CHAPTER 21

CHARACTERISTICS OF CIRCUIT FACILITIES

21.1 Classification of Wire Facilities

Transmission facilities or media employed in telephone and telegraph work, to be cataloged completely, would have to include both waveguides and free space, which is the medium of radio transmission. In this Chapter, however, we shall confine our attention to various types of wire conductors, including coaxials. The kind of wire line facility to be used in a particular case depends upon economic considerations and the transmission requirements to be met. Ordinary wire facilities may be classified in several ways according to their uses, or on the basis of their physical or electrical characteristics.

It is customary first to make a general distinction between facilities used for toll (long distance) and for exchange area transmission. The latter facilities include the greater part of the total telephone plant since local or short haul service is naturally used much more frequently than long distance service. Accordingly, it is economically desirable to design these facilities primarily on the basis of providing satisfactory transmission within the exchange area. For toll or long distance connections, of which local facilities necessarily form a part in every case, more costly types of facilities are used for the long distance links in order that the transmission shall remain satisfactory. This arrangement is in the interest of overall economy because the long distance facilities are relatively few as compared with the local facilities. It means in general that the latter facilities do not have to meet as exacting requirements as do the toll facilities with respect to attenuation per unit length, impedance regularity, or balance against noise and crosstalk. In exchange area cables, for example, wire conductors as fine as 22, 24, or 26-gage are widely used, whereas the minimum gage in long toll cables is 19. Generally similar distinctions as between local and toll transmission apply in the case of open wire facilities. However, it may be noted that there is a certain middle ground where exchange area trunks are of such great length in some cases that their transmission requirements are not widely different from those of the shorter toll circuits. Loading is frequently applied to such trunks and in some cases it may be necessary to use telephone repeaters as well.

The principal types of toll or long distance wire facilities are considered separately in the following Articles.

21.2 Open Wire Facilities

In both open wire and cable circuits, the development of the telephone art has involved the use of many different types of circuit facilities. At any given time, accordingly, the working plant may include facilities ranging from earlier types to newly developed types which are barely out of the experimental stage. Before the advent of the telephone repeater, the majority of long distance facilities were open wire and, in order to keep the attenuation down, practically all of this open wire was loaded with relatively high inductance coils spaced at intervals of about 8 miles. The conductors used were almost entirely 165, 128, or 104 hard drawn copper wire and each group of four wires was usually arranged to carry a phantom circuit.

The wires were carried on crossarms in the manner indicated in Figure 21-1. Here each crossarm carries 10 wires which are numbered consecutively starting with the left-hand pin of the top crossarm when looking in the direction of the pole numbering of the line. The standard wire layout

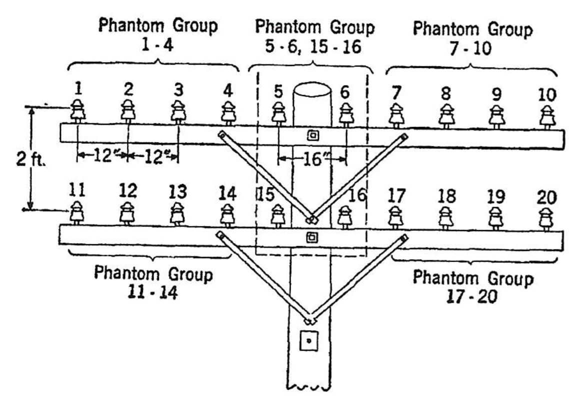


Fig. 21-1 Wire Configuration for Open Wire Line Carrying Voice-frequency Side and Phantom Circuits

on two crossarms, shown in the Figure, provides ten **side** and five **phantom** circuits. Phantoms are derived from wires 1-4, 7-10, 11-14, 17-20, and 5-6, 15-16. The last is called a **vertical** or **pole-pair** phantom and has somewhat different electrical characteristics than the other phantoms because of the different spacing and configuration of the wires. Similarly the characteristics of the "non-pole-pair" side circuits such as 1-2 or 9-10, with 12 inch spacing between wires, are slightly different from those of the pole-pair circuits like 15-16, where the distance between wires is 18 inches.

Many open wire lines, with an arrangement of wires on poles as shown in Figure 21-1, are still in use in the long distance plant. Loading, however, is no longer used on open wire facilities. This is a result of the fact that the characteristics of open wire circuits—particularly the leakage—change markedly with varying weather conditions. In dry weather, open wire loading is effective in reducing the attenuation of the circuits considerably. But, due principally to the increased leakage, loading may actually increase the attenuation of open wire circuits in wet weather.

