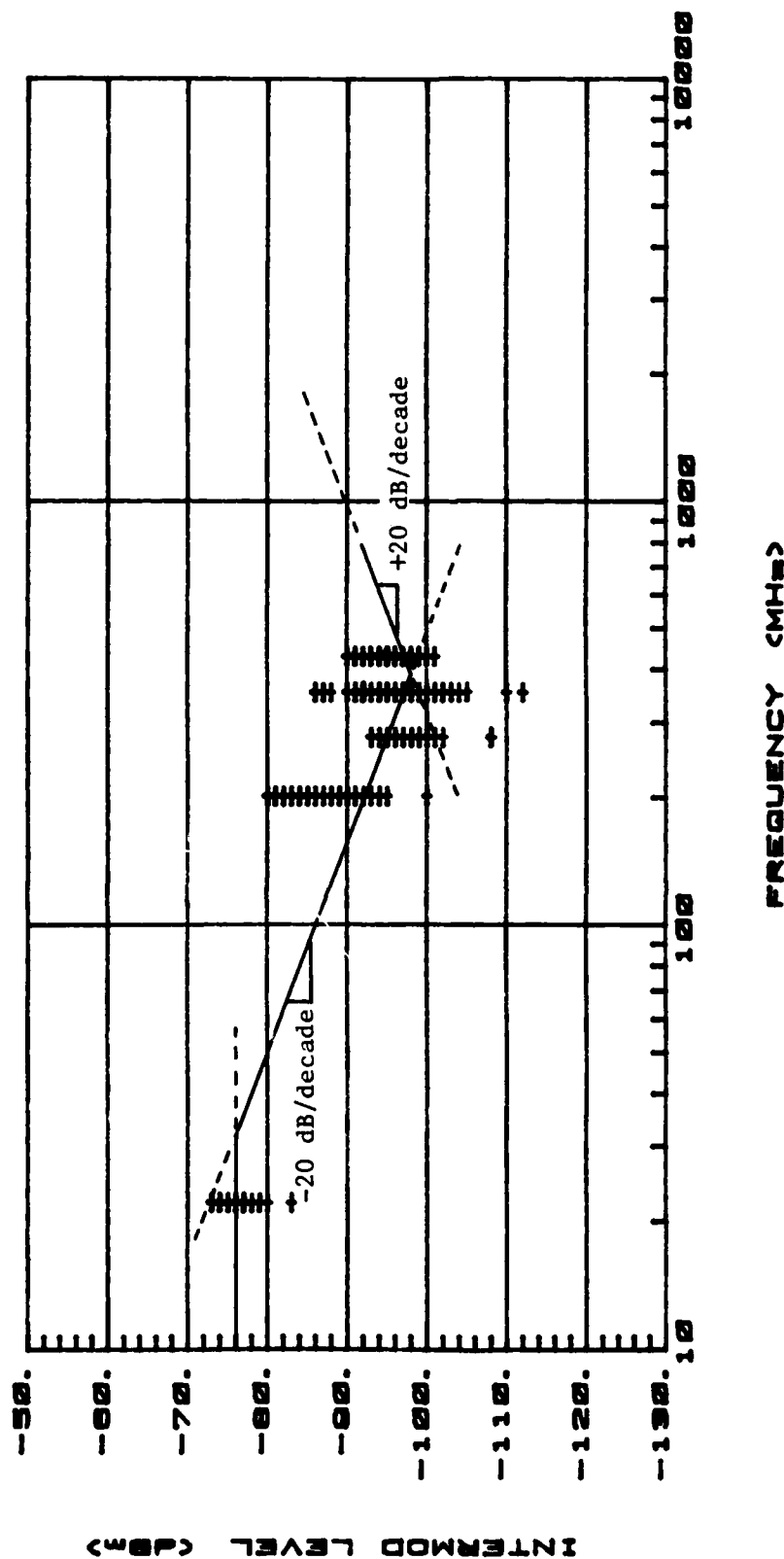


Figure 18. Piecewise Linear Frequency Model for Cable-Connector Combinations Plotted on Refined IM Data (Normalized to 4.5-ft Cables with Silver-plated, Type N Connectors at +44 dBm Input Power).

Similarly, using the piecewise linear frequency representation of Figure 18 in Equation (12), the IM model for cable-connector combinations is

$$\begin{aligned}
 P_{IM} &= 1.9P_{IN} - 2.5\alpha\ell + (k_{conn} + k_{plt} + 11.2\alpha - 76) && \text{for } f \leq 30 \\
 &= 1.9P_{IN} - 2.5\alpha\ell + (k_{conn} + k_{plt} + 11.2\alpha - 46) \\
 &\quad - 20 \log f && \text{for } 30 \leq f \leq 375 \\
 &= 1.9P_{IN} - 2.5\alpha\ell + (k_{conn} + k_{plt} + 11.2\alpha - 149) \\
 &\quad + 20 \log f && \text{for } f \geq 375 \quad (13)
 \end{aligned}$$

where

- P_{IM} = IM level in dBm generated in the cable-connector combination;
- P_{IN} = total input power in dBm to the cable-connector combination, i.e., linear sum of the two equal fundamental input powers;
- α = cable attenuation in dB/ft;
- ℓ = cable length in ft;
- k_{conn} = constant related to connector type,
 - = 0 dB for Type N and TNC and
 - = -2 dB for Type HN;
- k_{plt} = constant related to connector plating,
 - = 0 dB for silver and beryllium-copper silver,
 - = 2 dB for gold, and
 - = 11 dB for nickel; and
- f = IM frequency in MHz for f between 20 and 450 MHz.

6.0 CONCLUSIONS AND RECOMMENDATIONS

A sensitive test setup was designed and constructed which can be used to accurately and repeatedly measure the levels of the IM products produced by passive devices. Test samples were then selected and constructed from coaxial cables, connectors, and cable-connector combinations with varying cable and connector parameters. The test samples were measured at different frequencies and input power levels, and models were developed from the data which predict the IM levels as a function of the causative parameters. Finally, the models were verified by measuring the IM levels of new test samples and comparing the results to predicted values. The following general conclusions and recommendations resulting from this process are offered:

- (1) A test setup can be constructed which measures the levels of the IM products generated in coaxial cables, connectors, and cable-connector combinations. However, the inherent IM level of this test setup is extremely sensitive to many factors. Any of these factors can cause a dramatic increase in the inherent IM level which, in general, is neither predictable or repeatable. In "real world" situations, the effect of each factor is expected to be equal or greater. Therefore, the following factors are especially significant in the reduction of IM product interference in the field:
 - Vibration of equipment or connections can cause increases in IM levels as much as 40 dB. Therefore, equipment and interconnections should be rigidly mounted.
 - Threaded connectors are especially important. When connectors are incorrectly screwed together, IM levels can increase 40 dB or more. Therefore, connectors should be carefully threaded and tightened with hand tools.
 - Oxidized or dirty surfaces between connections can cause increases in IM levels. Hence connectors should be cleaned regularly.
 - Seemingly identical components or pieces of equipment can have significantly different IM product generation characteristics. Several units of each piece of equipment should be tested for the lowest IM generation.
- (2) With consideration given to the previous conclusions and recommendations involving the test setup, the third-order IM products generated in coaxial cables, connectors, and cable-connector combinations were measured. Levels

range from -126 dBm to -47 dBm for input powers between +26 dBm (0.4 watts) and +51 dBm (126 watts) and frequencies between 22 MHz and 425 MHz. The following general conclusions about the test samples were formulated:

- Exceptionally low level IM cable-connector combinations can be constructed by carefully following established procedures (i.e., those of MIL-HDBK-216). However, if care is not exercised in mounting connectors on cables, significantly high IM levels can result. In some instances, the IM levels produced in typically constructed cable-connector assemblies, which appear adequate in terms of attenuation, VSWR, etc., can be appreciably reduced by removing the connectors and remounting them with greater care. Therefore, the method of construction employed in joining the cables to connectors appears to be more important to the absolute IM levels than the intrinsic parameters of the cables or connectors.
 - By carefully following established construction practices (i.e., MIL-HDBK-216) variations of less than 3 dB can be achieved.
 - Connectors are the major source of IM product generation in cable-connector combinations.
 - The level of IM products generated in coaxial cables is much lower than from other sources, and, therefore, cable effects are expected to be minimal.
 - Connector test samples and cable-connector combination test samples have different IM product generation characteristics.
- (3) The effect of each causative parameter was determined and models were developed which predict the IM levels. The variations of IM levels with each parameter can be summarized as follows:
- No effect due to cable types.
 - IM level is a linear function (in dB) of input power.
 - IM level is a linear function (in dB) of length in cable-connector combinations.
 - IM levels vary with connector platings; silver produces the lowest levels with nickel as much as 11 dB higher.
 - IM levels vary with connector types; Type LC produces the lowest levels with TNC as much as 9 dB higher.

- (4) The verification of the model for cable-connector combinations showed that it was accurate to within ± 4 dB for every parameter except frequency. The following observations concerning frequency can be made:
- Variations as high as 21 dB were detected when parts of the test setup were changed at the same frequency. Therefore, the absolute value of the IM products measured at any given frequency may be test setup dependent.
 - The function that most accurately models the measured IM product data versus frequency is a cubic function for frequencies between 20 and 450 MHz. However, because of the limited number of frequencies that were measured, the exact relation with frequency is uncertain. Therefore, a simpler piecewise linear model that ignores fine details with frequency may be more appropriate. Additional measurements are needed to better define variations with frequency.
- (5) As long as the same test setup is used, the relative variations with other parameters are predictable. Additional investigations are required to determine the effects of various components in test setups and in actual C^3 installations.

7.0 REFERENCES

1. S. M. Perlow, "Third-Order Distortion in Amplifiers and Mixers," RCA Review, Vol. 37, June 1976, pp. 234-266.
2. H. W. Denny, "Linearization Techniques for Broadband Transistor Amplifiers," 1970 IEEE Electromagnetic Compatibility Symposium Record, July 1970, pp. 61-70.
3. D. Kornfield, et al., "Investigation of RFI Due to Nonlinearities in Transistor Amplifiers," 1967 IEEE Electromagnetic Compatibility Symposium Record, July 1967, p. 19.
4. J. L. Allen, "Investigation of Low Level Aircraft Nonavionic Nonlinear Interference," RADC-TR-81-26, Contract No. F30602-78-C-0120, University of South Florida, Tampa, FL, April 1981.
5. J. A. Betts & D. R. Ebenezer, "Intermodulation Interference in Mobile Multiple-Transmission Communication Systems Operating at High Frequencies (3-30 MHz)," Proc. IEEE, Vol. 120, No. 11, Nov. 1973, pp. 1337-1344.
6. R. C. Chapman, J. C. Darlington, A. Savarin, R. Steinberg, A. Paul and R. Moss, "Intermodulation Generation in Normally Passive Linear Components," Philco-Ford Corp. Rep. WDL-TR5242, Aug. 24, 1973.
7. V. Peterson and P. Harris, "Harmonic Testing Pinpoints Passive Component Flaws," Electronics, July 11, 1966, pp. 97-98.
8. N. E. Feldman, et al., Communication Satellites for the 70's: Systems, MIT Press, Cambridge, MA, 1971, p. 375.
9. F. S. McCartney, et al., "FLTSATCOM Program Review: Requirements, Design and Performance," EASCON '78 Record, p. 442.
10. "Report on Electromagnetic Interference problems of SA-5", Electromagnetic Section Engineering Support Division Assistant Director for Instrumentation, IN-K-ES2-64-1, Feb. 14, 1964, J. F. Kennedy Space Center.
11. Chase, W. M., and T. L. Whalen, "Receiving System Intermodulation Interference - An investigation of Typical Devices and a Steel Wire as Sources of RF Interference, NEL Report 1264, U.S. Navy Electronics Laboratory, San Diego, CA 92152.
12. Lustgarten, M. N., "Preliminary Review of 'Rusty Bolt' Phenomena," ECAD-TN-71-18, Electromagnetic Compatibility Analysis Center (ECAC), Annapolis, MD 21402, April 1971.
13. Chase, W. M., et al., "A Method of Control of Shipboard Topside Intermodulation Interference," 1977 IEEE International Symposium on Electromagnetic Compatibility, Seattle, Washington, Aug. 2-4, 1977, pp. 163-165.

14. M. B. Amin and F. A. Benson, "Coaxial Cables as Sources of Intermodulation Interference at Microwave Frequencies, IEEE Trans. EMC, Vol. EMC-20, No. 3, August 1978, pp. 376-384.
15. F. Arazm and F. A. Benson, "Nonlinearities in Metal Contacts at Microwave Frequencies," IEEE Trans. EMC, Vol. EMC-22, No. 3, August 1980, pp. 142-149.
16. J. C. Lee, "Intermodulation Measurement in the UHF Band and an Analysis of Some Basic Conducting Materials, Technical Note 1979-70, ESD-TR-79-269, Contract No. F19628-80-C-0002, Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, MA, November 1979.
17. "RF Transmission Lines and Fittings," MIL-HDBK-216, 4 January 1962 (including Notices 1 through 7).

APPENDIX A

TEST SAMPLES

The coaxial test samples which were chosen for measurement and modeling of IM generation consist of three main types: (1) cables, (2) connectors, and (3) cable-connector combinations. All of the test samples are listed in Table A-1. They were selected so as to vary the physical and material parameters of the coaxial cables and connectors. Specifically, the cable test samples were chosen to vary dielectric material, center conductor design, center conductor plating, number of shields, and shield plating. The parameters of each cable type are given in Table A-2.

A cable test jig was constructed in order to measure the IM generation of cable test samples alone, and still be able to easily connect samples to the test setup. A cable test sample consists of a coaxial cable with each end mounted into a different sex of the test jig. The test jig was designed to incorporate concepts expected to produce very low IMP's (see Figure A-1). For example, the contact points were silver plated to increase conductivity, the test jig was designed to be relatively large so as to reduce current density, and a clamping device, with adaptations to allow for different cable diameters, was used to secure the braided shield firmly.

Initial measurements showed, however, that large diameter cables with silver-plated Type N connectors had lower, more repeatable IM levels than when mounted in the test jig. Conversely, small diameter cables mounted in the test jig had lower IM levels than when mounted in connectors. It was, therefore, decided that for large diameter cables (i.e. RG-9/U, RG-213/U, RG-214/U, RG-225/U) a cable test sample would be constructed the same as a cable-connector combination with Type N, silver-plated connectors.

It became obvious that a cable could not be mounted in the test jig for cable tests and subsequently in connectors for cable-connector-combination tests without modification. The length of the center conductor relative to the dielectric material and the length of the shield had to be significantly different for the two cases. Therefore, cable test samples in the test jig were 5-ft long and were 4.5-ft long in the cable-connector combinations because the need to redress the ends of the cables for connector assembly.

The connector test samples were chosen to vary the parameters of physical size, body material and plating, and contact material and plating. The specific connectors selected and their parameters are listed in Table A-3. Each connector test sample

consists of a male and female connector of the same type and plating connected by a rigid airline as shown in Figure A-2.

The cable-connector combinations were selected to provide representative pairings of the cables in Table A-2 and the connectors in Table A-3. A male connector was used on one end of the cable while a female connector was employed on the other end to facilitate connection into the test setup. In order to simulate cable-connector combinations as they exist on a C³ platform, the procedures outlined in MIL-HDBK-216 were followed exactly in mounting the connectors to the cables.

TABLE A-1
SELECTED TEST SAMPLES

<u>CABLE</u>			<u>CONNECTOR</u>		<u>PLATING</u>
<u>TYPE</u>		<u>LENGTH</u> (ft)	<u>TYPE</u>		
None	-		TNC	Silver	
None	-		TNC	Gold	
None	-		N	Silver	
None	-		N	Gold	
None	-		N	Nickel	
None	-		N	Stainless Steel	
None	-		N	Beryllium Copper	
				- Silver	
None	-		HN	Silver	
None	-		LC	Silver	
RG-9/U	4.5		N	Silver	
RG-9/U	4.5		N	Nickel	
RG-9/U	4.5		HN	Silver	
RG-9/U	5.0		Test Jig	-	
RG-55/U	4.5		TNC	Silver	
RG-55/U	4.5		TNC	Gold	
RG-55/U	5.0		Test Jig	-	
RG-55/U	10.0		Test Jig	-	
RG-55/U	15.0		Test Jig	-	
RG-55/U	25.0		Test Jig	-	
RG-55/U	30.0		Test Jig	-	
RG-55/U	50.0		Test Jig	-	
RG-55/U	60.0		Test Jig	-	
RG-55/U	75.5		Test Jig	-	
RG-55/U	91.7		Test Jig	-	
RG-55B/U	4.5		TNC	Silver	

(Continued)

TABLE A-1 (Concluded)

SELECTED TEST SAMPLES

Cable		Connector	
Type	Length (ft)	Type	Plating
RG-55B/U	5.0	Test Jig	-
RG-58B/U	4.5	TNC	Silver
RG-58B/U	5.0	Test Jig	-
RG-213/U	4.5	N	Silver
RG-213/U	4.5	N	Gold
RG-213/U	4.5	N	Nickel
RG-213/U	5.0	Test Jig	-
RG-214/U	4.5	N	Silver
RG-214/U	10.0	N	Silver
RG-214/U	15.0	N	Silver
RG-214/U	20.0	N	Silver
RG-214/U	45.0	N	Silver
RG-214/U	60.0	N	Silver
RG-214/U	4.5	N	Gold
RG-214/U	4.5	N	Nickel
RG-223/U	4.5	TNC	Silver
RG-223/U	4.5	TNC	Gold
RG-223/U	5.0	Test Jig	-
RG-225/U	4.5	N	Silver
RG-225/U	10.0	N	Silver
RG-225/U	15.0	N	Silver
RG-225/U	30.0	N	Silver
RG-225/U	42.5	N	Silver
RG-225/U	60.0	N	Silver
RG-225/U	4.5	N	Gold
RG-225/U	4.5	N	Nickel

TABLE A-2
PARAMETERS OF SELECTED COAXIAL CABLES

<u>Cable Types</u>	<u>Outer Shield Material</u>	<u>Inner Shield Material</u>	<u>Dielectric</u>	<u>Center Conductor Type</u>	<u>Center Conductor Material</u>
RG-9/U	Copper	Silvered Copper	Polyethylene	Stranded	Silvered Copper
RG-55/U	Tinned Copper	Tinned Copper	Polyethylene	Stranded	Silvered Copper
RG-55B/U	Tinned Copper	Tinned Copper	Polyethylene	Solid	Silvered Copper
RG-58B/U	-	Tinned Copper	Polyethylene	Solid	Copper
RG-213/U	-	Copper	Polyethylene	Stranded	Copper
RG-214/U	Silvered Copper	Silvered Copper	Polyethylene	Stranded	Silvered Copper
RG-223/U	Silvered Copper	Silvered Copper	Polyethylene	Solid	Silvered Copper
RG-225/U	Silvered Copper	Silvered Copper	Teflon	Stranded	Silvered Copper

