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THE BOEING COMPANY
WICHITA DIVISION

CODE IDENT. NO. 81205

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TITLE POWER HANDLING CAPABILITY OF RF COAXIAL CABLES

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MODEL CONTRACT N00140-71-C-0003

ISSUE NO. ISSUED TO

PREPARED BY R. Morgan W. Lewis L. Wren

SUPERVISED BY R. Dowell

APPROVED BY E. Norman

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ABSTRACT

Representative coaxial cable types were subjected to high power CW and pulse tests. The tests were conducted over a range of frequencies and ambient temperature and pressure attitudes. The resulting data was used to develope recommended maximum power ratings for each cable type.

RETRIEVAL REFERENCE WORDS:

Coaxial Cables
Microwave Measurements
Power Handling Capability
Testing
High Power

REV LTR:

E-3042 R1

CONTENTS

1.0 INTRODUCTION

This document sets forth maximum recommended RF power levels for ten selected types of solid dielectric coaxial cables. The power ratings are given for both CW (temperature limited) and pulse (voltage limited) conditions. The influence of RF frequency, ambient temperature, ambient altitude and VSWR is also considered. The recommended ratings are based on numerous pulse and CW power tests conducted on the ten cable types. Test frequencies and test ambient conditions were selected to provide a best distribution of data points over the electrical and environmental operating range of each cable type. Interpolation and extrapolation required to develop rating curves from the measured data points took into consideration the thermal and mechanical properties of the cable components as well as measured attenuation values which were corrected to the test specimen temperature.

The work reported in this document was accomplished in the High Power Microwave Test Laboratory at the Wichita Division of The Boeing Company for the Naval Ship Research and Development Laboratory, Annapolis, Maryland and was authorized by Contract No. N00140-71-C-0003.

2.0 BACKGROUND

Designers of high power RF equipment installations must Select RF transmission lines compatible with both the equipment power levels and frequencies and with the system operational environment. Existing information on which to base such selections is limited to historical experiences with similar systems, theoretical calculations, or data from isolated tests. Comprehensive design information is unavailable in most cases. The consequences are often gross over or under design. Similar problems are encountered by the field engineer in attempting to provide a solution for recurring field failures. He has available the same limited information which determined the original installation supplemented only by the evidence provided by the failure. The resultant fix often takes the form of a treatment of the symptoms and provides no real cure for the illness. This situation is one of long standing and is becoming more acute with the increased power of modern electronic systems and with the ever present need to conserve weight and space.

In recognition of these problems, an engineering and testing program was established to determine the power handling capability of typical types of RF coaxial cables. Test specimens were selected to provide application data on Teflon, polyethelene, and silicone rubber dielectric cables over a range of dielectric sizes. Tests were conducted on eight RG cable types and two commercial cable types. Operating ambient temperature ranges of $-100^{\circ}F$ to $+160^{\circ}F$ for polyethylene cables, $-100^{\circ}F$ to $+300^{\circ}F$ for Teflon cables and $-100^{\circ}F$ to $+200^{\circ}F$ for silicone rubber cables were considered. The pressure altitude range for all dielectric types was from sea level to 200,000 feet.

3.0 TECHNICAL APPROACH

3.1 General

Detailed planning of the test phase of the program followed final definition of the test cable types as indicated in Table I. This detailed planning revealed two significant problem areas: (1) the method of applying the required RF power levels to the input of the test cables, and (2) the method of determining test cable center conductor temperature during the test. The solutions to these problems are discussed in Paragraphs 3.2 and 3.3 respectively. A description of the test methods employed for CW and pulse testing is contained in Paragraph 3.4.

3.2 Waveguide-to-Cable Transitions and Chamber Feedthrough

Initial program planning called for the design and fabrication of environmental chamber RF feedthroughs having electrical properties commensurate with the planned test frequencies and anticipated power levels. The feedthroughs were also intended to provide thermal isolation of the test cables from the chamber walls and from the external environment. A more detailed analysis, however, following the final determination of test cable types led to the rather definite conclusion that any practical feedthrough which incorporated a connector interface with the test cable would be susceptible to failure at that interface prior to achieving the power limitation of the test cable, or would have to be of a dimensional configuration which would impose upper frequency limitations substantially below the upper frequency rating of the test cable.

TABLE I

PHYSICAL CHARACTERISTICS OF CABLE TYPES TESTED*

CABLE TYPE	INNER CONDUCTOR	DIELECTRIC	OUTER CONDUCTOR	JACKET**
RG58C/U	0.0355" OD (19 Strands 0.0071") Tinned Copper	0.116" OD Solid Polyethylene	1 Braid Tinned Copper	Type IIA
RG214/U	0.0888" OD (7 Strands 0.0296") Silver Covered Copper	0.285" OD Solid Polyethylene	2 Braids Silver Covered Copper	Type IIA
RG218	0.195" OD Bare Copper	0.680" OD Solid Polyethylene	1 Braid Bare Copper	Type IIA
RG180B/U	0.0120" OD (7 Strands .0040" Silver Covered Copper Covered Steel)	Solid Polytetra-fluoroethylene	1 Braid Silver Covered Copper	Type IX
RG142B/U	0.0390" OD Silver Covered Copper Covered Steel	Solid Polytetra-fluoroethylene	2 Braids Silver Covered Copper	Type IX
RG225A/U	0.0936" OD (7 Strands .0312" Silver Covered Copper)	Solid Polytetra-fluoroethylene	2 Braids Silver Covered Copper	Type V
RG117A/U	0.1880" OD Bare Copper	Solid Polytetra-fluoroethylene	1 Braid Bare Copper	Type V
RG296/U	0.235" OD (37 Strands 0.0336" Silver Covered Copper)	0.906" OD Silicone Rubber	1 Braid Silver Covered Copper	Extruded Polychloro-prene
BIW-84-82-C-G26	No. 26 AWG (7 Strands No. 34 AWG) Silver Covered Copper-Weld	0.083" OD Silicone Rubber	1 Braid Tinned Copper	Extruded Chloro-Sulfonated Polyethylene
BIW-7870-C-G24	No. 24 AWG Silver Covered Copper-Weld	0.195" OD Silicone Rubber	1 Braid Tinned Copper	Extruded Chloro-Sulfonated Polyethylene

* BASED ON VENDOR CATALOG DATA
** TYPE NO. REFERS TO MIL-C-170 TYPE DESIGNATIONS

Alternate approaches which were investigated identified the most feasible method as being the use of the actual test cable as the means of entry and exit from the environmental chamber.

Tests were conducted on a variety of cable types and sizes simulating the feedthrough section of the test cables to determine the nature of the "heat sinking" effect and to define the distance within the environmental chamber where this effect could be neglected. These tests were conducted by artifically (non-RF) heating the sample center conductor and monitoring center conductor, dielectric, outer conductor and jacket temperatures along the length of the sample. This was accomplished at representative temperatures and altitudes distributed over the intended test ranges. The actual test cables were configured to a length which, in addition to providing chamber entry and exit, resulted in the desired length of cable suspended along the centerline of the chamber. The measured input power levels were then corrected to compensate for cable loss to the location where "heat sinking" could be neglected.

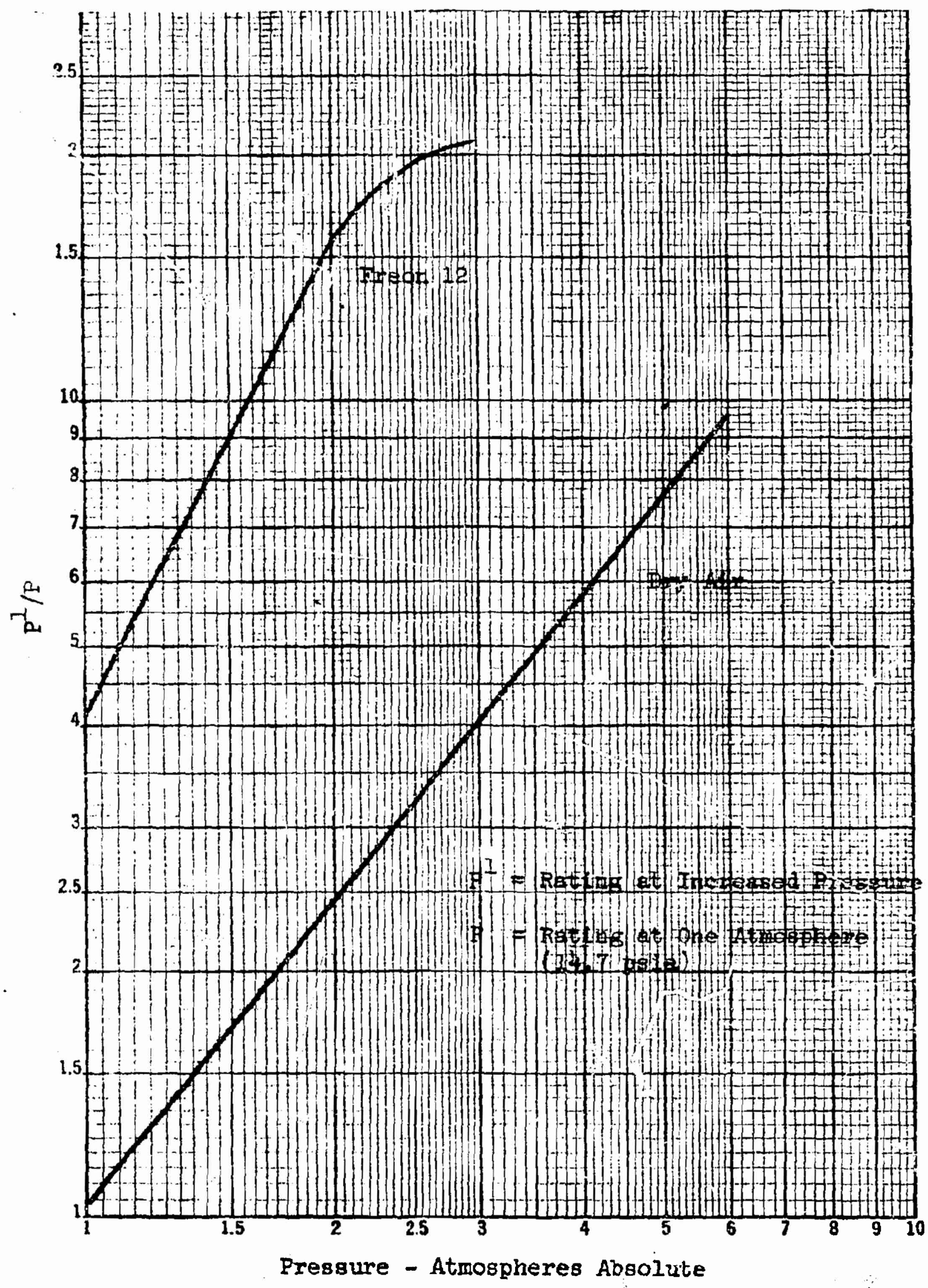
Another problem which became apparent early in the program was that the output fittings of most of the RF power sources were waveguide and none of the available waveguide to coax adapters -- even those developed for high power ECM systems -- would withstand the anticipated test power levels. The solution of the problem was the design and fabrication of special transitions which accommodated the test cable entry into the waveguide without the use of intervening coaxial connectors. A series of these transitions was developed in the waveguide sizes required to cover the test frequencies and was used to terminate the test cables at both input and output (waveguide loads) ends. The transitions were further stophisticated to provide a feature wherein the coaxial half of the transition of any particular cable would "plug-in" to any of the waveguide sizes thereby eliminating the need to disturb the cable braid terminating mechanism when changing test frequency. The reflection coefficients of the transitions were a best compromise considering all of the cable sizes and in most cases were less than 1.5:1 VSWR without tuning. For a few of the frequency-cable-size combinations, however, waveguide E-H tuners were used to reduce VSWR. To further enhance the breakdown withstanding characteristics of the transitions for the pulse power testing they were pressurized to approximately 25 psig using Freon 12. A plot showing the relative breakdown values for dry air and Freon 12 versus pressure is shown in Figure 1.

The design philosophy for the transitions was merely to transfer the RF energy from the waveguide TE_{10} mode to the coaxial TEM mode in the smoothest possible manner without creating any areas of undue voltage concentration in the process. A configuration commonly referred to as a "door knob" transition backed by a waveguide short circuit was selected and optimized for reflection coefficient over the range of frequencies and cable sizes of interest. The unique feature of the transitions is that the cables actually "plug in" to the waveguide, with the cable dielectric engaging the surface area of the door knob surrounding the cable center conductor contact. A typical transition and several associated cable terminations are shown in Figure 2. A typical cutaway drawing is shown in Figure 3.

3.3 Cable Temperature Analysis

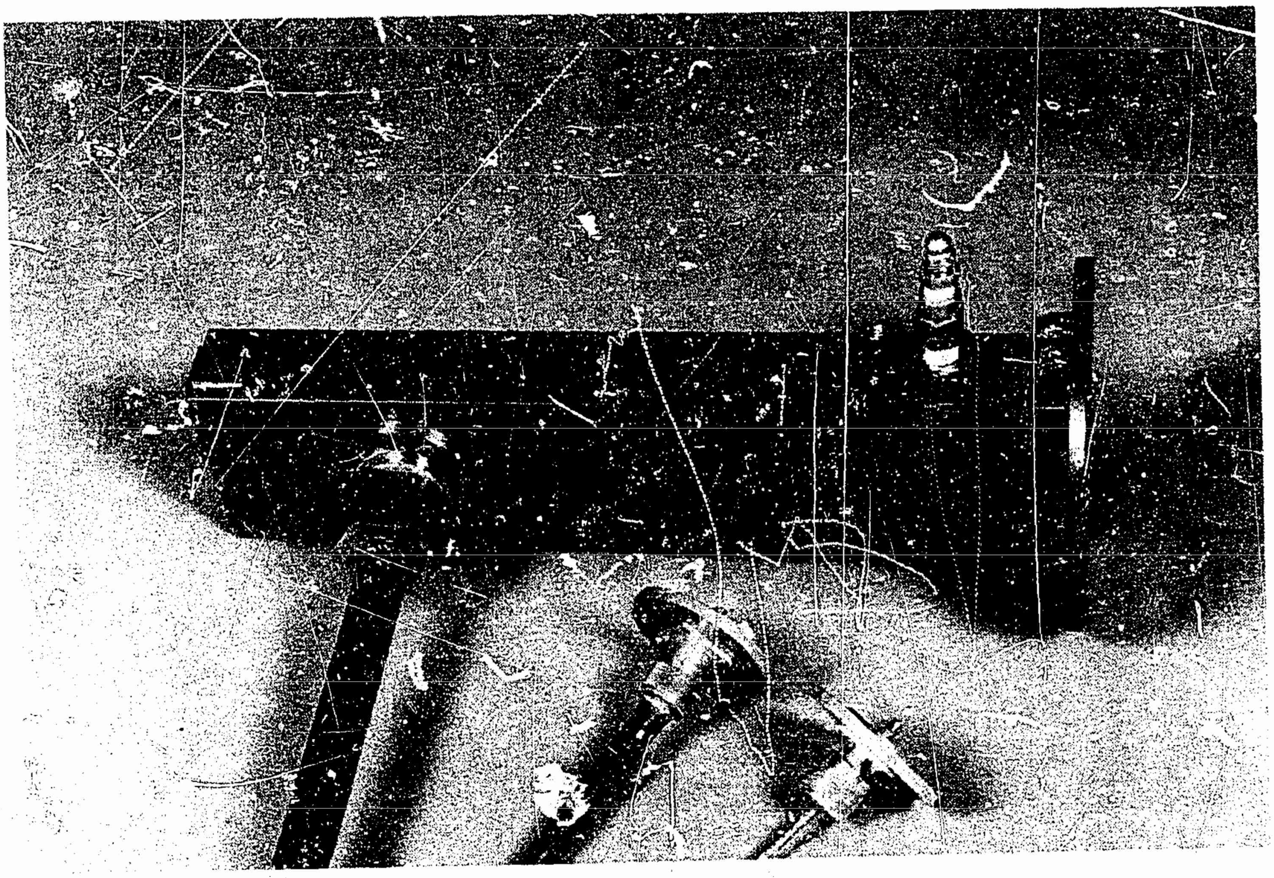
3.3.1 Theoretical Analysis

The criteria upon which the maximum power handling capability was established is based on the maximum allowable surface temperatu[illegible] the cable



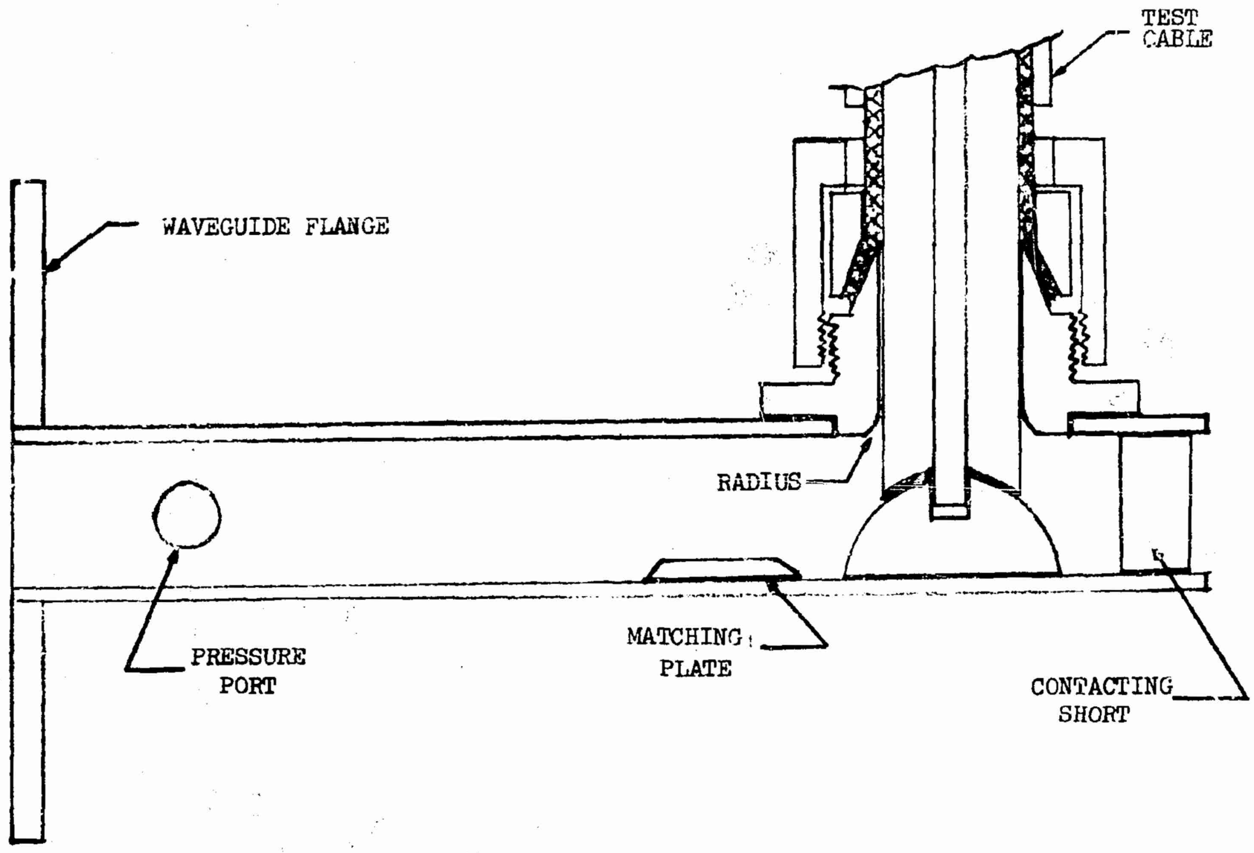
VARIATION OF PEAK POWER RATING WITH ABSOLUTE PRESSURE
DRY AIR VERSUS FREON 12

FIGURE 1



HIGH POWER WAVEGUIDE-TO-CABLE TRANSITION

FIGURE 2



CONTRUCTION SKETCH OF HIGH POWER
WAVEGUIDE TO CABLE TRANSITION

FIGURE 3

center conductor. Determination of this temperature during the power test obviously could not be done by direct measurement so extensive analysis was undertaken both theoretically and experimentally to determine the thermal characteristics of each cable. The center conductor temperature was determined indirectly by measuring the cable jacket temperature and applying the heat transfer characteristics of the specific cable under test to these measured temperatures.

