NATIONAL RADIO ASTRONOMY OBSERVATORY

VLA ELECTRONICS MEMORANDUM NO. 10

March 15, 1968

PHASE AND GROUP DELAY OF COAXIAL CABLE

S. Weinreb

Definitions

There are two closely related definitions of the delay time of a network. these are the phase delay, τ_ϕ , and the group delay, τ_G. The phase delay is usually of importance when signals having a wide percentage bandwidth (such as pulses) are considered, whereas the group delay is important for consideration of small percentage bandwidth signals (such as modulated carriers).

The phase velocity and group velocity of a cable are simply the length of the cable divided by the phase delay or group delay, respectively.

Phase Delay

The phase delay, τ_ϕ, of any two-port network is defined as Θ/ω where Θ is the difference in phase angle (in radians) between input and output signals at frequency, ω. For a cable or delay line the phase delay has only a small variation with frequency, ω. This variation is qualitatively termed the dispersion of the cable or delay line.

The measurement of phase delay requires a phase measuring instrument such as a phase bridge, X-Y oscilloscope, or one of the sampling vector voltmeters manufactured by the Hewlett Packard Corporation. A counter to accurately measure frequency is also required.

A problem exists because all of the above phase-measuring instruments can only measure phase modulo 2π radians. That is, the true phase is related to the measured phase, Θ_m, by,

$$\Theta = \Theta_m + 2\pi N$$

where N is an unknown integer. This integer can be determined by either of two methods:

1) At very low frequencies N = 0 for any network. Thus, if Θ_m is measured as a function of frequency, starting at a very low frequency, it is possible to keep track of N.

2) Group delay (to be described next) can be measured without this ambiguity. Since the phase delay is very close to the group delay, N can be estimated from the group delay measurement.

Group Delay

The group delay, τ_G, is defined as the frequency derivative of the phase angle change in a network

$$\tau_G = \frac{d\Theta}{d\omega}$$

This quantity is measured by observing the change in Θ as ω is varied by a small amount. In particular, if f_R is the frequency difference which produces a 2π change in Θ, then the group delay is simply, $1/f_R$. The quantity, f_R, is sometimes called the repetition frequency of the cable or delay line.

The group delay can be expressed in terms of the phase delay in the following way:

$$\tau_G = \frac{d\Theta}{d\omega} = \frac{d}{d\omega}(\tau_\phi \omega)$$

$$= \tau_\phi + \omega \frac{d\tau_\phi}{d\omega}$$

Thus, at any frequency where the phase delay is constant, it is equal to the group delay.

Measurement Procedure

Measurements of the phase delay and group delay of four large rolls of coaxial cable were made during the period January 20 to March 8, 1968. The rolls of cable are described as follows:

Manu-facturer	Type	Approx. Length	Description
Prodelin	64-1625	1045'	1 5/8" semi-rigid, jacketed, 50 ohm cable, aluminum-outer and copper-inner conductors, longitudinal dielectric configuration.
Prodelin	64-1625	880'	Same as above.
Prodelin	64-875	990'	Same as above except 7/8" diameter.
Andrew	HU 7-50A	1000'	1 5/8" semi-rigid, jacketed, 50 ohm cable, corrugated copper inner and outer conductors, helical dielectric configuration.

A block diagram of the measurement system is shown in Figure 1. The phase comparison was performed with a Hewlett Packard 8410A Network Analyzer for frequencies above 1 GHz; a Hewlett Packard 8405A Vector Voltmeter was used at frequencies below 1 GHz. The phase accuracy of the measurement is estimated to be ± 1°.