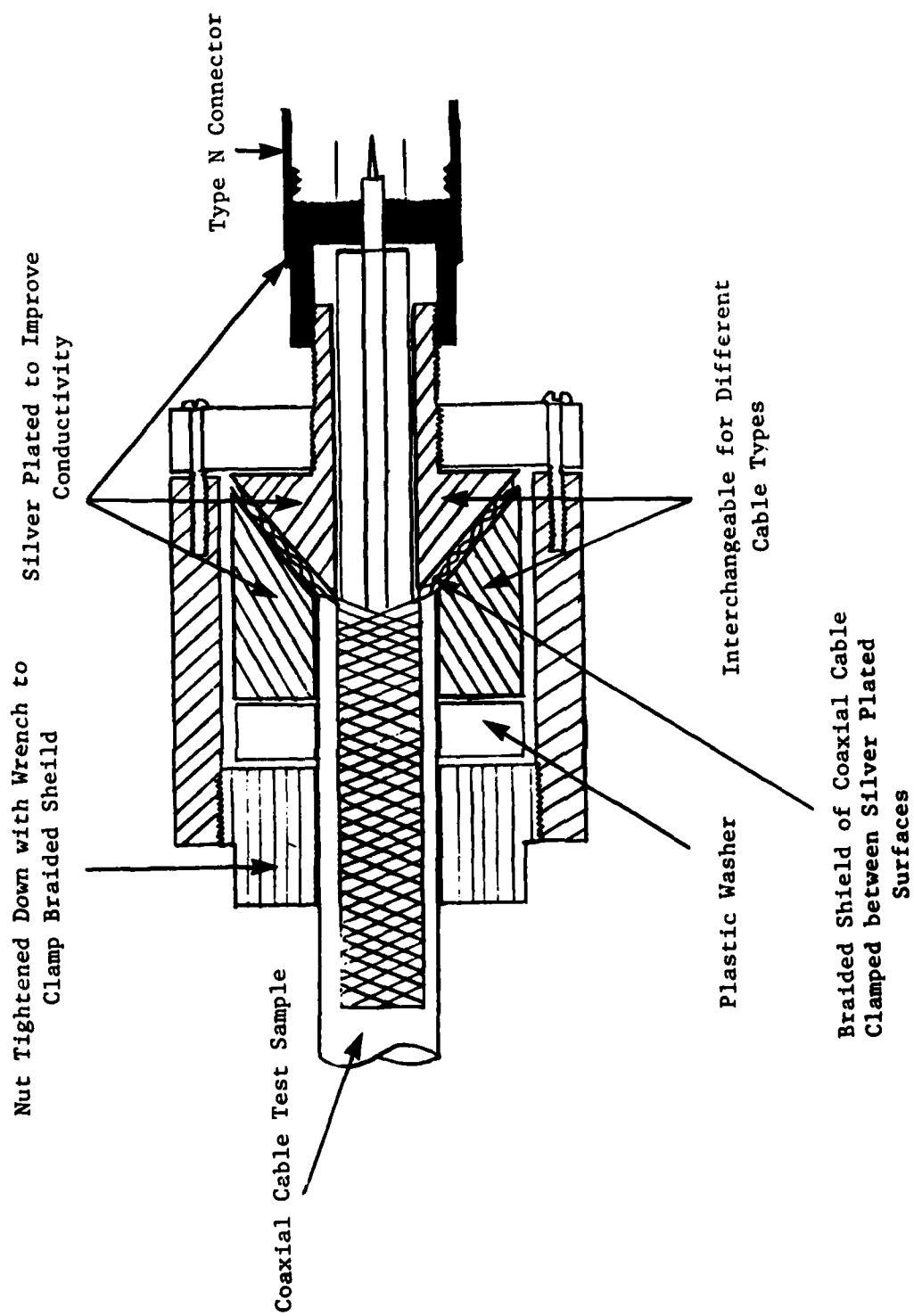


Figure A-1. Cross-Sectional View of Coaxial Cable Test Jig

TABLE A-3
PARAMETERS OF SELECTED COAXIAL CONNECTORS

Connector Types	Military Number	Description	Body		Contact	
			Material	Plating	Material	Plating
HN	UG-59E/U	Plug	Brass	Silver	Brass	Silver
HN	UG-60E/U	Jack	Brass	Silver	Brass	Silver
N	UG-21E/U	Plug	Brass	Silver	Brass	Silver
N	UG-21E/U	Plug	Brass	Nickel	Brass	Nickel
N	UG-21E/U	Plug	Brass	Gold	Brass	Gold
N	- -	Panel Mount Plug	Stainless Steel	-	Stainless Steel	-
N	UG-23E/U	Jack	Brass	Silver	Beryllium Copper	Silver
N	UG-23E/U	Jack	Brass	Nickel	Brass	Nickel
N	UG-23E/U	Jack	Brass	Gold	Brass	Gold
N	Equivalent to UG-58/U	Jack	Stainless Steel	-	Stainless Steel	-
TNC	M39012/26-0011	Plug	Brass	Silver	Brass	Silver
TNC	M39012/26-0011	Plug	Brass	Gold	Brass	Gold
TNC	M39012/27-0011	Jack	Brass	Silver	Brass	Silver
TNC	M39012/27/0011	Jack	Brass	Gold	Beryllium Copper	Gold
LC	UG-154B/U	Plug	Brass	Silver	Brass	Silver
LC	UG-352B/U	Jack	Brass	Silver	Brass	-

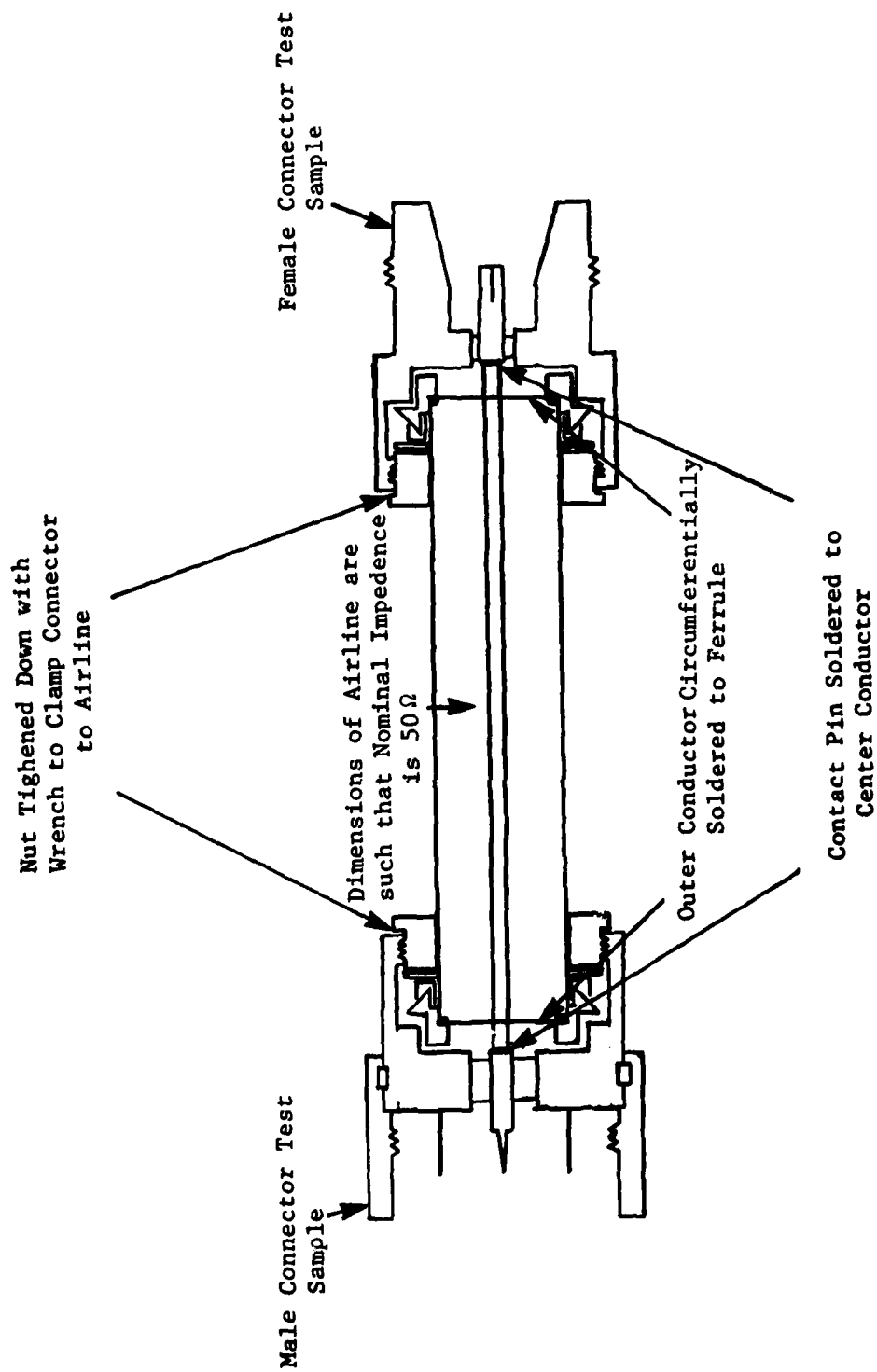


Figure A-2. Cross-Sectional View of Connector Test Jig

APPENDIX B

IM MEASUREMENT SCHEME

An engineering design study was conducted to develop a repeatable, accurate, and sensitive measurement scheme for use in collecting data to characterize the IM interference signal levels generated in passive devices, specifically coaxial cables and connectors. This design study consisted of analyses of various test setups and of potential elements in the test setups. Specific investigations and analyses were made concerning frequency and power limitations of available test setup elements, predicted IM signal levels generated by the test samples, and sensitivity requirements achievable with commercially available detection instruments. These analyses included a comprehensive literature review and preliminary measurements of the characteristics of potential elements of the test setup.

The study resulted in the development of two test setups: one for an IM frequency of 22 MHz and the other for IM frequencies between 200 and 425 MHz. Descriptions of these test setups are summarized in this appendix.

B.1 HF Test Setup

A block diagram of the HF test setup is given in Figure B-1. It consists of four major sections: (1) the Power Source/Combiner Section, (2) the Test Sample Section, (3) the Load/Detector Section, and (4) the Cancellation/Power Level Indicator Section.

The purpose of the Power Source/Combiner Section is to generate the required levels of RF power at fundamental frequencies of 17.88 and 19.89 MHz and to combine these two fundamental signals so that they can be applied to the test samples. These specific frequencies were chosen because of the availability of HF filters. The resulting third-order IM product is at a frequency of 21.9 MHz (nominally 22 MHz). The specific equipment and components employed in this section of the test setup are identified in Table B-1.

The power combiner in Table B-1 consists of two Pi-network impedance transformers with a common output as illustrated in Figure B-2. (This figure also shows the interconnection of the power combiner with the other elements of the Power

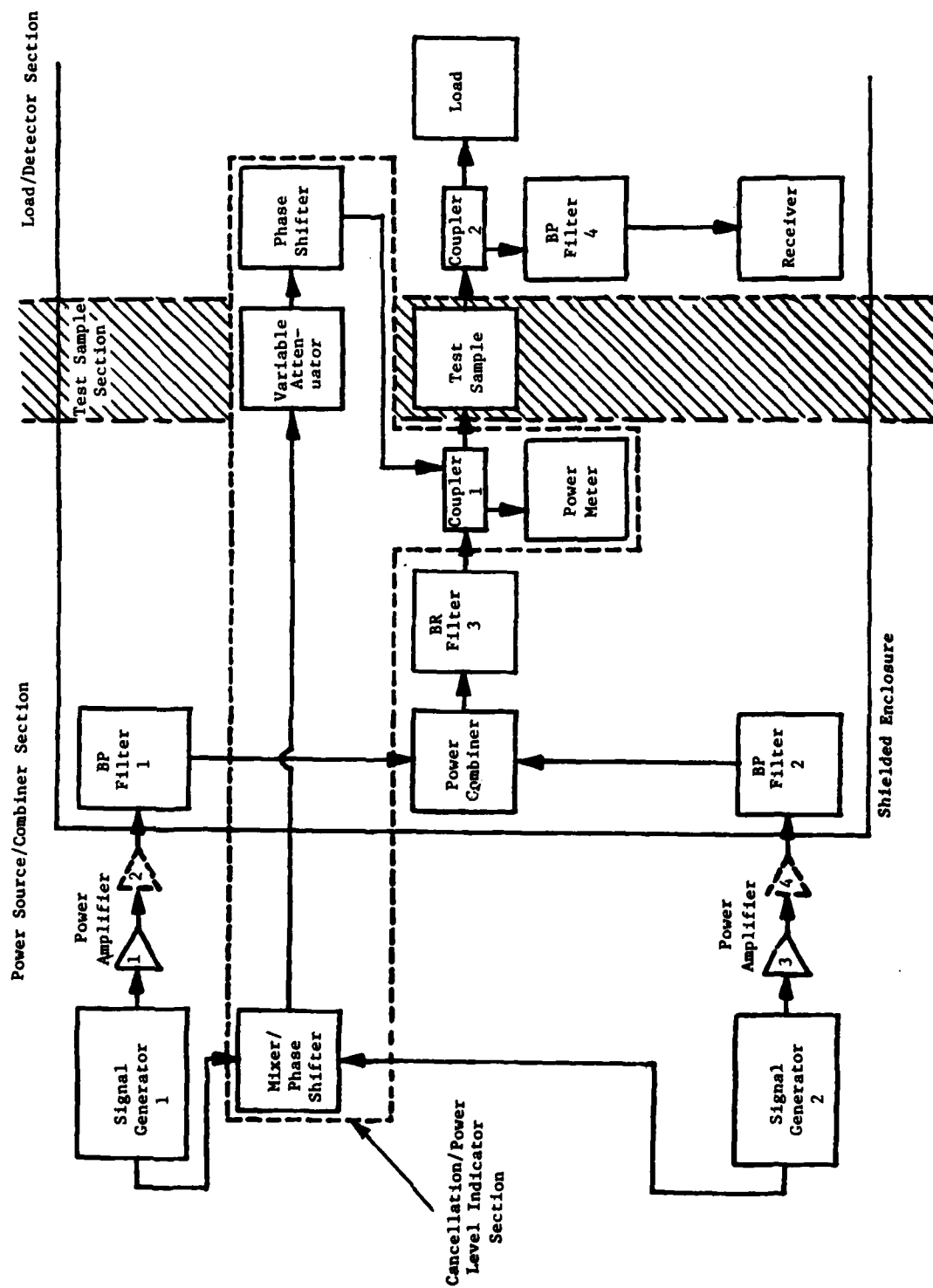


Figure B-1. HF Measurement Setup

TABLE B-1
COMPONENTS OF THE HF TEST SETUP

<u>Test Setup Section</u>	<u>Test Setup Component</u>	<u>Component Description</u>
Power Source/ Combiner	Signal Generator 1	HP 8640B Signal Generator
	Signal Generator 2	HP 8640B Signal Generator
	Power Amplifier 1	AILTECH 5020 Broadband Amplifier
	Power Amplifier 2*	Drake L-4B Linear Amplifier
	Power Amplifier 3	Amplifier Research 100L Broadband Amplifier
	Power Amplifier 4*	Heath Kit SB-221 Linear Amplifier
	BP Filter 1	Bandpass Filter--Helical Resonator tuned to 17.88 MHz
	BP Filter 2	Bandpass Filter--Lumped-constant filter tuned to 19.89 MHz
	BR Filter 3	Band-reject Filter--Lumped-constant filter tuned to 21.9 MHz
	Power Combiner	Two Pi-Network Impedance Transformers with a common output
Load/Detector	Coupler 2	HP 778D Dual Directional Coupler (or Georgia Tech constructed 20 dB directional coupler)* with 50-ohm termination on reverse port
	Load	Bird Termaline 8251 Coaxial Resistor

(Continued)

TABLE B-1 (Concluded)

COMPONENTS OF THE HF TEST SETUP

<u>Test Setup Section</u>	<u>Test Setup Component</u>	<u>Component Description</u>
	BP Filter 4	Two Bandpass Filters--Lumped-constant filters tuned to 21.9 MHz
	Receiver	HP 141T Spectrum Analyzer with HP 8554L RF Section and HP 8552B IF Section
Cancellation/ Power Level Indicator	Mixer/Phase Shifter	Lumped-constant, active phase shifter and mixer (see Figure B-3)
	Variable Attenuator	Weinschel 905 Variable Attenuator
	Phase Shifter	GR 874-LK20 Constant Impedance Adjustable Line and GR 874- LTL Trombone Constant Impedance Adjustable Line
	Coupler 1	Narda 3020 Bi-Directional Coupler
	Power Meter	HP 435A Power Meter

*Used for input powers greater than 44 dBm.

Source/Combiner Section of the test setup.) The characteristic impedance of the transformers is 50 ohms such that their output impedances, $Z_{out}(f)$ are given by

$$Z_{out} = \frac{(50)^2}{Z_B} \quad (B-1)$$

where Z_B is the frequency dependent output impedance of the bandpass filter. At frequency f_1 , the output impedance, Z_{B1} , of the bandpass filter for f_1 is 50 ohms. Hence, from Equation (B-1) the output impedance of Pi-network #1 at f_1 is 50 ohms. Also, at frequency f_1 , the output impedance of the bandpass filter for f_2 is very low; therefore, again from Equation (B-1), the output impedance of Pi-network #2 at f_1 is very high. Hence, very little of the f_1 signal couples through Pi-network #2 and the bandpass filter for f_2 . The output impedance of the power combiner at frequency f_1 is essentially 50 ohms (from Pi-network #1) in parallel with a very high impedance (from Pi-network #2) or is approximately 50 ohms. Thus, essentially all of the signal at f_1 is coupled to the combined output port. At frequency f_2 the roles of Pi-network #1 and bandpass filter for f_1 interchange with those of Pi-network #2 and bandpass filter for f_2 . Hence, very little of the signal at f_2 couples to the signal generator and amplifiers for f_1 and essentially all of the f_2 signal appears at the output of the power combiner. In summary, the Power Combiner helps isolate the two fundamental signals and combines them at a common output with very little loss.

During the development of the measurement scheme and test setups, it was noted that the inherent IM level of the HF setup was excessively high when compared with the UHF test setup (see Section B.2). Therefore, it was necessary to use a band-reject (i.e., notch) filter in the HF test setup prior to the test sample. This filter which had an attenuation of 60 dB at the IM frequency was placed at the output of the power combiner as shown in Figure B-1.

The Test Sample Section of the test setup consists of only the test sample, i.e., a length of coaxial line, a pair of connectors, or a combination of a cable and connectors. The test sample is located between the Power Source/Combiner and Load/Detector Sections of the test setup and is connected to the output of the signal combiner.

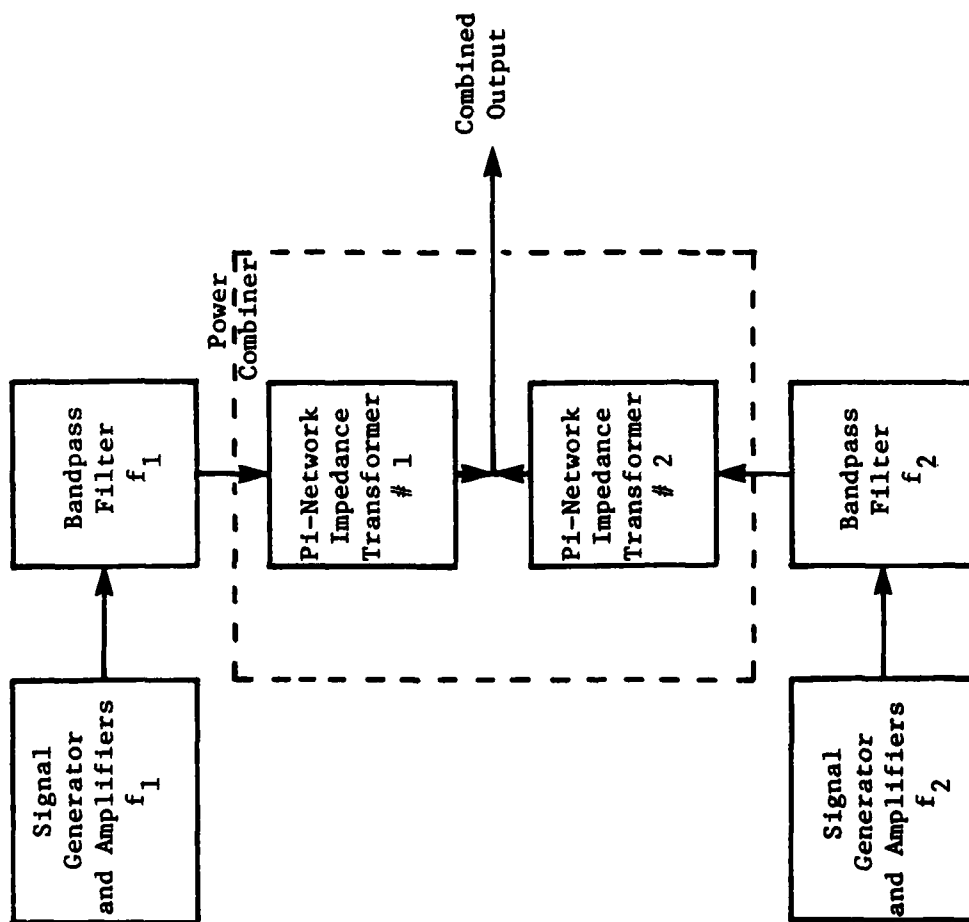


Figure B-2. HF Power Combiner

The Load/Detector Section of the test setup is connected to the output of the test sample. The purpose of this section is to provide an appropriate termination, i.e., 50-ohm load, for the test sample and to provide a means of detecting the IM signals and measuring their levels. The equipment and components in this section of the test setup are also listed in Table B-1. Between the test sample and the load, a directional coupler is used to sample the generated IM products for detection with the receiver. This directional coupler and the two IM bandpass filters are used to attenuate the two fundamental frequency signals so that they do not create IM products in the receiver.

The purpose of the Cancellation/Power Level Indicator Section which is shown in Figure B-1 is to cancel the inherent IM product of the test setup and to monitor the input power levels of the two fundamental signals to the test sample. The specific equipment and components used in this section are also identified in Table B-1. The buffered outputs of the signal generators are fed to an active phase shifter/mixer element that generates an "artificial" IM product and allows its phase to be shifted. A block diagram of this element is given in Figure B-3. The "artificial" IM product is then routed through an adjustable length airline and a variable attenuator and coupled back into the test setup immediately prior to the test sample with a dual-directional coupler. The phase and amplitude of this "artificial" IM product can then be adjusted* to cancel the inherent IM product of the test setup at the input to the test sample.

The other port of the dual-directional coupler is connected to a power meter. After calibrating the insertion loss between the power meter and the test sample (see Appendix C), the power meter is used to measure the level of the two fundamental signals at the input to the test sample.