A coaxial cable can be simulated by a hot composite cylinder in a cooler gas. The heat is transferred from the cable to the media surrounding it by three different means: (1) conduction through the concentric layers of the cable, (2) by convection into the surrounding gas, and (3) by radiation. The heat transfer problem is assumed to be one dimensional, as the cable can be considered symmetric about and in varient in size and shape along the axis of the center conductor. Test parameters such as power input, chamber temperature and altitude were changed slowly so that the thermal parameters varied in a quasistatic manner and were then held until full thermal stabilization was realized before a test step was considered complete. For this reason, steady state equations describing the heat transfer could be considered applicable.

If the center conductor is considered a heated element, then the heat flow (q) through the remaining concentric layers may be determined by the steady state heat conduction equation,

$$q = \frac{2\pi L \left(T_i - T_{n+1}\right)}{\sum_i^n \left[\left(\frac{1}{k_i}\right) \ln \left(\frac{D_i + 1}{D_i}\right)\right]}$$

where i is an index denoting the layer

L = length of the cable

k_i = thermal conductivity of the i^{th} layer

T_i = temperature of the inside surface of the i^{th} layer, and

D_i = the inside diameter of the i^{th} layer.

When the heat has arrived at the surface of the cable jacket, it is transferred by both convection and radiation into the surrounding media.

The chamber in which the cable power tests were run is cylindrical in shape and has a large radius relative to the radius of the cable. The black coating on the chamber's inner surface approximates a black body from a radiation standpoint. The only airflow around the cable was generated by the natural bouyancy of the air heated in the film around the cable jacket surface. This allows the use of the equations for free or natural convection in determining the heat transfer to the air surrounding the cable.

The equations defining free convection heat transfer are basically emperical but are well known and based on a large amount of experimental data. The most accepted of free convection equations for a single horizontal cylinder is

$$N_u = \frac{2}{\ell n \left[1 + \frac{2}{C \left(G_r \, P_r \right)^d} \right]}$$

where C and d are constants to be determined experimentally.

N_u is the Nusselt number (dimensionless),

G_r is the Grashof number (dimensionless), and

P_r is the Prandtl number (dimensionless).

For large cylinders where $\frac{2}{C \left(G_r \, P_r \right)^d}$ is a small number, the denominator $\ell n \left[1 + \frac{2}{C \left(G_r \, P_r \right)^d} \right]$ can be approximated by $\frac{2}{C \left(G_r \, P_r \right)^d}$ so that

$$N_u \approx C \left(G_r \, P_r \right)^d .$$

For a cylindrical surface, the Grashof number is defined as

$$G_r = \frac{D^3 \, \rho_f^{\,2} \beta \, g \, \Delta t}{\mu_f^{\,2}}$$

where
- D = diameter of the cylinder
- ρ_f = film density
- β = coefficient of volumetric expansion
- g = acceleration due to gravity (4.17×10^8 ft/hr^2)
- μ_f = absolute viscosity of the film gas

Δt = temperature difference of the gas and the cylinder surface

The Prandtl number is defined as

$$P_r = \frac{C_p \, \mu_f}{k_f}$$

where

C_p = specific heat at constant pressure

k_f = thermal conductivity of the gas

The Nusselt number is defined as

$$N_u = \frac{h_c D}{k_f}$$

where h_c = coefficient of heat transfer between the cable surface and the gas due to convection.

In all the above definitions, the film parameters such as k_f, μ_f, and ρ_f are determined at a ficticious temperature t_f which is defined as the mean temperature between the cylindrical surface (t_s) and the gas (t_g) or

$$\left(t_f = \frac{t_s = t_g}{2} \right).$$

For the particular set of cylindrical cable samples considered for this report, the constants C and d are defined as C = 0.41 and d = 0.25.

The coefficient of heat transfer by convection is therefore

$$h_c = \frac{k_f}{D} \left\{ \frac{2}{\ell n \left[1 + \dfrac{2}{.41 \left(\dfrac{D^3 \rho_f^2 \beta g \Delta t}{\mu_f^2} \cdot \dfrac{c_p \mu_f}{k_f} \right)} \right]} \right\}$$

The heat flow from the jacket surface into the surrounding gas is defined as:

$$q = \left(h_r + h_c \right) A_0 \left(T_0 - T_1 \right)$$

where T_0 and T_1 = temperature of the jacket and surrounding gas respectively

h_c = coefficient of heat transfer by convection

h_r = coefficient heat transfer by radiation, and

A_0 - jacket surface area.

We must, therefore, find both the heat transfer coefficient for convection and radiation before we can evaluate the heat flow from the jacket to the surrounding media.

Since the cable tests were run in a cylindrically shaped chamber, and since the cable was positioned in the center of this cylinder, the thermal radiation problem is somewhat simplified. The heat transfer equation for radiation alone is

$$q = F_A F_\epsilon A_0 \sigma \left(T_0^4 - T_1^4\right)$$

where F_A = geometric or configuration factor

F_ϵ = emissivity correction factor

σ = Stefan-Boltzman constant ($.173 \times 10^8$ BTU/$h_r{}^2$ $^\circ R^4$)

A_0 = area of the cable surface

T_0 and T_1 = absolute temperature of the cable and chamber surface respectively.

The radiant heat transfer coefficient is generally defined as $q = h_r A_0 \left(T_0 - T_1\right)$ which is merely a statement of heat balance. Therefore, solving for the heat transfer coefficient (hr) we have

$$h_r = \frac{F_A F_G \sigma \left(T_0^4 - T_1^4\right)}{T_0 - T_1}$$

For the simplified case considered here,

$$F_A = 1, \text{ and } F_G = \frac{1}{\frac{1}{\epsilon_0} + \frac{A_0}{A_1}\left[\frac{1}{\epsilon_1} - 1\right]}$$

where ϵ_0 = emissivity of the cable jacket

ϵ_1 = emissivity of the enclosing chamber surface, and

A_0 and A_1 = the areas of the cable surface and chamber surface respectively

Therefore, the radiant heat transfer coefficient is

$$h_r = \frac{\sigma\left(T_0^{\,4} - T_1^{\,4}\right)}{\left[\frac{1}{\epsilon_0} + \frac{A_0}{A_1}\left(\frac{1}{\epsilon_1} - 1\right)\right]\left(T_0 - T_1\right)}$$

By applying the conduction equations to the parameters of each specific layer of material in the cable and by applying the convection and radiation equations to the parameters of the environment surrounding the cable jacket surface, we can simulate the thermal characteristics of the cable with a mathematical model.

A digital computer analysis program was written utilizing these equations. The temperatures of each interfacing layer of each cable tested in this program were calculated as a function of ambient temperature and pressure altitude for the chosen limiting center conductor temperatures.

3.3.2 Temperature Measurements

In addition to the calculated values described in Paragraph 3.3.1, experimental data was developed to both increase the level of confidence in the math model and to make fine adjustments to the calculations where limited material thermal and radiation parameter data was available or where engineering estimates had to be made to perform the calculations.

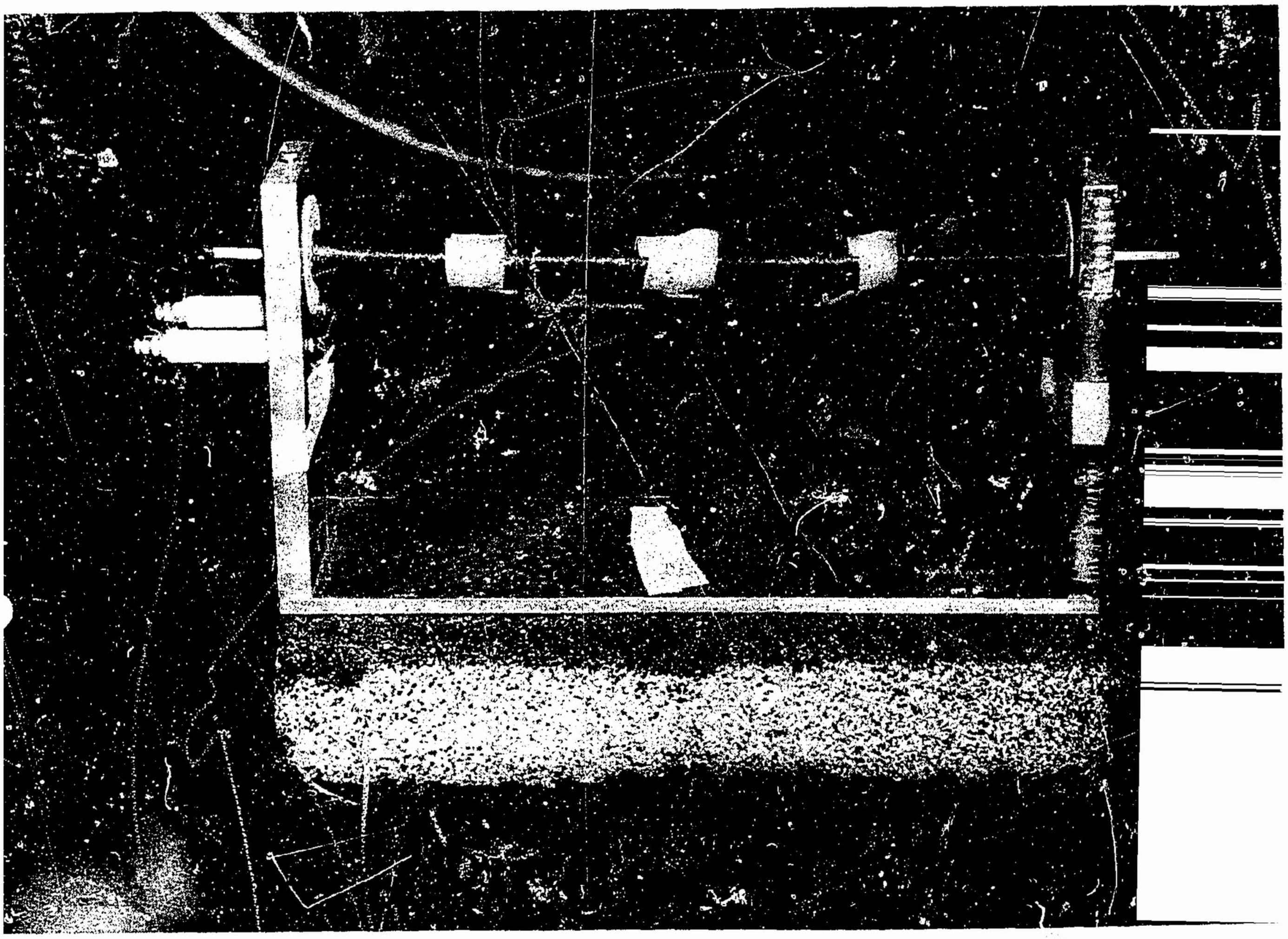
The experimental tests were performed by artifically (non-RF) heating the center conductor, or a simulation of the center conductor, in a relatively short cable sample while monitoring the resultant temperature levels with thermocouples at the various cable material interfaces. These measurements were performed at multiple ambient temperatures and altitudes. Figures 4 through 8 show the test fixture utilized in these tests and several of the test samples. The center conductor temperatures used as test limits were 176°F for polyethelene dielectric cables, 400°F for teflon dielectric cables, and 300°F for the silicone dielectric cables.

Experimental testing was also performed on cable samples by applying RF energy in increasing levels with the sample mechanically stressed in a manner which would cause center conductor migration toward the outer conductor with a slight thermal deterioration of the dielectric. This deterioration was detected by making time domain reflectometer measurements after each increase in the RF power level. This information was also used in adjusting the computed jacket temperatures to take into account the thermal contributions due to dielectric and outer conductor losses.

3.4 Description of Tests

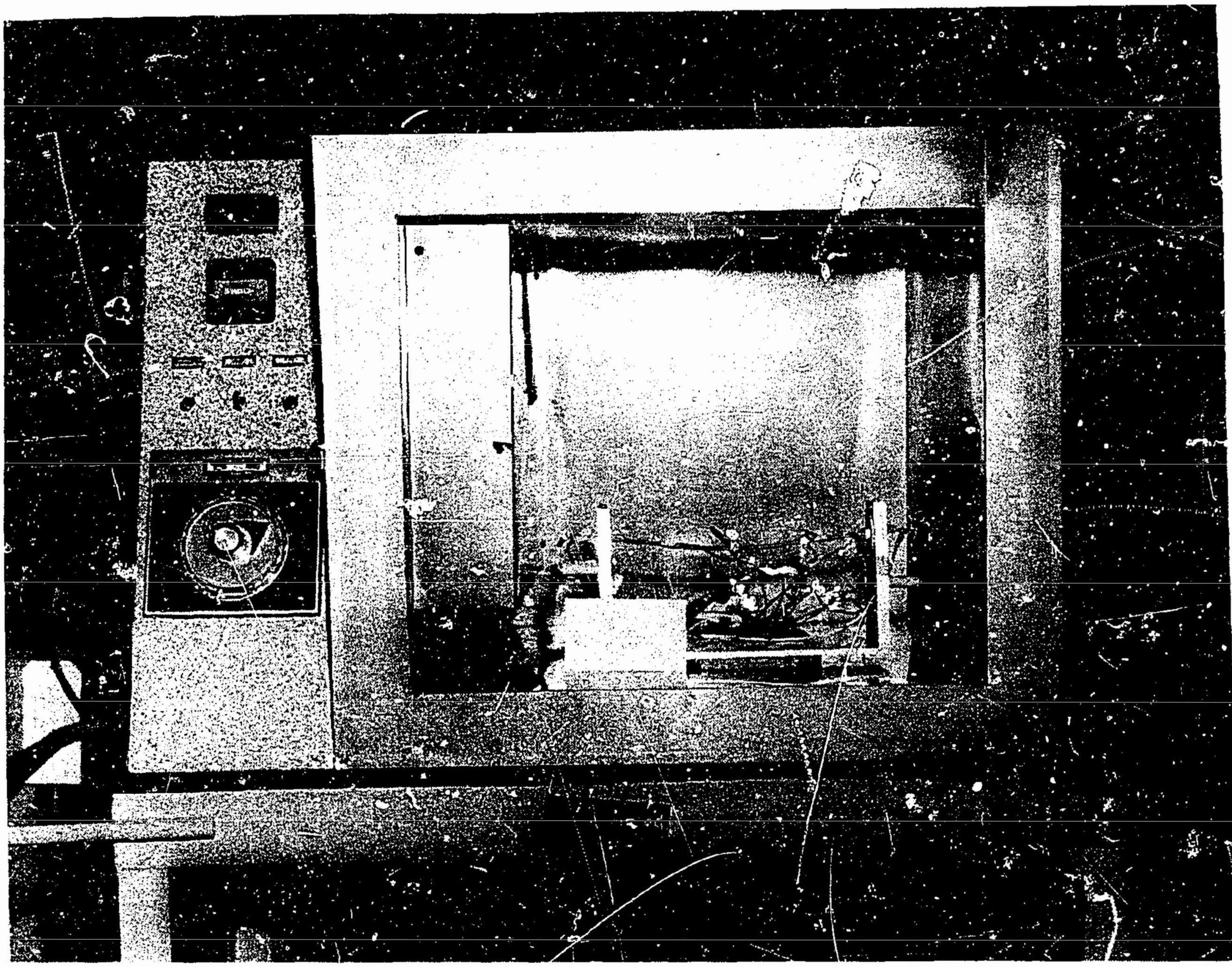
Two basic types of RF power tests were accomplished: (1) CW tests to determine the cables power handling capability as limited by heating due to conductor and dielectric losses, and (2) low duty cycle pulse tests to determine the RF voltage breakdown capability of the cables. The testing was accomplished at several frequencies over the operating range of the test cables to provide the data points which were the basis for the resultant power capability versus frequency curves. The tests were repeated at sufficient temperature and altitude conditions to determine the dependency of power rating on these factors.

The tests were conducted by installing the test cable in a temperature-altitude chamber and instrumenting the length of the cable with 22 thermocouples.



