PHASE STABILITY
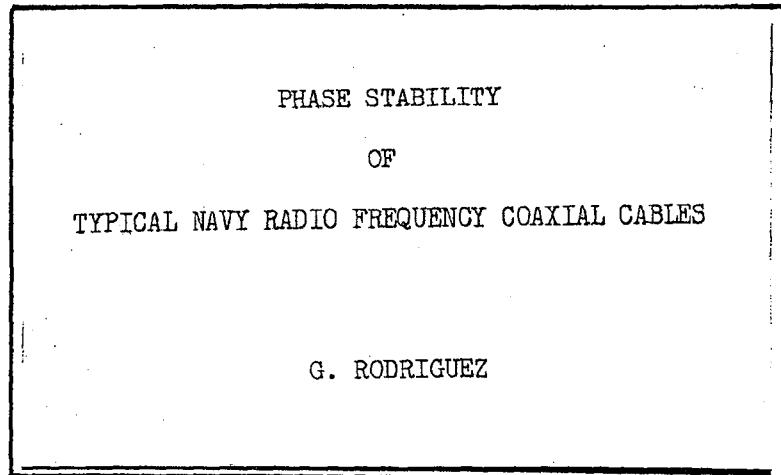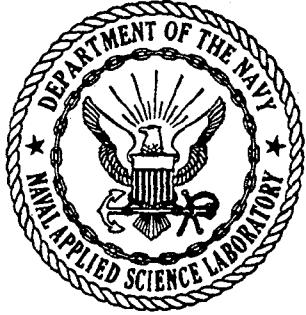
OF

TYPICAL NAVY RADIO FREQUENCY COAXIAL CABLES

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In systems where electrical energy is fed from a common source or collected
from scattered sources through transmission lines, the phase distortion at
the far end of the lines depends on the equality of the electrical length of
the transmission lines.

Many of the present military installations utilize highly phase-sensitive
electronic systems, of which radio frequency coaxial cables are essential
components. It follows that the change in electrical length (the physical
length of an air line of equal delay) of the transmission line is an important
factor in the coaxial cable design. In phase-sensitive systems temperature
variations, bending and flexing, frequency, vibrations, mechanical tension,
humidity and equality of physical length are contributing factors affecting
phase stability. This paper is mainly concerned with braided coaxial cables
and the only factor considered is the variation of electrical length with
temperature. Most of the other factors have been considered by Kushner[1].
Phase stability is defined in this paper as the ability of a cable to main-
tain a constant velocity of phase propagation throughout a temperature range.

When a coaxial cable is exposed to temperature variations its electrical
length is affected by changes in dielectric constant and by changes in the
physical length. Practical non-polar dielectric materials decrease in density
as the temperature increases, with corresponding (but not necessarily propor-
tional) decrease in dielectric constant. Actually, some polar dielectrics
increase in dielectric constant with rising temperature but these materials
are not used for high frequency dielectrics. Since velocity is inversely
proportional to the square root of the dielectric constant, and electrical
length as defined in this paper is inversely proportional to velocity, the
consequence is that electrical length decreases with increasing temperature
if changes in mechanical length are neglected. For solid polyethylene between
0°C and 60°C the specific volume increases about 600 parts per million per
degree Centigrade (PPM/°C) and the dielectric constant decreases about 350
PPM/°C. Arbuthnott, Gehn and Nevin[2] measured the dielectric constant change
of solid polyethylene between 25°C to 65°C as about 325 PPM/°C and that of one
type of foamed polyethylene between 25°C to 40°C as about 110 PPM/°C and
between 45°C to 65°C as about 15 PPM/°C. Fluorinated polyolefins change about
half as much.