As shown in Figure B-1, part of the Power Source/Combiner and Cancellation/Power Level Indicator Sections and all of the Test Sample and Load/Detector Sections are located inside a shielded enclosure. Specifically, the high power signal sources are located outside the shielded enclosure and the test sample and detection systems are located inside the enclosure. Thus, the enclosure wall provides isolation between the high level signals and the sensitive parts of the test setup. A high degree of isolation was necessary to prevent undesired coupling within the test setup.

* The attenuator adjusts the amplitude while the active phase shifter/mixer and adjustable airline provides coarse and fine phase adjustments, respectively.

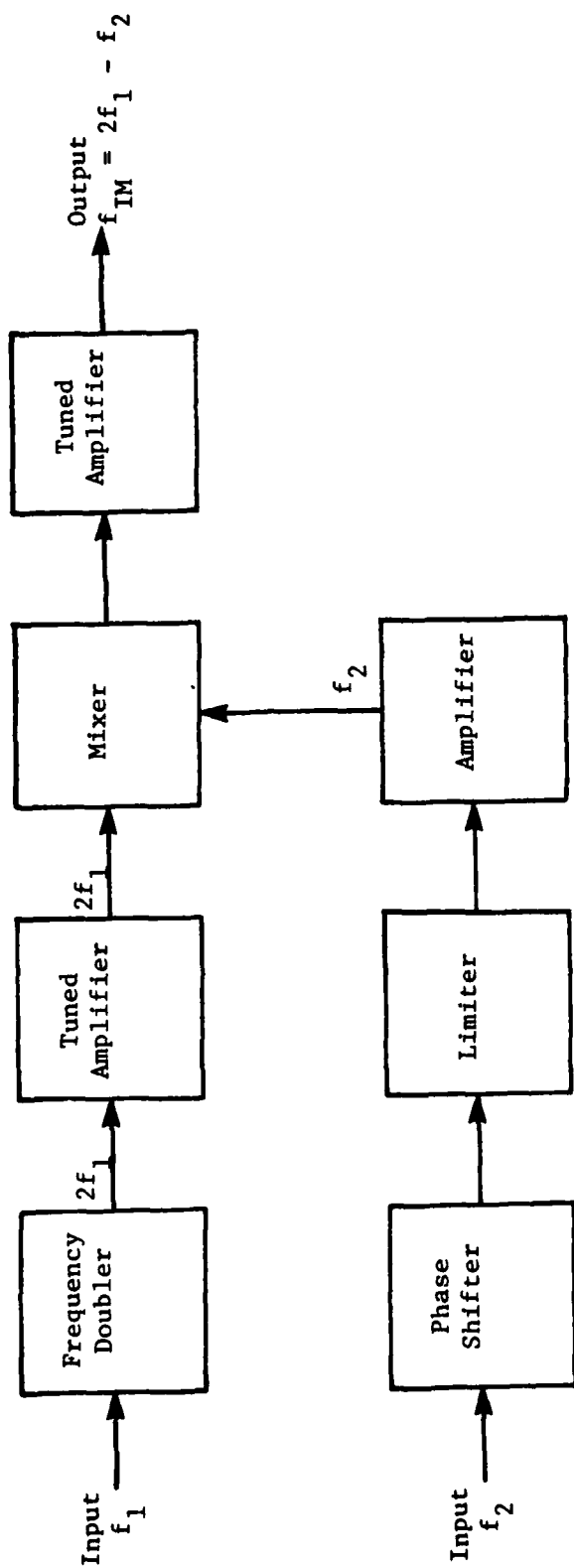


Figure B-3. Block Diagram of Active Phase Shifter/ Mixer Element of HF Test Setup in Figure B-1

B.2 UHF Test Setup

A block diagram of the UHF test setup is given in Figure B-4. The equipment and components used in this test setup are identified in Table B-2. The general arrangement of the UHF test setup is identical to the HF test setup. Since a few changes were necessary as a result of the change in frequency, these differences are described in this section.

The fundamental signal frequencies were selected to be 225 and 250 MHz and 375 and 400 MHz based on trade offs between the following considerations:

- the desire for the fundamental frequencies, f_1 and f_2 , to cover the maximum frequency range of the BP filters;
- the need for the frequency separation between f_1 and f_2 to be sufficiently large so that the attenuations of BP Filter 1 at f_2 and of BP Filter 2 at f_1 are maximized, and
- the need for the frequency separation to be small such that f_1 and f_2 are both within the bandwidth of the power combiner.

The UHF power combiner consisted of a stripline hybrid specifically designed for each pair of fundamental frequencies in accordance with published design procedures*. Since the dielectric constant of the Type G-10 PC board used was not known exactly it was necessary to experimentally determine the width of the stripline that gives a 50-ohm characteristic impedance. This width was then scaled according to frequency and impedance for each hybrid. The two input ports to each hybrid were chosen to provide maximum isolation between the fundamental signals and the output port was to give the least insertion loss. The fourth port was terminated in a 50-ohm load. It was noted that an extremely linear load for this port was important in reducing the inherent IM level of the test setup. A 250-ft length of RG-223/U coaxial cable with a 50-ohm termination was found to provide the necessary linearity.

* H. Howe, Jr., Stripline Circuit Design, Artech House, Inc., Dedham, MA, 1979, pp 77-79.

I. J. Bahl and D. K. Trivedi, "A Designer's Guide to Microstrip Line," Microwaves, Vol. 16, No. 5, May 1977, pp 174-182.

A. H. Kwon, "Design of Microstrip Transmission Line," Microwave Journal, Vol. 19, No. 1, January 1976, pp 61-63.

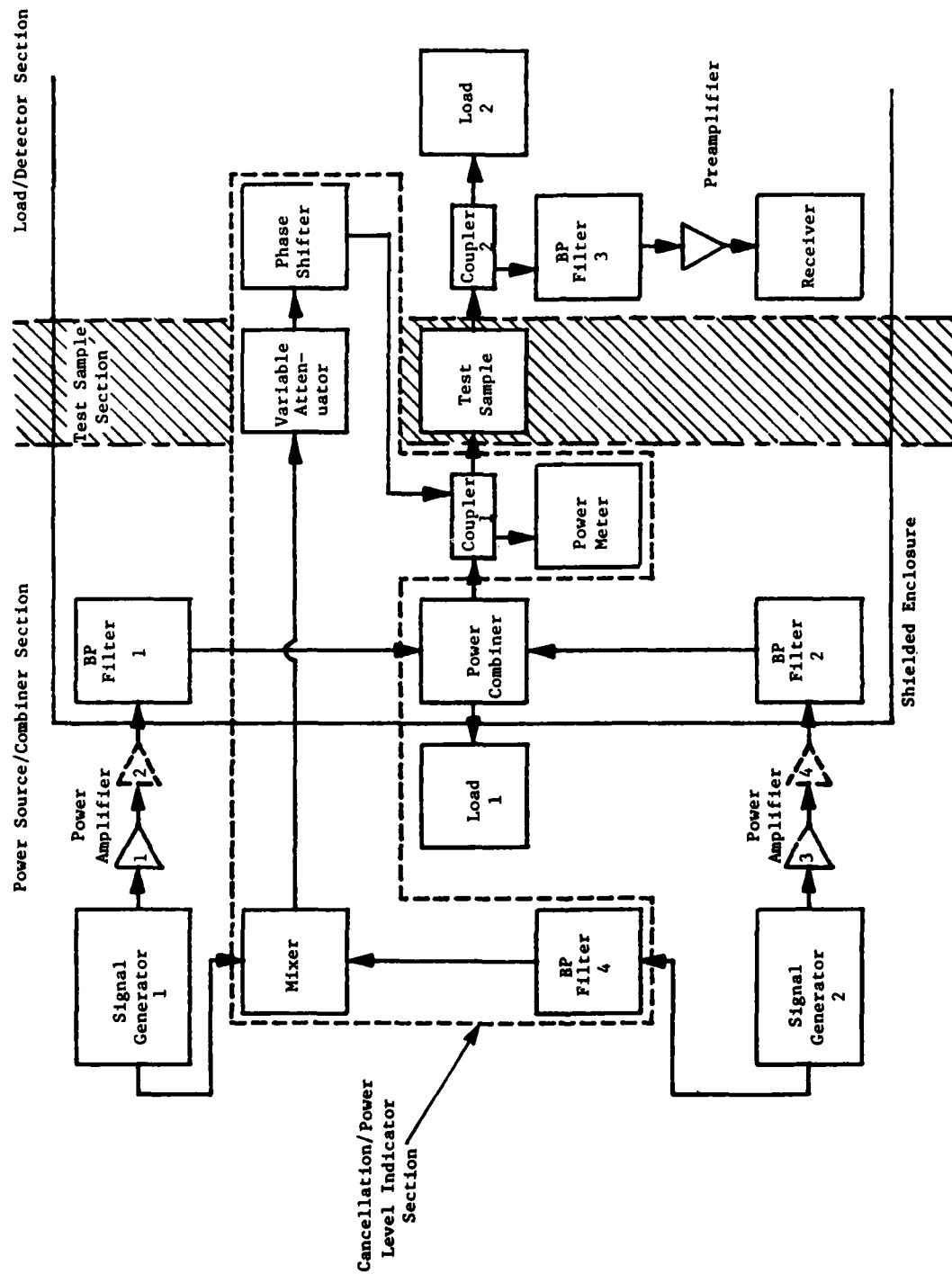


Figure B-4. UHF Measurement Setup

TABLE B-2
COMPONENTS OF THE UHF TEST SETUP

<u>Test Setup Section</u>	<u>Test Setup Component</u>	<u>Component Description</u>
Power Source/ Combiner	Signal Generator 1	HP 8640B Signal Generator
	Signal Generator 2	HP 8640B Signal Generator
	Power Amplifier 1	AILTECH 20512 Broadband Amplifier
	Power Amplifier 2*	ARCOS UHF-500 Power Amplifier
	Power Amplifier 3*	AILTECH 35512 Broadband Amplifier
	Power Amplifier 4	ARCOS UHF-500 Power Amplifier
	BP Filter 1	Bandpass Filter--single tuned, high Q cavity resonator (218 to 408 MHz)
	BP Filter 2	Bandpass Filter--Collins 156C-2 Multicoupler (220 to 400 MHz)
	Power Combiner	Stripline Hybrid--designed for either 237.5 MHz or 387.5 MHz (see text)
	Load 1	250-ft length of RG-223/U with a 50-ohm termination
Load/Detector	Coupler 2	HP 7780 Dual Directional Coupler (or Georgia Tech constructed, 20 dB Direction Coupler)* with 50-ohm termination on reverse port
	Load 2	Bird Termaline 8251 Coaxial Resistor

(Continued)

TABLE B-2 (Concluded)

COMPONENTS OF THE UHF TEST SETUP

<u>Test Setup Section</u>	<u>Test Setup Component</u>	<u>Component Description</u>
	BP Filter 3	Telonic TTA375-3-5EE Tunable Bandpass Filter
	Preamplifier	Miteq AM-3A-000110 Preamplifier
	Receiver	HP 141T Spectrum Analyzer with HP 8554L RF Section and HP 8552B IF Section
Cancellation/ Power Level Indicator	Mixer	HP 10514A Mixer
	BP Filter 4	Bandpass Filter--signal tuned, high Q cavity resonator
	Variable Attenuation	Weinschel 905 Variable Attenuator
	Phase Shifter	GR 874-LK20 Constant Impedance Adjustable Line and GR 874-LTL Trombone Constant Impedance Adjustable Line
	Coupler 1	Narda 3020 Bi-Directional Coupler
	Power Meter	HP 435A Power Meter

*Used for input powers greater than 44 dBm.

The major change in the configuration of the Load/Detector Section between the HF and UHF test setups was that a preamplifier could be used at the input to the receiver in the UHF Test Setup. (This preamplifier could not be employed in the HF Test Setup because the resulting amplified fundamental signals produced IM products in the receiver.) The low noise figure (2 dB), high gain (36 dB) preamplifier improved the measurement sensitivity of the UHF Test Setup by more than 20 dB.

The only difference in the Cancellation/Power Level Indicator Section of the UHF Test Setup relative to the HF Setup is the mixer and phase shifter. For UHF, a commercially available mixer (see Table B-2) was used and the adjustable length airline was sufficient for shifting the phase of the "artificially" generated IM signal.

APPENDIX C

TEST PROCEDURES

The purpose of this appendix is to outline the basic test procedures followed in measuring a test sample. In general, the test procedures include three basic, sequential steps: (1) calibrate the test setup, (2) prepare the test sample and set the input power levels, and (3) measure the level of the IM product generated by the test sample.

After the test set up has been configured according to Appendix B, the Load/Detector Section and the Cancellation/Power Level Indicator Section are calibrated. A calibrated signal at the frequency of the IM product is applied to the input of the Load/Detector Section which is also the output of the Test Sample Section (see Figures B-1 and B-4). The level at the receiver is then measured. The difference between the input level and the measured level is Calibration Factor 1. Typical values are +21 dB for the HF and -14 dB for the UHF test setups. This calibration factor is then added to the measured IM level at the receiver to obtain the actual level of the IM product generated in the test sample. The Power Level Indicator is similarly calibrated by applying a signal at the frequency of each fundamental to the input of the dual directional coupler in this section which is also the output of the Power Source/Combiner Section (see Figures B-1 and B-4). The power level at this point is the same as at the input of the test sample because the insertion loss of the directional coupler is significantly less than 1 dB. The level of each signal is then read on the power level meter. The difference between the two input levels and the two measured levels are Calibration Factors 2 and 3. These calibration factors are then added to the power meter readings to determine the power level of each fundamental signal at the input of the test sample.

The test samples are prepared according to Appendix A. The test setup is connected without a test sample. Using Calibration Factors 2 and 3, the power level of each fundamental signal is set equal to the desired level as indicated by the power meter.

To measure the test sample, the receiver (spectrum analyzer) is tuned to the IM frequency and adjusted for maximum sensitivity (i.e., 300 Hz bandwidth and 10 Hz video filter). The phase shifter and variable attenuator in the Cancellation/Power Level Indicator Section are then alternately adjusted until the inherent IM level of the test setup is cancelled to a minimum. The level of this "initial" IM product is

corrected using Calibration Factor 1 and is then recorded along with the linear sum of the input power levels for the two fundamentals, the frequency of the IM product, and the various test sample parameters. The RF power of each signal source is then turned off and a test sample is inserted in the test setup. The connectors of the test sample are tightened hand tight to simulate field conditions as closely as possible. The RF powers are turned on and the level of the IM product is measured, corrected using Calibration Factor 1, and recorded. The RF power is again turned off, the test sample removed, and the test setup reconnected without the test sample. The RF power is turned on and the "final" level of the cancelled inherent IM product is measured and recorded. All of the recorded values are given in Appendix A.

This procedure is repeated, except for calibration of the test setup, for one test sample enough times to insure repeatability of measurements. Once repeatability is verified, the other test samples are measured in the same manner.

For each new IM frequency the test setup is prepared according to Appendix B and the entire procedure repeated.

APPENDIX D

CONSIDERATIONS/PRECAUTIONS

During the conduct of this program, several observations were made which indicate that various factors other than those intrinsically associated with cable and connector material, construction, and size influence the levels of the IM products generated in coaxial cables and connectors. These factors must be considered in the design of the test setup, the preparation of the test sample, and the performance of the tests required to measure "super" low level IM products in the laboratory. Because of their nature, these factors are also expected to influence the levels of IM products generated on C³ platforms as well as the techniques utilized to minimize the resulting IM interference. This appendix discussed the precautions which must be considered to measure low level IM products and reduce their amplitudes.

The first factor that must be taken into account is that a test setup consists in concept of a large number of test samples. That is, the point or points in a test sample at which a nonlinear current-voltage characteristic occurs and at which IM product generation results is duplicated many times in a test setup constructed of similar parts and materials. Therefore, the inherent IM product level of the test setup is often equal to or higher than the level produced by the test sample. However, the measurement of the test sample must not be influenced by the inherent IM level of the test setup. This consideration led to the design of the cancellation schemes described in Appendix B.

Other factors such as mechanical stability, pressure between contact points, surface conditions of conductors and contact points, and specific test setup elements which are used all affect the inherent IM level of the test setup as well as the IM levels of the test samples. Furthermore, each of these factors caused dramatic increases in the IM levels which in general were neither predictable nor repeatable. In "real world" situations the effect of each of those factors is expected to be equal or greater. Therefore, the following discussion is especially significant in the reduction of IM interference in the field. For example, it was discovered that vibration of the test equipment could cause variations in the inherent IM level of the test setup of as much as 40 dB. To insure the lowest and most stable inherent IM level, each component of the test equipment was rigidly mounted so as to reduce the vibrational effect. The entire Load/Detector Section was rigidly mounted to a heavy

moveable cart. This section could then be rolled in and out as a single unit to insert and remove the test sample and the individual components of this section could be maintained fixed relative to each other.

Also, threaded connectors showed variations of 40 dB or more. Several precautions were taken to minimize these variations. The surface of the threads were blown free of particles and filings before they were threaded together. Each female connector was checked for the condition of the center pin. If it was bent, oxidized, or out of line the connector was repaired or replaced. Each connection was threaded together carefully and then tightened with a wrench. Nevertheless, a certain number of connections were still found to be "bad". They caused an increase of 40-60 dB in the inherent IM level of the test setup and these increased levels were generally of an intermittent nature. This problem could usually be remedied by unscrewing the connections completely and then carefully screwing them together again and tightening them with a wrench.

The test samples were treated in the same manner as the other threaded connections in the test setup except they were only screwed together "hand" tight as described in Appendix C. The test samples were inspected before each measurement to insure that the connectors were rigidly mounted as described in Appendix A and to insure that all their parts were in good condition.

Even after all of the above precautions, it was discovered that two seemingly identical pieces of equipment could have large differences in inherent IMP generation. For example, two "identical" dual directional couplers were each tried in the Load/Detector Section of the test setup. One resulted in an inherent IM level 20 dB higher than the other. Therefore, when possible, several units of each piece of test equipment were substituted into the test setup in order to find the one which resulted in the lowest level inherent IM product. (This practice may also be useful in reducing IM levels on C³ aircraft.)

At the IM frequency of 425 MHz, the inherent IM level of the test setup was dependent on the length of cables in the test setup and upon small variations in the IM frequency. If the frequency of the fundamentals were changed slightly so that the IM frequency changed, a variation in the inherent IM level was noticed. A similar result was obtained if different lengths of coaxial cable were used to transmit the fundamental signals from the amplifiers to the hybrid. This phenomenon did not appear to affect the measured IM levels of the test samples and was not observed at the other test frequencies.

The final inherent IM level of the test setup is a sum of all the IM products generated at each point in the test setup adding in and out of phase at the receiver. In order to measure the test samples at input power levels greater than +44 dBm, the test setup had to be disassembled and then reassembled with different components in different relative orientations. Even with the above precautions, the inherent IM level of the test setup was found to vary as much as 17 dB with these changes. These changes in the test setup also resulted in variations of as much as 21 dB in the measured IM levels of the test samples at +44 dBm. An explanation for these variations was not found. However, when the test setup was later reassembled using the original components in their original orientations the measured IM levels were repeatable within 3 dB.

In summary, several additional factors were observed to affect the levels of IM products generated in coaxial cables and connectors. In future measurements and in actual C³ installations, these factors must be considered and appropriate precautions must be taken.

APPENDIX E
MEASURED IM PRODUCT DATA

The IM product data measured for coaxial cables and connectors are listed in this appendix. The connector data is listed on the first two pages followed by the cable-connector combination data. The cable data obtained by using the test jig and silver-plated Type N connectors is included within the cable-connector combination data. The data are grouped by frequency, connector type, connector plating, cable type, cable length, and power. The list gives cable type, cable length in feet, cable identification number (CABLE I.D. #), connector type, connector plating (CONNECTOR PLTG), connector identification number (CONNECTOR I.D. #), input power in dBm, level in dBm to which the IM product generated in the test setup was cancelled (INITIAL IM LEVEL), level in dBm of the measured IM product generated in the test sample (MEAS. IM LEVEL), IM level in dBm of the test setup following the measurement of the test sample (FINAL IM LEVEL), and IM test frequency in MHz (FREQ.)