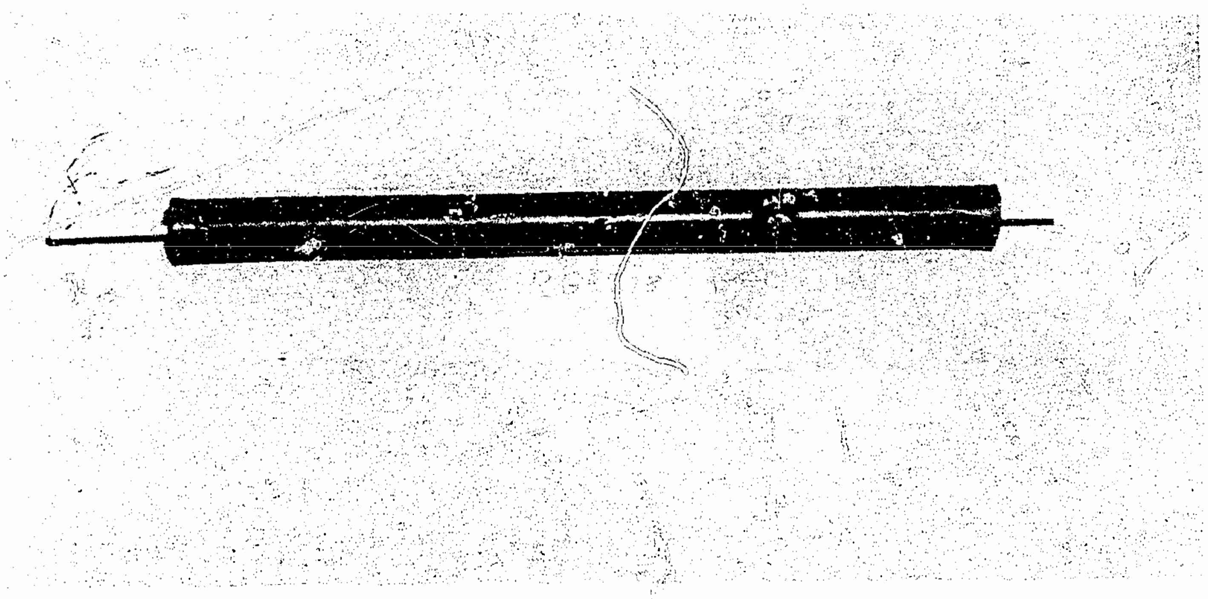
JACKET TEMPERATURE TEST FIXTURE, RG117A/U INSTALLED

FIGURE 4



JACKET TEMPERATURE TEST FIXTURE, RG142B/U INSTALLED

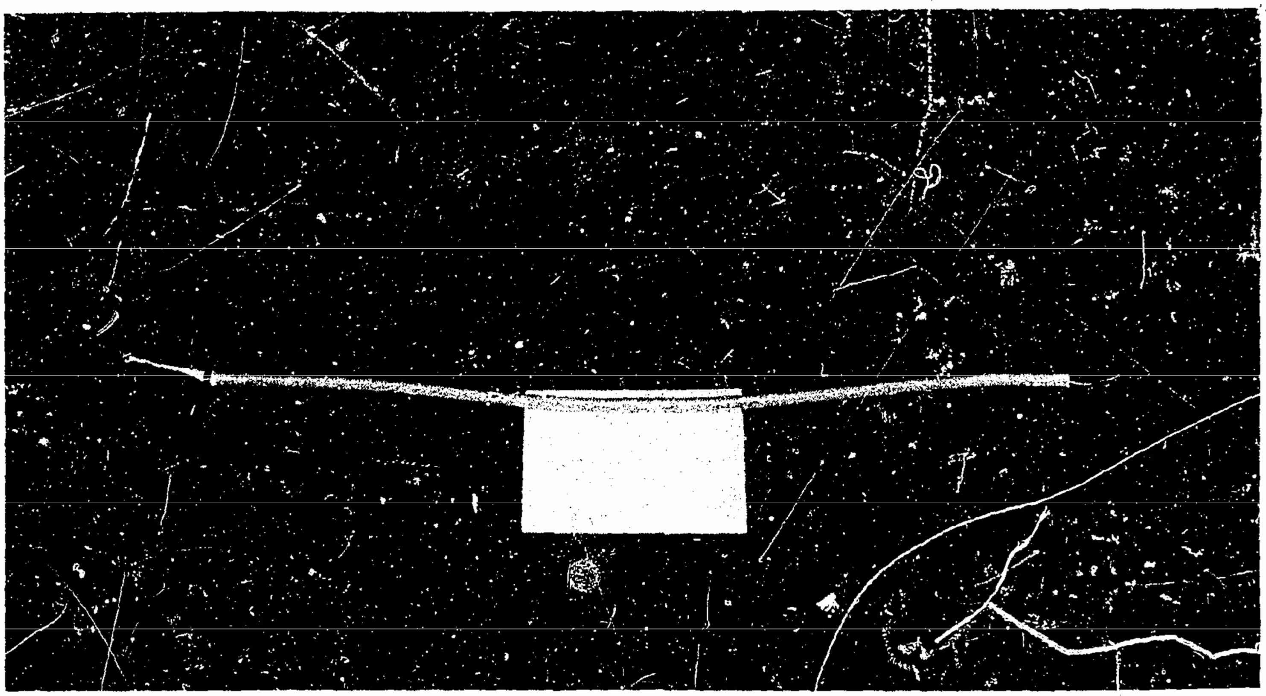
FIGURE 5



JACKET TEMPERATURE

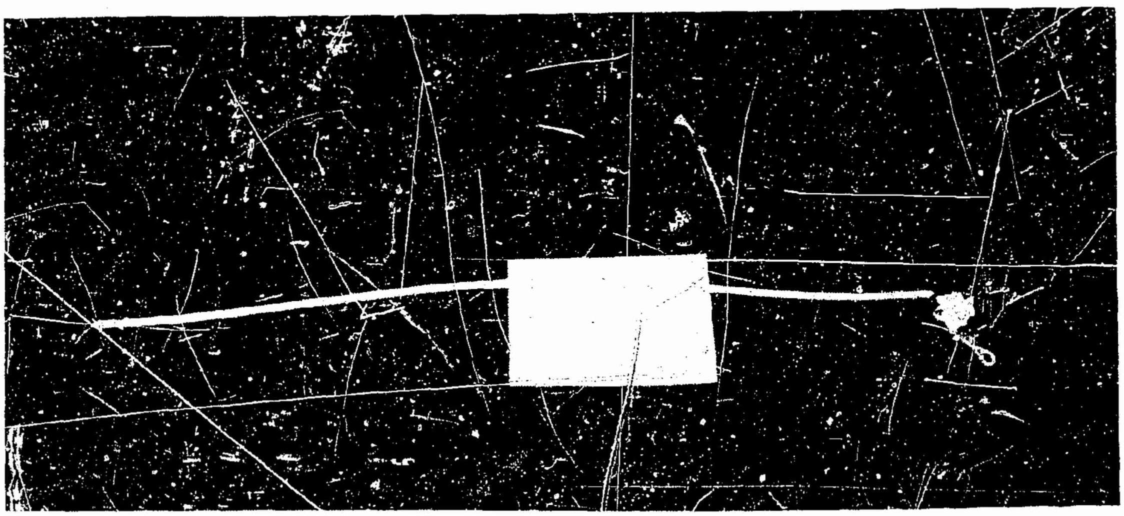
TEST SAMPLE, RG218/U

FIGURE 6



JACKET TEMPERATURE TEST SAMPLE, RG142B/U

FIGURE 7

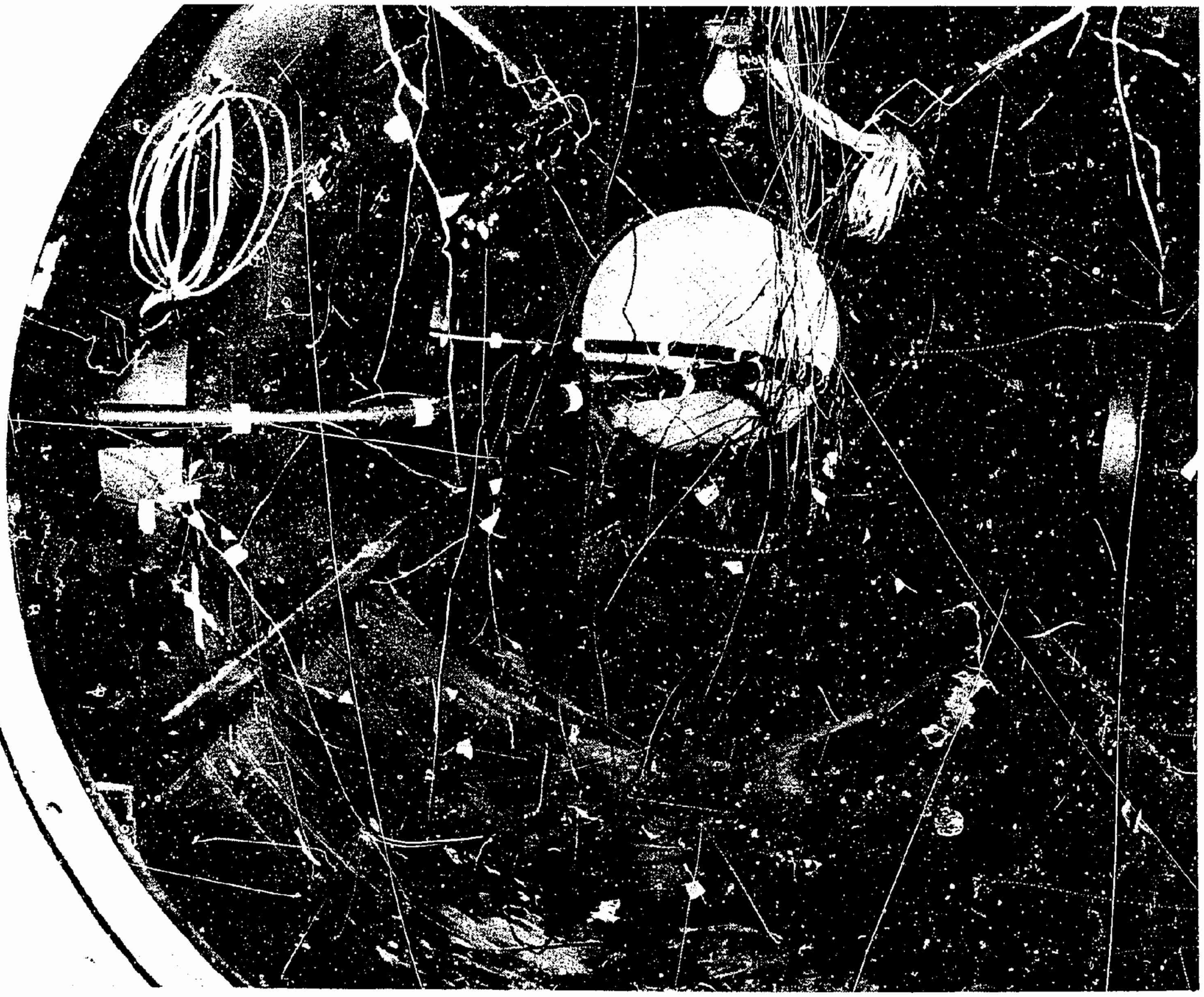


JACKET TEMPERATURE TEST SAMPLE, RG180B/U

FIGURE 8

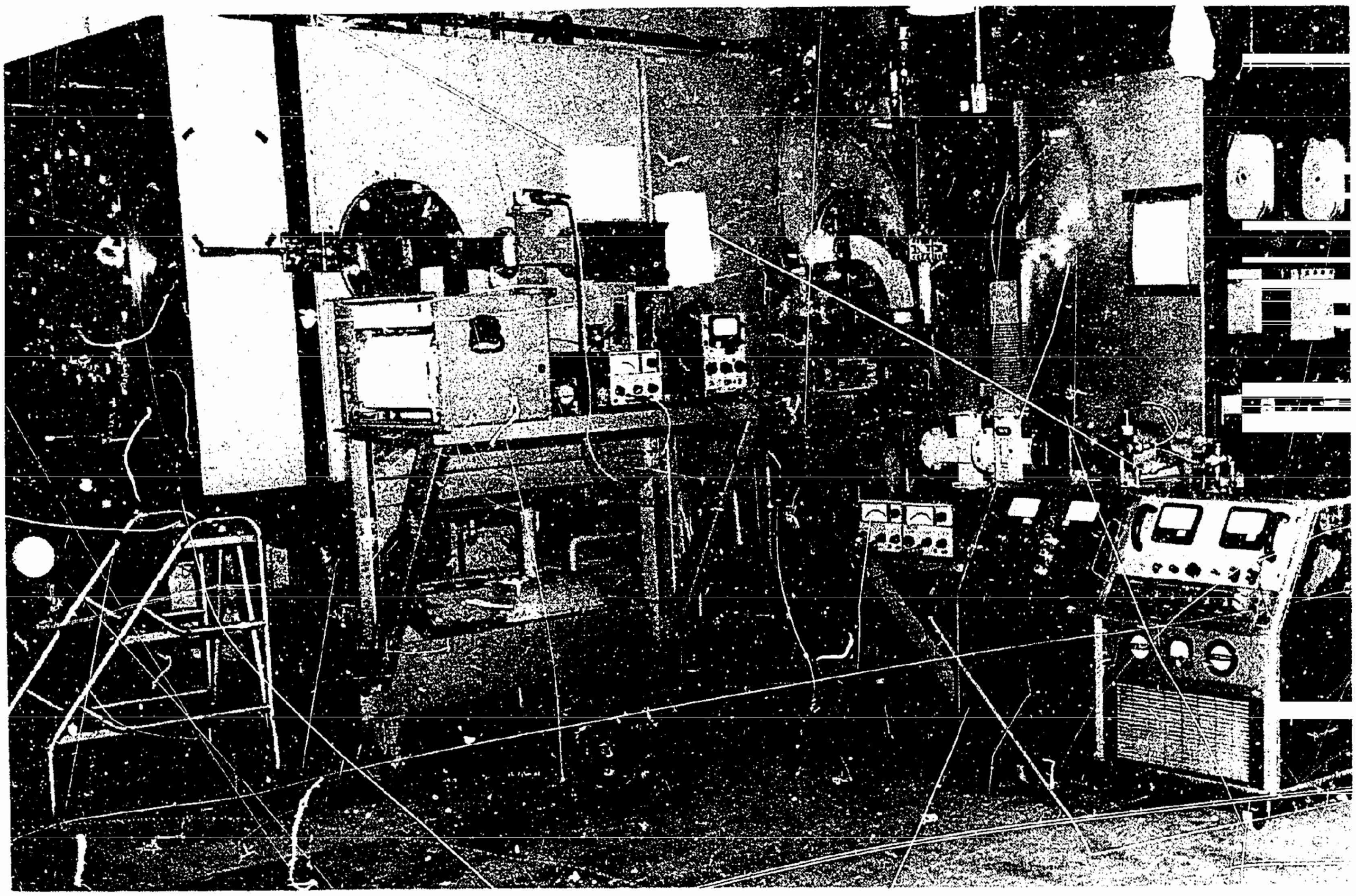
Thermocouple spacing was every six inches starting at the cable input for the first eight feet with the remaining thermocouples distributed uniformly over the remainder of the cable. Test cables were approximately 14 feet in length. A typical chamber and thermocouple installation is shown in Figure 9. An overall view of a typical test is shown in Figure 10. Entry and exit from the test chamber was accomplished by means of the test cable as discussed in Paragraph 3.2. Both the input and output ends of the test cable were terminated in specially designed cable-to-waveguide transitions which were in turn connected to the RF power source or a high power waveguide termination through calibrated power monitoring directional couplers and power meters. Input forward and reflected power, output forward power, test sample thermocouple readings and test chamber temperature and pressure were monitored and recorded throughout each test. A schematic diagram showing a typical test setup is shown in Figure 11.

The detailed test sequence consisted of installing and instrumenting the test cable in the test chamber and establishing the desired chamber altitude and temperature condition. The cable was then allowed to "soak" under these conditions until temperature stabilization at the desired desired temperature was accomplished. The chamber was maintained at these conditions for the remainder of the test. RF power was applied to the input of the test cable in small increasing steps until the cable jacket temperature stabilized at the predetermined limiting temperature as discussed in Paragraph 3.3. This process was then repeated for all scheduled temperature and altitude conditions and for each additional test frequency.