The physical length of a transmission line with a tubular outer conductor in-
creases with temperature at a rate determined mainly by the coefficient of
expansion of the metal conductors, 18 PPM/°C for copper. Actually polyethylene
(or other resin) expands at about 10 times this rate but with such a low modulus

compared to copper that the length is mostly fixed by the conductors. The increase in physical length therefore opposes the decrease in electrical length caused by the change in density. Cables having a braided outer conductor sometimes decrease in mechanical length as the temperature rises. This may be caused by the braid acting as a Kellem's grip in reverse or by excessive orientation of the dielectric during extrusion. Appendix A of reference 3 contains an analysis of the effect of the braid angle. If the cable shortens, the change in mechanical length adds to the effect of change in density. The effective density of semi-solid dielectrics, but not of foamed dielectrics, changes but little with temperature, if the dielectric is confined physically, particularly when the outer conductor is a tube which does not distort appreciably under the pressure of the dielectric. In such cables the solid part of the dielectric expands by displacing some of the air rather than by increasing the volume between the inner and outer conductors.

In order to ascertain the magnitude of change in velocity representative cables with polyethylene (PE), Teflon (TFE), and Polystyrene Tapes (PST) dielectrics were selected for investigation of changes in electrical length with temperature. Table 1 shows the types of cable used and their braid angles.

Cable specimens for phase stability measurements were placed in a conditioning chamber at room temperature. One end of the cable was left unterminated and the other end was brought out of the chamber and connected to one end of a slotted line. The other end of the slotted line was connected to a radio frequency oscillator through a 5 db pad. The VSWR of the system, without the cable, was less than 1.01 at 400 MHz, when terminated with a 50 ohm load. Frequency (400 MHz) was monitored to within 0.01 MHz by use of a heterodyne frequency meter loosely coupled to the oscillator. Figure 1 is a block diagram of the circuit used for the investigation. Using the probe position of the null of the voltage standing wave indicator as reference, the changes in position of the probe were observed while the cable temperature was varied. The temperature of the forced draft conditioning chamber was varied through a heat cycle consisting of at least 2 hours at 27°C, 2 hours at 0°C, 2 hours at -40°C, 2 hours at 27°C, 2 hours at 40°C, 2 hours at 60°C, 2 hours at 85°C and 2 hours at 27°C. The difference between the reference null and the null at each temperature was taken as the change in electrical length of the cable. In some instances a cable sample was exposed to several cycles and probe position observed at other temperatures within the cycle. Results of the increase in electrical length of the cables are shown in Table 2.

The coefficient of increase in electrical length or coefficient of phase stability of each cable was computed in the temperature range from 27°C to 85°C, except types RG-252/U, Phase Stable Cables 1 and 2, and RG-236/U which were computed in the temperature range from 27°C to 60°C and type RG-268/U was computed between 27°C and 70°C. The following formula was used to compute the coefficient of increase in electrical length:

$$K = \frac{\Delta N \times V \times 10^6}{\Delta T \times L}$$

3

where   K = coefficient of increase in electrical length
            in parts per million per degree centigrade

ΔN = change in probe position in meters

ΔT = change in temperature in °C

L = length of cable in oven in meters

V = velocity of propagation of cable dielectric
    in per cent.

Table 3 shows the computed values of coefficient of phase stability for each cable and figures 2, 3 and 4 are graphical representations of results from samples No. 12, 13 and 14, respectively.

Change in mechanical length of 15 foot specimens of types RG-8A/U, RG-9B/U, RG-116/U and RG-62A/U was measured in the temperature range from 30°C to 85°C to determine if changes in mechanical length due to heat are significant compared to changes in dielectric constant. A simplified drawing of the method used to determine the changes in mechanical length is shown in figure 5. The cables were heated by circulating current through the outer conductor braid and the temperature was measured with thermocouples. Average changes in parts per million per degree were as follows:

Cable Type	Change in mechanical length, PPM/°C
RG-8A/U	-15
RG-9B/U	+10
RG-116/U	+5
RG-62A/U	+5

These changes in mechanical length are in terms of physical length and must be divided by the velocity of propagation of the dielectric to obtain the change in electrical length. It is noted that the change in mechanical length due to the 5 lb. weight attached to the cable was neglected, although theoretically for these types of cable the change in mechanical length due to this weight could be as much as about 125 parts per million[1]. Even with these corrections the effect of mechanical length changes is considerably less than the effect of changes in dielectric constant. It was noted that the mechanical length of the sample of RG-8A/U increased from 25°C to 40°C and then decreased as the temperature was further increased.