In the data list, several notations are utilized for convenience. For example, zero (0) for a parameter indicates that particular parameter was not applicable. Cable Types 550 and 580 indicate RG-55B/U and RG-58B/U cables, respectively. The following notations are used for connector types:

- 1 = TNC
- 2 = N
- 3 = HN
- 4 = test jig
- 5 = LC

Similarly, the following notations are used for connector platings:

- 1 = silver
- 2 = gold
- 3 = nickel
- 4 = stainless steel
- 5 = beryllium copper-silver

CABLE			CONNECTOR				INPUT POWER (dBm)	INITIAL IN LEVEL (dBm)	MEAS. IN LEVEL (dBm)	FINAL IN LEVEL (dBm)	FREQ. (MHz)
TYPE	LENGTH (ft)	I.D.#	TYPE	PLTG.	I.D.#						
0	0.0	0	1	1	2 3		44.0	-86	-83	-83	22
0	0.0	0	1	2	24 25		44.0	-86	-82	-83	22
0	0.0	0	2	1	7 13		44.0	-87	-85	-87	22
0	0.0	0	2	1	7 13		44.0	-87	-85	-87	22
0	0.0	0	2	2	10 11		44.0	-87	-80	-87	22
0	0.0	0	2	2	10 11		44.0	-88	-81	-88	22
0	0.0	0	2	3	19 20		36.0	-88	-84	-88	22
0	0.0	0	2	3	19 20		38.0	-87	-80	-87	22
0	0.0	0	2	3	19 20		40.0	-88	-79	-86	22
0	0.0	0	2	3	19 20		42.0	-86	-73	-86	22
0	0.0	0	2	3	19 20		42.7	-88	-74	-81	22
0	0.0	0	2	3	19 20		44.0	-88	-70	-85	22
0	0.0	0	2	3	19 20		44.0	-87	-69	-87	22
0	0.0	0	2	3	19 20		44.0	-87	-69	-87	22
0	0.0	0	2	3	19 20		44.0	-87	-70	-86	22
0	0.0	0	2	3	19 20		44.0	-88	-72	-88	22
0	0.0	0	2	4	0 62		44.0	-87	-84	-87	22
0	0.0	0	3	1	26 27		44.0	-88	-88	-88	22
0	0.0	0	4	0	0 0		44.0	-85	-80	-85	22
0	0.0	0	5	1	0 58		44.0	-88	-83	-87	22
0	0.0	0	1	1	3 2		43.6	-110	-81	-110	200
0	0.0	0	1	1	3 2		43.6	-118	-82	-118	200
0	0.0	0	1	2	24 25		43.6	-115	-79	-112	200
0	0.0	0	1	2	24 25		43.6	-115	-81	-110	200
0	0.0	0	2	1	7 13		33.3	-122	-113	-122	200
0	0.0	0	2	1	7 13		36.2	-119	-107	-119	200
0	0.0	0	2	1	7 13		38.3	-120	-100	-120	200
0	0.0	0	2	1	7 13		41.4	-122	-91	-110	200
0	0.0	0	2	1	7 13		43.4	-115	-87	-104	200
0	0.0	0	2	2	10 11		43.4	-115	-82	-100	200
0	0.0	0	2	3	19 20		42.5	-115	-81	-100	200
0	0.0	0	2	4	0 62		42.4	-110	-78	-105	200
0	0.0	0	2	4	0 62		43.5	-120	-77	-115	200
0	0.0	0	2	5	21 22		43.4	-115	-86	-100	200
0	0.0	0	2	5	21 22		43.7	-115	-86	-110	200
0	0.0	0	3	1	26 27		43.0	-122	-84	-95	200
0	0.0	0	3	1	26 27		43.8	-118	-84	-100	200
0	0.0	0	5	1	0 58		42.5	-115	-88	-105	200
0	0.0	0	1	1	3 2		43.0	-115	-100	-115	275
0	0.0	0	1	2	24 25		43.0	-115	-101	-115	275
0	0.0	0	2	1	7 13		42.5	-119	-100	-118	275
0	0.0	0	2	1	7 13		42.5	-115	-100	-115	275
0	0.0	0	2	2	10 11		42.5	-118	-102	-118	275
0	0.0	0	2	3	19 20		42.5	-115	-97	-105	275
0	0.0	0	2	4	0 62		42.5	-115	-91	-115	275
0	0.0	0	3	1	26 27		42.5	-115	-99	-115	275
0	0.0	0	5	1	0 58		43.0	-115	-94	-115	275
0	0.0	0	1	1	3 2		39.1	-119	-101	-119	350
0	0.0	0	1	1	3 2		44.0	-118	-87	-113	350
0	0.0	0	1	2	24 25		44.0	-118	-90	-113	350

CABLE			CONNECTOR			INPUT POWER (dBm)	INITIAL IN LEVEL (dBm)	MEAS. IN LEVEL (dBm)	FINAL IN LEVEL (dBm)	FREQ. (MHz)
TYPE	LENGTH (ft)	I.D.#	TYPE	PLTG.	I.D.#					
0	0.0	0	2	1	7 13	39.1	-123	-110	-120	350
0	0.0	0	2	1	7 13	44.0	-122	-94	-122	350
0	0.0	0	2	1	7 22	44.1	-120	-97	-112	350
0	0.0	0	2	2	10 11	36.3	-123	-112	-123	350
0	0.0	0	2	2	10 11	39.1	-123	-103	-123	350
0	0.0	0	2	2	10 11	44.0	-120	-92	-114	350
0	0.0	0	2	3	17 18	44.2	-118	-87	-114	350
0	0.0	0	2	3	17 18	44.3	-120	-86	-106	350
0	0.0	0	2	3	17 18	44.5	-120	-84	-120	350
0	0.0	0	2	3	17 18	44.5	-124	-84	-104	350
0	0.0	0	2	5	21 22	39.1	-123	-110	-123	350
0	0.0	0	2	5	21 22	44.0	-119	-96	-111	350
0	0.0	0	3	1	26 27	44.2	-113	-92	-104	350
0	0.0	0	3	1	26 27	44.3	-113	-92	-113	350
0	0.0	0	5	1	0 58	44.3	-120	-98	-113	350
0	0.0	0	1	1	3 2	28.9	-126	-109	-126	425
0	0.0	0	1	1	3 2	36.1	-126	-89	-124	425
0	0.0	0	1	1	3 2	36.1	-126	-88	-120	425
0	0.0	0	1	1	3 2	36.1	-126	-88	-116	425
0	0.0	0	1	1	3 2	36.1	-126	-88	-120	425
0	0.0	0	1	2	24 25	28.9	-126	-110	-124	425
0	0.0	0	1	2	24 25	36.1	-126	-91	-126	425
0	0.0	0	1	2	24 25	36.1	-126	-89	-126	425
0	0.0	0	2	1	7 13	36.3	-126	-99	-126	425
0	0.0	0	2	2	10 11	28.9	-126	-119	-126	425
0	0.0	0	2	2	10 11	36.1	-125	-98	-122	425
0	0.0	0	2	2	10 11	36.1	-126	-99	-121	425
0	0.0	0	2	2	10 11	36.1	-125	-97	-115	425
0	0.0	0	2	2	10 11	36.1	-126	-98	-125	425
0	0.0	0	2	3	17 18	31.5	-126	-108	-126	425
0	0.0	0	2	3	17 18	31.5	-126	-109	-126	425
0	0.0	0	2	3	17 18	36.3	-126	-94	-118	425
0	0.0	0	2	3	17 18	36.3	-126	-94	-126	425
0	0.0	0	2	5	21 22	28.9	-126	-121	-122	425
0	0.0	0	2	5	21 22	28.9	-126	-122	-120	425
0	0.0	0	2	5	21 22	28.9	-126	-120	-126	425
0	0.0	0	2	5	21 22	36.1	-126	-100	-126	425
0	0.0	0	3	1	26 27	28.9	-126	-121	-126	425
0	0.0	0	3	1	26 27	31.5	-126	-119	-126	425
0	0.0	0	3	1	26 27	36.1	-126	-104	-126	425
0	0.0	0	3	1	26 27	36.3	-126	-102	-120	425
0	0.0	0	3	1	26 27	36.3	-126	-103	-126	425
0	0.0	0	3	1	26 27	36.3	-126	-101	-119	425
0	0.0	0	5	1	0 58	43.5	-113	-82	-92	425

CABLE			CONNECTOR			INPUT POWER (dBm)	INITIAL IN LEVEL (dBm)	MEAS. IN LEVEL (dBm)	FINAL IN LEVEL (dBm)	FREQ. (MHz)
TYPE	LENGTH (ft)	I.D.#	TYPE	PLTG.	I.D.#					
55	4.5	1	1	1	33 34	44.0	-86	-77	-83	22
550	4.5	31	1	1	33 34	44.0	-86	-74	-86	22
580	4.5	37	1	1	33 34	44.0	-86	-75	-86	22
223	4.5	23	1	1	33 34	44.0	-85	-73	-86	22
55	4.5	1	1	2	5 6	44.0	-85	-74	-86	22
223	4.5	23	1	2	5 6	44.0	-86	-73	-86	22
9	4.5	8	2	1	49 50	42.7	-88	-81	-81	22
9	4.5	63	2	1	64 65	44.0	-91	-70	-66	22
9	4.5	63	2	1	64 65	44.0	-93	-86	-93	22
9	4.5	63	2	1	64 65	44.0	-88	-86	-88	22
9	4.5	63	2	1	64 65	44.0	-88	-86	-88	22
9	4.5	63	2	1	64 65	44.0	-88	-86	-88	22
9	4.5	63	2	1	64 65	44.0	-91	-87	-90	22
9	4.5	8	2	1	49 50	44.0	-82	-75	-82	22
9	4.5	63	2	1	64 65	46.0	-86	-77	-86	22
9	4.5	63	2	1	64 65	48.0	-86	-71	-86	22
9	4.5	63	2	1	64 65	49.3	-78	-70	-74	22
213	4.5	12	2	1	49 50	44.0	-86	-74	-85	22
214	4.5	15	2	1	49 50	40.0	-88	-85	-86	22
214	4.5	15	2	1	49 50	42.0	-86	-80	-86	22
214	4.5	94	2	1	49 50	44.0	-93	-89	-93	22
214	4.5	94	2	1	49 50	44.0	-88	-86	-88	22
214	4.5	15	2	1	49 50	44.0	-87	-73	-86	22
214	4.5	94	2	1	49 50	46.0	-86	-78	-86	22
214	4.5	94	2	1	49 50	48.0	-80	-73	-80	22
214	4.5	94	2	1	49 50	48.0	-86	-72	-86	22
214	4.5	94	2	1	49 50	49.3	-78	-70	-77	22
214	4.5	94	2	1	49 50	51.0	-68	-64	-68	22
214	10.0	59	2	1	14 9	44.0	-88	-76	-88	22
214	15.0	61	2	1	21 22	44.0	-87	-86	-87	22
214	15.0	61	2	1	21 22	44.0	-87	-86	-87	22
214	20.0	60	2	1	21 22	44.0	-88	-74	-88	22
214	45.0	53	2	1	14 9	44.0	-87	-84	-87	22
225	4.5	16	2	1	49 50	44.0	-88	-76	-88	22
225	10.0	57	2	1	14 9	44.0	-88	-76	-88	22
225	15.0	55	2	1	21 22	44.0	-87	-87	-87	22
225	30.0	54	2	1	21 22	44.0	-88	-88	-88	22
225	42.5	56	2	1	14 9	44.0	-85	-77	-85	22
214	4.5	15	2	2	10 11	40.0	-88	-85	-86	22
214	4.5	15	2	2	10 11	42.0	-86	-80	-86	22
214	4.5	15	2	2	10 11	44.0	-86	-74	-85	22
214	4.5	15	2	2	10 11	44.0	-88	-75	-85	22
225	4.5	16	2	2	10 11	42.7	-88	-81	-81	22
225	4.5	75	2	2	73 74	44.0	-88	-86	-88	22
225	4.5	75	2	2	73 74	44.0	-88	-81	-83	22
225	4.5	16	2	2	10 11	44.0	-87	-75	-87	22
225	4.5	75	2	2	73 74	46.0	-86	-79	-82	22
225	4.5	75	2	2	73 74	46.0	-87	-79	-86	22
225	4.5	75	2	2	73 74	48.0	-80	-74	-79	22
225	4.5	75	2	2	73 74	49.3	-78	-72	-78	22

AD-A122 634

INVESTIGATION OF INTERMODULATION PRODUCTS GENERATED IN
COAXIAL CABLES AND CONNECTORS(U) GEORGIA INST OF TECH
ATLANTA J A WOODY ET AL. SEP 82 GIT-A-2845-F

2/2

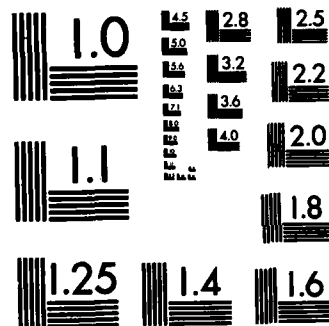
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RADC-TR-82-240 F30602-81-C-0059

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				10000									



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

CABLE			CONNECTOR			INPUT POWER (dBm)	INITIAL IN LEVEL (dBm)	MEAS. IN LEVEL (dBm)	FINAL IN LEVEL (dBm)	FREQ. (MHz)
TYPE	LENGTH (ft)	I.D.#	TYPE	PLTG.	I.D.#					
213	4.5	12	2	3	17 18	44.0	-88	-63	-88	22
214	4.5	15	2	3	17 18	36.0	-88	-81	-88	22
214	4.5	15	2	3	17 18	38.0	-87	-75	-87	22
214	4.5	15	2	3	17 18	40.0	-87	-72	-85	22
214	4.5	15	2	3	17 18	42.0	-87	-67	-87	22
214	4.5	15	2	3	17 18	42.7	-88	-68	-81	22
214	4.5	15	2	3	17 18	44.0	-85	-62	-84	22
214	4.5	70	2	3	68 69	44.0	-93	-77	-93	22
214	4.5	70	2	3	68 69	44.0	-88	-75	-88	22
214	4.5	15	2	3	17 18	44.0	-88	-77	-88	22
214	4.5	15	2	3	17 18	44.0	-87	-63	-87	22
214	4.5	15	2	3	17 18	44.0	-77	-62	-77	22
214	4.5	15	2	3	17 18	46.0	-86	-74	-86	22
214	4.5	70	2	3	68 69	46.0	-86	-76	-86	22
214	4.5	15	2	3	17 18	46.0	-87	-74	-75	22
214	4.5	15	2	3	17 18	46.0	-87	-74	-81	22
214	4.5	15	2	3	17 18	48.0	-80	-69	-78	22
214	4.5	70	2	3	68 69	48.0	-80	-70	-79	22
214	4.5	15	2	3	17 18	48.0	-80	-70	-80	22
214	4.5	70	2	3	68 69	49.3	-78	-68	-74	22
214	4.5	15	2	3	17 18	49.3	-78	-66	-76	22
214	4.5	15	2	3	17 18	49.3	-78	-67	-78	22
214	4.5	70	2	3	68 69	49.3	-77	-69	-70	22
214	4.5	15	2	3	17 18	51.0	-68	-59	-68	22
225	4.5	16	2	3	17 18	44.0	-86	-63	-85	22
9	4.5	30	3	1	29 28	44.0	-88	-75	-88	22
9	5.0	38	4	0	0 0	44.0	-83	-78	-84	22
55	5.0	35	4	0	0 0	44.0	-85	-74	-82	22
55	5.0	43	4	0	0 0	44.0	-85	-75	-84	22
55	10.0	40	4	0	0 0	44.0	-87	-75	-87	22
55	15.0	41	4	0	0 0	44.0	-88	-87	-88	22
55	25.0	44	4	0	0 0	44.0	-87	-76	-86	22
55	30.0	39	4	0	0 0	44.0	-88	-86	-88	22
55	60.0	37	4	0	0 0	44.0	-88	-88	-88	22
550	5.0	46	4	0	0 0	44.0	-84	-75	-83	22
580	5.0	47	4	0	0 0	44.0	-86	-77	-84	22
213	5.0	48	4	0	0 0	44.0	-85	-77	-85	22
223	5.0	45	4	0	0 0	44.0	-85	-73	-82	22
55	4.5	4	1	1	33 34	42.5	-110	-92	-116	200
580	4.5	32	1	1	33 34	43.6	-118	-82	-110	200
580	4.5	32	1	1	33 34	43.6	-119	-81	-105	200
223	4.5	23	1	1	33 34	42.6	-115	-89	-105	200
55	4.5	4	1	2	5 6	43.6	-115	-86	-110	200
55	4.5	4	1	2	5 6	43.6	-115	-87	-115	200
9	4.5	8	2	1	49 50	31.4	-122	-118	-122	200
9	4.5	8	2	1	49 50	33.3	-122	-109	-122	200
9	4.5	8	2	1	49 50	36.2	-120	-105	-120	200
9	4.5	8	2	1	49 50	38.3	-120	-99	-120	200
9	4.5	8	2	1	49 50	41.4	-115	-96	-110	200
9	4.5	8	2	1	49 50	42.5	-120	-93	-103	200

CABLE			CONNECTOR			INPUT POWER (dBm)	INITIAL IN LEVEL (dBm)	MEAS. IN LEVEL (dBm)	FINAL IN LEVEL (dBm)	FREQ. (MHz)
TYPE	LENGTH (ft)	I.D.#	TYPE	PLTG.	I.D.#					
9	4.5	8	2	1	49 50	43.7	-115	-86	-112	200
213	4.5	12	2	1	21 22	42.5	-110	-87	-110	200
214	4.5	15	2	1	14 9	31.4	-122	-118	-122	200
214	4.5	15	2	1	14 9	33.3	-122	-114	-122	200
214	4.5	15	2	1	14 9	36.2	-122	-105	-119	200
214	4.5	15	2	1	14 9	38.3	-122	-99	-118	200
214	4.5	15	2	1	14 9	41.4	-122	-91	-110	200
214	4.5	15	2	1	14 9	43.8	-115	-86	-104	200
214	10.0	59	2	1	21 22	42.2	-112	-88	-112	200
214	15.0	61	2	1	21 22	42.3	-115	-84	-110	200
214	20.0	60	2	1	14 9	42.2	-115	-88	-112	200
214	45.0	53	2	1	14 9	42.2	-115	-91	-105	200
225	4.5	16	2	1	21 22	42.5	-122	-85	-105	200
225	10.0	57	2	1	14 9	42.4	-110	-94	-105	200
225	10.0	57	2	1	14 9	42.4	-110	-94	-105	200
225	15.0	55	2	1	49 50	43.4	-115	-83	-110	200
225	30.0	54	2	1	14 9	43.4	-110	-88	-110	200
225	42.5	56	2	1	21 22	42.2	-110	-91	-105	200
214	4.5	15	2	2	10 11	42.5	-120	-96	-110	200
214	4.5	15	2	2	10 11	42.5	-115	-96	-100	200
225	4.5	16	2	2	10 11	42.2	-115	-86	-115	200
225	4.5	16	2	2	10 11	42.2	-115	-86	-115	200
214	4.5	15	2	3	17 18	31.4	-122	-103	-122	200
214	4.5	15	2	3	17 18	33.3	-122	-98	-122	200
214	4.5	15	2	3	17 18	36.2	-122	-94	-120	200
214	4.5	15	2	3	17 18	38.3	-120	-90	-120	200
214	4.5	15	2	3	17 18	41.4	-122	-86	-120	200
214	4.5	15	2	3	17 18	43.4	-115	-80	-102	200
214	4.5	15	2	3	17 18	43.8	-115	-80	-110	200
225	4.5	16	2	3	19 20	43.4	-115	-90	-110	200
9	4.5	30	3	1	28 29	43.8	-115	-85	-100	200
9	5.0	38	4	0	0 0	42.4	-110	-93	-105	200
55	5.0	35	4	0	0 0	43.4	-115	-92	-110	200
55	10.0	40	4	0	0 0	42.7	-115	-88	-108	200
55	15.0	41	4	0	0 0	43.0	-115	-84	-110	200
55	25.0	44	4	0	0 0	42.8	-115	-84	-108	200
55	30.0	39	4	0	0 0	42.8	-115	-86	-105	200
55	50.0	43	4	0	0 0	42.4	-115	-90	-100	200
55	60.0	37	4	0	0 0	43.0	-115	-94	-110	200
580	5.0	47	4	0	0 0	42.5	-115	-82	-100	200
213	5.0	48	4	0	0 0	42.4	-110	-92	-105	200
213	5.0	48	4	0	0 0	42.4	-110	-92	-100	200
55	4.5	1	1	1	33 34	42.3	-118	-102	-110	275
55	4.5	4	1	1	33 34	43.0	-120	-110	-120	275
55	4.5	4	1	1	33 34	43.0	-120	-110	-120	275
55	4.5	4	1	1	33 34	43.0	-120	-110	-120	275
550	4.5	31	1	1	33 34	43.0	-120	-97	-115	275
580	4.5	32	1	1	33 34	43.0	-115	-100	-113	275
223	4.5	23	1	1	33 34	43.0	-120	-103	-115	275
55	4.5	4	1	2	5 6	43.0	-115	-100	-115	275