Before the test cable was measured it was replaced by a short Type N coupler and the instrument phase zero and line lengths were adjusted so that the phase meter was within ± 1° of zero over the frequency range of interest. The test cable was then inserted and frequencies which produced zero phase were measured. A zero-phase frequency occurs approximately every megahertz for 1000' of cable. It was not necessary to measure all of these frequencies; points were taken every 50 MHz in the 1 GHz region and every 10 MHz in the 100 MHz region. A sample of three points of the data on the Andrew's cable and the resulting computations are shown below:

Zero-Phase Frequency, kc f_N	Wave Lengths N	Difference Frequency $f_{N_1} - f_{N_2}$	$N_1 - N_2$	Phase Delay N/f_N	Group Delay $\frac{N_1 - N_2}{f_{N_1} - f_{N_2}}$
1,450,684.4	1608			1108.44	
		49,522.2	55		1110.6
1,500,216.6	1663			1108.50	
		50,417.7	56		1110.7
1,550,634.3	1719			1108.57	

Results

The phase and group delay of the 1045' roll of 1 5/8" Prodelin cable is shown in Figure 2; the same quantities for the Andrew cable are shown in Figure 3. (Note the change in vertical scale.)

Of particular interest to the VLA IF transmission system application is the maximum change in phase delay over any 50 MHz band in the 1050-1950 MHz range. This occurs at the upper end of the band for both cables and is 0.12 ns/50 MHz and 0.02 ns/50 MHz for 1000' of the Andrew and Prodelin cables, respectively.

The 880' roll of 1 5/8" Prodelin cable was also measured. The resulting value of $\Delta\tau/\tau$ was almost exactly identical to the 1045' roll of cable.

Measurements of the phase delay of the 1 5/8" Prodelin cable over a wider frequency range and also the phase delay of the 7/8" Prodelin cable are shown in Figure 4. The increasing delay at lower frequencies is due to the cable loss. It can be shown that 6.6° of extra phase shift will occur for each dB of cable loss. This relation is closely followed for 1 5/8" cable at frequencies below 500 MHz.

The measurements of the 7/8" Prodelin cable show that the frequencies for minimum delay of 7/8" and 1 5/8" cable are in the same ratio as the cable diameters. This indicates that the anomalous dispersion effect at the high frequency is due to a geometrical effect rather than dispersion of the dielectric.

Accurate attenuation measurements of the Prodelin 1 5/8" cable were also made; these results are shown in Figure 5. The cable has an attenuation of 3.49 dB/1000' at 225 MHz and 13.2 dB/1000' = 34.6 dB/800 meters at 2 GHz. The attenuation slope between 1 and 2 GHz is 12.9 dB/800 meters.

Conclusions

The dispersion of the helical dielectric cable in the upper half of its frequency range is not surprising since it has been predicted in references (1) and (2). This effect can also be observed in the response to a sharp pulse as reported in reference (3). The dispersion is apparently due to the periodic discontinuity of the helical dielectric as encountered by the electric field in any one plane.

The longitudinal dielectric cable has a factor of 6 less dispersion in the 1-2 GHz range. The cause of this dispersion is not known; the effect is repeated from one cable to another and does not occur in the same frequency range for 7/8" cable of identical manufacture. Some effect of cutoff TE or TM modes is suspected.

References

(1) Kaden, H., "The Performance of Helical Membrane Coaxial Cable in the Frequency Range above 1000 Mcs," Royal Aircraft Establishment, Farnborough, England, Library Translation No. 528, September 1955.

(2) Griemsmann, J. W. E., "An Approximate Analysis of Coaxial Line with a Helical Dielectric Support," IRE Trans., MTT-4, 13-23, January 1956.

(3) Kushner, Allen M., "Discussion of Alumispline Air Dielectric Semiflexible Cable," Times Wire and Cable Tech Memo No. 10, October 28, 1964.