4

Generally it can be said that conventional coaxial cables require several cycles of heating and cooling before they become stabilized within the temperature range of the heating and cooling cycle. It has been commonly observed that cable type RG-62A/U requires about one or two cycles to reach a stable capacitance value. This is what was observed on cable type RG-62A/U above, it took 2 cycles to become stabilized.

Changes in electrical length of the presently available coaxial cables are caused mainly by the change in dielectric constant of the dielectric between the inner and outer conductors. The observed change in mechanical length is much smaller and usually opposes the effect of the change in the dielectric. Cables with semi-solid dielectric change less than cables with solid dielectric and cables with TFE dielectric change less than cables with polyethylene dielectric. Types RG-252/U and RG-236/U (air articulated transmission lines) are superior to coaxial cables with braided outer conductor. The high performance of such lines is ascribable to the balancing of dielectric change against mechanical change because of the possibility of varying the per cent of space occupied by the dielectric. Thermal stability decreases with increasing temperature, at least with solid polyethylene, indicating that test of such cables should include the highest temperature range of interest for the intended application.

This paper demonstrates the degree of phase stability with temperature variations within the range of -40°C to 85°C that exists for currently available standard cables. These cables offer coefficient of phase stability with magnitudes ranging from 6 to 480 parts per million per degree centigrade. The following should be considered as rough guides for the selection of cables in applications where phase stability is required:

a. Where a decrease in electrical length of 400 PPM/°C is tolerable use any cable as determined by other requirements of the application.

b. Where a decrease of 100 to 400 PPM/°C is the maximum tolerable use semi-solid cables similar to RG-62A/U or semi-flexible lines. (Foamed dielectric is not considered to be "semi-solid" in this paper).

c. Where a decrease of 20 PPM/°C is allowable use air-articulated lines such as RG-252/U.

d. Where a decrease 5 PPM/°C is allowable use air-articulated lines such as RG-236/U.

e. If higher degree of phase stability is required such as 2 PPM/°C or less, there are commercially available cables with phase stability of 1 PPM/°C[4] within a limited range of temperature.

When selecting a cable where phase stability is the prime factor, the temperature range as well as other environmental and electrical conditions should be carefully analyzed because a cable with a normally high phase stability, within a narrow range of temperature, may have sufficient stability to satisfy the needs of the particular application.

Table 3 indicates a coefficient of 3 PPM/°C. This is the low limit of accuracy of the measuring method used. More accurate results can be obtained using twin leg interferometers or other methods such as those described in references 5 through 10. In the measuring method used in this paper the frequency stability of the oscillator, the possibility of multiple reflections on the system and uncertainty of the exact length of the cable inside the conditioning chamber are the three sources of error in the accuracy of the method. The three sources of error were partially compensated as follows: (a) the unknown length by bringing only a short portion of the cable out of the conditioning chamber (6 inches including the connector), (b) frequency stability by measuring the frequency whenever a reading was made, (c) multiple reflections by selecting a measuring frequency at which the available connectors and slotted line have a low VSWR. This was partially controlled by measuring the VSWR of the system without the cable to 1.01.