CABLE			CONNECTOR			INPUT POWER (dBm)	INITIAL IM LEVEL (dBm)	MEAS. IM LEVEL (dBm)	FINAL IM LEVEL (dBm)	FREQ. (MHz)
TYPE	LENGTH (ft)	I.D.#	TYPE	PLT6.	I.D.#					
9	4.5	8	2	1	49 50	33.2	-125	-120	-122	275
9	4.5	8	2	1	49 50	37.4	-125	-111	-125	275
9	4.5	8	2	1	49 50	40.3	-120	-107	-120	275
9	4.5	8	2	1	49 50	42.5	-119	-102	-116	275
9	4.5	8	2	1	49 50	42.5	-116	-100	-115	275
9	4.5	8	2	1	49 50	43.0	-118	-102	-118	275
213	4.5	12	2	1	21 22	43.0	-118	-98	-115	275
214	4.5	15	2	1	14 9	42.5	-117	-103	-115	275
214	4.5	15	2	1	14 9	42.5	-115	-103	-115	275
225	4.5	16	2	1	21 22	42.5	-115	-100	-115	275
225	4.5	16	2	2	10 11	42.2	-118	-100	-110	275
214	4.5	15	2	3	17 18	42.5	-115	-85	-115	275
214	4.5	15	2	3	17 18	42.5	-115	-86	-115	275
9	4.5	30	3	1	28 29	42.5	-115	-102	-115	275
9	5.0	38	4	0	0 0	42.4	-115	-96	-115	275
55	5.0	35	4	0	0 0	42.5	-118	-103	-115	275
580	5.0	47	4	0	0 0	43.0	-120	-94	-115	275
213	5.0	48	4	0	0 0	42.3	-118	-95	-118	275
55	4.5	1	1	1	3 2	44.3	-118	-87	-114	350
55	4.5	1	1	1	3 2	44.3	-117	-86	-112	350
550	4.5	31	1	1	33 34	44.2	-113	-94	-108	350
580	4.5	32	1	1	33 34	44.2	-113	-91	-113	350
223	4.5	23	1	1	3 2	44.3	-120	-85	-109	350
223	4.5	23	1	1	3 2	44.5	-120	-85	-114	350
55	4.5	4	1	2	5 6	44.3	-120	-88	-114	350
55	4.5	4	1	2	5 6	44.3	-118	-88	-114	350
9	4.5	15	2	1	14 9	36.3	-123	-116	-123	350
9	4.5	15	2	1	14 9	36.3	-123	-116	-122	350
9	4.5	15	2	1	14 9	39.1	-123	-105	-117	350
9	4.5	15	2	1	14 9	39.1	-123	-107	-117	350
9	4.5	15	2	1	14 9	39.1	-123	-104	-113	350
9	4.5	8	2	1	7 9	40.2	-121	-107	-114	350
9	4.5	8	2	1	7 9	41.2	-114	-104	-108	350
9	4.5	63	2	1	64 65	43.8	-90	-76	-95	350
9	4.5	8	2	1	14 9	44.0	-120	-96	-118	350
9	4.5	8	2	1	7 9	44.1	-106	-96	-106	350
9	4.5	8	2	1	7 9	44.2	-120	-97	-106	350
9	4.5	15	2	1	14 9	44.3	-113	-97	-113	350
9	4.5	63	2	1	64 65	47.0	-90	-65	-74	350
9	4.5	63	2	1	64 65	50.0	-75	-58	-70	350
9	4.5	63	2	1	64 65	50.0	-70	-51	-60	350
9	4.5	63	2	1	64 65	50.6	-75	-54	-75	350
213	4.5	12	2	1	49 50	44.0	-120	-95	-108	350
213	4.5	12	2	1	49 50	44.0	-120	-97	-120	350
214	4.5	15	2	1	14 13	44.1	-112	-97	-106	350
214	4.5	15	2	1	14 13	44.3	-124	-98	-114	350
214	10.0	59	2	1	49 50	44.3	-118	-97	-113	350
214	15.0	61	2	1	49 50	44.4	-115	-96	-113	350
214	15.0	61	2	1	49 50	44.4	-115	-96	-104	350
214	20.0	60	2	1	14 9	44.3	-118	-95	-115	350

CABLE			CONNECTOR			INPUT POWER (dBm)	INITIAL IM LEVEL (dBm)	MEAS. IM LEVEL (dBm)	FINAL IM LEVEL (dBm)	FREQ. (MHz)
TYPE	LENGTH (ft)	I.D.#	TYPE	PLTG.	I.D.#					
214	20.0	60	2	1	14 9	44.3	-118	-95	-118	350
214	45.0	53	2	1	14 9	44.4	-120	-96	-106	350
214	45.0	53	2	1	14 9	44.4	-113	-97	-107	350
214	60.0	51	2	1	49 50	44.1	-120	-98	-108	350
214	60.0	51	2	1	49 50	44.1	-120	-98	-110	350
225	4.5	16	2	1	14 13	44.3	-120	-90	-114	350
225	4.5	16	2	1	14 13	44.3	-120	-90	-124	350
225	10.0	57	2	1	49 50	44.3	-120	-100	-115	350
225	15.0	55	2	1	49 50	44.3	-118	-93	-106	350
225	15.0	55	2	1	49 50	44.4	-113	-95	-113	350
225	30.0	54	2	1	14 9	44.4	-113	-94	-113	350
225	42.5	56	2	1	14 9	44.3	-120	-99	-110	350
225	60.0	52	2	1	14 9	44.2	-120	-102	-109	350
225	60.0	52	2	1	14 9	44.2	-124	-103	-123	350
213	4.5	12	2	2	10 11	44.3	-120	-94	-106	350
213	4.5	12	2	2	10 11	44.3	-120	-94	-114	350
213	4.5	12	2	2	10 11	44.3	-120	-96	-99	350
214	4.5	15	2	2	10 11	44.3	-121	-91	-120	350
214	4.5	15	2	2	10 11	44.3	-120	-92	-120	350
214	4.5	15	2	2	10 11	44.5	-120	-93	-104	350
225	4.5	16	2	2	10 11	44.1	-114	-89	-104	350
225	4.5	16	2	2	10 11	44.2	-106	-88	-106	350
225	4.5	16	2	2	10 11	44.2	-116	-90	-100	350
9	4.5	8	2	3	19 20	44.0	-119	-84	-114	350
214	4.5	15	2	3	17 18	39.1	-123	-90	-123	350
214	4.5	15	2	3	17 18	39.1	-123	-90	-123	350
214	4.5	70	2	3	68 69	43.8	-90	-62	-80	350
214	4.5	15	2	3	17 18	44.0	-120	-81	-113	350
214	4.5	15	2	3	19 20	44.2	-120	-82	-120	350
214	4.5	15	2	3	19 20	44.3	-120	-82	-104	350
214	4.5	15	2	3	19 20	44.3	-120	-82	-115	350
214	4.5	70	2	3	68 69	47.0	-80	-54	-80	350
214	4.5	70	2	3	68 69	50.0	-70	-47	-58	350
214	4.5	70	2	3	68 69	50.6	-75	-51	-60	350
9	4.5	30	3	1	28 29	44.2	-113	-99	-106	350
9	4.5	30	3	1	28 29	44.2	-113	-100	-108	350
9	5.0	38	4	0	0 0	39.3	-126	-103	-126	350
9	5.0	38	4	0	0 0	44.3	-115	-90	-113	350
9	5.0	38	4	0	0 0	44.3	-115	-91	-113	350
55	5.0	35	4	0	0 0	44.3	-127	-92	-117	350
55	5.0	35	4	0	0 0	44.3	-125	-92	-118	350
55	5.0	35	4	0	0 0	44.3	-125	-92	-105	350
55	10.0	40	4	0	0 0	44.1	-126	-97	-125	350
55	10.0	40	4	0	0 0	44.1	-126	-101	-120	350
55	10.0	40	4	0	0 0	44.2	-120	-101	-107	350
55	15.0	41	4	0	0 0	44.1	-120	-92	-118	350
55	15.0	41	4	0	0 0	44.1	-120	-91	-102	350
55	15.0	41	4	0	0 0	44.1	-120	-92	-115	350
55	15.0	41	4	0	0 0	44.1	-120	-100	-120	350
55	15.0	41	4	0	0 0	44.1	-120	-102	-120	350

CABLE			CONNECTOR				INPUT POWER (dBm)	INITIAL IN LEVEL (dBm)	MEAS. IN LEVEL (dBm)	FINAL IN LEVEL (dBm)	FREQ. (MHz)
TYPE	LENGTH (ft)	I.D.#	TYPE	PLTG.	I.D.#						
55	25.0	44	4	0	0 0		44.1	-124	-113	-121	350
55	25.0	44	4	0	0 0		44.1	-124	-115	-121	350
55	30.0	39	4	0	0 0		43.9	-126	-109	-120	350
55	30.0	39	4	0	0 0		44.1	-12	-105	-120	350
55	30.0	39	4	0	0 0		44.1	-126	-107	-117	350
55	50.0	43	4	0	0 0		44.1	-124	-111	-121	350
55	50.0	43	4	0	0 0		44.1	-124	-114	-121	350
55	50.0	43	4	0	0 0		44.2	-124	-113	-121	350
55	60.0	37	4	0	0 0		44.1	-124	-101	-124	350
55	60.0	37	4	0	0 0		44.3	-115	-103	-115	350
55	60.0	37	4	0	0 0		44.3	-115	-103	-115	350
55	75.5	42	4	0	0 0		44.2	-124	-117	-120	350
55	75.5	42	4	0	0 0		44.2	-124	-115	-120	350
55	91.7	36	4	0	0 0		44.3	-126	-126	-113	350
55	91.7	36	4	0	0 0		44.3	-126	-120	-120	350
550	5.0	46	4	0	0 0		44.2	-120	-92	-113	350
550	5.0	46	4	0	0 0		44.2	-120	-92	-114	350
580	5.0	47	4	0	0 0		44.3	-120	-94	-112	350
580	5.0	47	4	0	0 0		44.3	-120	-94	-108	350
213	5.0	48	4	0	0 0		44.0	-120	-92	-110	350
223	5.0	45	4	0	0 0		44.1	-118	-92	-118	350
223	5.0	45	4	0	0 0		44.1	-120	-92	-117	350
550	4.5	31	1	1	3 2		36.3	-126	-107	-111	425
550	4.5	31	1	1	3 2		36.3	-126	-107	-126	425
580	4.5	32	1	1	3 2		36.3	-126	-114	-122	425
223	4.5	23	1	1	3 2		36.3	-126	-116	-122	425
223	4.5	23	1	1	3 2		36.3	-126	-114	-126	425
55	4.5	4	1	2	5 6		31.5	-126	-119	-126	425
55	4.5	4	1	2	5 6		31.5	-126	-116	-126	425
55	4.5	1	1	2	24 25		31.5	-126	-119	-126	425
55	4.5	4	1	2	5 6		36.3	-126	-111	-122	425
55	4.5	4	1	2	5 6		36.3	-126	-113	-121	425
55	4.5	4	1	2	5 6		36.3	-126	-111	-126	425
55	4.5	4	1	2	5 6		36.3	-126	-111	-121	425
223	4.5	23	1	2	24 25		31.5	-126	-115	-126	425
223	4.5	23	1	2	24 25		36.3	-126	-107	-126	425
223	4.5	23	1	2	24 25		36.3	-126	-108	-125	425
214	4.5	15	2	1	14 9		31.5	-126	-124	-126	425
214	4.5	15	2	1	14 9		36.3	-126	-112	-120	425
214	10.0	59	2	1	49 50		43.1	-118	-98	-114	425
214	10.0	59	2	1	49 50		43.3	-119	-97	-114	425
214	15.0	61	2	1	49 50		43.4	-113	-97	-107	425
214	20.0	60	2	1	14 9		43.3	-113	-102	-111	425
214	20.0	60	2	1	14 9		43.5	-113	-102	-109	425
214	45.0	53	2	1	49 50		36.2	-124	-114	-124	425
214	45.0	53	2	1	49 50		43.1	-118	-102	-113	425
214	45.0	53	2	1	49 50		43.1	-118	-106	-113	425
214	45.0	53	2	1	49 50		43.1	-119	-105	-111	425
214	60.0	51	2	1	49 50		43.1	-124	-102	-113	425
214	60.0	51	2	1	49 50		43.1	-115	-104	-115	425

CABLE			CONNECTOR				INPUT POWER (dBm)	INITIAL IN LEVEL (dBm)	MEAS. IN LEVEL (dBm)	FINAL IN LEVEL (dBm)	FREQ. (MHz)
TYPE	LENGTH (ft)	I.D.#	TYPE	PLTG.	I.D.#						
225	4.5	16	2	1	7 13		31.5	-126	-124	-126	425
225	4.5	16	2	1	7 13		36.3	-126	-115	-122	425
225	4.5	16	2	1	7 13		36.3	-126	-118	-119	425
225	10.0	57	2	1	49 50		43.1	-113	-99	-113	425
225	15.0	55	2	1	49 9		43.3	-115	-99	-113	425
225	15.0	55	2	1	49 9		43.3	-113	-98	-113	425
225	30.0	54	2	1	14 50		43.3	-115	-102	-115	425
225	30.0	54	2	1	14 50		43.3	-113	-102	-111	425
225	42.5	56	2	1	14 9		43.1	-113	-99	-113	425
225	60.0	52	2	1	14 9		43.1	-115	-98	-115	425
225	60.0	52	2	1	14 9		43.1	-124	-98	-124	425
213	4.5	12	2	2	10 11		31.5	-126	-118	-126	425
213	4.5	12	2	2	10 11		36.3	-126	-106	-122	425
225	4.5	16	2	2	10 11		36.3	-126	-113	-121	425
225	4.5	16	2	2	10 11		36.3	-126	-114	-126	425
9	4.5	8	2	3	19 20		28.9	-126	-118	-126	425
9	4.5	8	2	3	19 20		31.5	-126	-111	-126	425
9	4.5	8	2	3	19 20		31.5	-126	-110	-126	425
9	4.5	8	2	3	19 20		36.3	-126	-99	-126	425
214	4.5	15	2	3	19 20		26.0	-126	-119	-126	425
214	4.5	15	2	3	19 20		28.3	-124	-114	-124	425
214	4.5	15	2	3	17 18		28.9	-126	-112	-121	425
214	4.5	15	2	3	17 18		28.9	-126	-114	-126	425
214	4.5	15	2	3	19 20		32.3	-124	-105	-124	425
214	4.5	15	2	3	19 20		34.3	-124	-102	-124	425
214	4.5	15	2	3	19 20		34.3	-114	-102	-114	425
214	4.5	15	2	3	19 20		37.1	-114	-93	-114	425
214	4.5	15	2	3	19 20		37.1	-114	-95	-82	425
214	4.5	15	2	3	19 20		37.3	-120	-95	-124	425
214	4.5	15	2	3	19 20		39.1	-114	-92	-114	425
214	4.5	15	2	3	19 20		39.2	-120	-91	-120	425
214	4.5	15	2	3	19 20		41.1	-114	-87	-102	425
214	4.5	15	2	3	17 18		43.9	-114	-81	-106	425
214	4.5	15	2	3	19 20		44.0	-110	-80	-110	425
214	4.5	15	2	3	19 20		44.1	-104	-80	-96	425
214	4.5	15	2	3	19 20		44.2	-114	-82	-94	425
214	4.5	15	2	3	19 20		44.2	-99	-81	-102	425
214	4.5	15	2	3	19 20		44.2	-110	-80	-92	425
225	4.5	16	2	3	17 18		36.3	-124	-100	-119	425
225	4.5	16	2	3	17 18		36.3	-126	-99	-115	425
9	4.5	30	3	1	28 29		31.5	-126	-122	-126	425
9	4.5	30	3	1	28 29		36.3	-126	-113	-126	425
9	4.5	30	3	1	28 29		36.3	-126	-113	-126	425
55	5.0	35	4	0	0 0		43.4	-104	-96	-104	425
55	5.0	35	4	0	0 0		43.4	-113	-99	-112	425
55	5.0	35	4	0	0 0		43.4	-113	-97	-104	425
550	5.0	46	4	0	0 0		43.5	-118	-94	-110	425
223	5.0	45	4	0	0 0		43.1	-113	-91	-113	425

APPENDIX F
MEASURED HARMONIC DATA

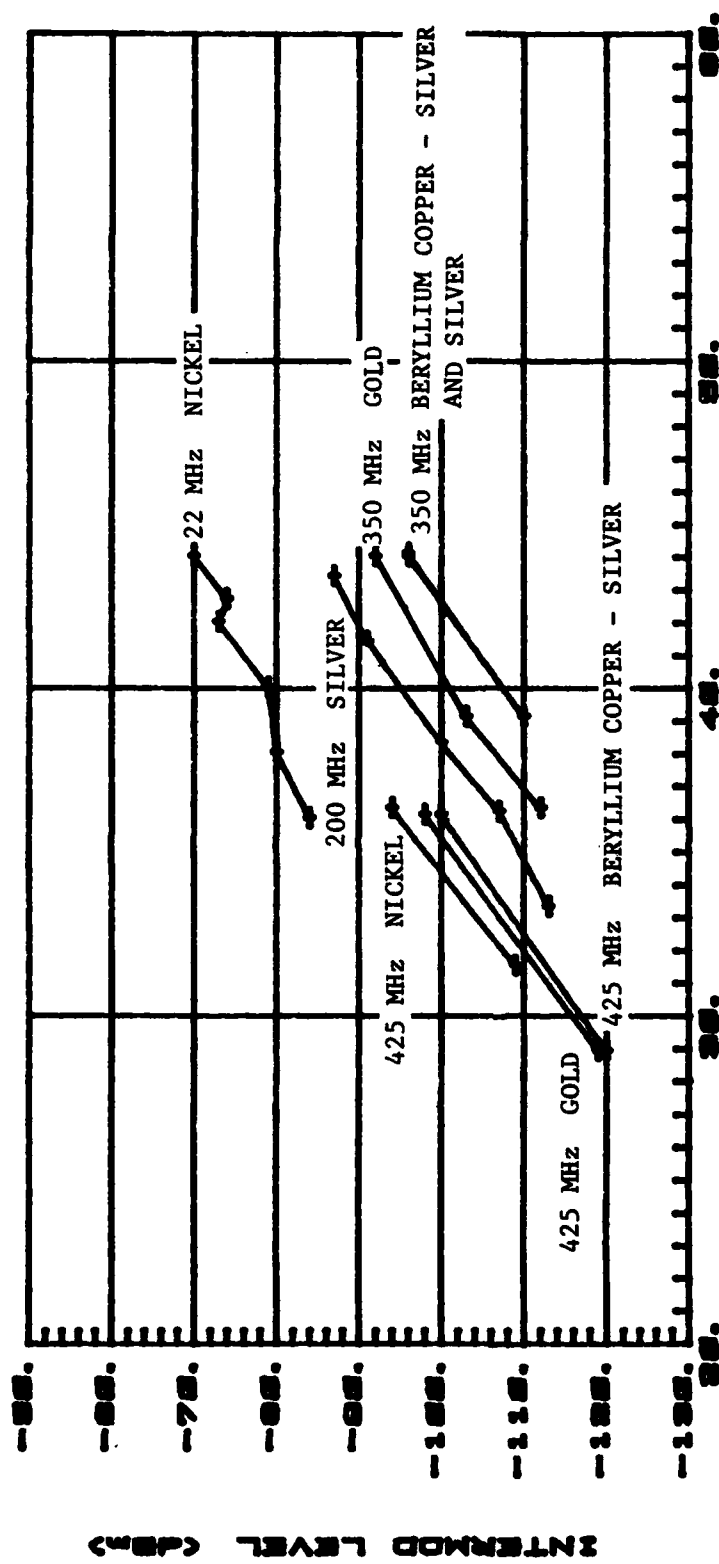
The harmonic data measured for coaxial cables and connectors are listed in this appendix. This data has been grouped in the same format, the same parameters are given, and the same notations are used as for the measured IM data (see Appendix E). The only difference is that the harmonic data was measured at a single frequency of 675 MHz, which is the third harmonic of a fundamental frequency at 225 MHz.

CABLE			CONNECTOR				INPUT POWER (dBm)	INITIAL IN LEVEL (dBm)	MEAS. IN LEVEL (dBm)	FINAL IN LEVEL (dBm)	FREQ. (MHz)
TYPE	LENGTH (ft)	I.D.#	TYPE	PLTG.	I.D.#						
0	0.0	0	1	1	3 2	36.8	-115	-115	-115	675	
0	0.0	0	1	2	24 25	36.8	-115	-115	-115	675	
0	0.0	0	2	1	13 7	36.8	-115	-100	-110	675	
0	0.0	0	2	2	10 11	36.8	-115	-108	-115	675	
0	0.0	0	2	3	19 20	36.8	-115	-105	-110	675	
0	0.0	0	2	4	0 62	36.8	-115	-115	-115	675	
0	0.0	0	2	4	0 62	36.8	-115	-115	-115	675	
55	4.5	1	1	1	33 34	36.8	-115	-115	-115	675	
9	4.5	8	2	1	49 50	36.8	-120	-108	-115	675	
9	4.5	8	2	1	49 50	40.8	-115	-99	-115	675	
225	4.5	16	2	2	10 11	36.8	-120	-114	-120	675	
225	4.5	16	2	2	10 11	40.8	-115	-108	-113	675	
214	4.5	16	2	3	17 18	36.8	-115	-104	-115	675	
214	4.5	16	2	3	17 18	36.8	-120	-102	-115	675	
214	4.5	15	2	3	17 18	40.8	-115	-97	-110	675	

APPENDIX G

The plots of IM level versus input power level are given in this appendix. The first three plots are for connector test samples with various platings measured at various IM test frequencies. The remaining six plots are for cable-connector combination test samples with various cable types measured at various IM test frequencies.