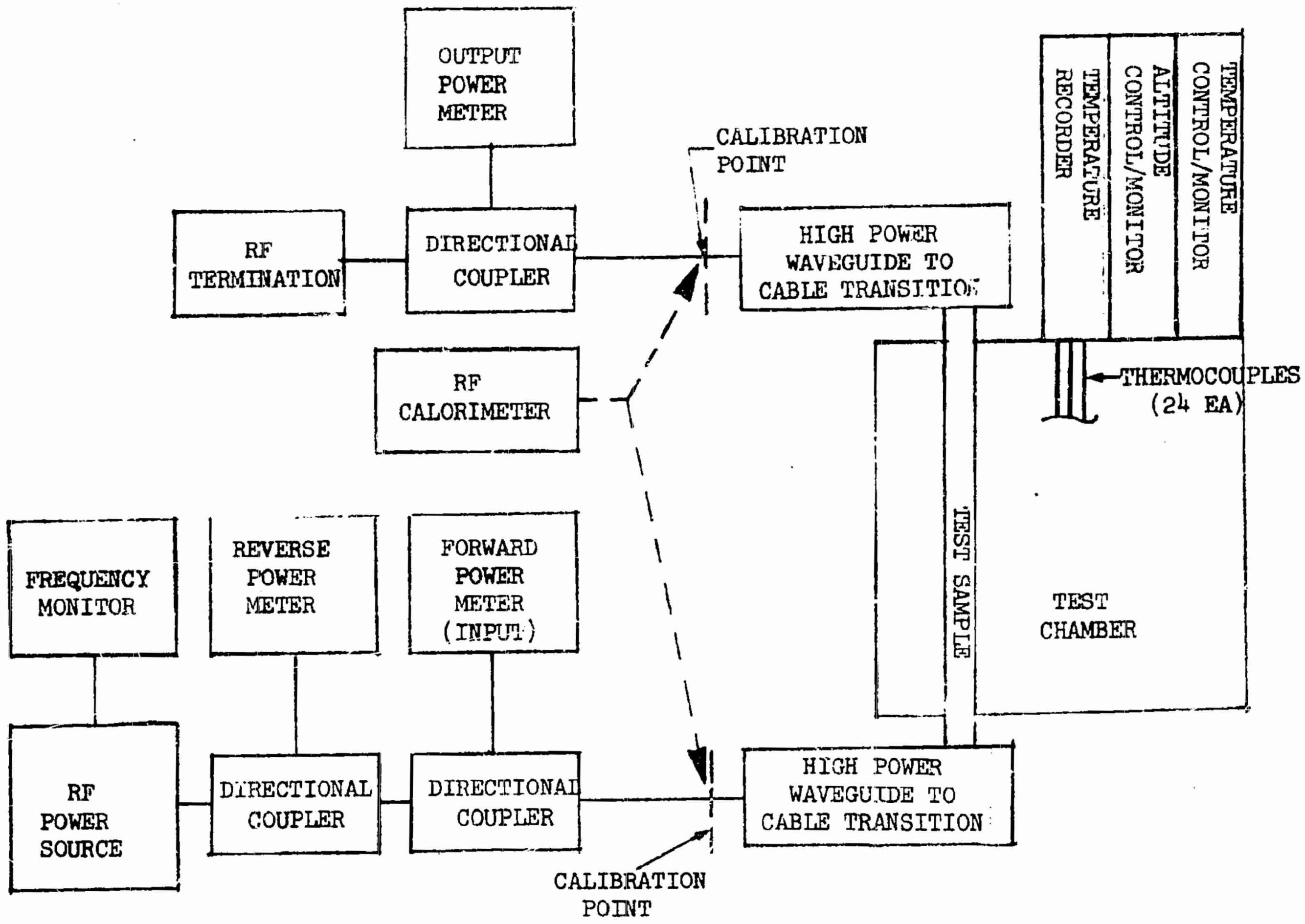
TYPICAL CHAMBER INSTALLATION, RG218/U INSTALLED

FIGURE 9



TYPICAL AVERAGE POWER TEST SETUP

FIGURE 10

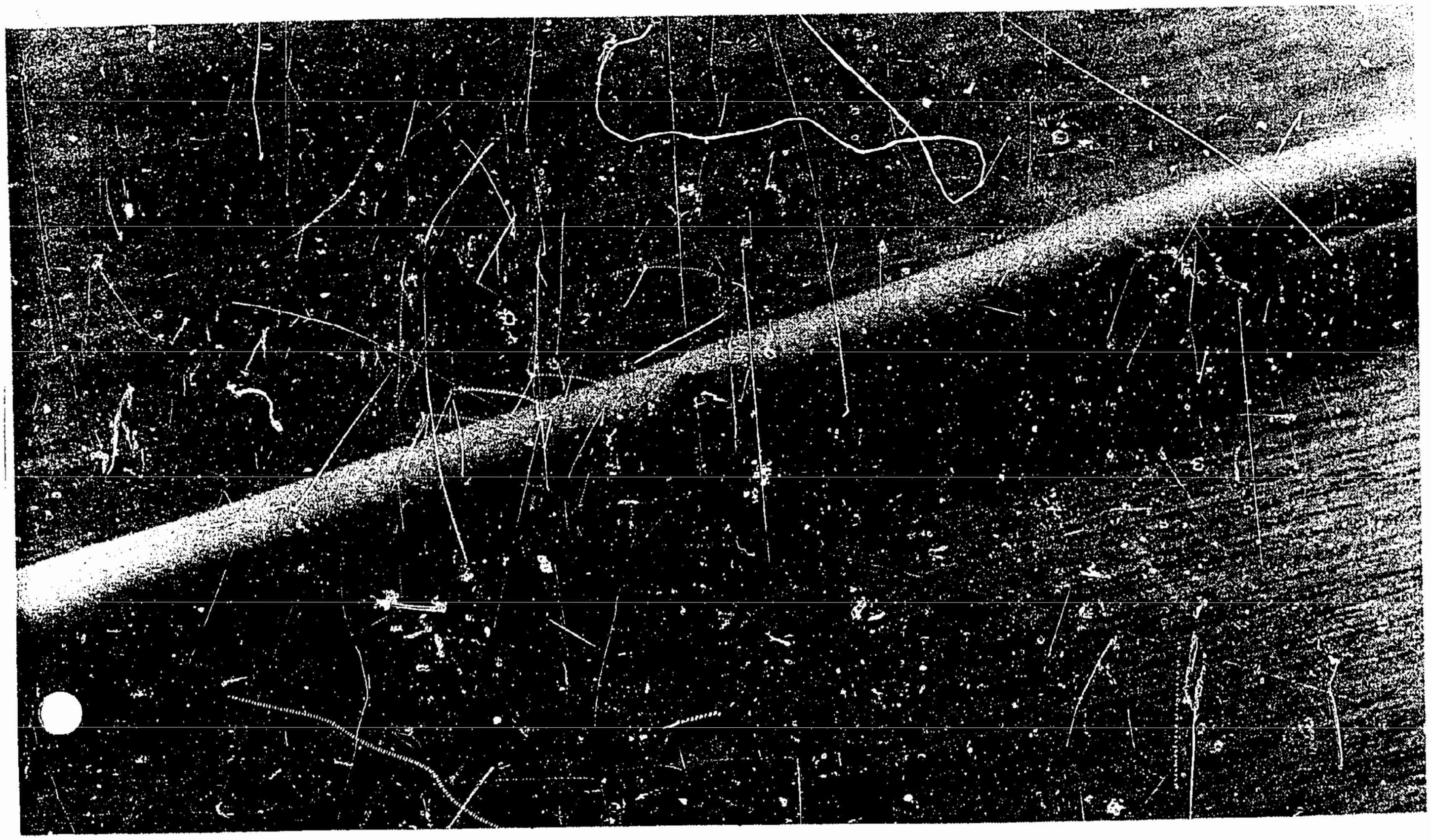


SCHEMATIC DIAGRAM OF TYPICAL POWER TEST SETUP

FIGURE 11

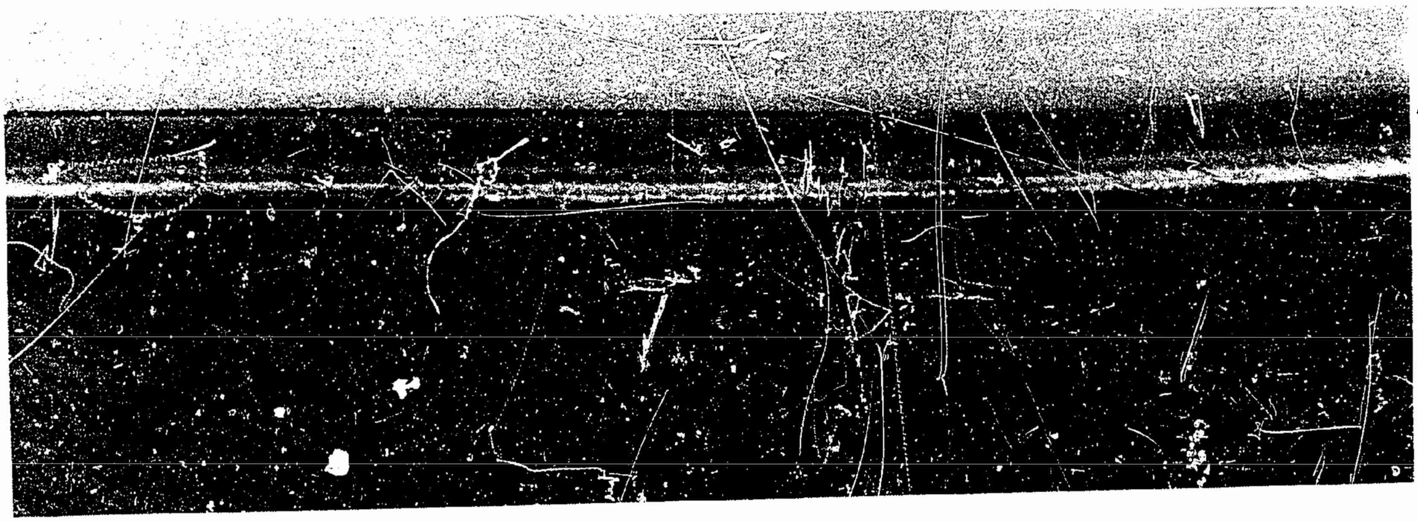
The CW test cables were visually examined before and after the entire test sequence and VSWR and Time Domain Reflectometer tests were conducted before and after the power tests at each test frequency to check for cable deterioration. After all testing was completed on a particular sample, segments were disected and the dimensions and condition of cable members was determined by inspection and deterioration or change noted.

RF pulse tests were conducted on different cable samples from those subjected to the CW tests. The pulse test samples were visually inspected and VSWR and Corona ignition and extinction tests were conducted prior to applying RF power. The actual conduct of the tests was very similar to the CW tests except that jacket temperatures were monitored for information and as a "not-to-be-exceeded" parameter. Peak power was increased slowly until the sample failed by dielectric voltage breakdown. Sections of cable where breakdown occurred were carefully examined and conditions noted. Sections of cable which were not catastrophically involved in the breakdown were inspected to ascertain less severe deterioration. Photographs of cable sections where breakdown occurred are shown in Figures 12 through 14.



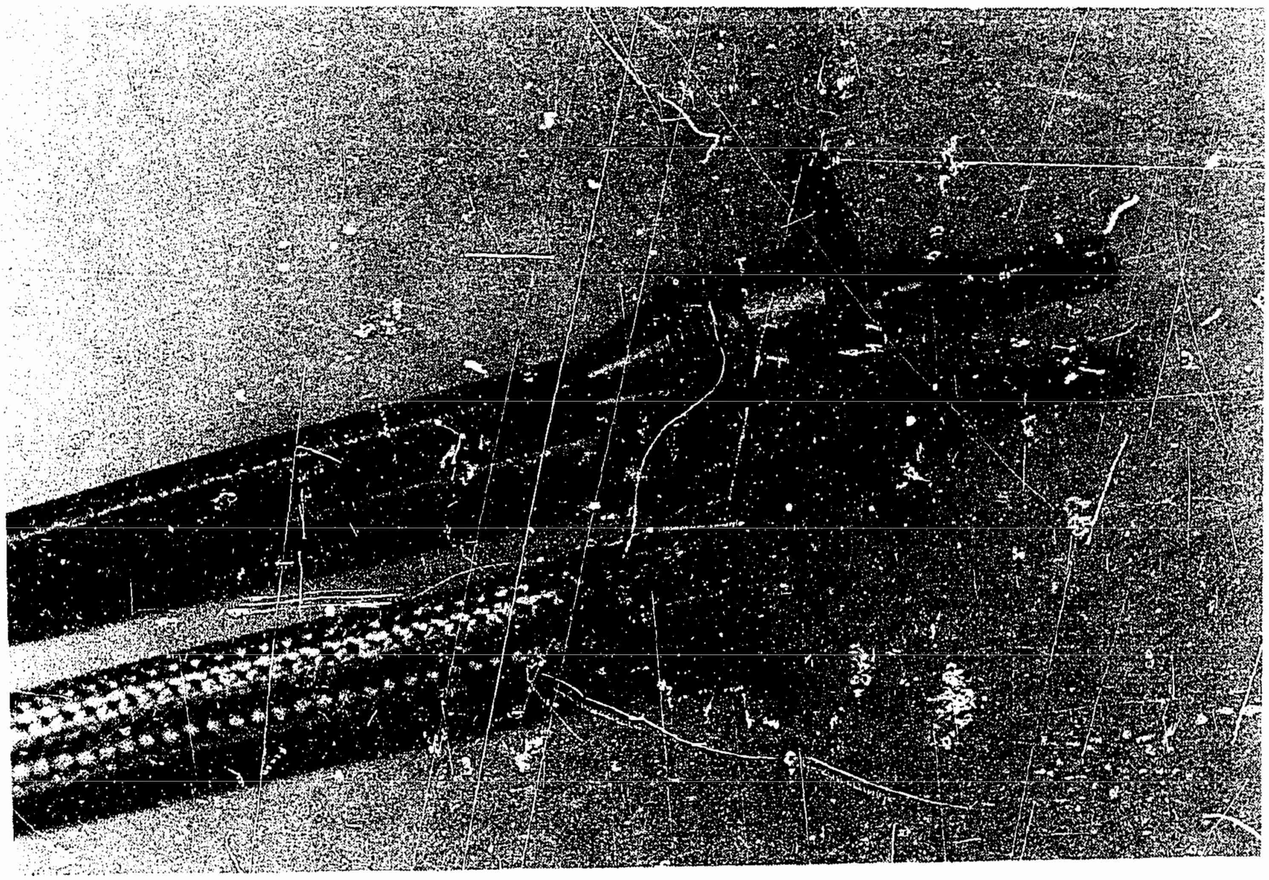
DIELECTRIC BREAKDOWN OF RG225A/U
PULSE POWER TEST SAMPLE

FIGURE 12



DIELECTRIC BREAKDOWN OF RG142B/U
PULSE POWER TEST SAMPLE

FIGURE 13



DIELECTRIC BREAKDOWN OF RG214/U PULSE POWER SAMPLE

FIGURE 14

4.0 TEST RESULTS

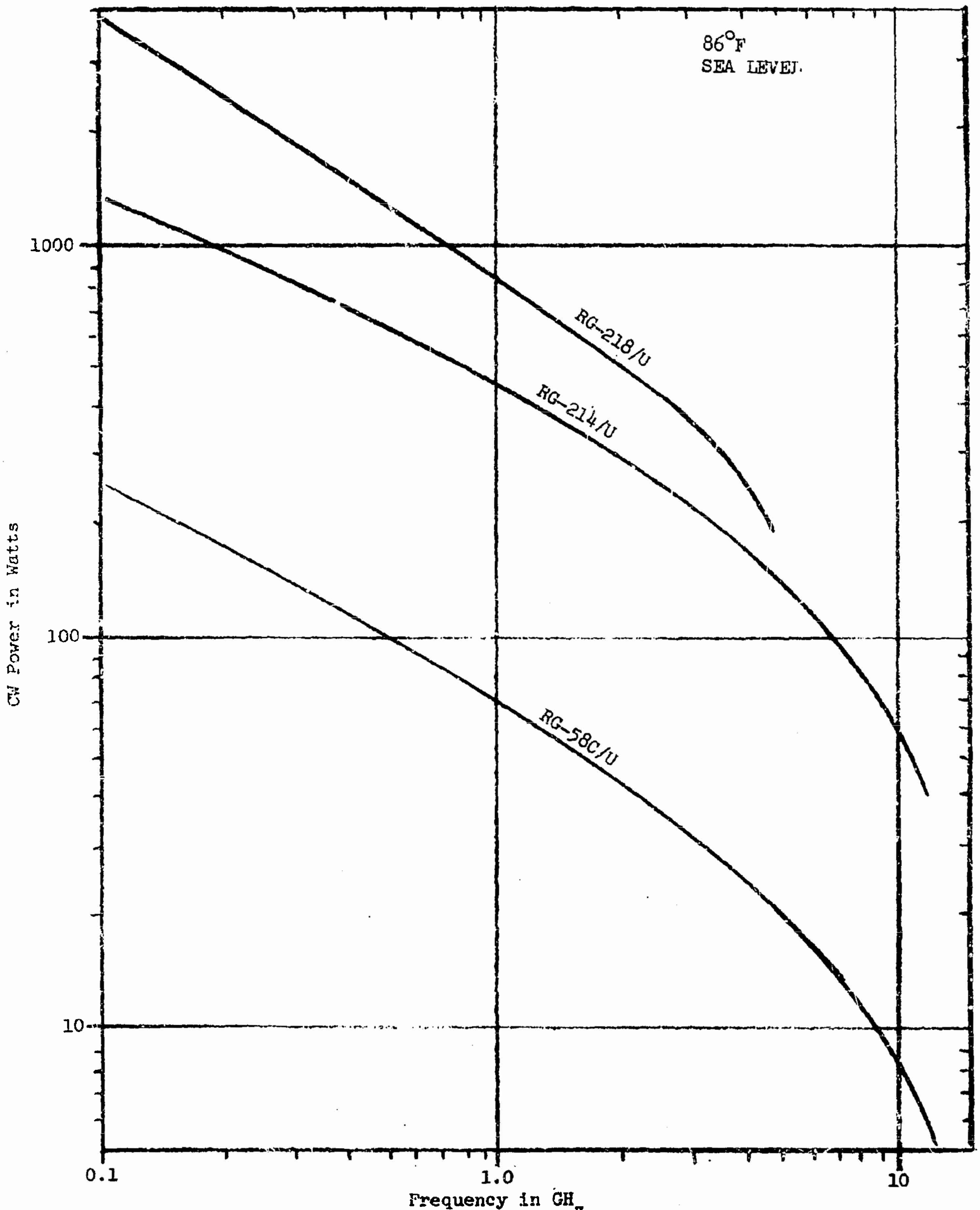
4.1 CW (Average Power) Tests

4.1.1 Teflon and Polyethelene Dielectric Cables

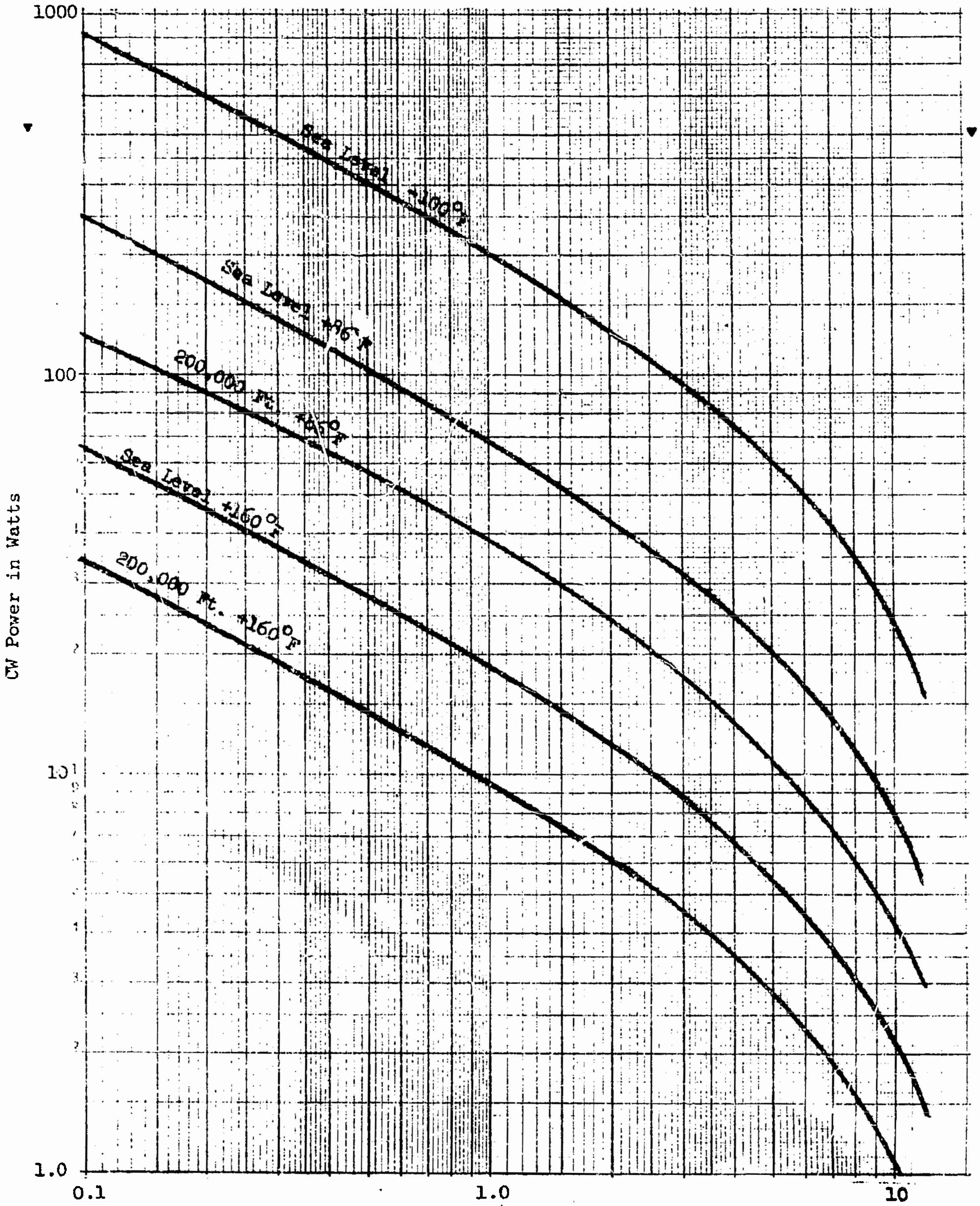
Curves of CW Power Handling capability versus frequency for the Teflon and Polyethelene cable types tested are shown in Figures 15 through 23. the curves, which are based on tests conducted as discussed in Paragraph 3, have been derated thirty percent below the actual test data points to accommodate the effects of typical system installations (i.e. bends, clamps, thermally insulated sections, etc.). The curves are plotted for a range of ambient temperatures and altitudes which correspond generally to the practical environmental operating range of the associated cable. Derating factors to account for VSWR values greater than 1.0 are shown in Figure 31. Information as to the rating of a cable at an intermediate environment may be determined by interpolation using the derating curves for altitude and ambient temperature given in Figures 32, 33, and 34.