6

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FREQUENCY METER

DETECTOR

CHAMBER

OPEN END

SPECIMEN

SIGNAL GENERATOR

5 db PAD
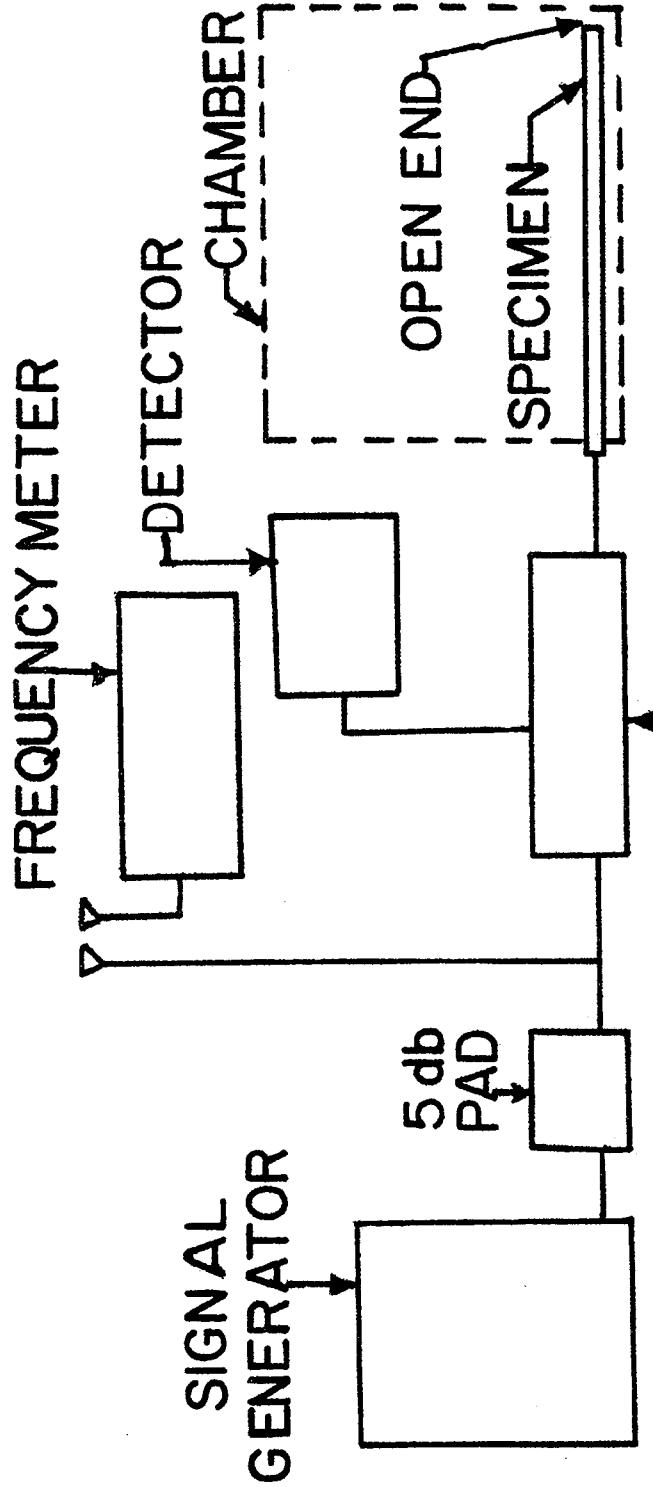
SLOTTED LINE

FIGURE I

BLOCK DIAGRAM OF MEASURING CIRCUIT

MINIMUM POSITION VS. TEMPERATURE, SAMPLE 12
FIGURE 2

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KEY
— CYCLE NO. I
--- CYCLE NO. 2
-·- CYCLE NO. 3