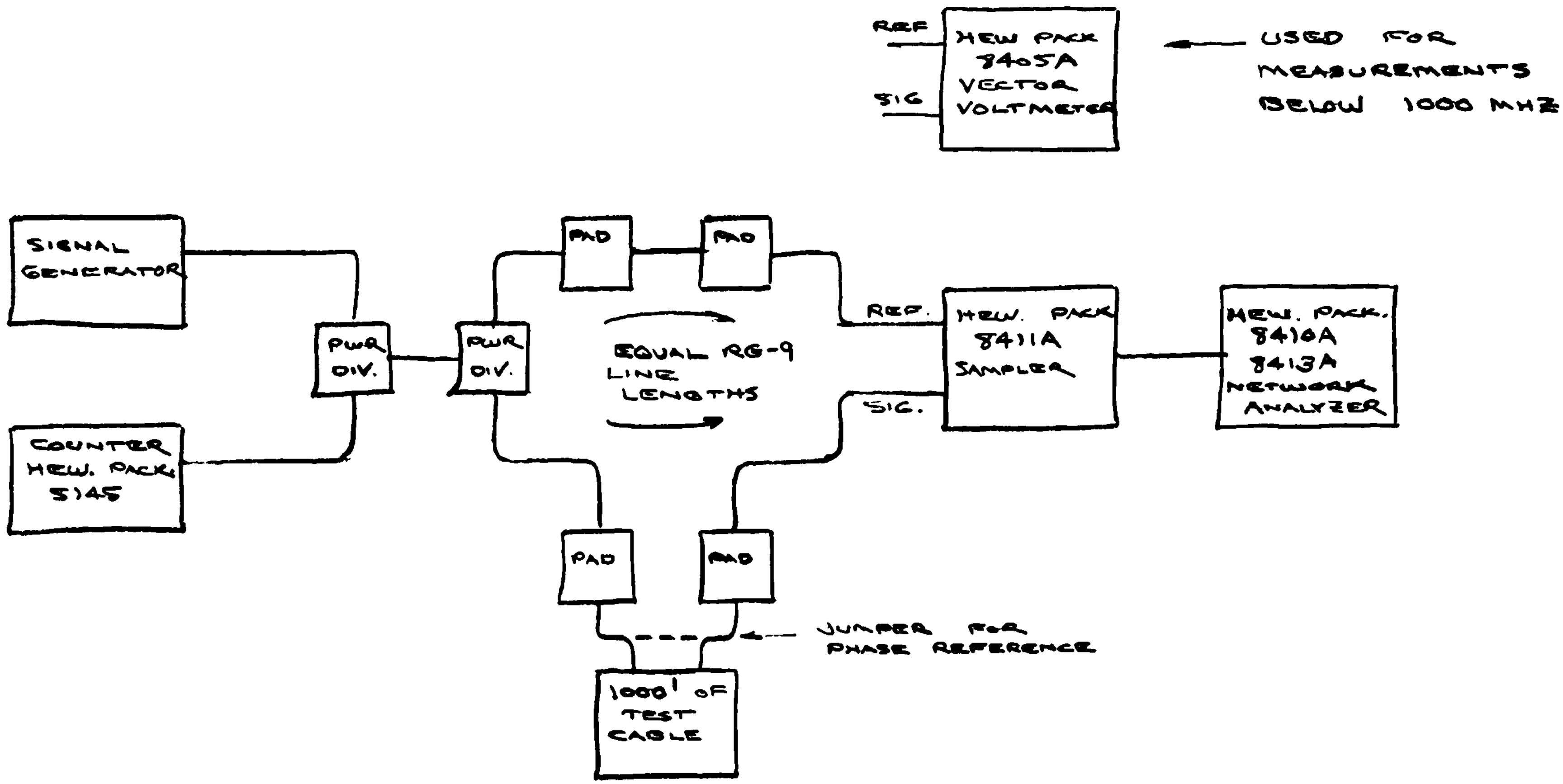

Figure 1 — Test set-up for measurement of cable dispersion. Small variations in the pads and connecting cables were made in the course of the measurements on different cables. These changes were seen to have negligible effect when the test cable was bypassed with a coaxial adaptor prior to the measurement.