4.1.2 Silicone Rubber Dielectric Cables

A cursory examination of predicted RF performance characteristics of the selected silicone cables indicated their practical operating frequency range to be confined to rather low frequencies. The initial series of CW tests on all three cable types supported the accuracy of these predictions. The cables become extremely lossy as frequency is increased above the HF range. They are essentially useless for the transmission of RF energy over most of the frequency range covered by this program.

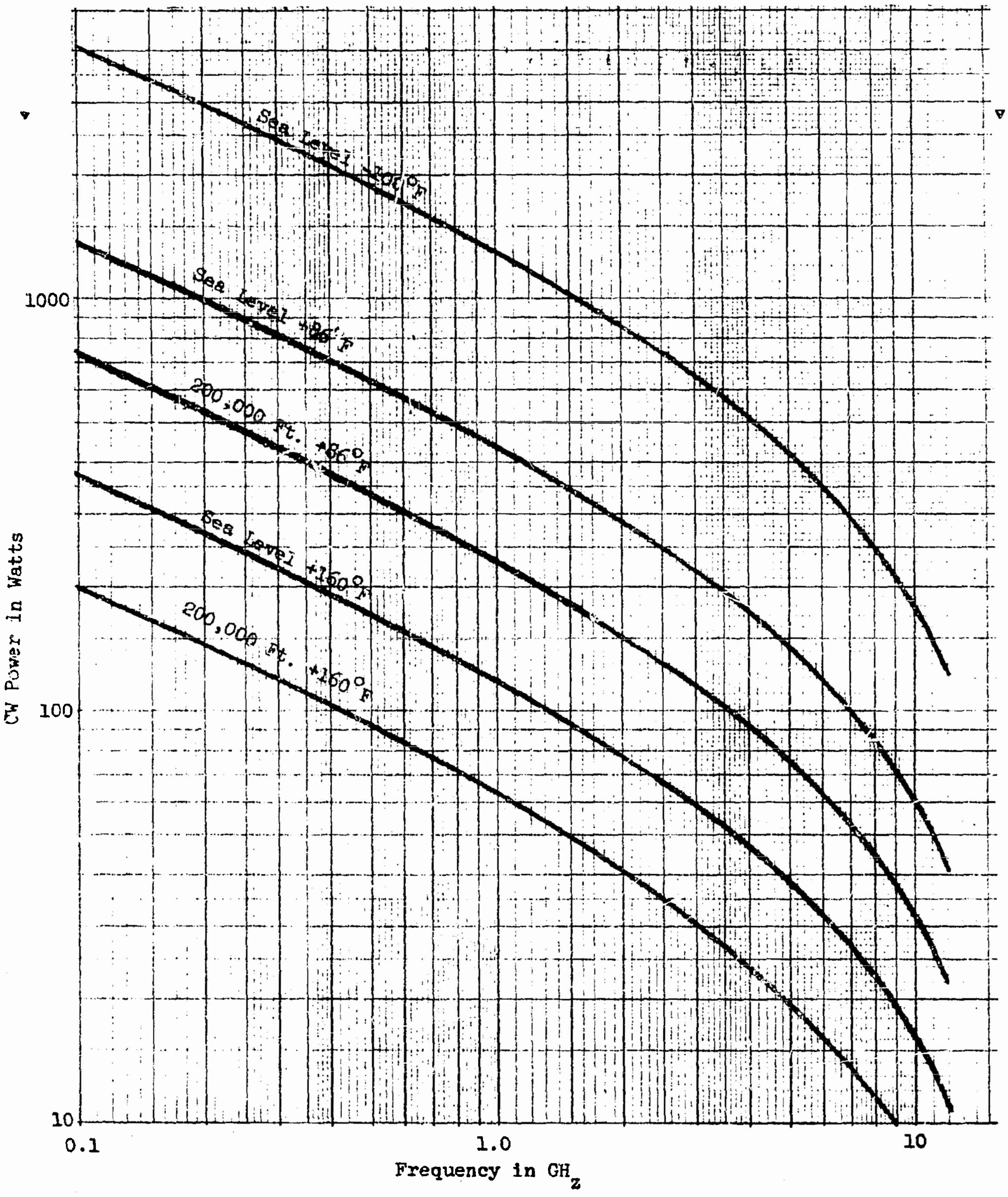


AVERAGE POWER RATING OF SELECTED
POLYETHYLENE DIELECTRIC CABLES
FIGURE 15



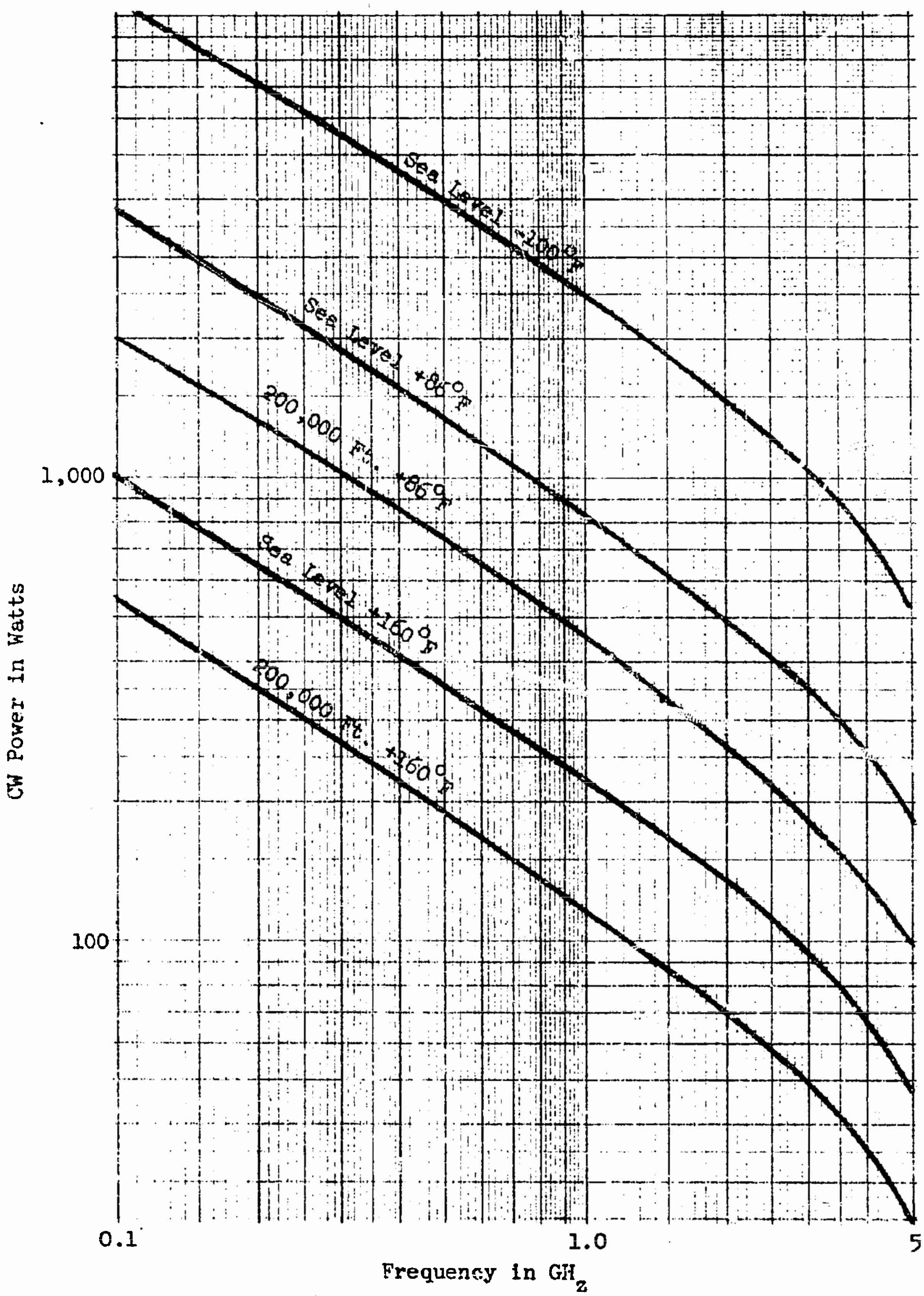
AVERAGE POWER RATING OF RG58C/U

FIGURE 16



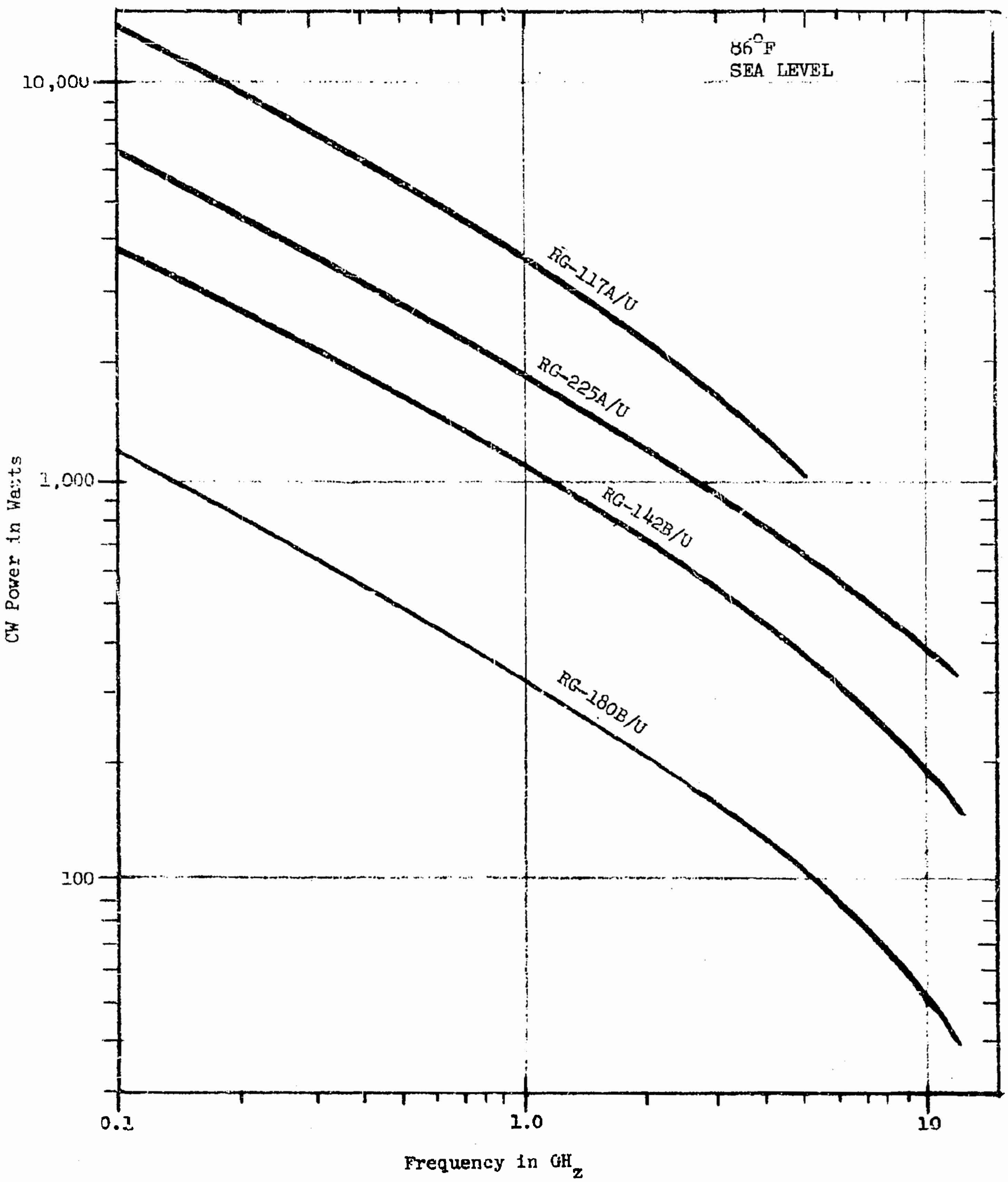
AVERAGE POWER RATING OF RG214/U

FIGURE 17



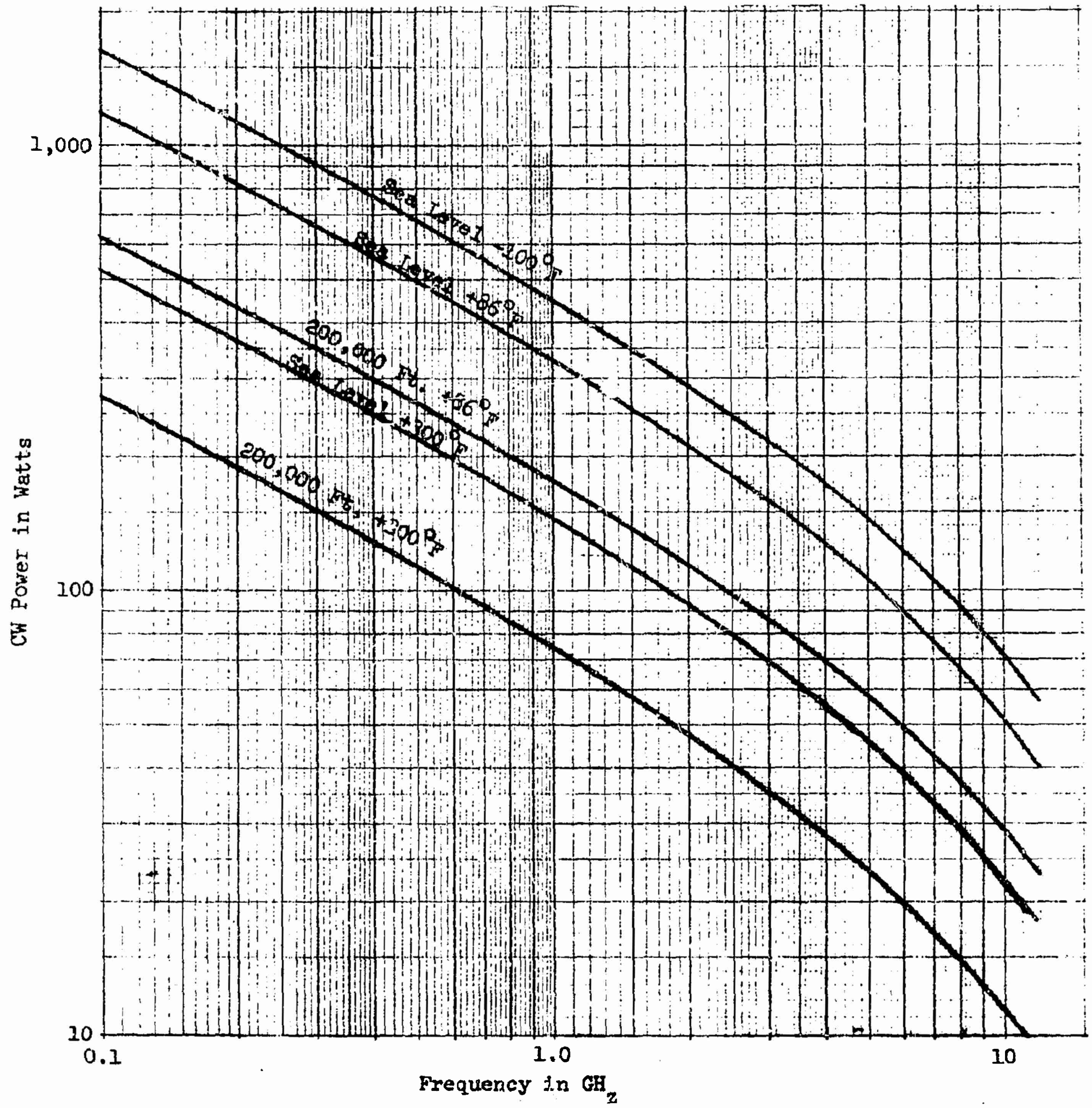
AVERAGE POWER RATING OF RG218/U

FIGURE 18



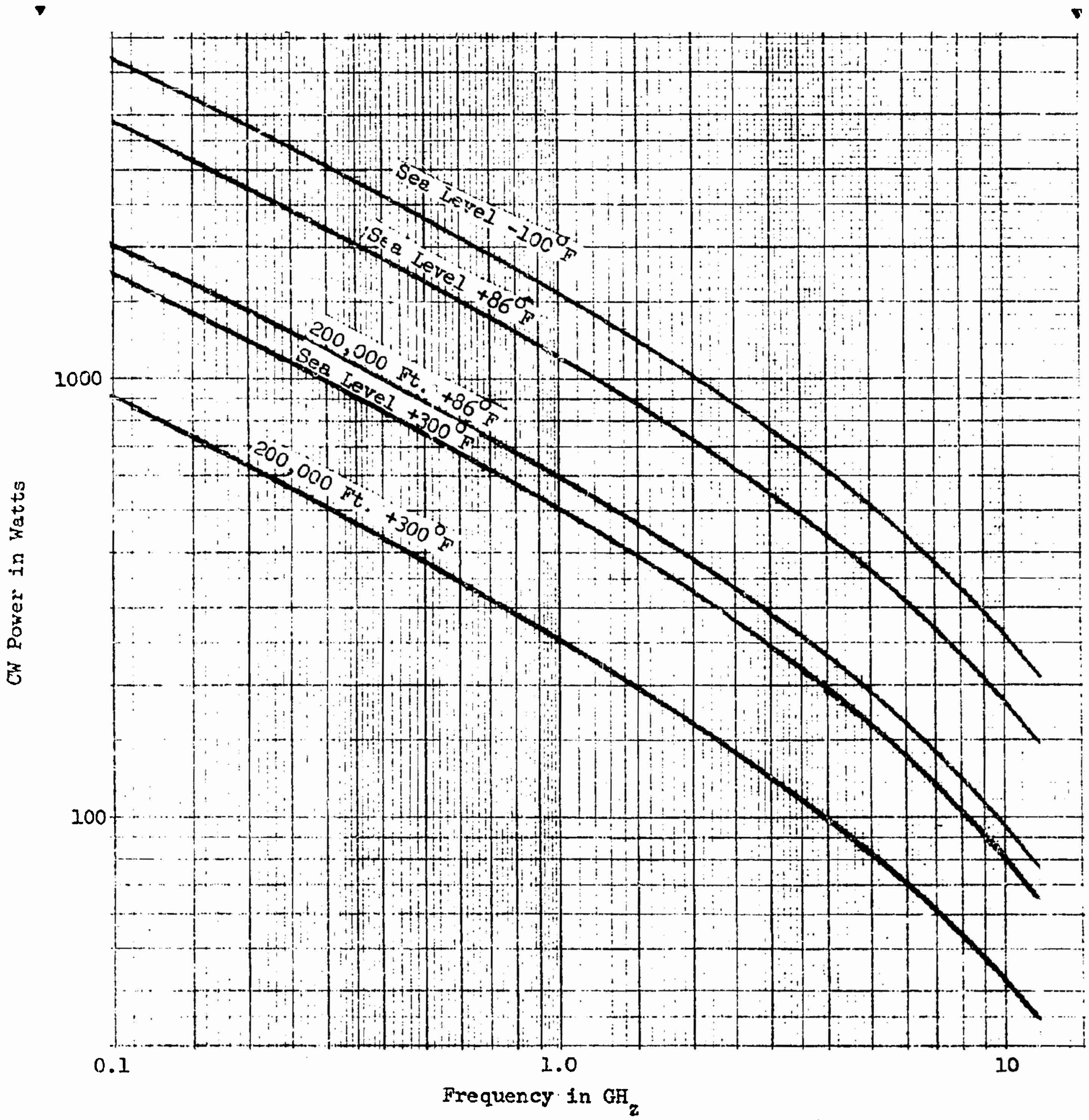
AVERAGE POWER RATING OF SELECTED TEFLON DIELECTRIC CABLES

FIGURE 19



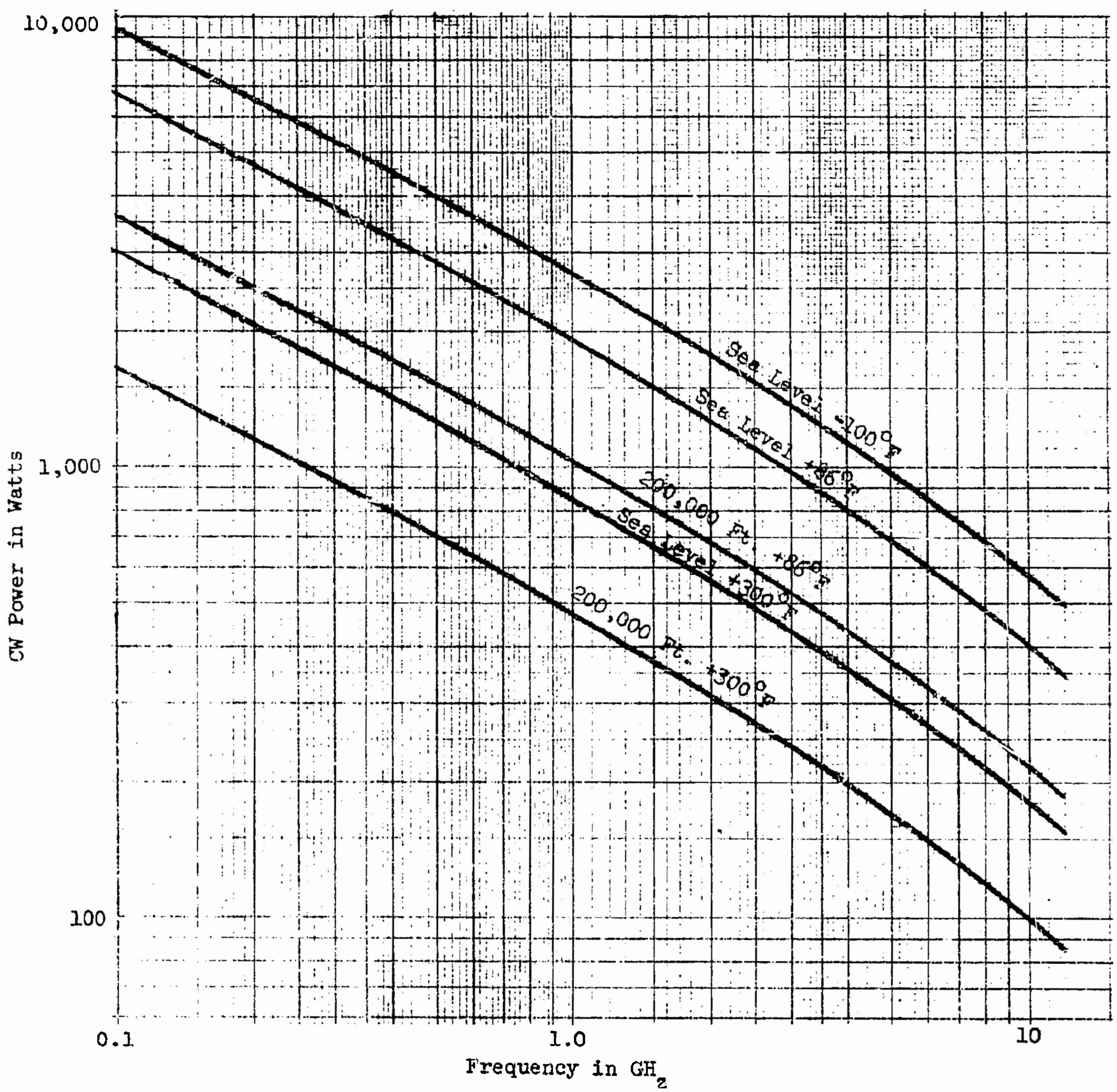
AVERAGE POWER RATING OF RG180B/U

FIGURE 20



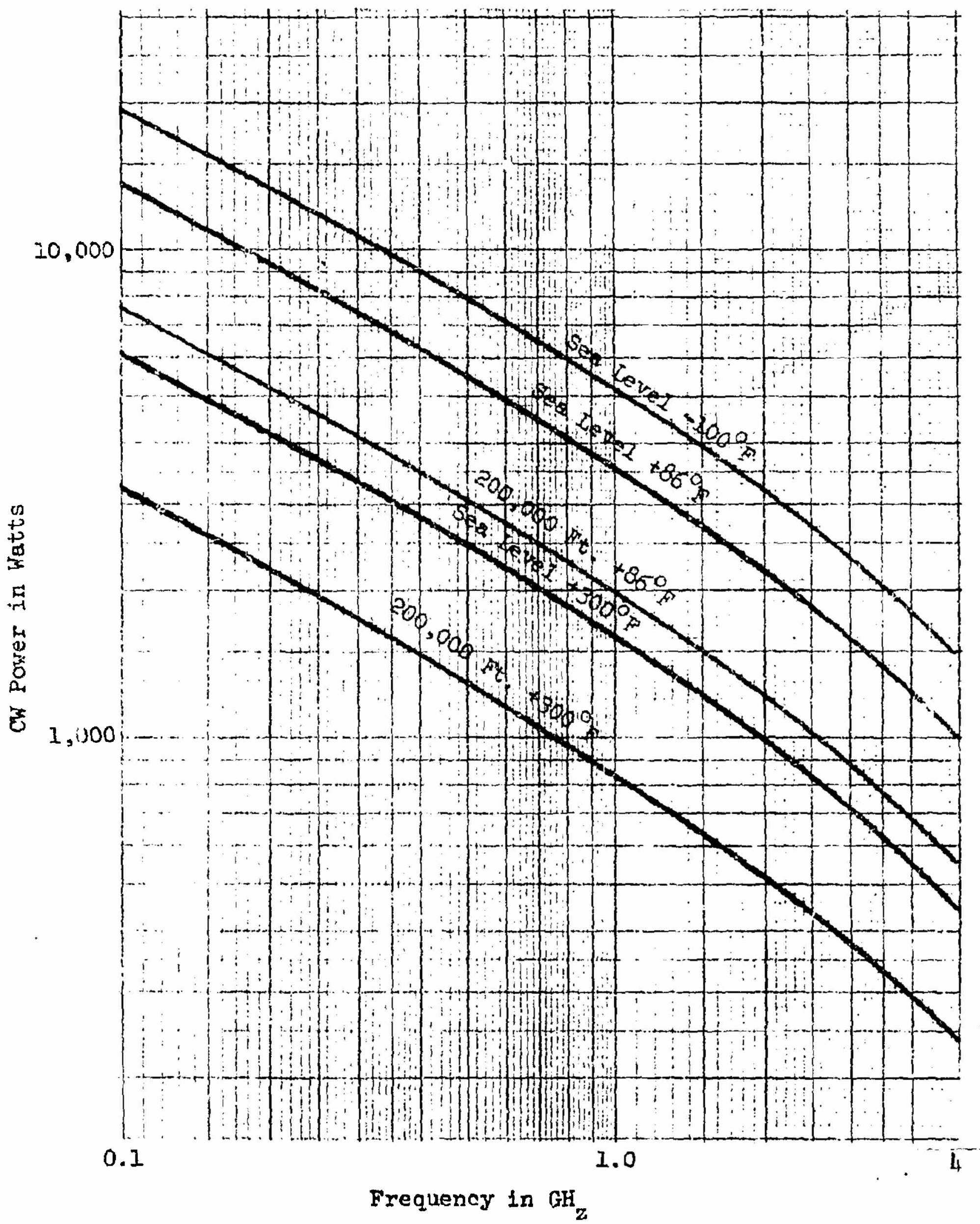
AVERAGE POWER RATING OF RG142B/U

FIGURE 21



AVERAGE POWER RATING FOR RG225A/U

FIGURE 22



AVERAGE POWER RATING OF RG117A/U

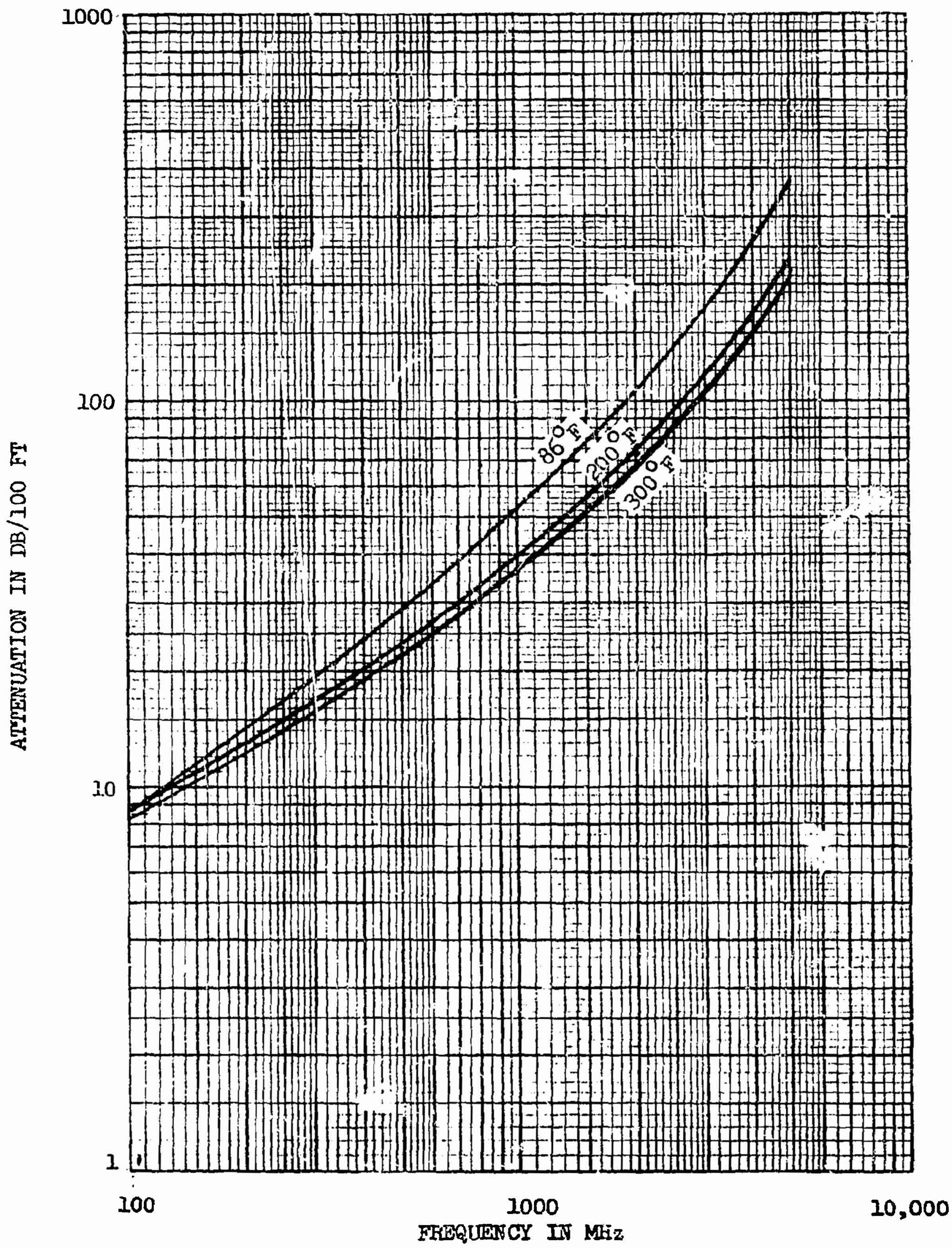
FIGURE 23