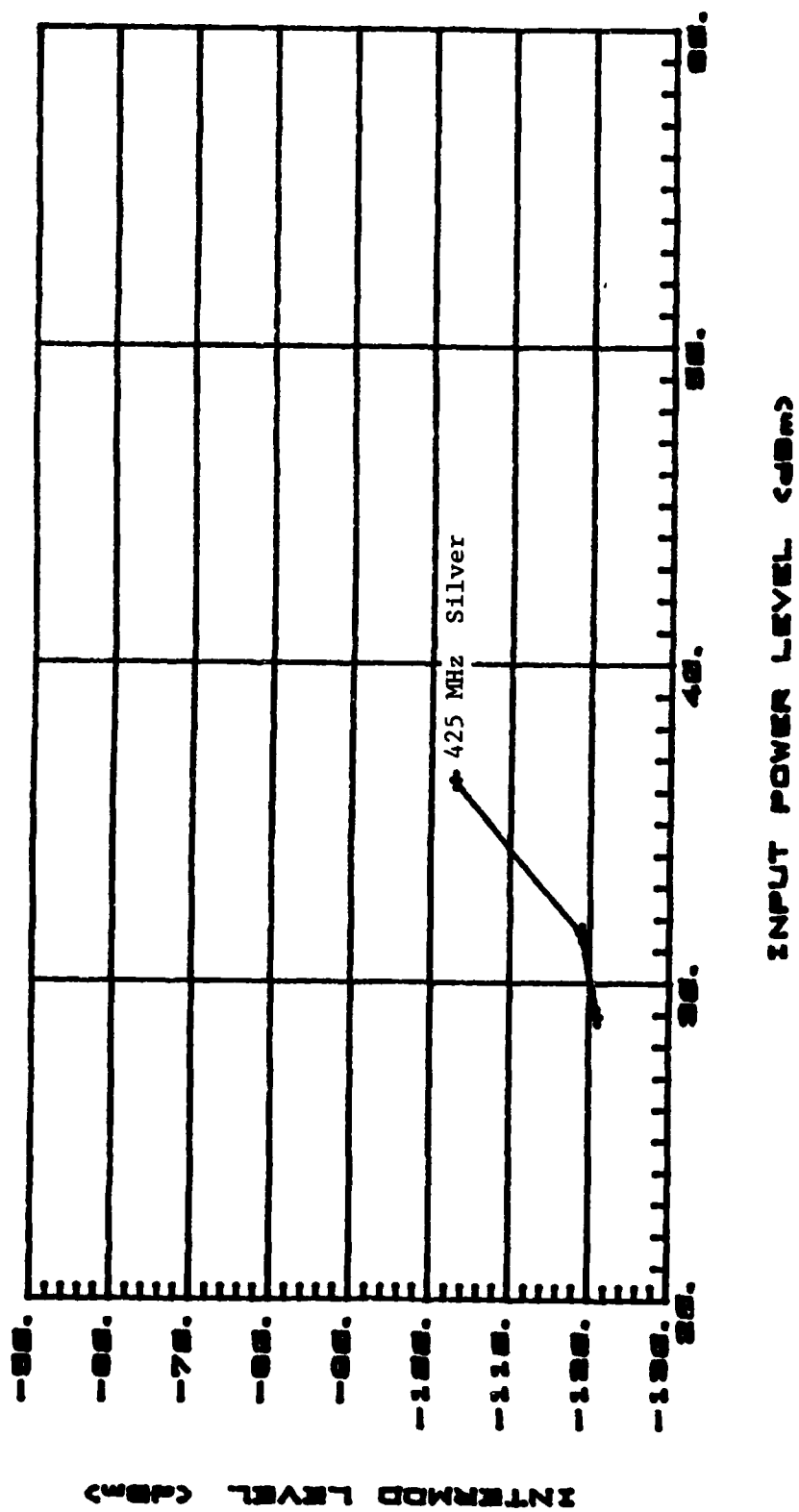
CABLE TYPE - NONE CONNECTOR TYPE - N



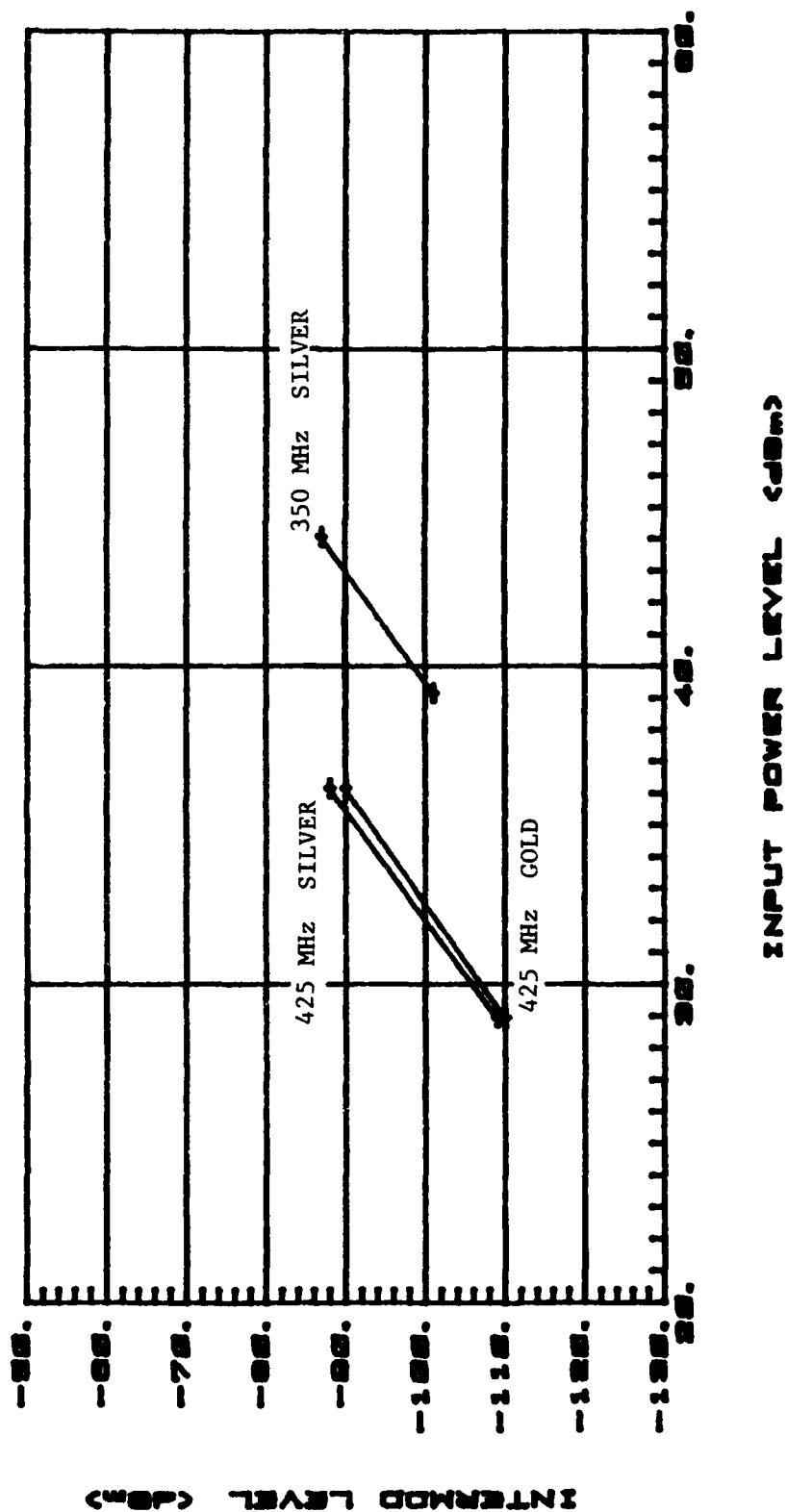
INPUT POWER LEVEL (dBm)

INTERNAL LEVEL (dBm)