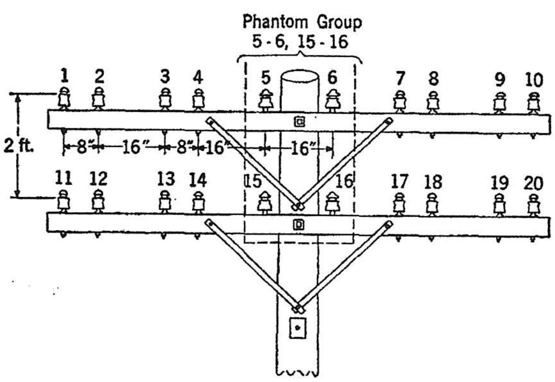


Fig. 21-2 Wire Configuration for Open Wire Line on which Type-C Carrier Systems are Superimposed

In order to increase the overall transmission stability of such circuits, accordingly, all loading was removed after the telephone repeater came into general use, and the resulting increase in attenuation was compensated for by the employment of additional repeaters.

The application of carrier systems to open wire lines has led to other changes in open wire facility arrangements. On account of the higher frequencies employed in carrier systems, the probability of crosstalk is increased. Since the greatest crosstalk hazard is between the side and phantom circuits of a phantom group, it is desirable in many cases to dispense with the phantom circuit altogether. Further reduction in crosstalk possibilities is effected by spacing the two wires of each pair closer together on the crossarm, and increasing the separation between pairs. Thus, Figure 21-2 shows a wire configuration used to a considerable extent on lines carrying Type-C telephone carrier systems (frequencies up to 30 kc) in which the non-pole pairs have eight inch spacing between wires and the separation between the nearest wires of adjacent pairs is 16 inches.

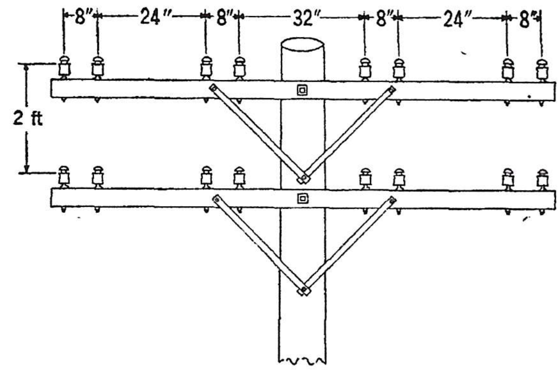


Fig. 21-3 Wire Configuration of 8-inch Spaced Open Wire Line for Type-J Carrier Operation

This configuration which is designated 8-16-8 includes a pole-pair phantom group which ordinarily would be used only for voice frequencies. The change in spacing from 12 inches to 8 inches reduces the linear inductance of the pair and increases its linear capacitance by about 8%. The resistance and leakage are not changed and the attenuation is slightly increased. The characteristic impedance is reduced by about 50 ohms.

Where open wire line facilities are designed to carry broad-band carrier systems (Type-J) em-

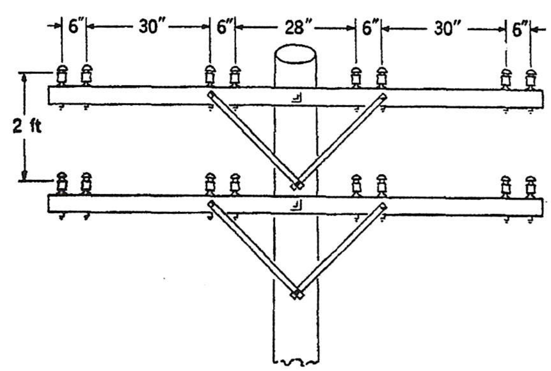


Fig. 21-4 Wire Configuration of 6-inch Spaced Open Wire Line for Type-J Carrier Operation

ploying frequencies up to 140 kc, 8 or 6 inch spacing between wires of a pair is employed, and the pole-pair groups are usually dispensed with. Each crossarm then carries 8 wires, with spacings and configurations as indicated in Figures 21-3 and 21-4, and no phantom circuits are provided for. These configurations are designated 8-24-8 and 6-30-6 respectively.

Open wire facilities are subject to the effects of leakage which increase attenuation losses, particularly at carrier frequencies, and which must be adequately controlled to obtain satisfactory transmission. This is done by insulating the wires from their supporting structure with glass insulators. The effectiveness of such insulators under given conditions of weather varies with their size, shape, and the kind of pin employed.

When new open wire facilities are placed on existing lines and are likely to be used for carrier operation at frequencies above 10 kc, it is necessary to take into account the manner in which the other pairs on the line are insulated. This arises from the fact that the wet weather attenuation of similar gage facilities equipped with different types of insulators is unequal and that as a result energy level differences may occur, which cause crosstalk. When this is the case, it may be desirable that all of the open wire facilities of the same gage which are to be used for carrier operation at frequencies above 10 kc be equipped with the same type insulators.

Table IX gives the more important physical and electrical constants of the commonly used types of open wire circuits. The values given are calculated for the single frequency of 1000 cycles and they apply only under more or less ideal conditions. Caution must therefore be used in applying them to practical problems. For example, the leakage of open wire conductors depends upon weather conditions. In wet weather the values for G given in the Table may be very considerably increased, and the various constants dependent to a greater or lesser extent on this value, such as attenuation, wavelength, and characteristic impedance, would change accordingly.