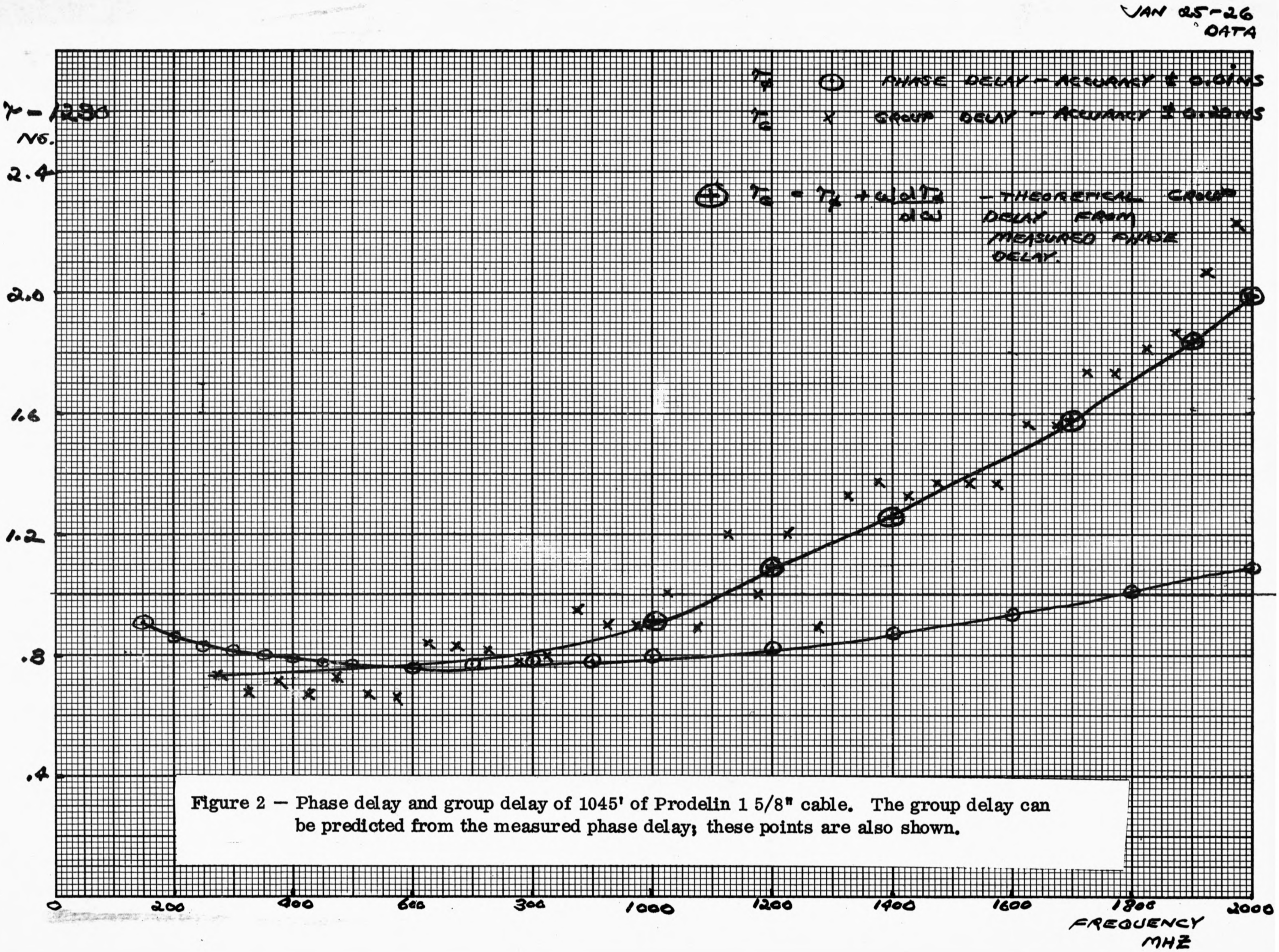

Figure 2 — Phase delay and group delay of 1045' of Prodelin 1 5/8" cable. The group delay can be predicted from the measured phase delay; these points are also shown.