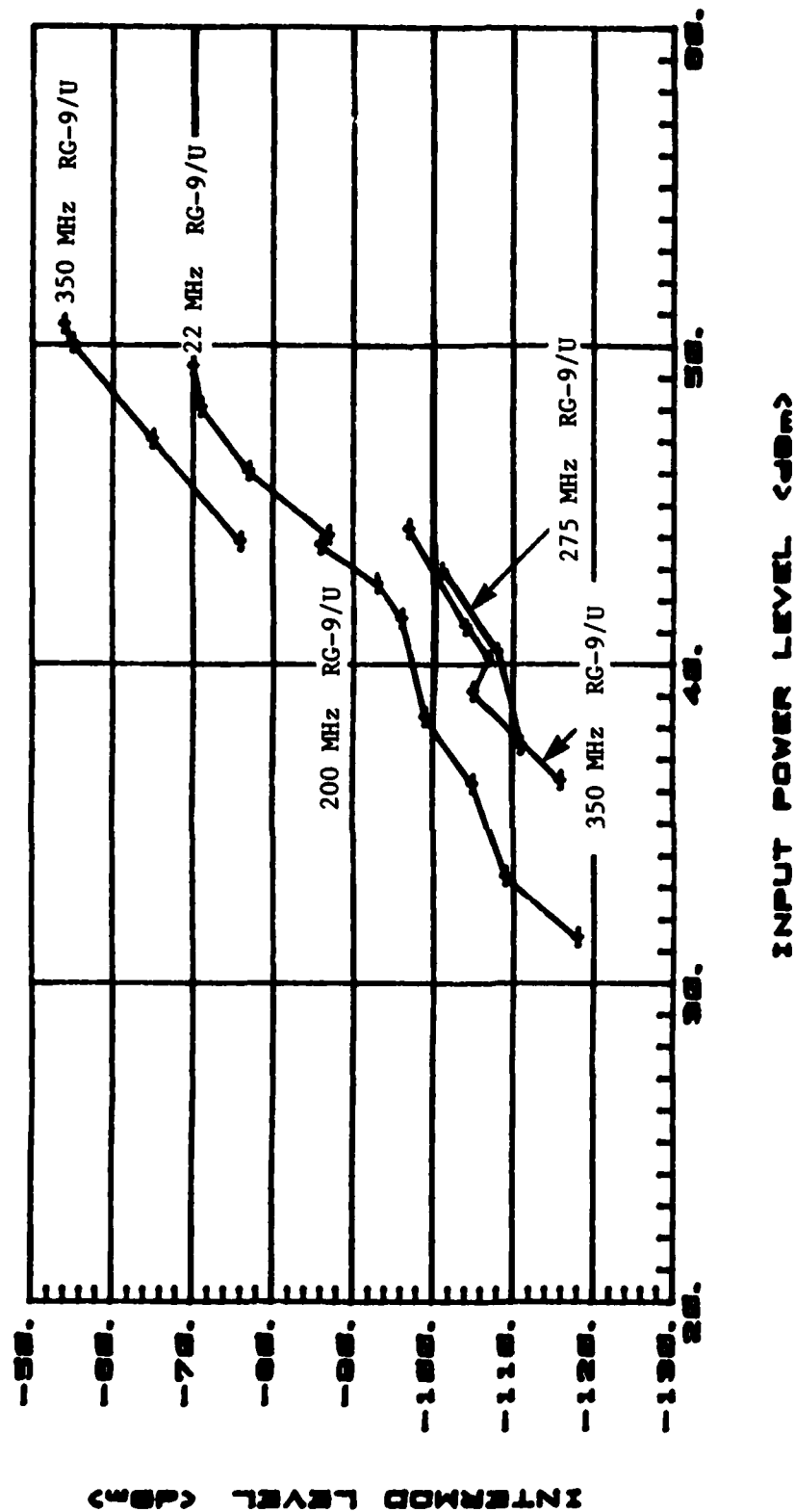
CABLE TYPE - NONE CONNECTOR TYPE - HN



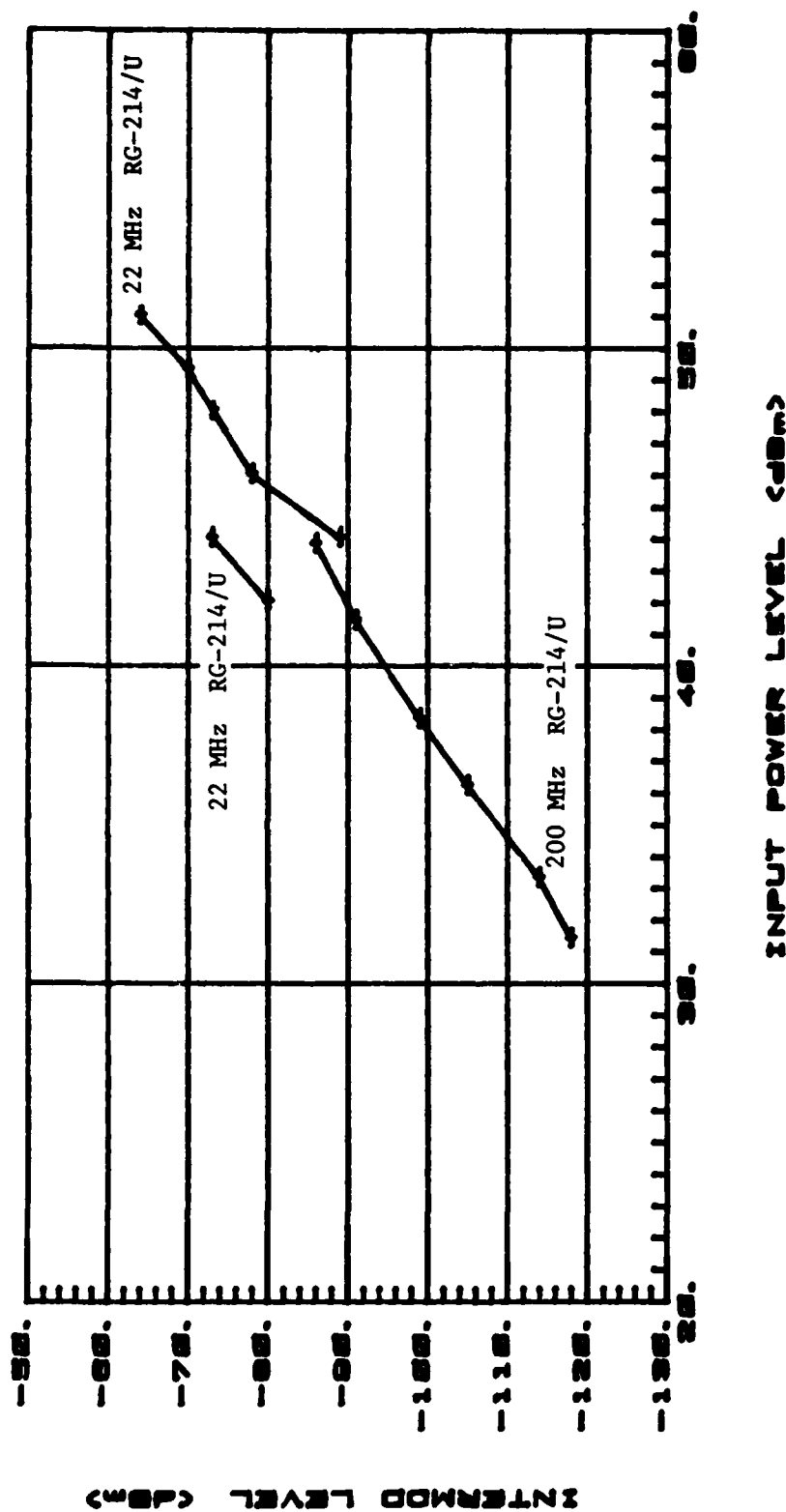
CABLE TYPE - NONE CONNECTOR TYPE - TNC



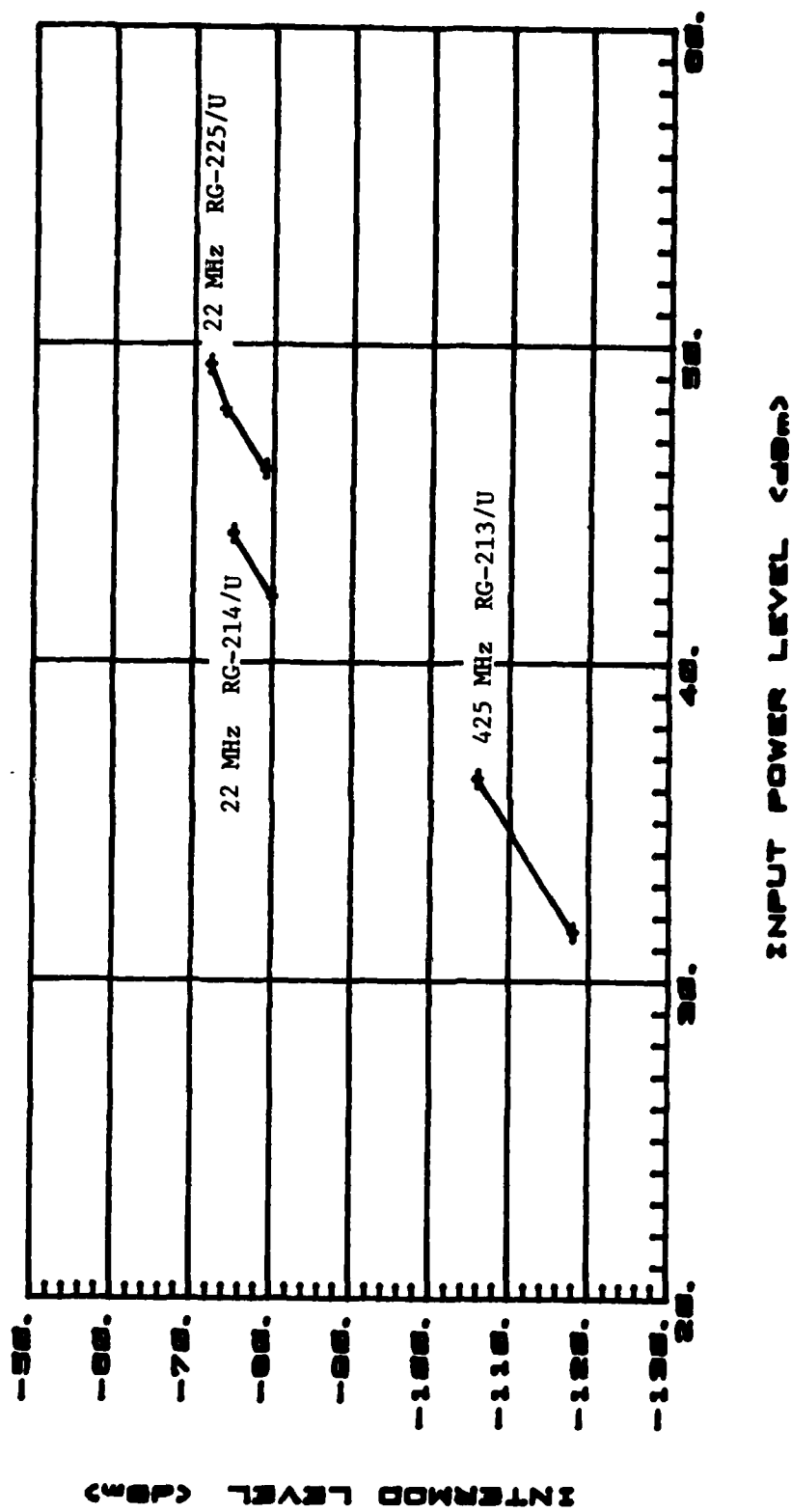
CONNECTOR TYPE - N
CONNECTOR PLATING - SILVER



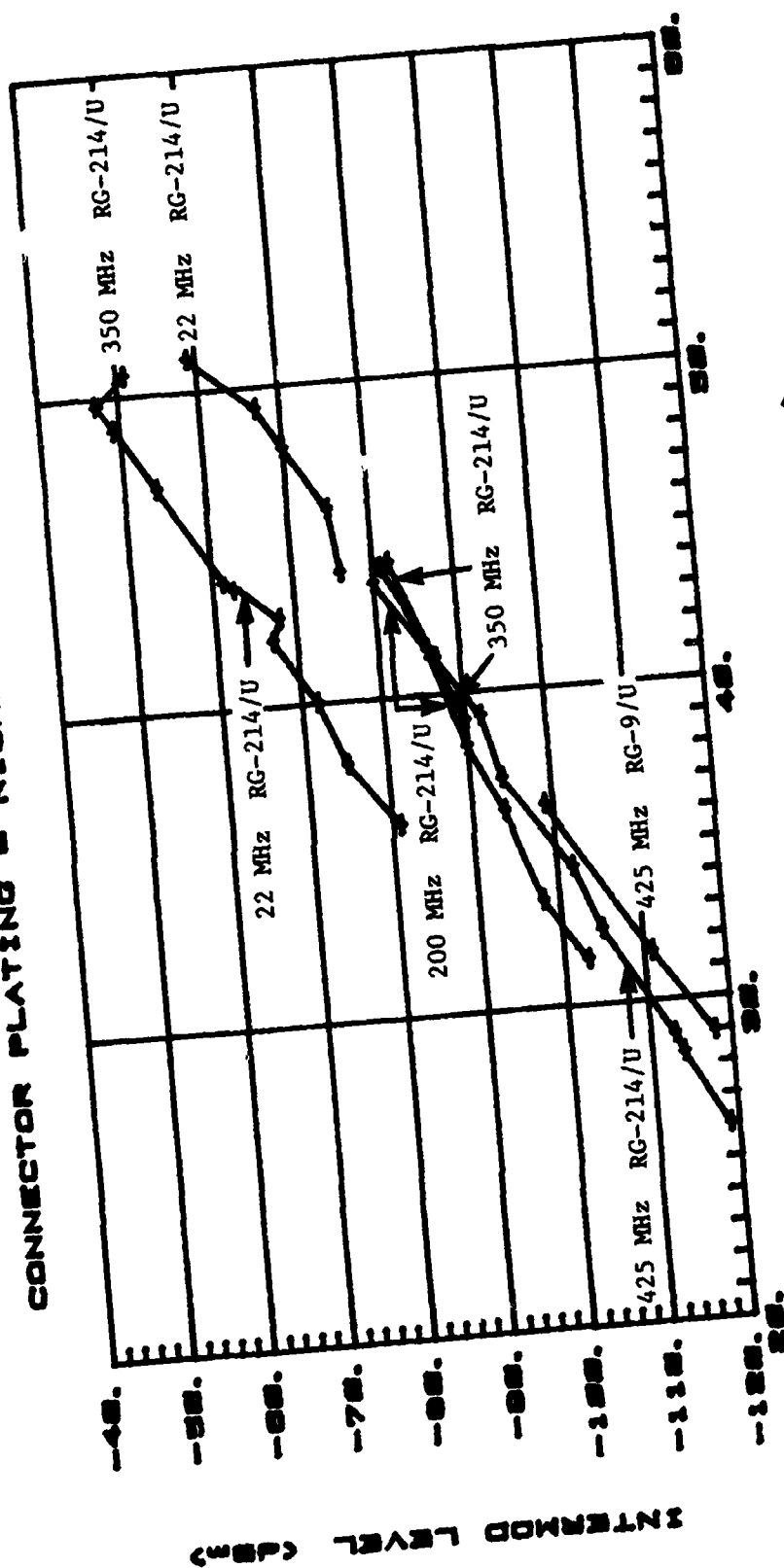
CONNECTOR TYPE - N
CONNECTOR PLATING - SILVER



CONNECTOR TYPE - N
CONNECTOR PLATING - GOLD

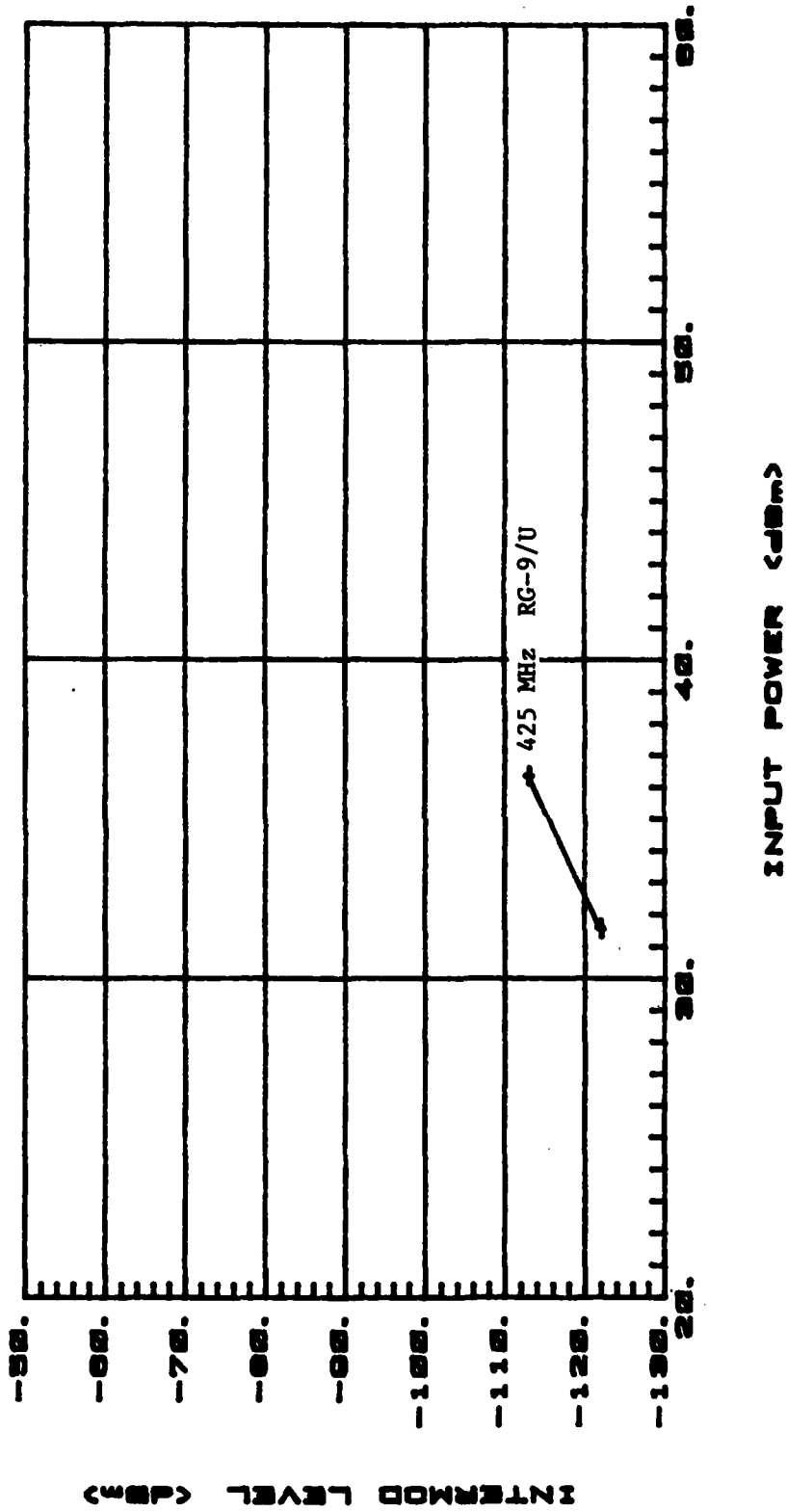


CONNECTOR TYPE - N
CONNECTOR PLATING - NICKEL

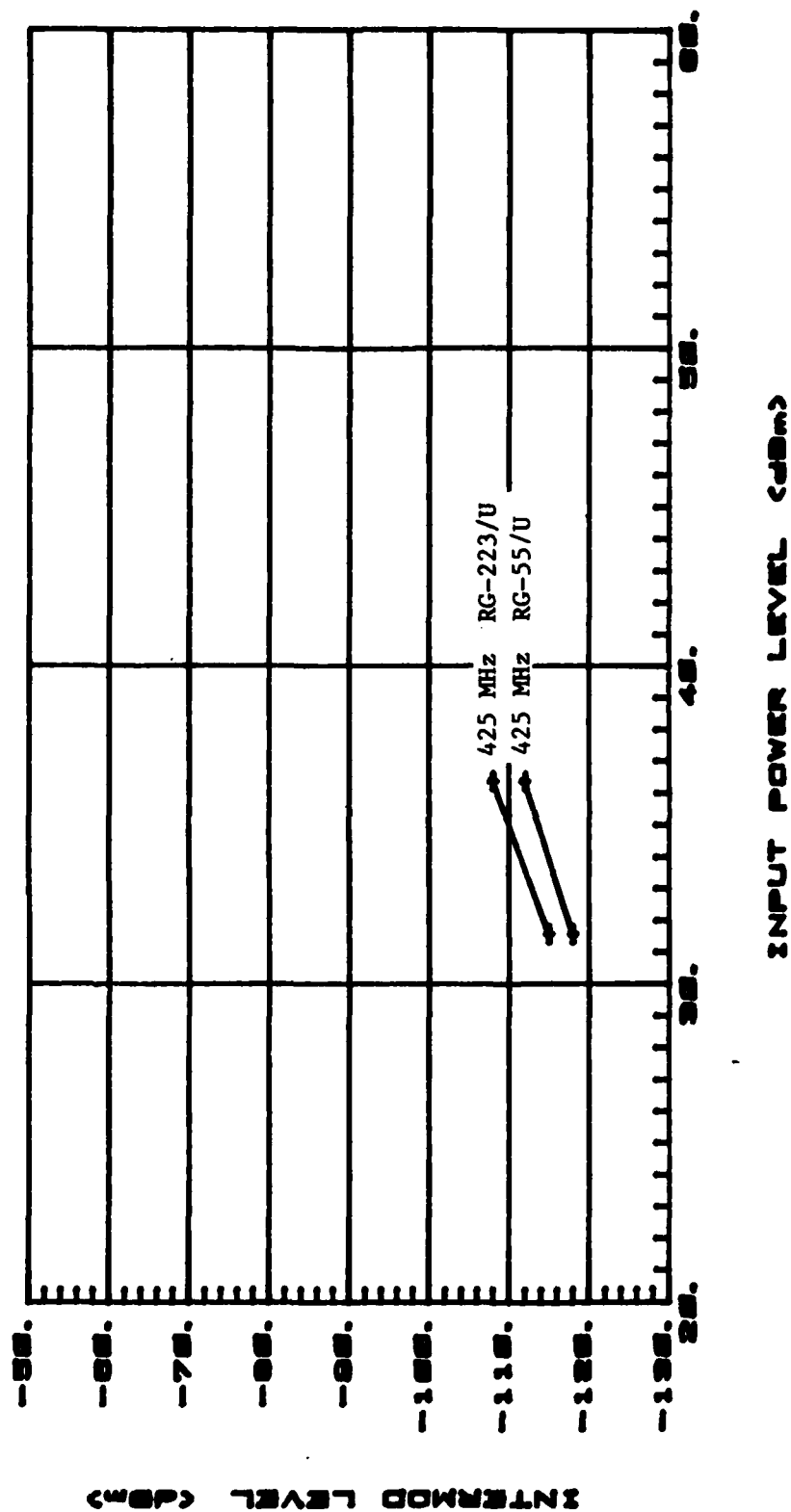


INPUT POWER LEVEL (dBm)