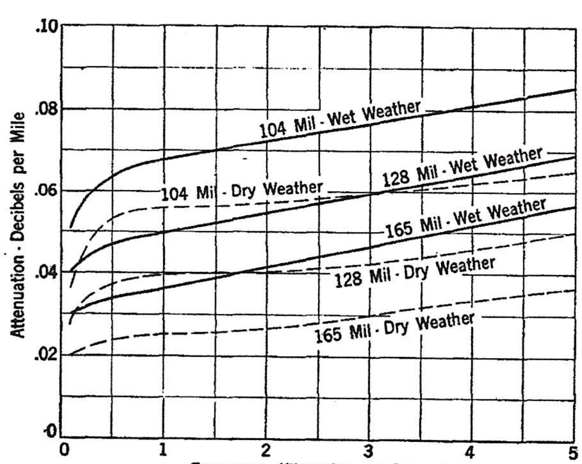


FIG. 21-5 ATTENUATION-FREQUENCY CHARACTERISTICS OF OPEN WIRE SIDE CIRCUITS OVER THE VOICE RANGE

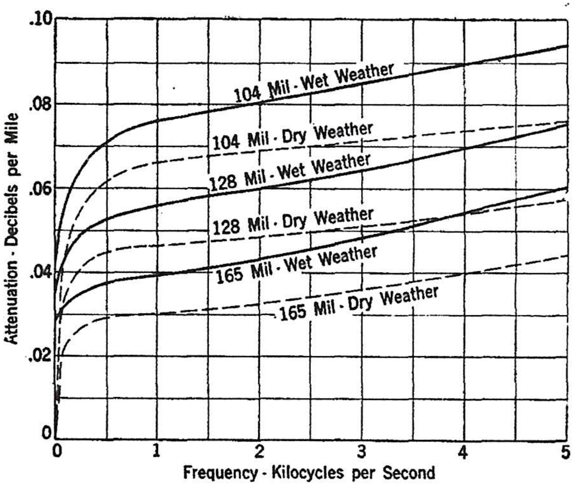


FIG. 21-6 ATTENUATION-FREQUENCY CHARACTERISTICS OF OPEN WIRE PHANTOM CIRCUITS OVER THE VOICE RANGE

The Table of course does not give information regarding any variations of the circuit constants through the voice-frequency range. In practically all cases, however, the attenuation, as well as certain of the other circuit constants, changes somewhat with changing frequency. The magnitude of this attenuation change can be determined from curves in which attenuation is plotted against frequency through the working range. Figures 21-5 and 21-6 give representative attenuation-frequency curves for 104, 128, and 165 open wire, side and phantom circuits, having the wire spacing and configuration shown in Figure 21-1, over the frequency range from 0 to 5000 cycles. Separate curves are given for dry and wet weather conditions but the latter curves naturally represent merely an average situation since the "degree of wetness" of the weather is a rather variable quantity. From these curves, it will be noted that, in general, there is an increase of attenuation between 500 and 5000 cycles of somewhere in the order of 50%.

As would be expected, when open wire circuits

TABLE IX

Characteristics of Standard Types of Open Wire Telephone Circuits at 1000 Cycles per Second

Type of Circuit	Gage of Wires (Mils)	Spacing of Wires (In.)	Constants per Loop Mile				Propagation Constant				Line Impedance				Wave-Length Miles	Velocity Miles per Second W	Trans-mission Equivalent DB per Mile
							Polar		Rectangular		Polar		Rectangular				
			R Ohms	L Henrys	C Mf.	G M.Mho.	Magni-tude	Angle Degrees +	α	β	Magni-tude	Angle Degrees −	R Ohms	X Ohms −			
Non-Pole Pair Side	165	12	4.11	.00337	.00915	.29	.0352	84.36	.00346	.0350	612	5.35	610	57	179.5	179,500	.030
Pole Pair Side	165	18	4.11	.00364	.00863	.29	.0355	84.75	.00325	.0353	653	5.00	651	57	178.0	178,000	.028
Non-Pole Pair Phan.	165	12	2.06	.00208	.01514	.58	.0355	85.34	.00288	.0354	373	4.30	372	28	177.5	177,500	.025
Pole Pair Phan.	165	18	2.06	.00207	.01563	.58	.0359	85.33	.00293	.0358	366	4.33	365	28	175.5	177,500	.025
Non-Pole Pair Phys.	165	8	4.11	.00311	.00996	.14	.0353	83.99	.00370	.0351	565	5.88	562	58	179.0	179,000	.032
Non-Pole Pair Phys.	165	6	4.11	.00292	.01070	.14	.0356	83.63	.00394	.0353	529	6.25	526	58	177.8	177,800	.034
Non-Pole Pair Side	128	12	6.74	.00353	.00871	.29	.0356	81.39	.00533	.0352	650	8.32	643	94	178.5	178,500	.046
Pole Pair Side	128	18	6.74	.00380	.00825	.29	.0358	81.95	.00502	.0355	693	7.72	686	93	177.0	177,000	.044
Non-Pole Pair Phan.	128	12	3.37	.00216	.01454	.58	.0357	82.84	.00445	.0355	401	6.73	398	47	177.0	177,000	.039
Pole Pair Phan.	128	18	3.37	.00215	.01501	.58	.0362	82.82	.00453	.0359	384	6.83	382	46	174.8	174,800	.039
Non-Pole Pair Phys.	128	8	6.74	.00327	.00944	.14	.0358	80.85	.00569	.0353	603	8.97	596	94	178.0	178,000	.049
Non-Pole Pair Phys.	128	6	6.74	.00308	.01011	.14	.0361	80.33	.00606	.0356	568	9.53	560	94	176.6	176,600	.053
Non-Pole Pair Side	104	12	10.15	.00366	.00837	.29	.0363	77.93	.00760	.0355	692	11.75	677	141	177.0	177,000	.066
Pole Pair Side	104	18	10.15	.00393	.00797	.29	.0365	78.66	.00718	.0358	730	10.97	717	139	175.5	175,500	.062
Non-Pole Pair Phan.	104	12	5.08	.00223	.01409	.58	.0363	79.84	.00640	.0357	421	9.70	415	71	176.0	176,000	.056
Pole Pair Phan.	104	18	5.08	.00222	.01454	.58	.0368	79.81	.00651	.0362	403	9.83	397	69	173.6	173,600	.056
Non-Pole Pair Phys.	104	8	10.15	.00340	.00905	.14	.0367	77.22	.00811	.0358	644	12.63	629	141	175.5	175,500	.070
Non-Pole Pair Phys.	104	6	10.15	.00322	.00967	.14	.0371	76.60	.00859	.0361	610	13.26	594	140	174.2	174,200	.075