A detailed examination of the materials used in these test cables revealed the primary contributor to loss was the silicone rubber dielectric. The magnitude of this dielectric loss does not remain constant versus frequency or temperature nor does it vary in a manner characteristic of most microwave dielectrics. Contacts with the cable supplier and subsequent information obtained from the silicone rubber supplier indicated a large dependency on RF frequency and temperature. Depending on the particular compound used, the dielectric loss tangent may increase by a factor of 5[1] with increasing frequency between 1 MHz and 10 GHz and may decrease by a similar factor with increasing temperature from 25°C to 200°C. Dielectric constant also undergoes a significant change as a function of temperature with the result that cable characteristic impedance is temperature sensitive. In addition, these variables are interrelated in a rather complicated manner and for a particular chemical compound are dependent upon the exact process (cure temperature, cure time, etc.) used during the fabrication of the cable. In general, the silicone rubber cables can be described as behaving in a manner quite unbecoming to a microwave transmission line.

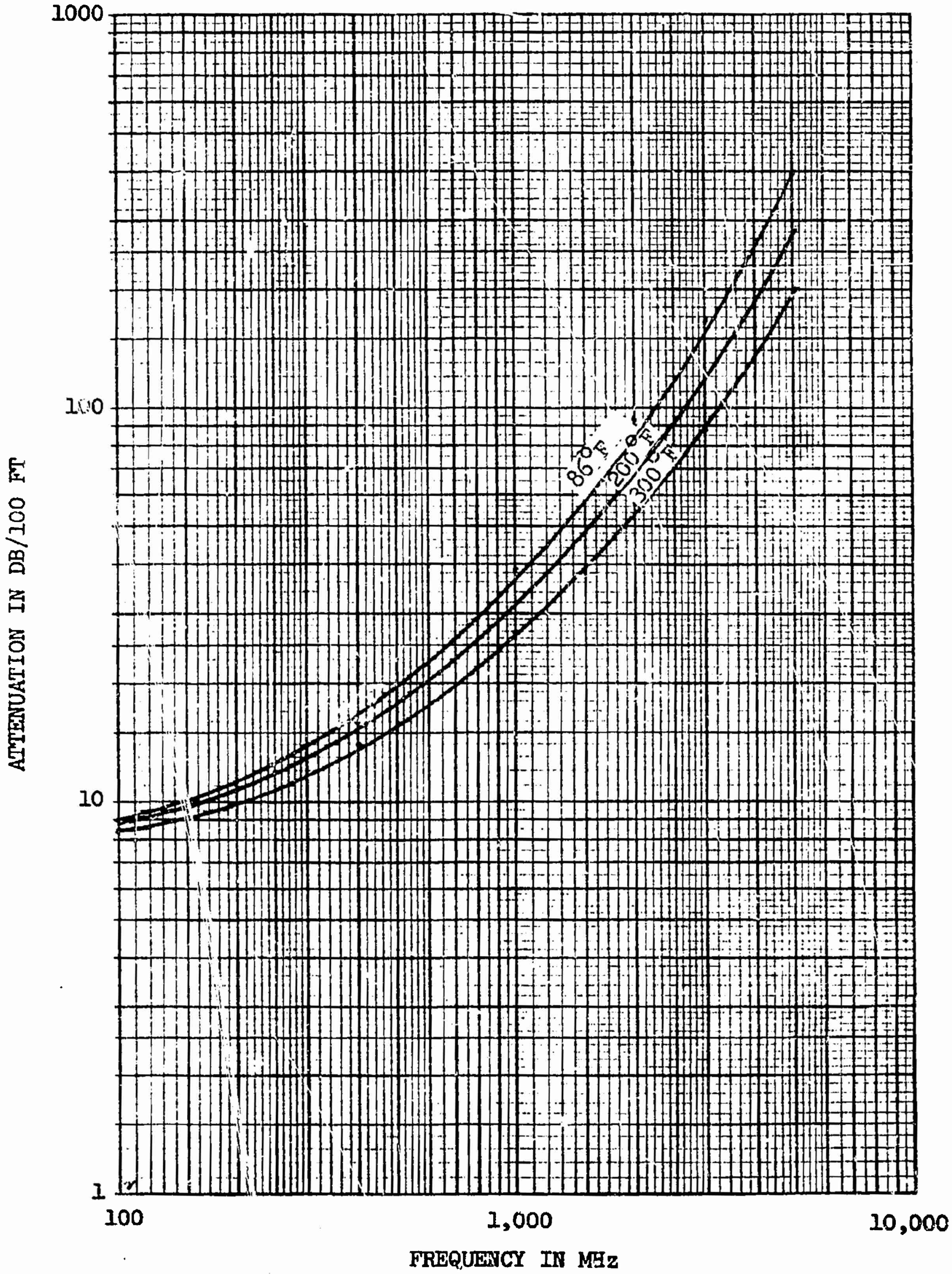
Attenuation measurements made at low power levels over a wide frequency range and under various temperature conditions confirmed the loss peculiarities as described above although the actual high power situation wherein a variation of dielectric temperature across the diameter of the dielectric could not be simulated. Plots of these attenuation measurements are shown in Figures 24, 25 and 26.