MINIMUM POSITION VS. TEMPERATURE, SAMPLE 13

FIGURE 3

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KEY

CYCLE NO.1
CYCLE NO.2
CYCLE NO.3
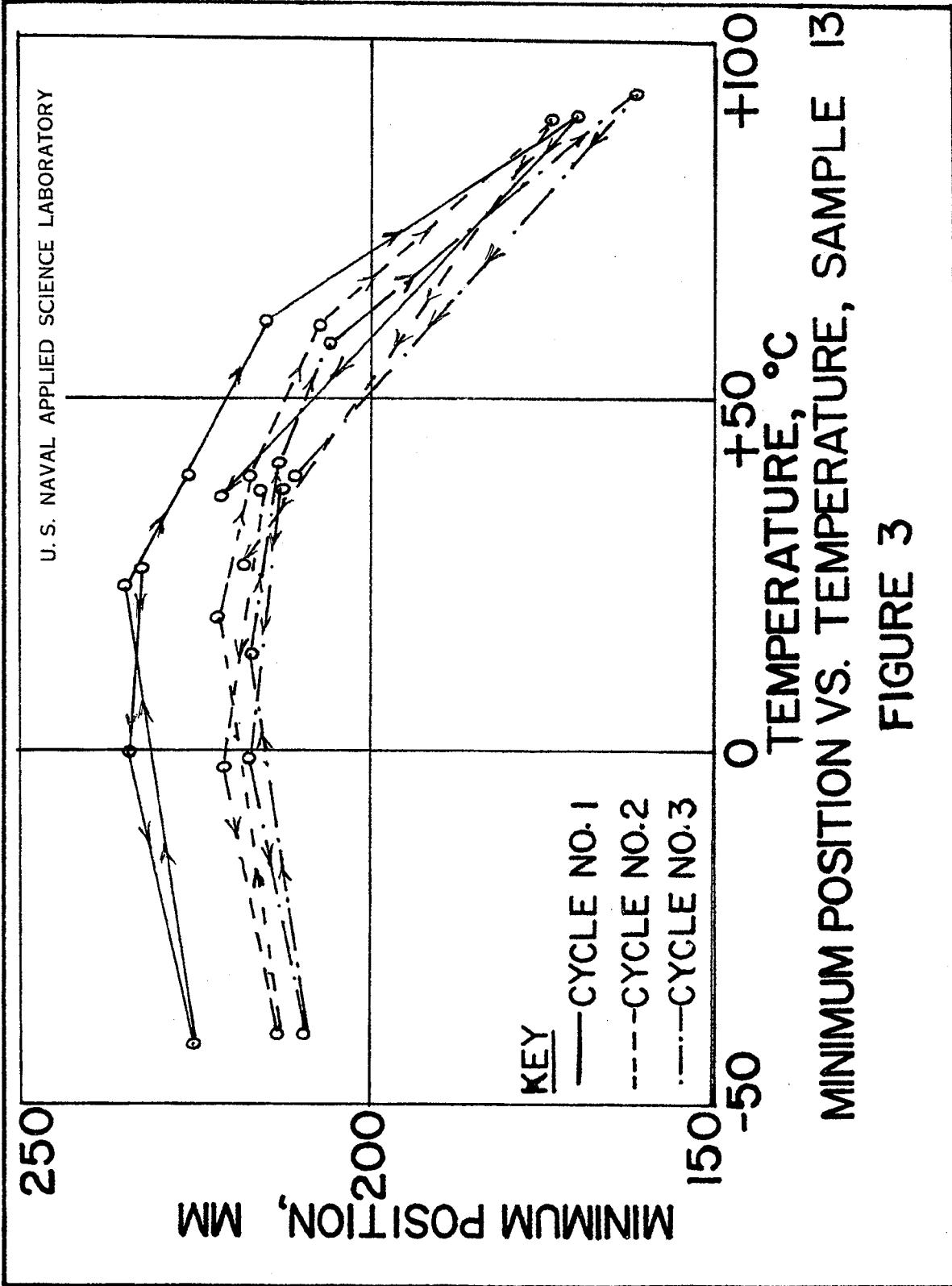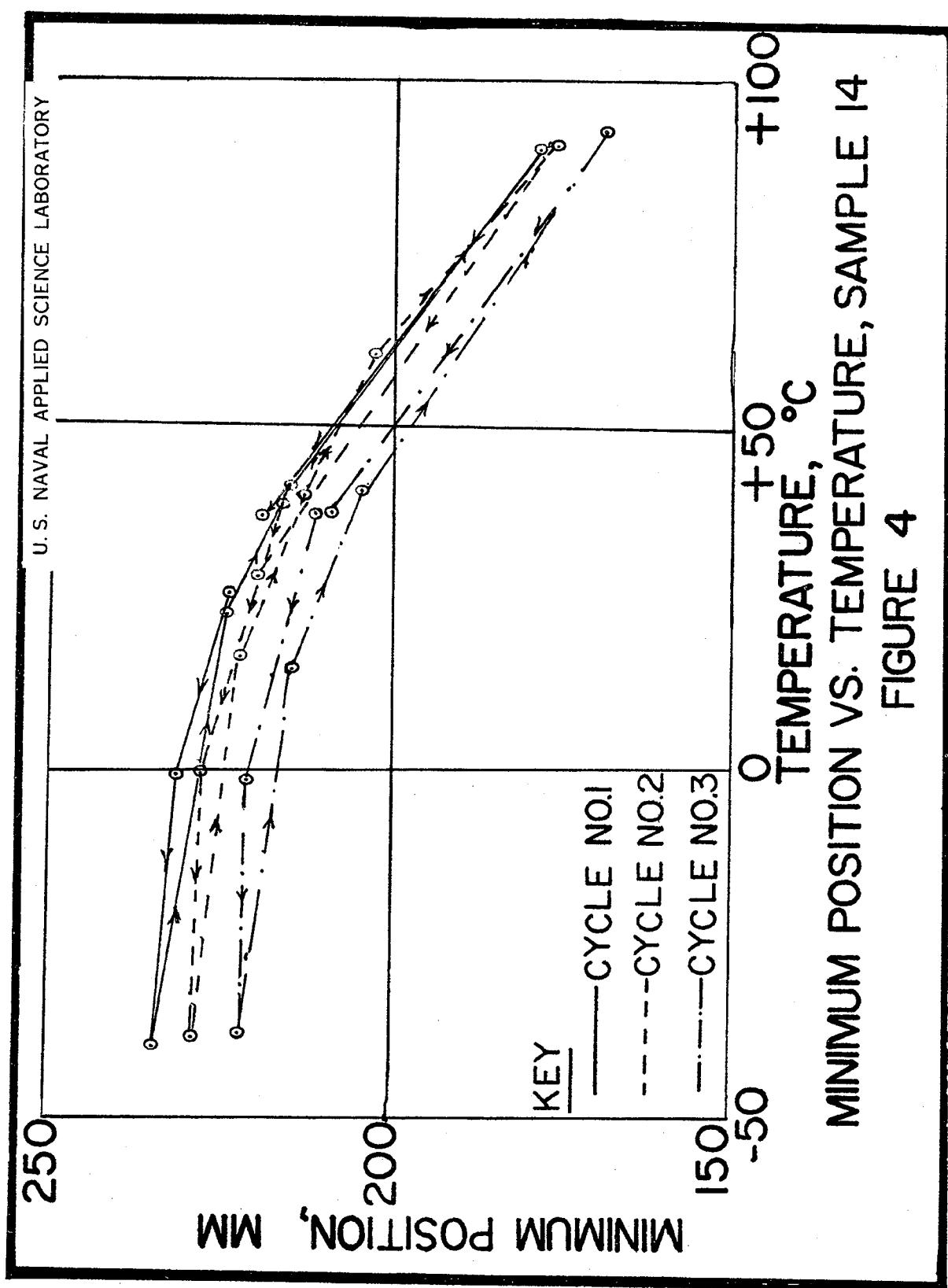
TEMPERATURE, °C