Notes: 1. All values are for dry weather conditions.
2. All capacity values assume a line carrying 40 wires.
3. Resistance values are for temperature of 20° C. (68° F.).

are used as conductors for carrier systems, the variation in attenuation from the low- to the high-frequency end of the transmission band is much greater. Thus, Figure 21-7 gives curves for 8 inch spaced, physical circuits, transposed for Type-C carrier, through the frequency range up to 50,000 cycles. Here, in the band between 5000 and 50,000 cycles, it will be seen that the attenuation more than doubles. Similarly as shown in Figure 21-8, the losses over the open wire broad-band carrier range (Type-J) increase by almost 300% in the range from 20 to 140 kc. Moreover, in the higher carrier ranges, the loss of open wire circuits may be increased to values very much larger than those indicated in this latter Figure by unusual weather conditions, such as ice, sleet or snow accumulating on the wires. Thus, Figure 21-9 gives a representative example of the measured effect of melting glaze of an estimated diameter of ½ inch on an 8-inch spaced pair of 165-gage wires. Here, the attenuation at 140 kc is some four times the normal wet weather attenuation.

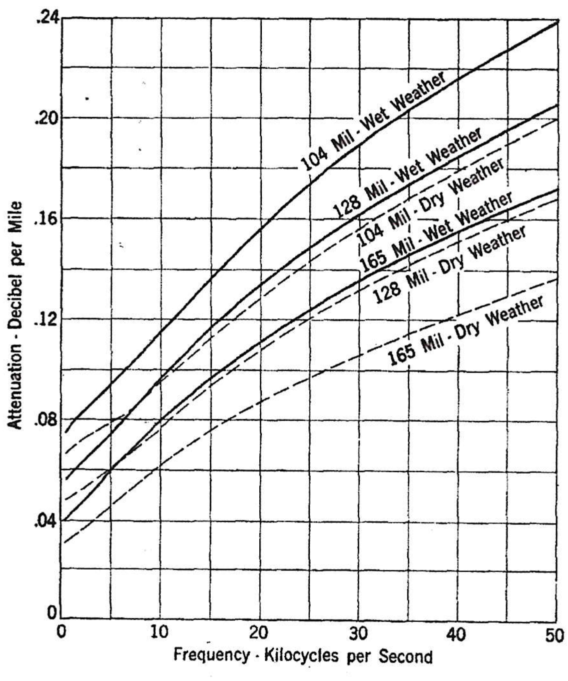


FIG. 21-7 ATTENUATION-FREQUENCY CHARACTERISTICS OF OPEN WIRE PHYSICAL CIRCUITS OVER THE TYPE-C CARRIER RANGE

21.3 Toll Cable Facilities

The use of cable conductors for long distance telephone transmission presented very considerable difficulties in the early days of the art. For