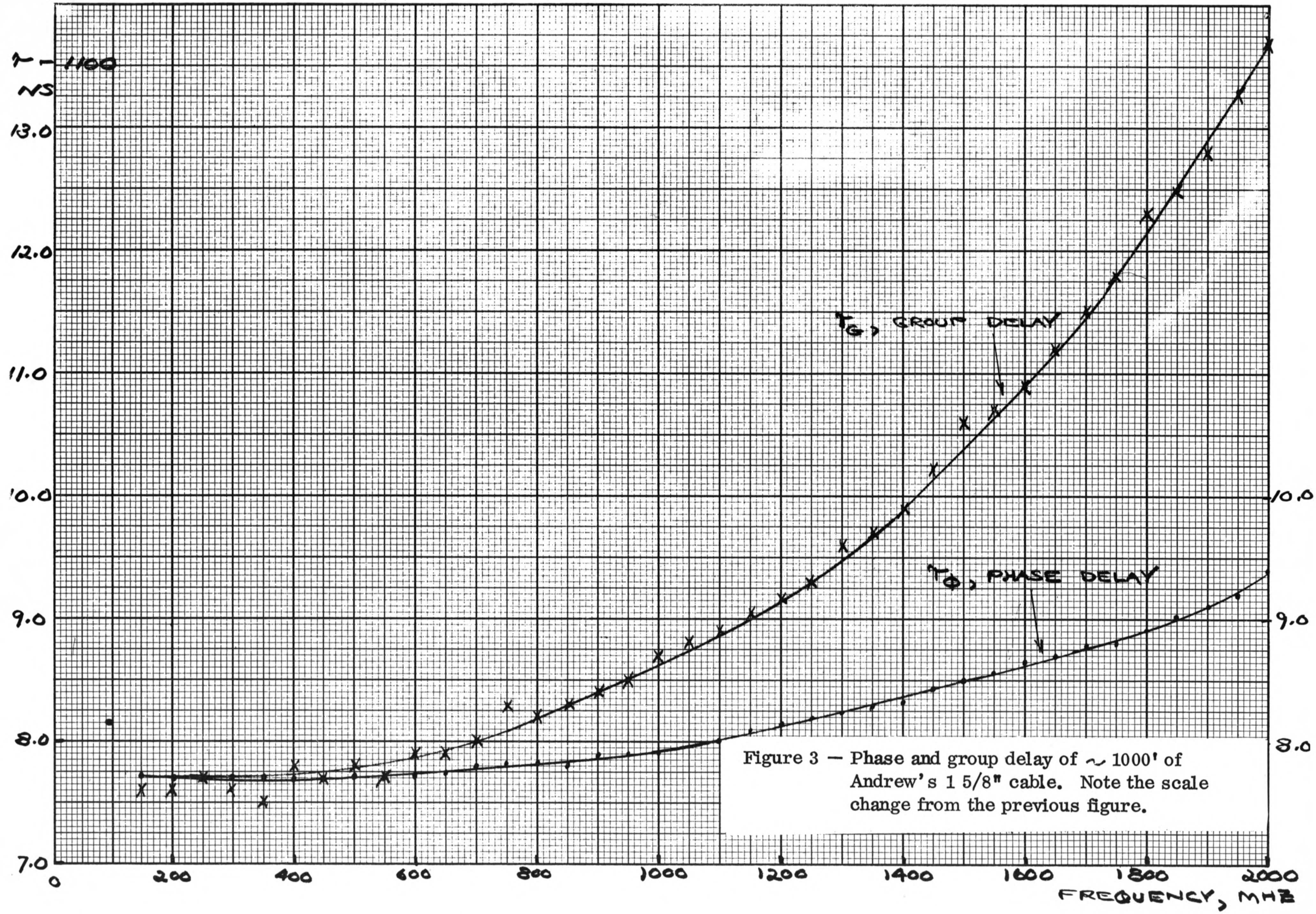

Figure 3 — Phase and group delay of ~ 1000' of Andrew's 1 5/8" cable. Note the scale change from the previous figure.