A second series of high power tests was conducted. The set of CW power rating curves based on these retests are shown in Figures 27 through 29.

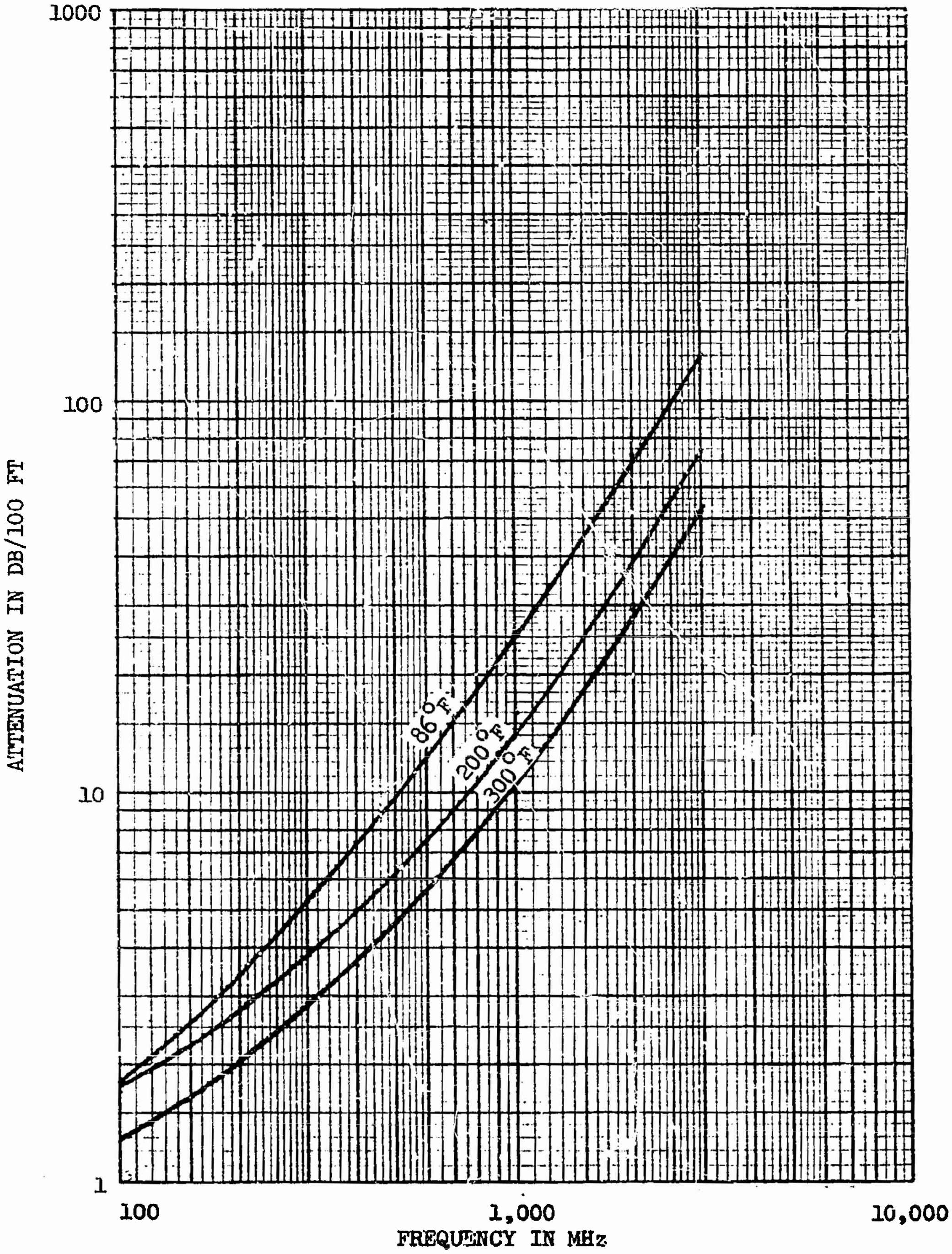
[1]Maynard G. Noble, Fundamental Electrical Properties of Silicone Rubber Compounds, October 8, 1956.



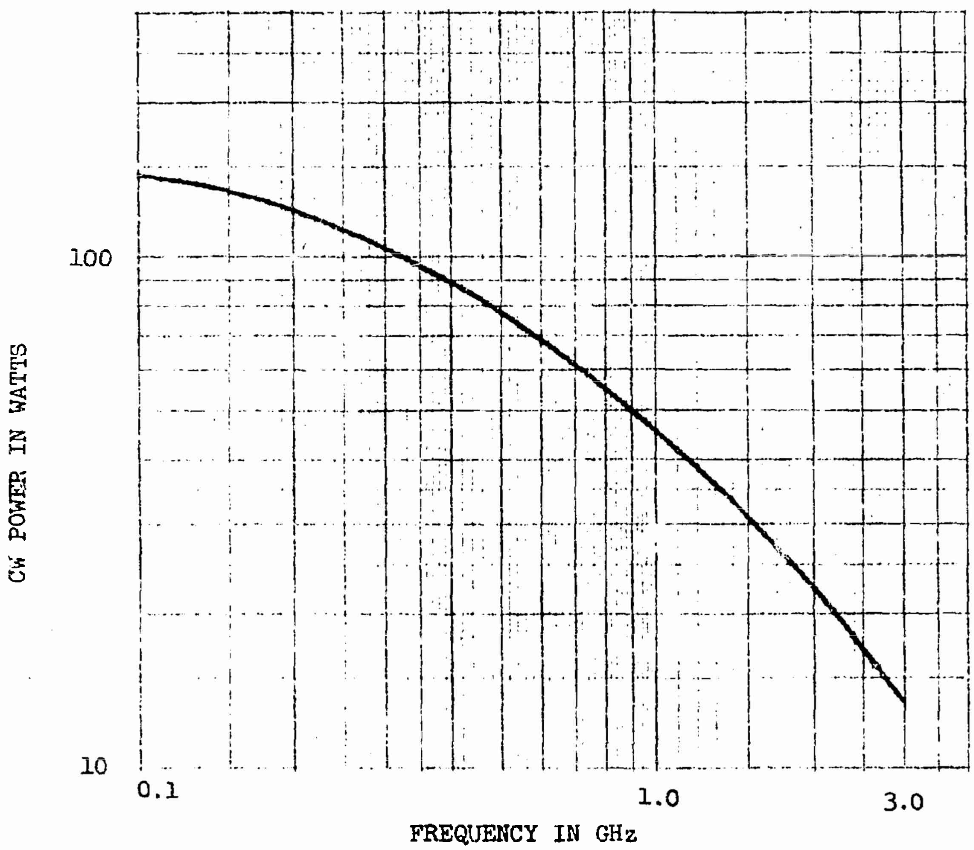
ATTENUATION VS FREQUENCY OF BIW-7870-C-G24
FIGURE 24



ATTENUATION VS FREQUENCY OF BIW-8482-C-G26
FIGURE 25

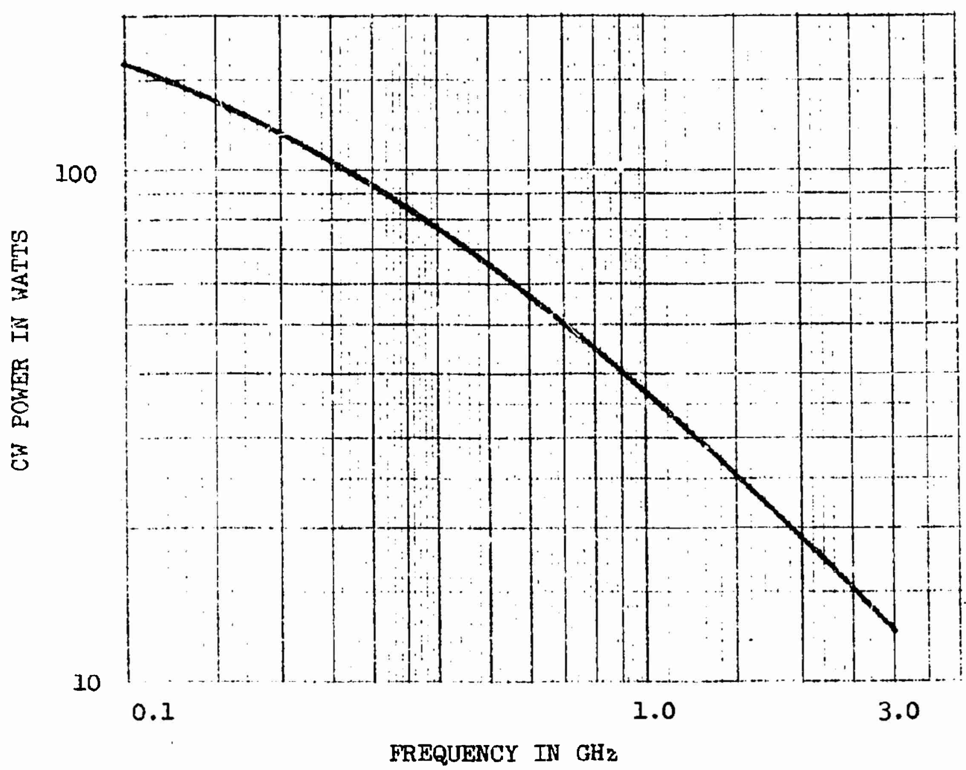


ATTENUATION VS FREQUENCY OF RG 296/U
FIGURE 26



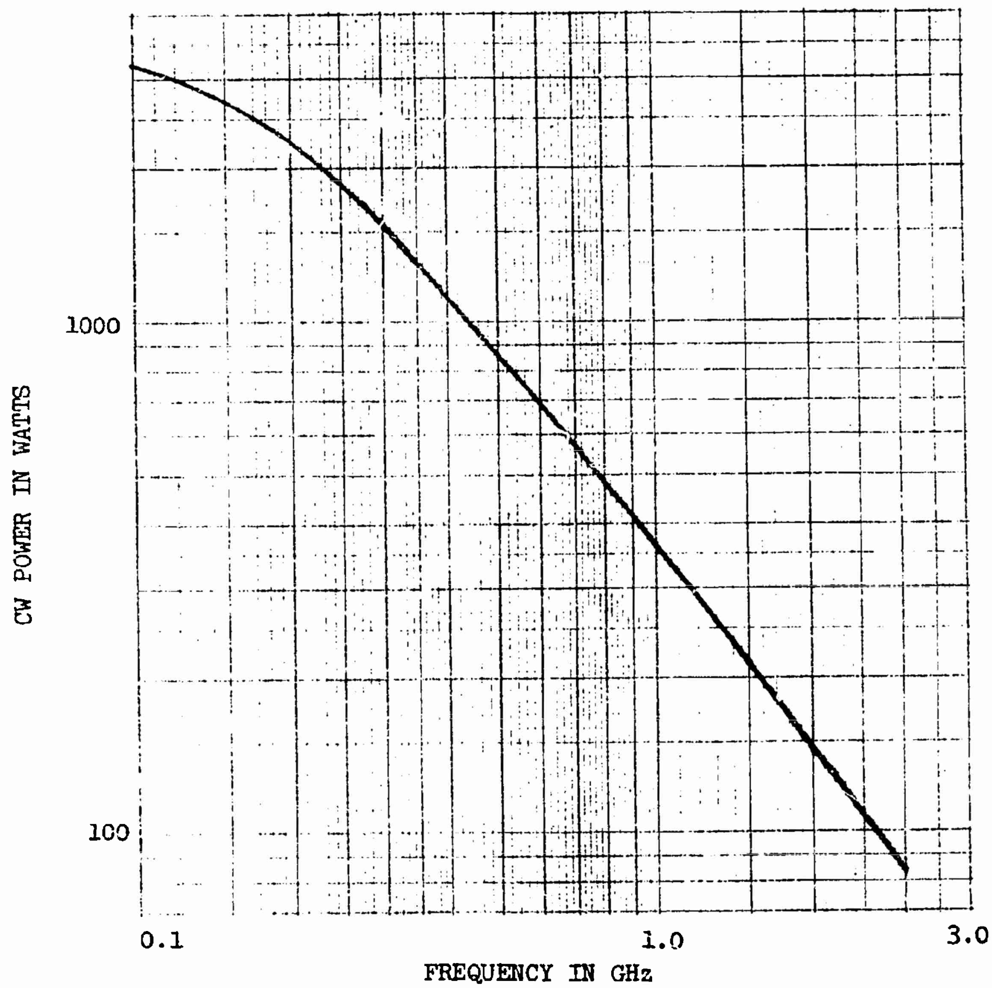
AVERAGE POWER RATING OF BIW-7870-C-G24

FIGURE 27



AVERAGE POWER RATINGS OF BIW-8482-C-G26

FIGURE 28



AVERAGE POWER RATINGS OF RG 296/U

FIGURE 29

4.2 Peak Power (Voltage Breakdown) Tests

Pulse power tests conducted on the ten cable types over the frequency and ambient environment ranges used for the CW tests revealed the breakdown power levels to be generally insensitive to frequency, to ambient temperature and to altitude within the operating ranges of the cables. The only exception being the teflon dielectric cables which exhibited a marked decrease in breakdown power level a higher ambient temperatures. A search of available literature[1] on the properties of teflon revealed that TFE Teflon undergoes a significant change (step function decrease) in dielectric strength of about 25 percent as temperature is increased above approximately 100°F. These relative voltage levels correspond favorably with breakdown power levels experienced on RG 225 samples which had similar corona extinction voltage levels but were power tested at room ambient temperature and at elevated temperatures.

A review of the characteristics of known categories of electronic systems which might be expected to approach the peak power ratings of the teflon cables tested revealed that average power heating would raise the cable center conductor temperature to the region where the lower power (higher temperature) rating would apply. For this reason the recommended maximum peak power ratings for teflon cables are with respect to this lower value.

A considerable variation in corona extinction voltage was noted in samples taken from adjacent locations on the procured lengths of cable - the largest variation being approximately 25 percent in RG 225 samples. The RF breakdown power

[1] Doban R.C., Sperati, C.A., and Sandt, B.W., The Physical Properties of "Teflon" Polytetrafluoroethylene, Society of Plastics Engineers Journal, Volume 11, Number 9, November 1955.

levels for samples exhibiting this difference in corona extinction values, varied by approximately 50 percent - the lower corona value corresponding to the lower breakdown level.

The available samples of BIW 8482-C-G26 cable possessed a mechanical condition wherein the cable center conductor exhibited periodic "kinks" resulting in a center conductor offset with respect to the centerline of the dielectric approximately every six to eight inches along its length. The offset was approximately equal to the diameter of the center conductor. As would be expected, RF breakdown occurred at these points. The breakdown level for this type of cable if properly constructed would undoubtedly be higher than that listed in Table II which is based on the test values.

Recommended maximum peak power levels for the ten cable types tested are listed in Table II. These tabulated values were obtained by derating the actual test breakdown power level values by 25 to 50 percent to take into account the differences between the long and short term breakdown properties of the dielectric involved, and the variation in the corona extinction values of the tested samples relative to the required minimum values specified in MIL-C-170.

TABLE II

MAXIMUM RECOMMENDED PULSE POWER RATINGS

CABLE TYPE	MAXIMUM RECOMMENDED PEAK POWER (WATTS x 10^6) VSWR = 1.0:1
RG 58C/U	.08
RG 214/U	.25
RG 218/U	2.50
RG 180B/U	.08
RG 142B/U	.30
RG 225A/U	.35
RG 117A/U	4.0
BIW 8482-C-G26	.10
BIW 7870-C-G24	.20
RG 296/U	3.0

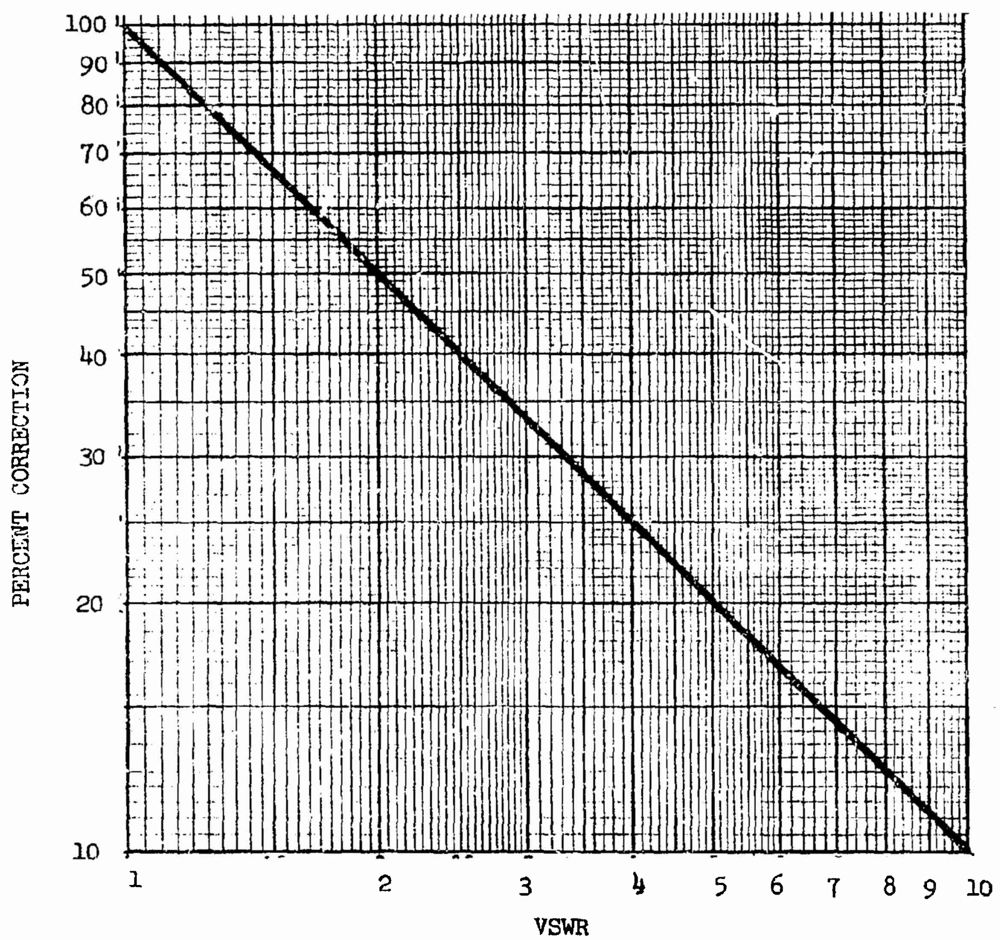
5.0 APPLICATION GUIDELINES

The recommended maximum power ratings provided by Figures 15 through 23, 27 through 29, and by Table II are based on a VSWR of unity and on the temperature and altitude conditions as noted. Corrections to account for other conditions may be determined as discussed in this section.