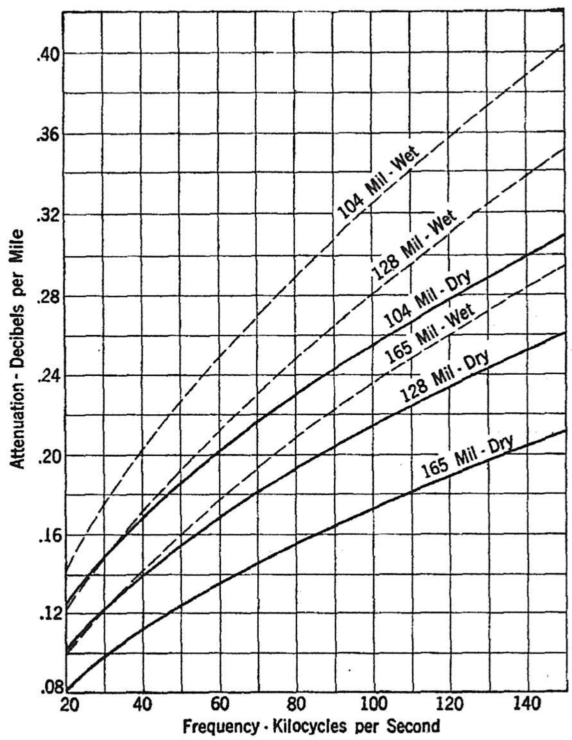


FIG. 21-8 ATTENUATION-FREQUENCY CHARACTERISTICS OF OPEN WIRE PHYSICAL CIRCUITS OVER THE TYPE-J CARRIER RANGE

obvious economic reasons, wire conductors in cables are of considerably finer gage than open wire conductors, which of course increases their attenuation per unit length. The much higher capacitance, caused by the necessary close spacing of the conductors within the cable sheath, also adds to their losses. In general, accordingly, cable conductors used for long distance voice-frequency transmission are loaded.