CONNECTOR TYPE - HN
CONNECTOR PLATING - SILVER



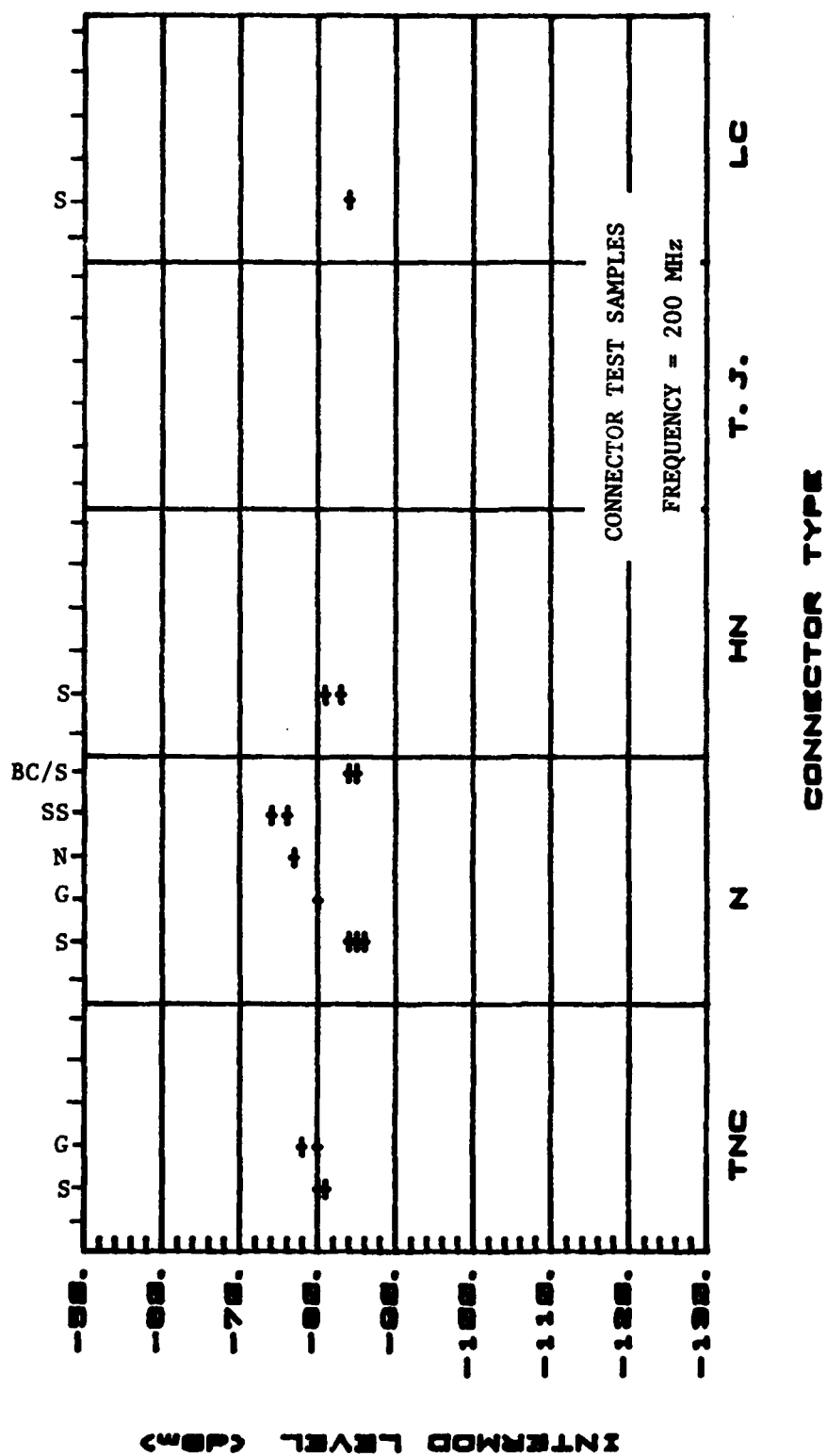
CONNECTOR TYPE - TNC
CONNECTOR PLATING - GOLD

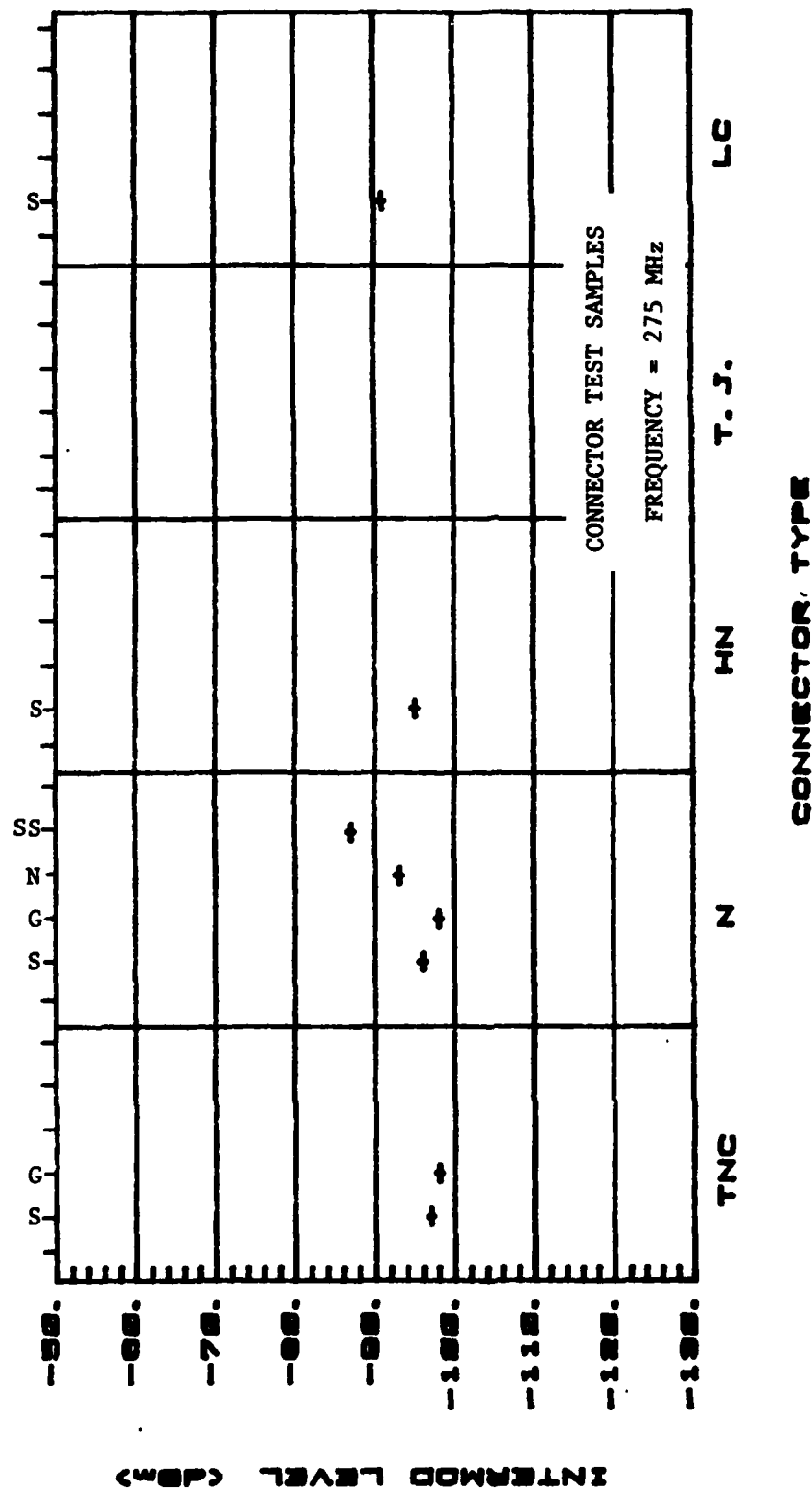


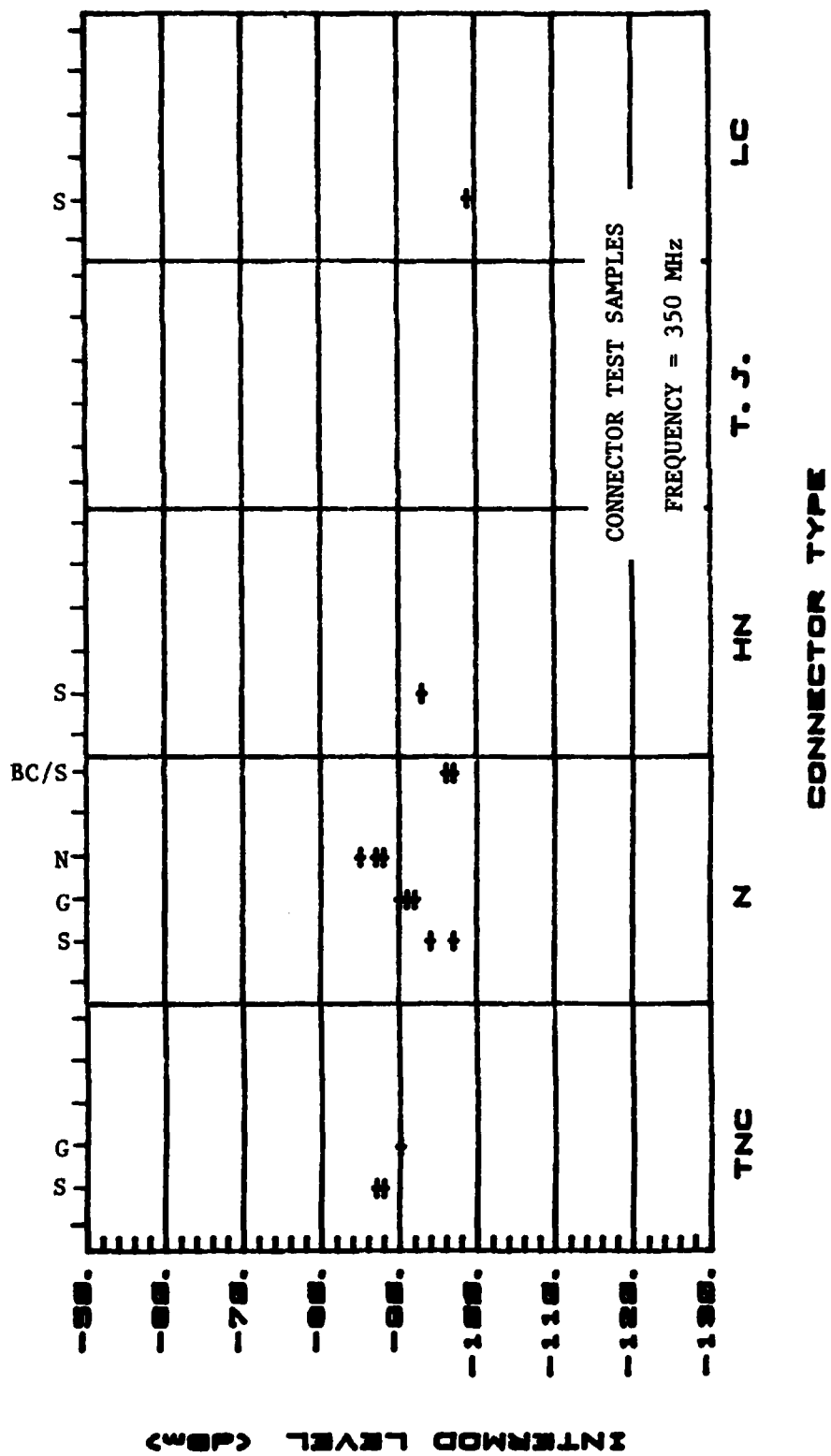
APPENDIX H

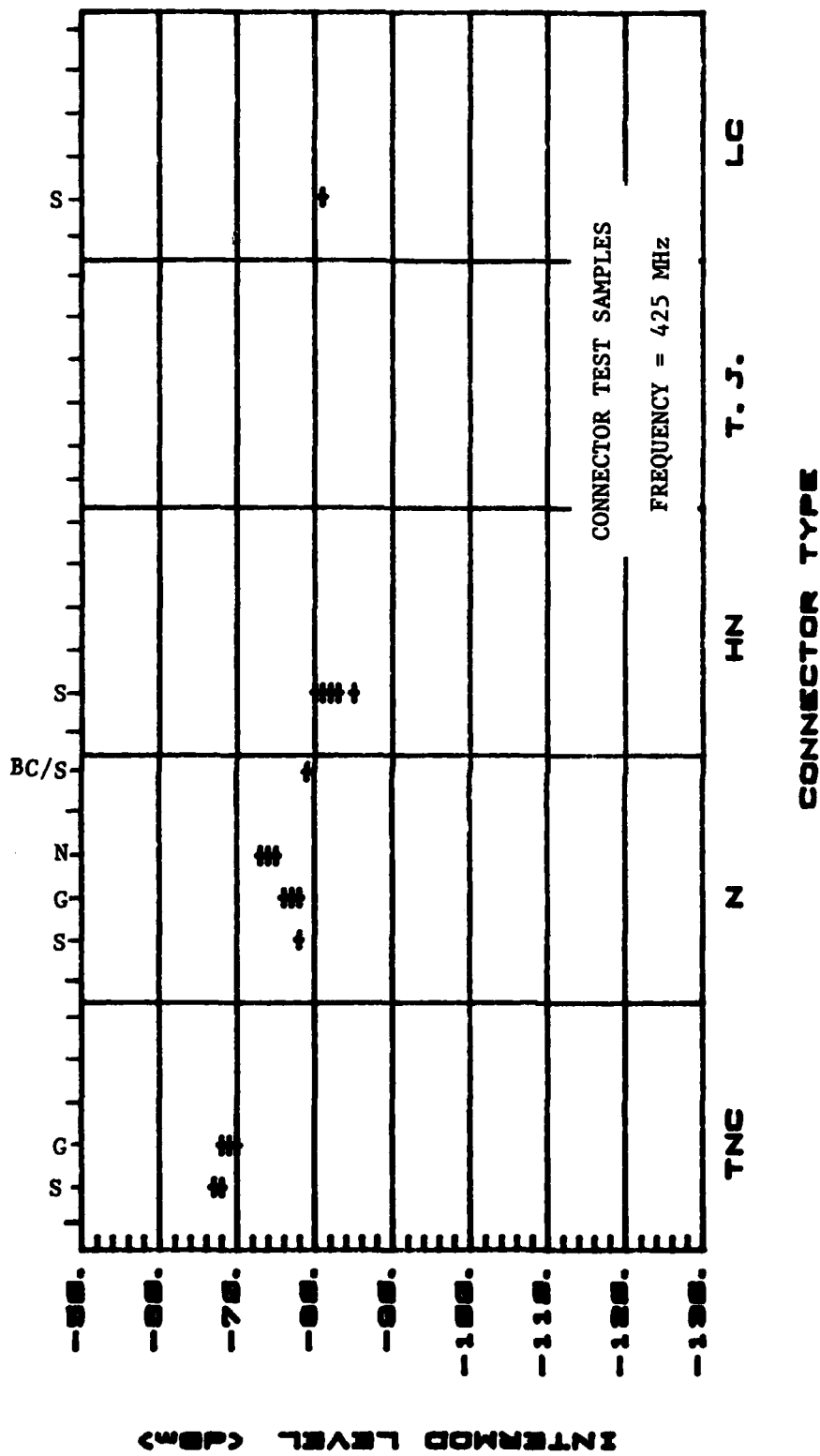
The variations of the normalized IM levels with connector types and platings are illustrated in this appendix. The IM levels have been normalized with respect to an input power of +44 dBm. The first five plots are for connectors at the five IM test frequencies while the last five plots are for cable-connector combinations at the five IM test frequencies. In each plot there are five vertical sections representing the five connector types, TNC, N, HN, LC, and test jig (T.J.). Within each vertical section, there are spaces for four connector platings, silver (S), gold (G), nickel (N), and stainless steel (SS), and a space for the test jig (T.J.). In these spaces, the actual measured IM levels are plotted. If no points are plotted then data was not measured for that combination of parameters.

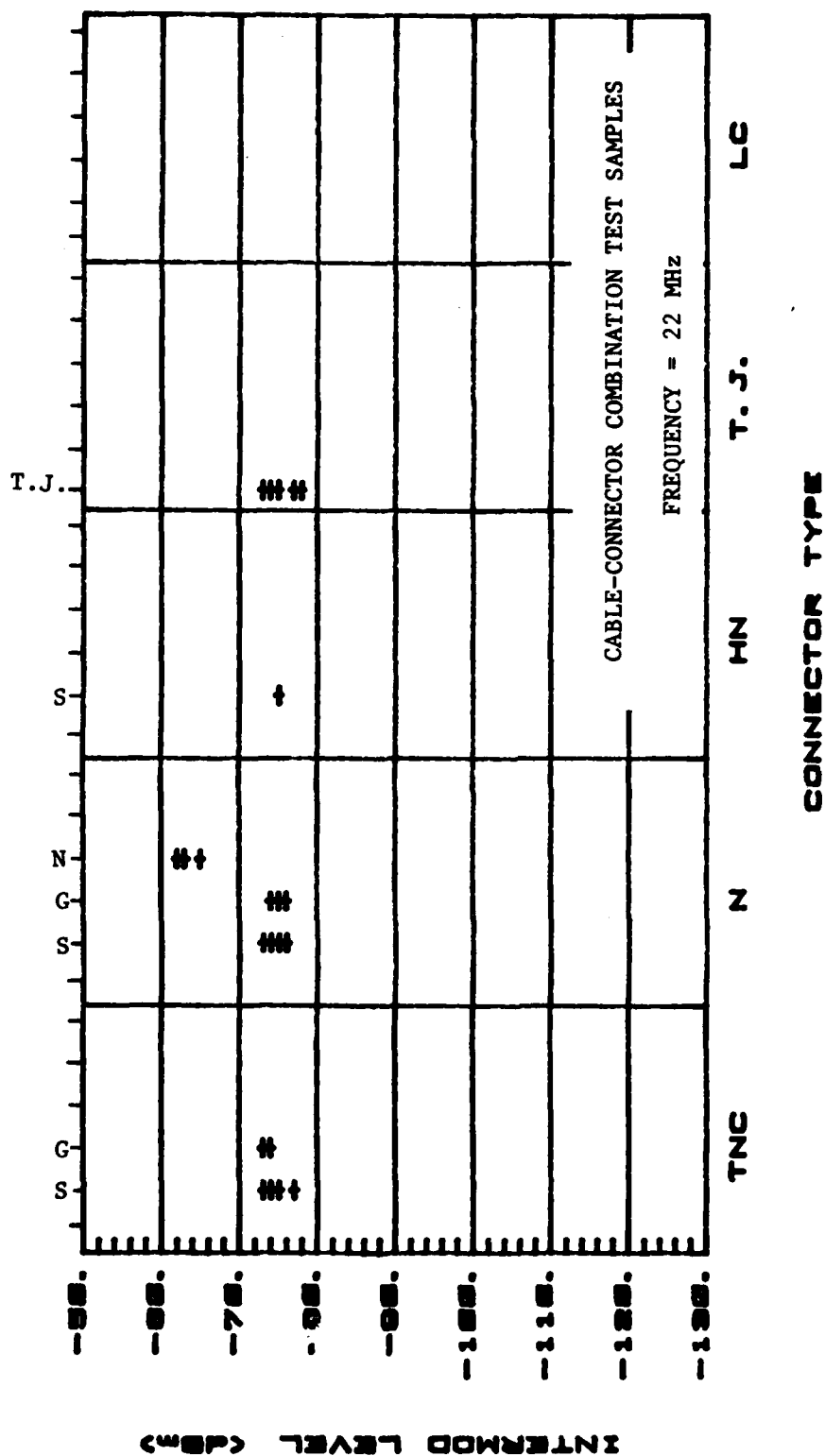


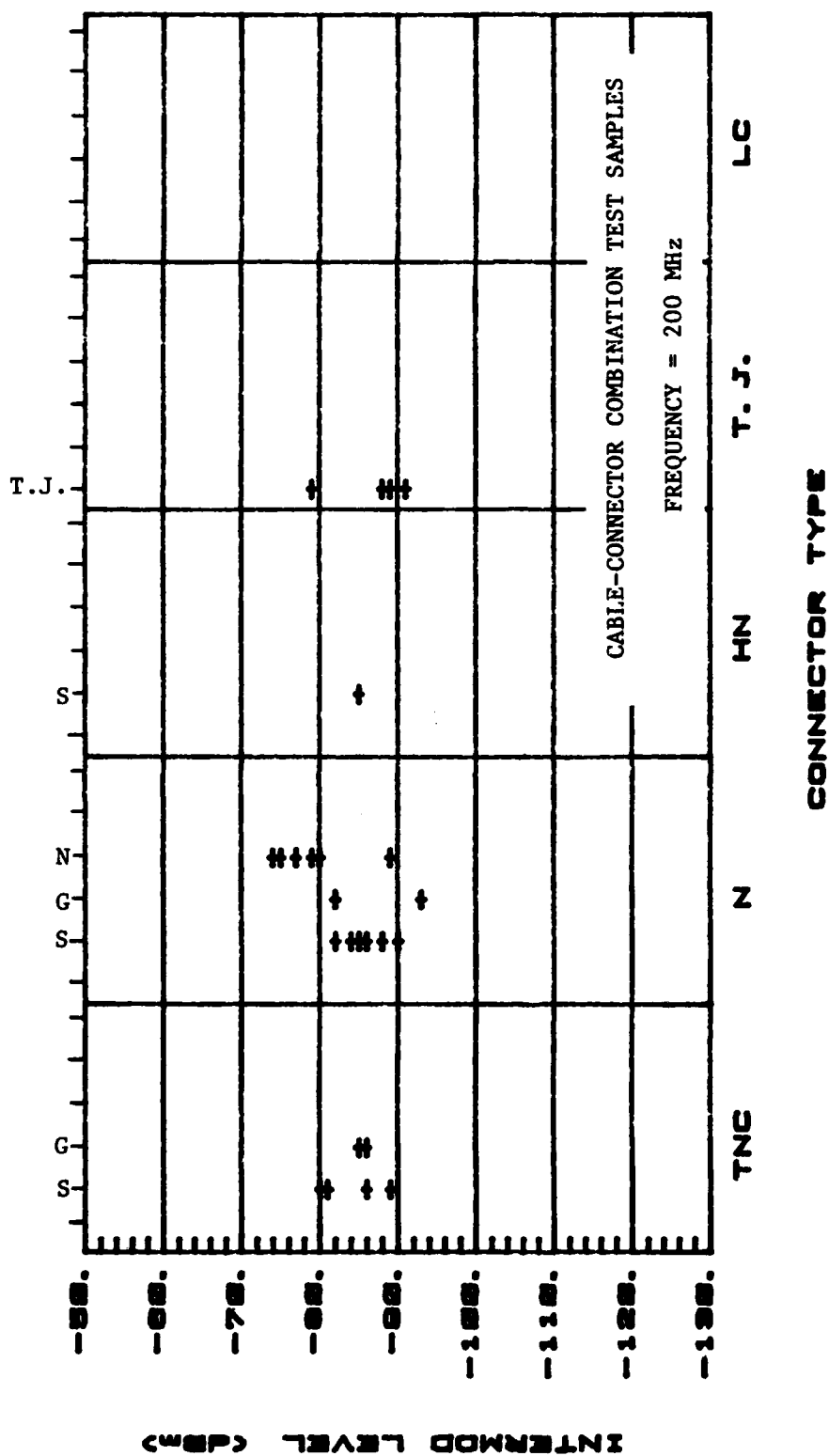


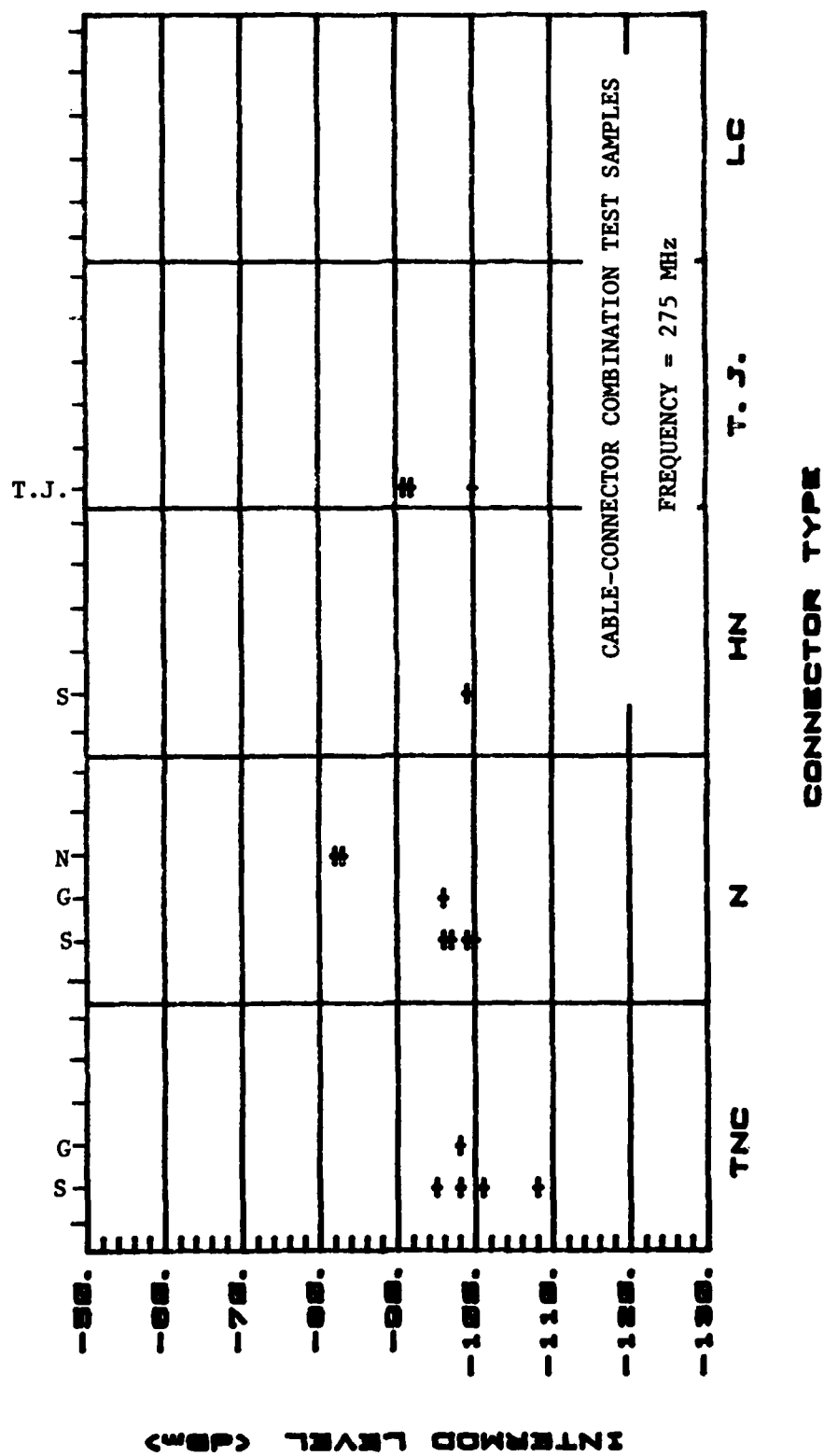


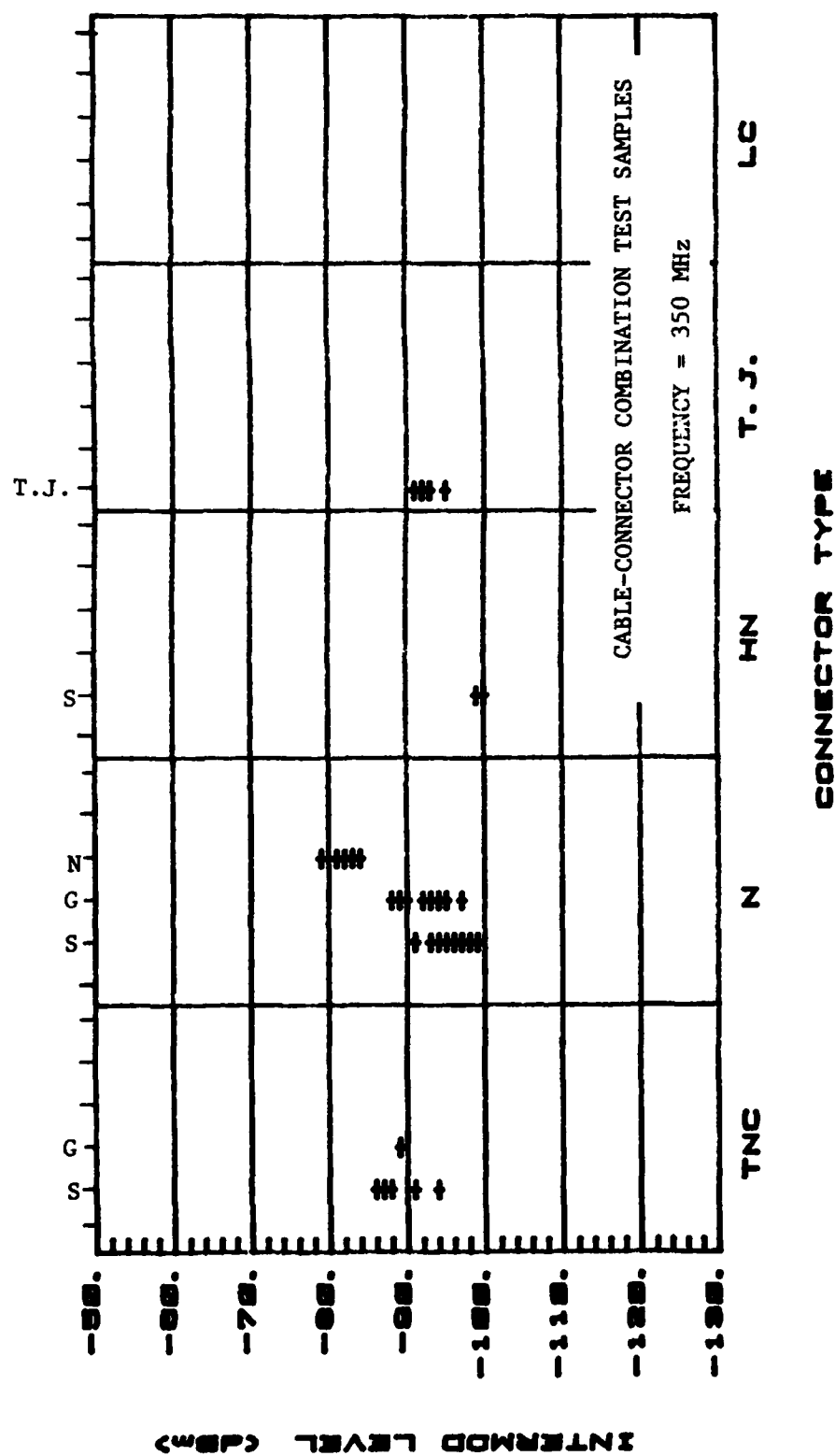












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