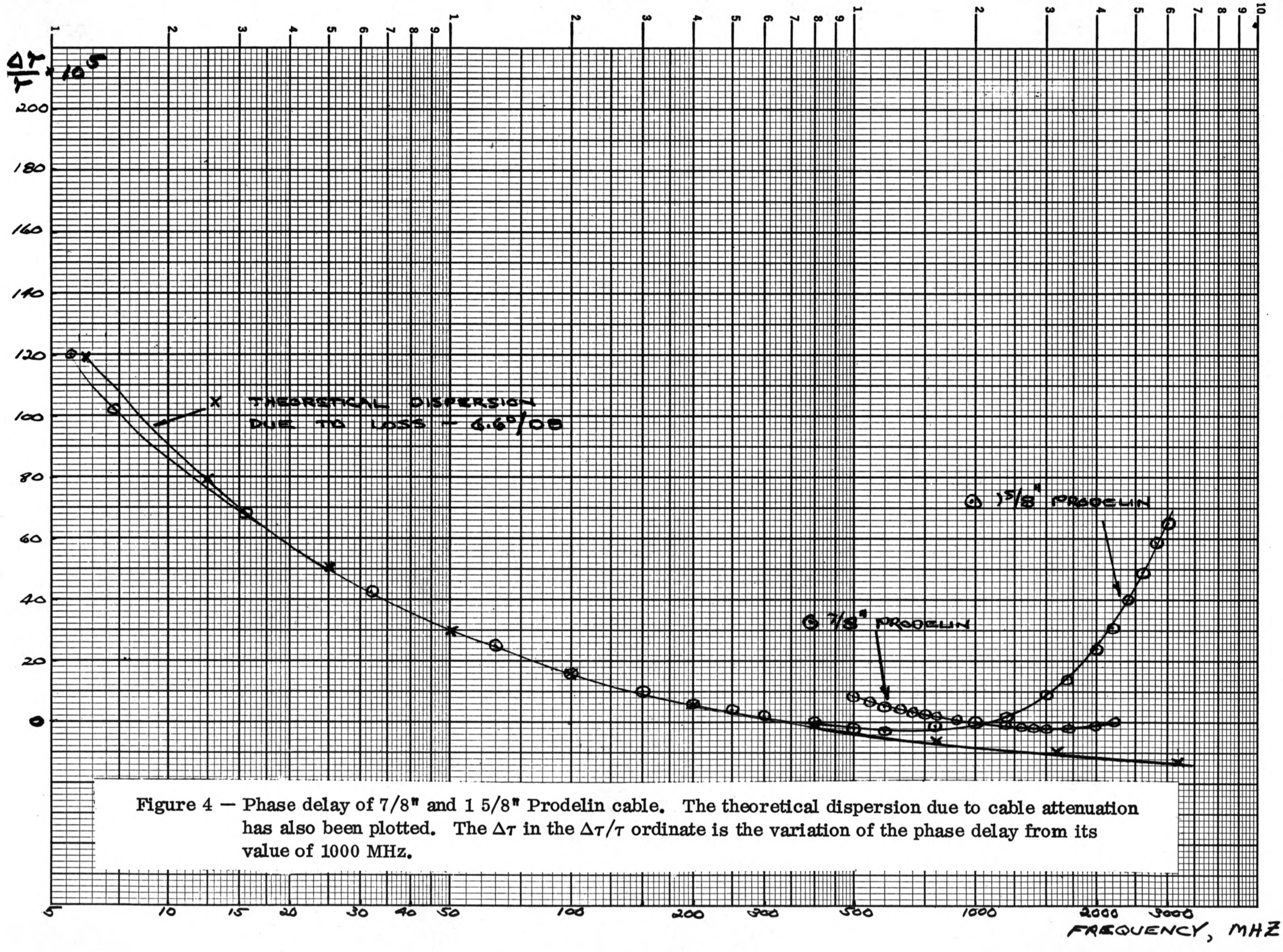

Figure 4 — Phase delay of 7/8" and 1 5/8" Prodelin cable. The theoretical dispersion due to cable attenuation has also been plotted. The $\Delta\tau$ in the $\Delta\tau/\tau$ ordinate is the variation of the phase delay from its value of 1000 MHz.