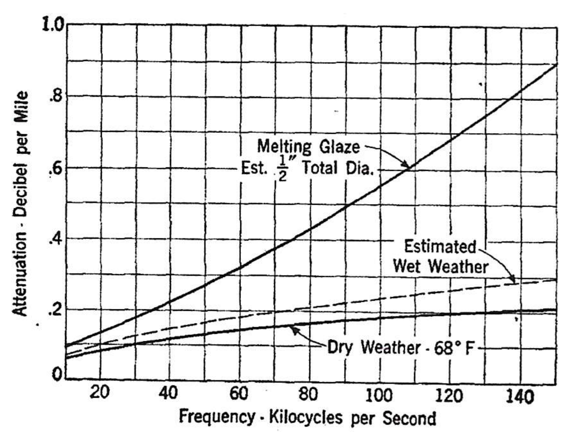
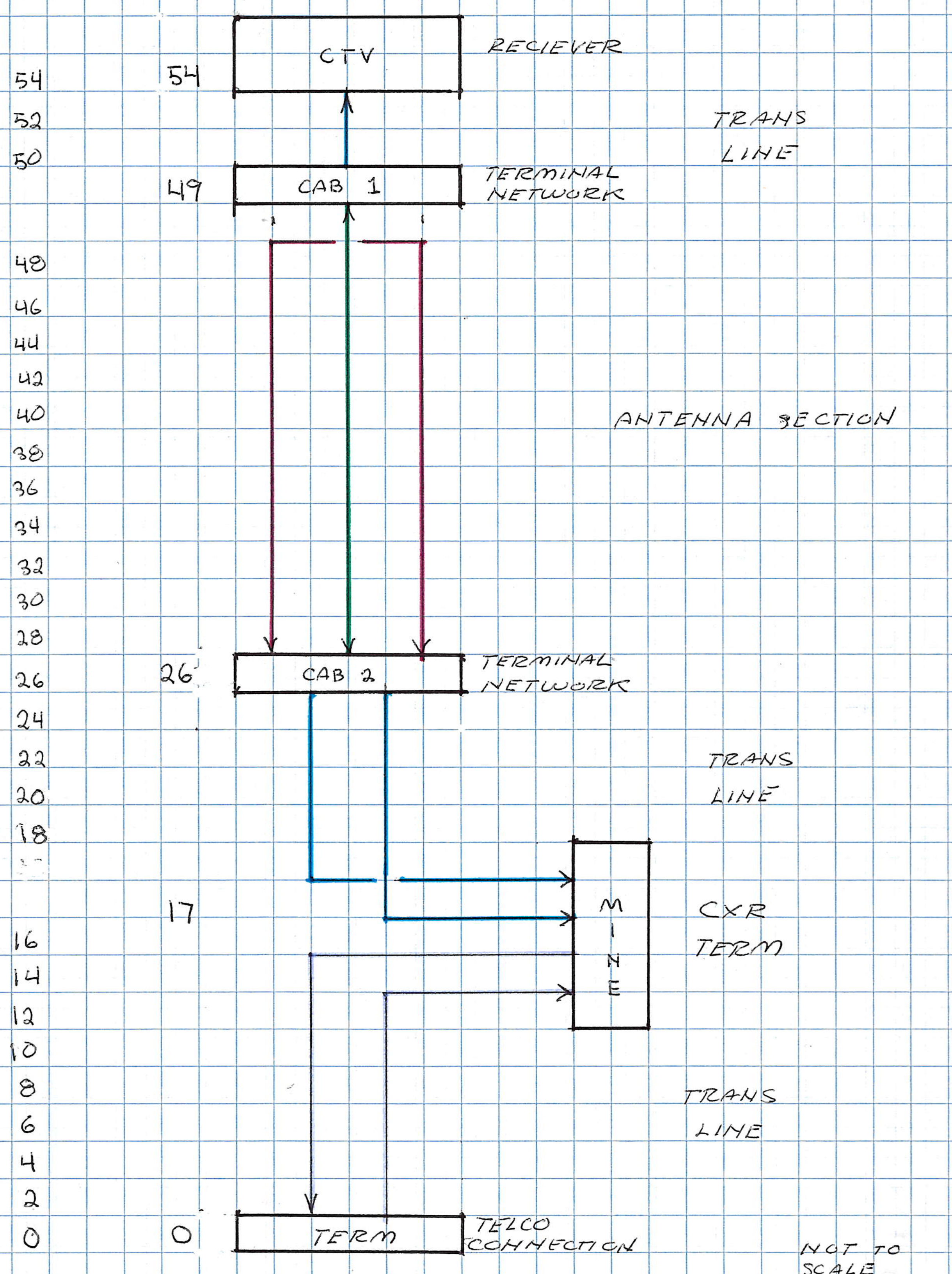
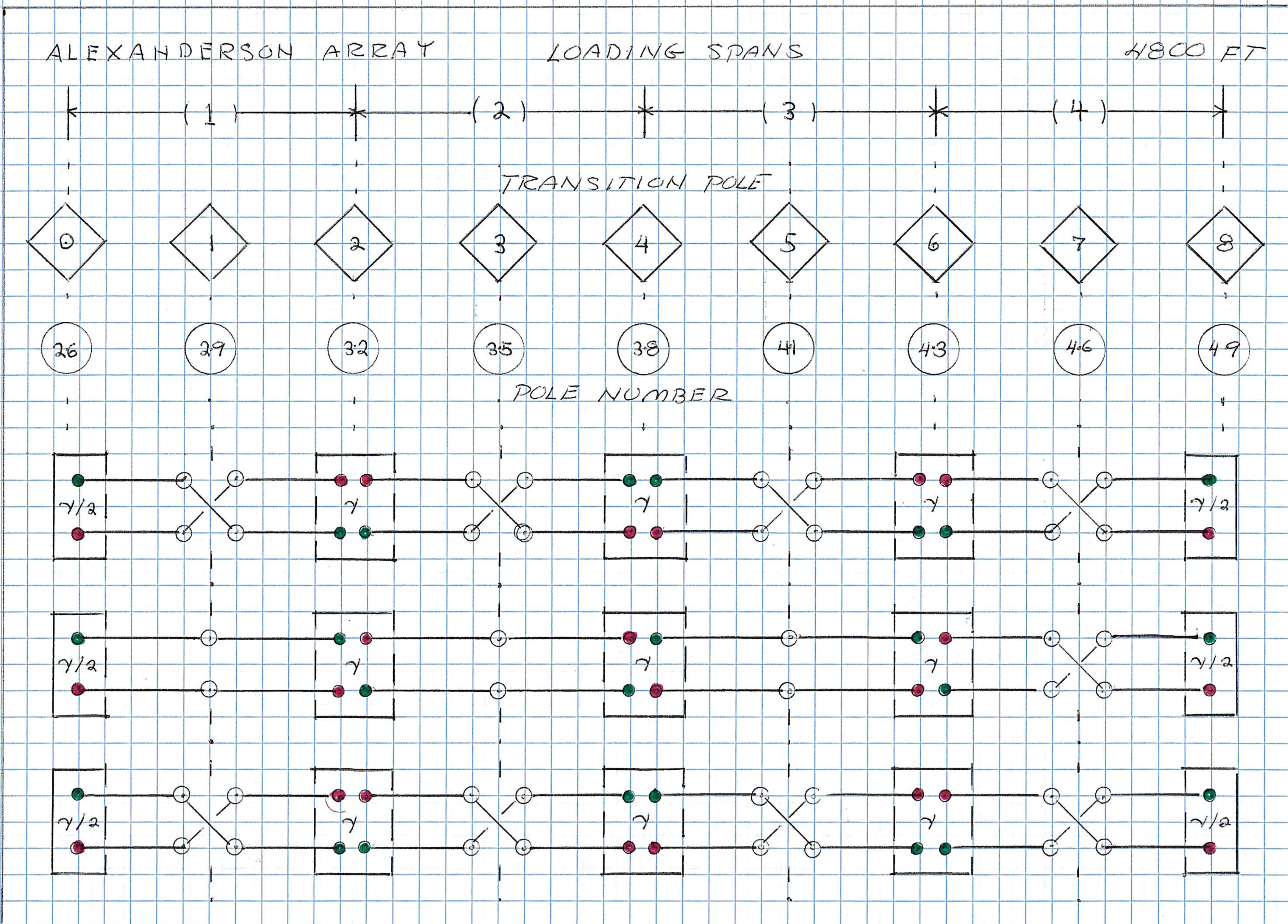