5.1 VSWR Derating

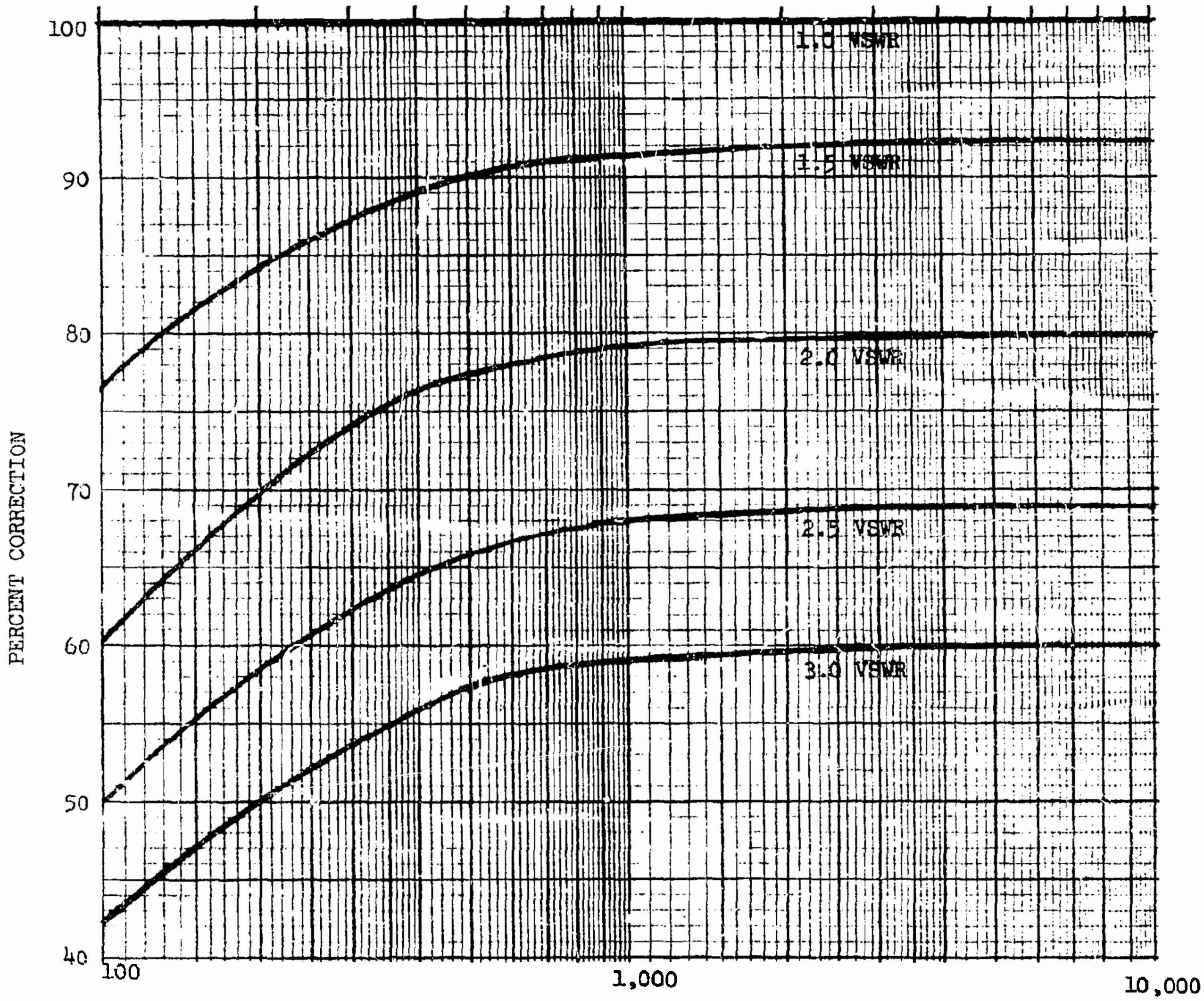
The pulse power rating of a cable based on a 1:1 VSWR must be decreased if a higher voltage standing wave exists on the cable. The magnitude of this necessary derating can be determined by the expression $\frac{1}{VSWR}$. Figure 30 shows percent derating versus VSWR and can be applied directly to the ratings given in Table II.

The CW power rating of a cable is also affected by voltage standing wave ratio, or rather by the associated power standing wave. In this case the relation is more complicated since it involves not only the magnitude of the standing wave but also the thermal characteristics of the cable and the physical spacing between the power standing wave peaks. For solid dielectric cables of the types considered by this program the thermal characteristics are predominately determined by cable diameter. The spacing between power maximums is determined by frequency. The magnitude of this necessary CW derating can be calculated from the expression $\frac{2\ (VSWR)}{(VSWR)^2 + 1 + K\ ((VSWR)^2 - 1)}$ where K is a factor which considers cable characteristics and frequency. Figure 31 shows percent derating versus frequency for VSWR values from 1.0 to 3.0 and can be applied directly to the curves of Figures 15 through 23 and 27 through 29.



VSWR CORRECTION - PULSE POWER

FIGURE 30



VSWR CORRECTION - AVERAGE POWER

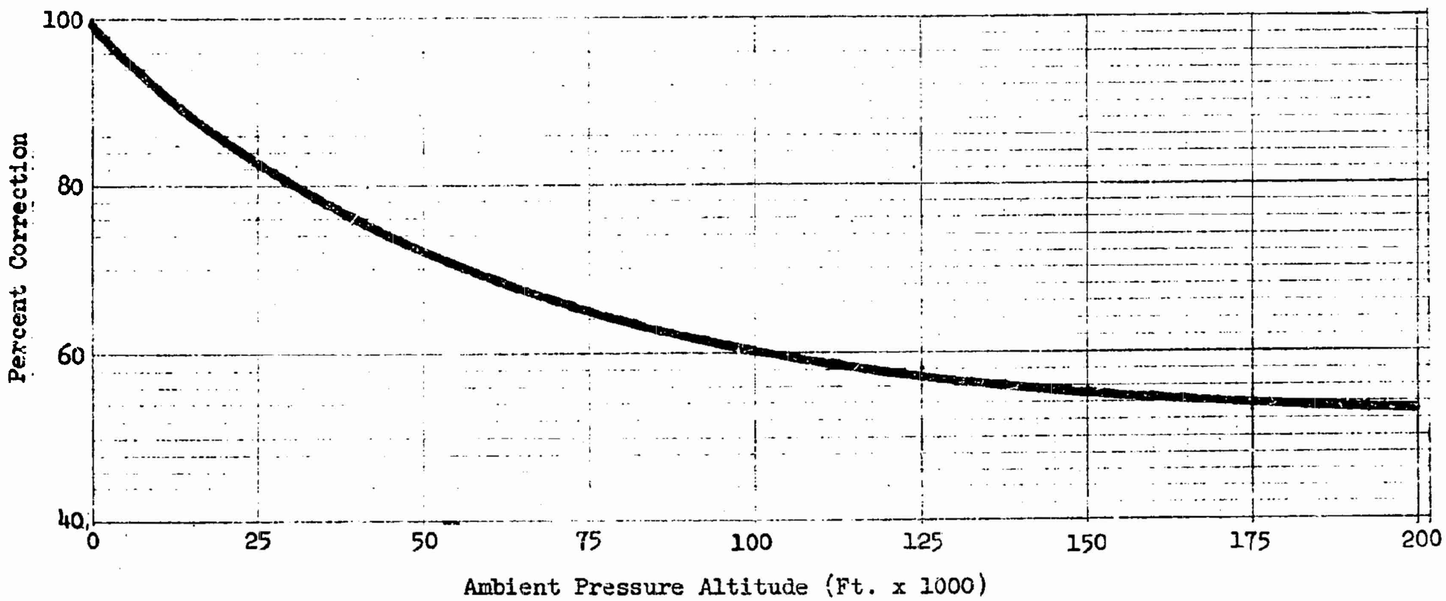
FIGURE 31

5.2 Intermediate Duty Cycles

The Pulse power ratings of Table II are based entirely on voltage breakdown limitations whereas the CW ratings are determined by allowable cable temperature. Both limitations must be recognized when choosing a cable for a particular application. This selection can be accomplished quite simply by first determining that the operating pulse power level, properly derated for system VSWR, will not exceed the value for the cable being considered (Table II). The required average power level is then determined from system pulse level and duty cycle and checked against the candidate cable CW rating curve which has been properly derated for system VSWR and operating environment.

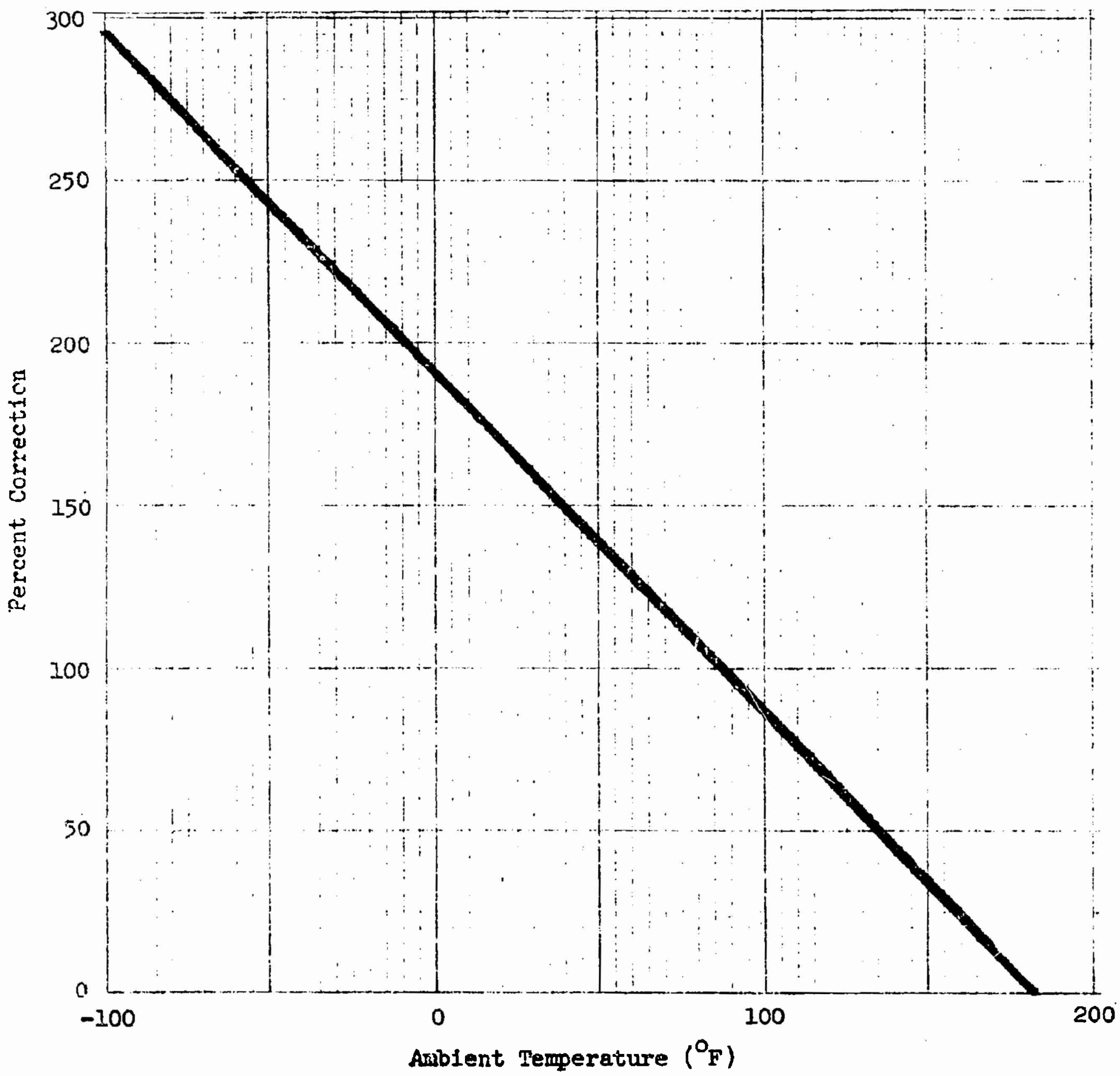
5.3 Intermediate Environments

The Pulse power test results indicate the RF voltage breakdown capability of the cable types tested to be fairly insensitive to environmental conditions with the exception of the temperature dependency of Teflon as discussed in paragraph 4.2. This obviously is not true in the case of CW or average power handling. Curves plotted in Figures 15 through 23 show CW power handling ratings for nominal (sea level - 86°F) and limiting environmental conditions. The rating for any intermediate environment may be obtained by referring to Figure 32 for the appropriate altitude derating factor and to Figures 33 or 34 for the proper temperature modifying factor. These corrections are then applied to the sea level 86°F power rating curve (Figures 15 or 19) for the cable type under consideration.

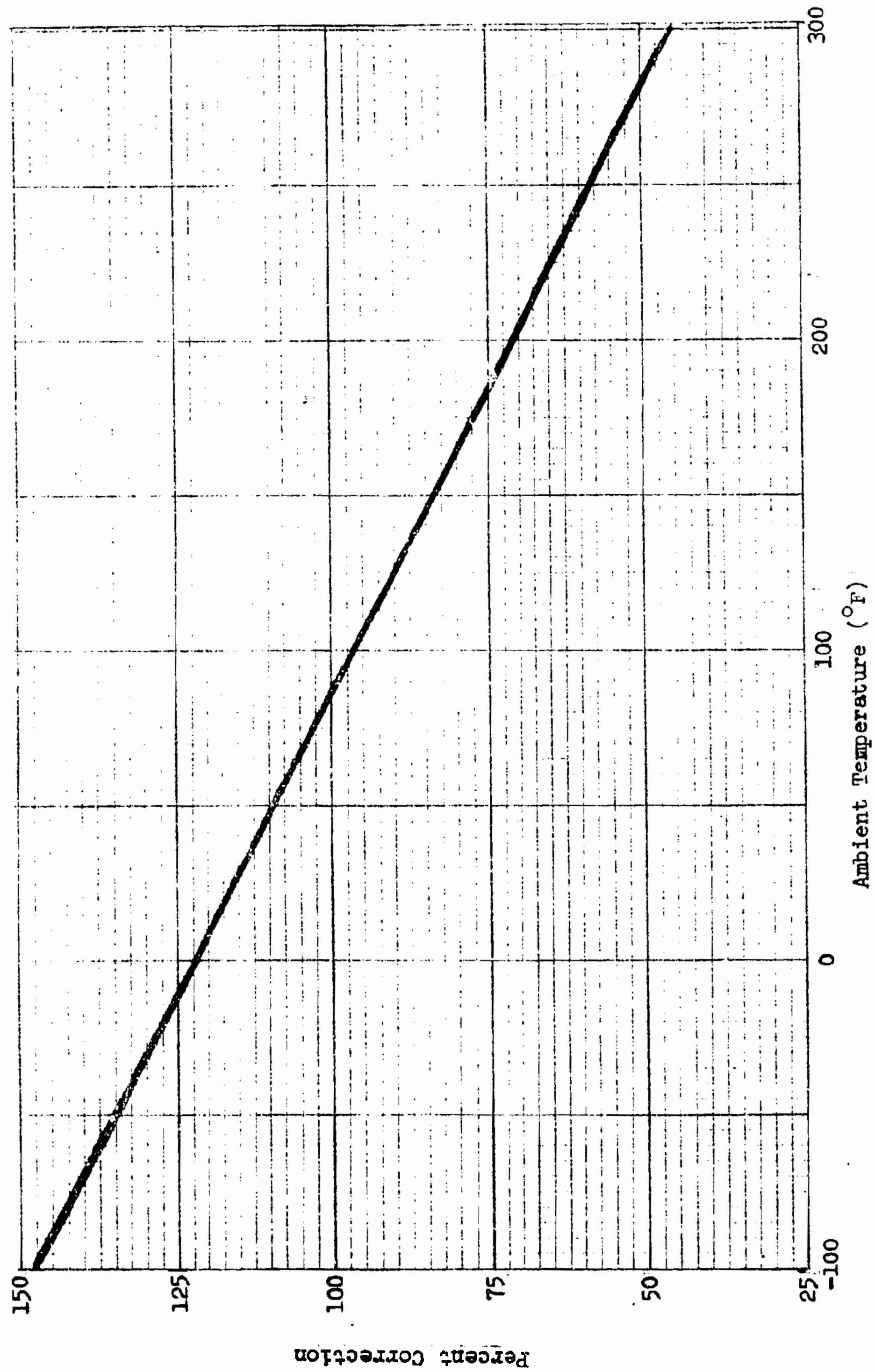


PRESSURE ALTITUDE CORRECTION

FIGURE 32



TEMPERATURE CORRECTION - POLYETHELENE DIELECTRIC
FIGURE 33



TEMPERATURE CORRECTION - TEFLON DIELECTRIC

FIGURE 34

6.0 SUMMARY AND RECOMMENDATIONS

The information contained in this document is based on extensive testing and subsequent analysis of the test results. This analysis recognized relevant practical considerations such as installation related factors and cable variations within the constraints of the associated controlling specification. The resulting recommended maximum values and application guidelines are intended to provide a safe and easily used system wherein the suitability of a given cable can be determined for a specific application.

Although not an element of this program, it should be recognized that the connectors required in a practical transmission line installation will usually impose a peak power limit and may impose a CW limit significantly below that of the associated cable. To complete a total transmission system design, the designer must have knowledge of the power handling capability of the intended connectors. It is recommended that a similar test and analysis program be conducted to determine power ratings for commonly used connector series.