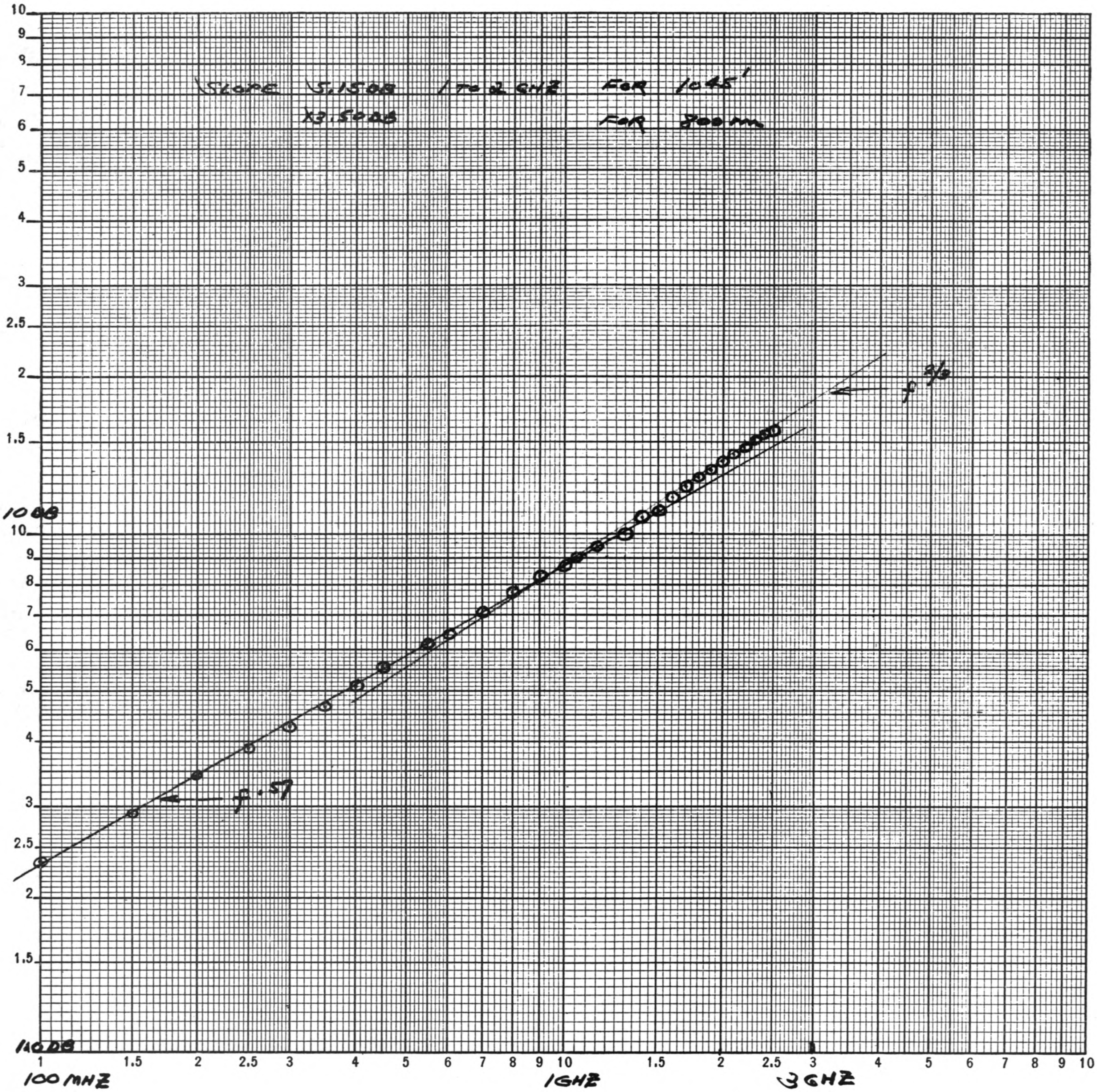

Figure 5 — Attenuation of 1045' of 1 5/8" Prodelin cable. These measurements were made to an accuracy of ± 0.1 dB with a Weinschel attenuation test set.