FIG. 21-9 CURVE SHOWING THE EFFECT OF SLEET DEPOSIT ON ATTENUATION OF OPEN WIRE CIRCUIT

ALEXANDERSON SYSTEM OVERHEAD LINES




ALEXANDERSON ARRAY
LOADING SPANS
4800 FT
(1)
(2)
(3)
(4)
TRANSITION POLE
0
1
2
3
4
5
6
7
8
26
29
32
35
38
41
43
46
49
POLE NUMBER
γ/2
γ
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γ
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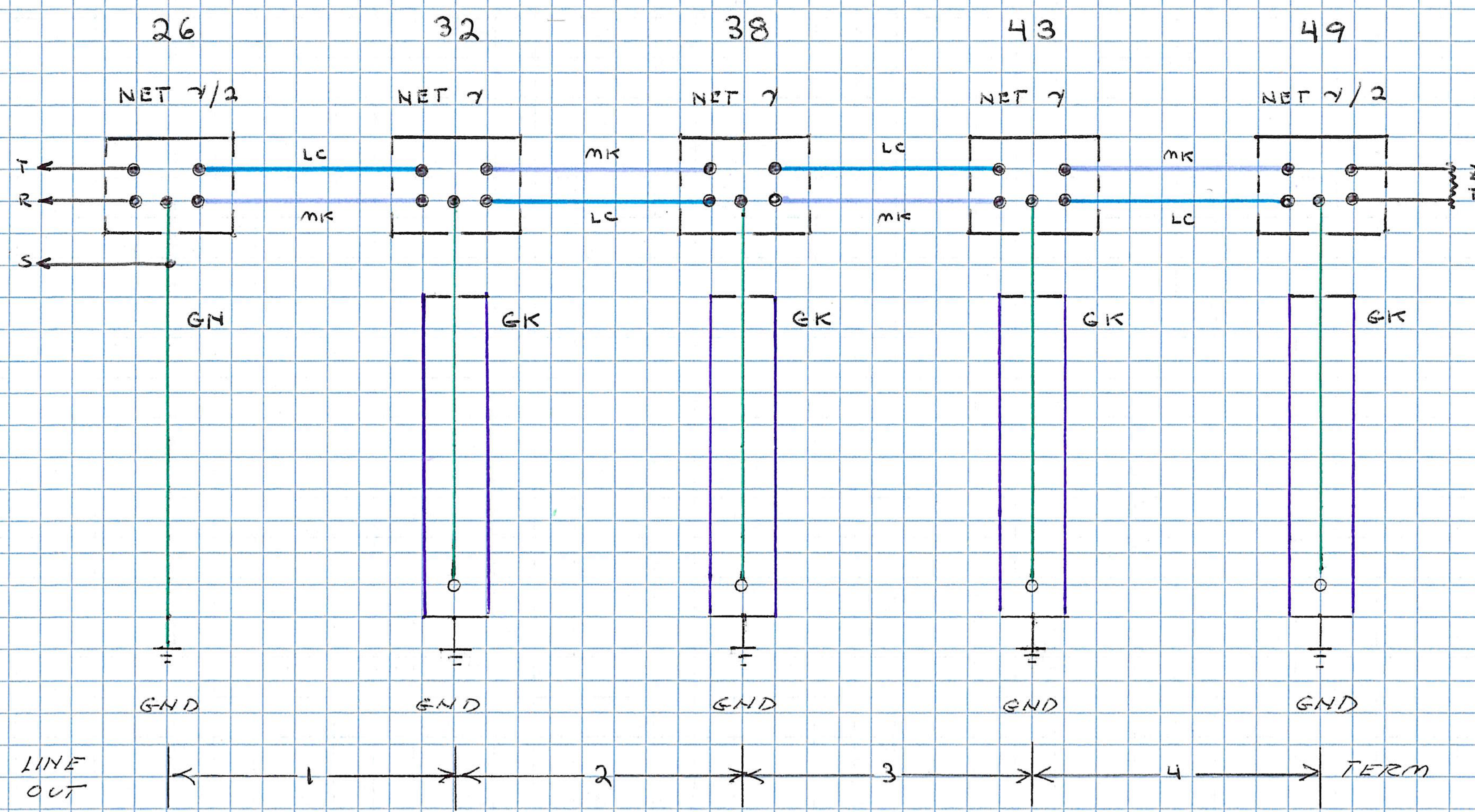
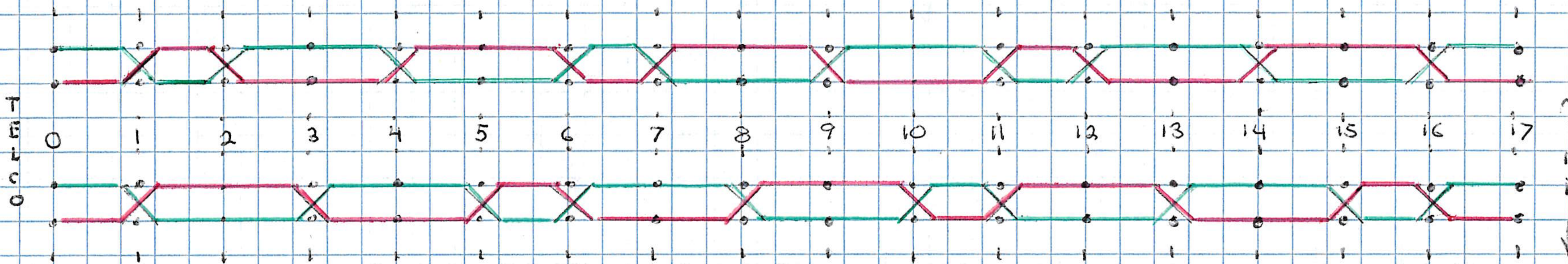
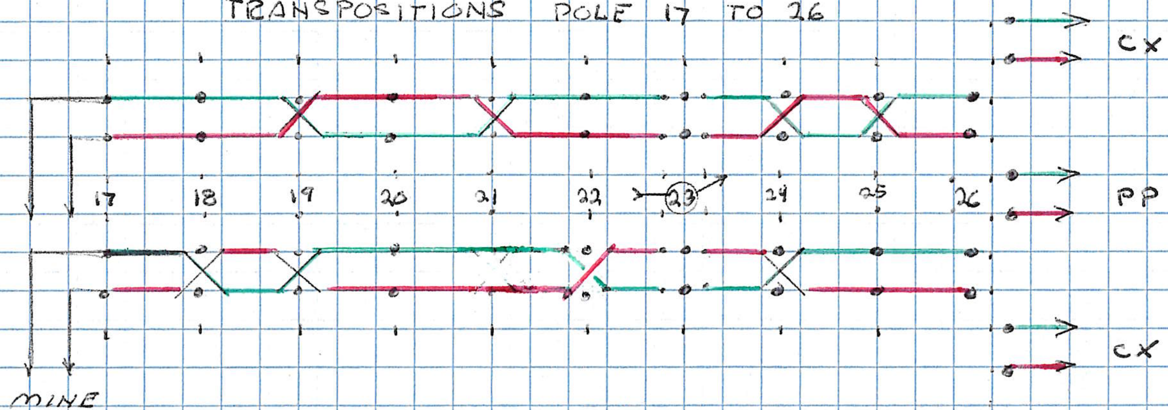
4800 FT
POLE PAIR