MINIMUM POSITION VS. TEMPERATURE, SAMPLE 14

FIGURE 4
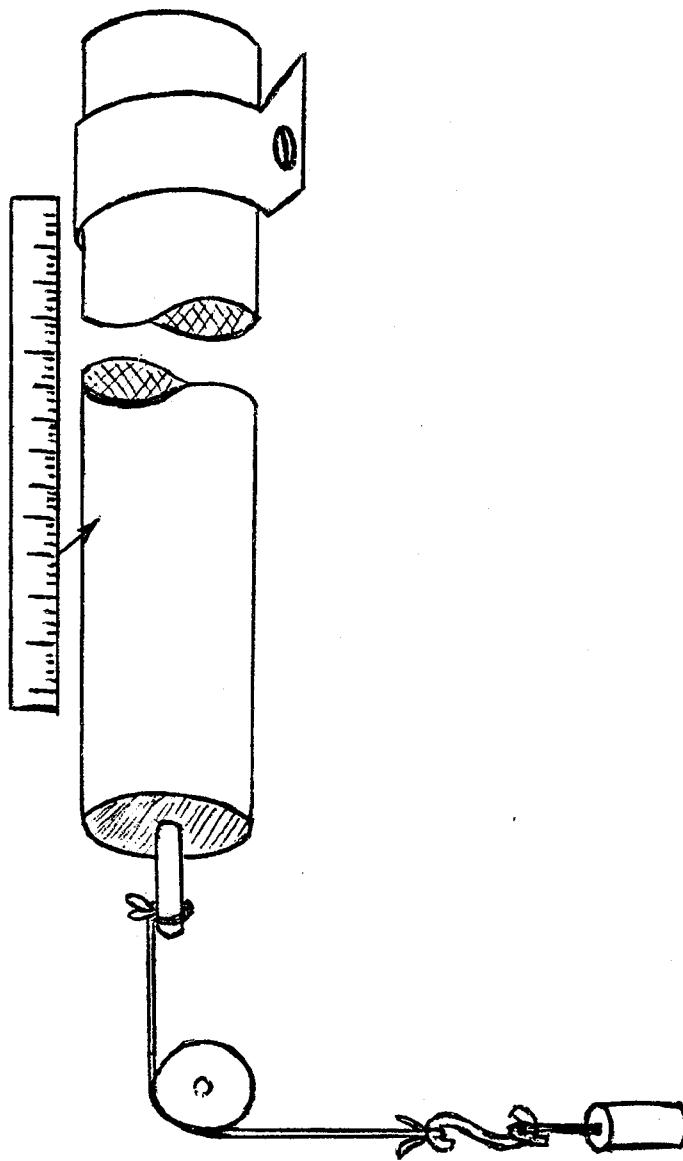
FIGURE – 5

METHOD TO MEASURE CHANGE IN
MECHANICAL LENGTH

Table 1

REPRESENTATIVE CABLE TYPES

Sample No.	Cable Type	Conductor Stranding	Dielectric	Braid Angle, Degrees
1	RG-8A/U	7	PE, solid	22
2	RG-9B/U	7	PE, solid	47
3	RG-62A/U	1	PE, semi-solid	23
4	RG-17/U	1	PE, solid	31
5	RG-116/U	7	TFE, solid	47
6	RG-141/U	1	TFE, solid	34
7	RG-252/U	1	PE, tubes	No braid
8	RG-58 C/U	19	PE, solid	29
9	RG-14/U	1	PE, solid	45
10	RG-59/U	1	PE, solid	24
11	RG-268/U (Foamed)	1	PE, foamed	No braid
12	RG-236/U	1	PST, helical	No braid
13	Phase Stable Cable-1	1	PE, solid	46
14	Phase Stable Cable-2	7	PE, solid	56

<p align="center">Table 2</p>

<p align="center">INCREASE IN ELECTRICAL LENGTH IN PARTS PER 1000</p>

Cable Type	Cycle No.	Temperature, Degrees Centigrade								
		27	0	-40	27	40	60	70	85	27
RG-252/U	1	0.0	-0.3	X	-	0.4	0.8	X	X	0.3
RG-252/U	2	0.3	X	X	-	0.4	X	X	X	0.4
RG-58/U	1	0.0	2.8	4.0	-	-	-	X	-27.3	-
RG-62 A/U	1	0.0	2.1	X	0.0	-	-2.3	X	-3.0	2.5
RG-62 A/U	2	2.5	X	X	-	-	-0.3	X	-3.1	2.7
RG-62A/U	1	0.0	1.7	3.4	-	-0.5	-2.6	X	-4.8	0.7
RG-116/U	1	0.0	1.1	1.6	-0.1	-0.7	-1.9	X	-2.8	-0.6
RG-141/U	1	0.0	3.8	X	-	-0.9	-	X	-5.2	-0.3
RG-17/U	1	0.0	3.2	X	0.4	-1.5	-6.5	X	-14.0	-2.4
RG-17/U	2	-2.4	X	X	-2.4	-3.8	-7.1	X	-15.0	-3.0
RG-17/U	3	-3.0	X	X	-3.0	-	-	X	-15.0	-5.0
RG-17/U	4	-5.0	X	X	-5.0	-	-	X	-15.0	-4.0
RG-14/U	1	0.0	6.7	X	0.6	-	-11.3	X	-22.0	-0.0
RG-14/U	2	0.0	X	X	0.0	-3.9	-10.7	X	-20.5	-0.2
RG-14/U	3	-0.2	X	X	-0.2	-	-	X	-22.0	-0.2
RG-59/U	1	0.0	4.1	X	0.0	-	-11.2	X	-20.6	-2.7
RG-59/U	2	-2.7	X	X	-2.7	-5.6	-10.9	X	-20.5	-3.6
RG-59/U	3	-3.6	X	X	-3.6	-	-	X	-20.8	-3.8
RG-9 B/U	1	0.0	3.0	X	0.0	-1.8	-5.4	X	-11.1	-0.1
RG-9 B/U	2	-0.1	X	X	-0.1	-2.0	-6.0	X	-11.3	-0.3
RG-9 B/U	3	-0.3	X	X	-0.3	-	-	X	-11.2	-0.2
RG-9 B/U	4	-0.2	X	X	-0.2	-	-	X	-11.5	-0.5
RG-8 A/U	1	0.0	2.4	X	0.2	-	-3.7	X	-11.3	-0.7
RG-8 A/U	2	-0.7	X	X	-0.7	-2.1	-5.5	X	-11.4	-1.2
RG-8 A/U	3	-1.2	X	X	-1.2	-	-	X	-11.4	-1.4
Phase stable cable-1	1	0.0	1.4	-0.8	0.2	-0.7	-2.2	X	-7.5	-1.4
Phase stable cable-1	2	-1.4	6.3	-2.0	-	-1.8	-2.7	X	-7.8	-2.0
Phase stable cable-1	3	-2.0	-7.7	-2.2	-1.3	-1.9	-2.9	X	-7.0	-1.8
Phase stable cable-1	4	-1.8	-8.1	-2.2	-1.3	-1.9	-3.2	X	-8.3	-2.4
Phase stable cable-2	1	0.0	-0.2	-0.3	-1.0	-2.0	-3.7	X	-6.2	-1.6
Phase stable cable-2	2	-1.6	-0.2	0.0	-0.9	-2.1	-3.2	X	-6.7	-1.9
Phase stable cable-2	3	-1.9	-0.7	-0.4	-1.3	-2.3	-3.5	X	-6.4	-1.5
Phase stable cable-2	4	-1.5	-1.0	-0.8	-1.5	-2.4	-3.9	X	-7.2	-1.4

Table 2 (Cont'd)

INCREASE IN ELECTRICAL LENGTH IN PARTS PER 1000

Cable Type	Cycle No.	Temperature, Degrees Centigrade								
		27	0	-40	27	40	60	70	85	27
RG-236/U	1	0.0	-0.2	-0.2	0.0	0.3	0.0	X	-	0.0
RG-236/U	2	0.0	0.0	-0.2	0.1	0.0	0.5	X	-	0.2
RG-236/U	3	0.2	-0.1	-0.2	0.4	0.3	0.4	X	-	0.0
RG-268/U	1	0.0	0.4	X	X	-0.2	X	-0.5	X	0.7
RG-268/U	2	X	X	X	X	0.4	X	-0.5	X	1.0
RG-268/U	3	X	X	X	X	0.5	X	X	X	0.9
RG-268/U	4	X	X	X	X	0.6	X	-0.4	X	1.1
RG-268/U	5	X	X	X	X	0.6	X	-0.4	X	1.1

NOTE: A dash indicates that specimen was exposed at the indicated temperature but length was not observed. An "X" indicates that specimen was not exposed to the indicated temperature during the cycle involved. Two specimens of RG-62 A/U were used, the second of which had been previously "seasoned" at 75°C.

2

Table 3

COEFFICIENT OF PHASE STABILITY

Sample No.	Cable Type	Length in Oven, Meters	Coefficient of Phase Stability, Parts per million per °C
1	RG-8A/U	5.6	-200
2	RG-9B/U	4.1	-200
3	RG-62A/U	5.2	-60
4	RG-17/U	4.3	-260
5	RG-116/U	4.8	-50
6	RG-141/U	5.7	-90
7	RG-252/U	30.5	+15
8	RG-58 C/U	5.2	-480
9	RG-14/U	5.8	-360
10	RG-59/U	4.9	-330
11	RG-268/U (Foamed)	30.0	-30
12	RG-236/U	6.6	+3
13	Phase Stable Cable-1	5.6	-39
14	Phase Stable Cable-2	5.7	-48