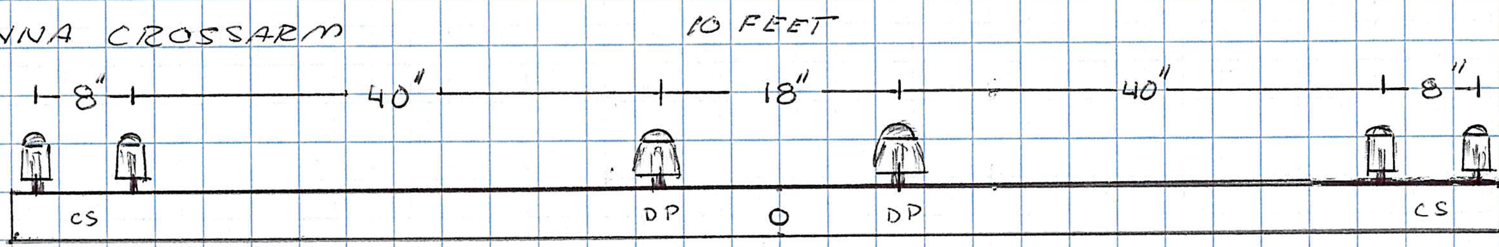
TRANSPOSITIONS POLE 0 TO 17



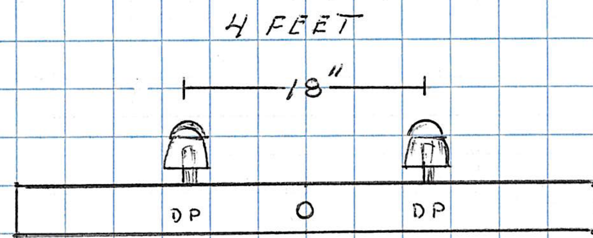
TRANSPOSITIONS POLE 17 TO 26



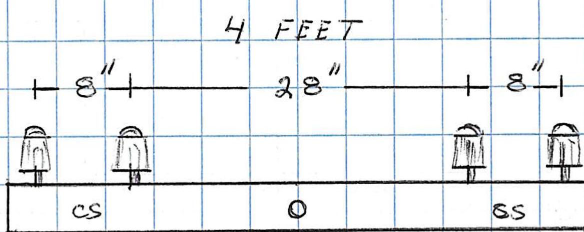
ANTENNA CROSSARM



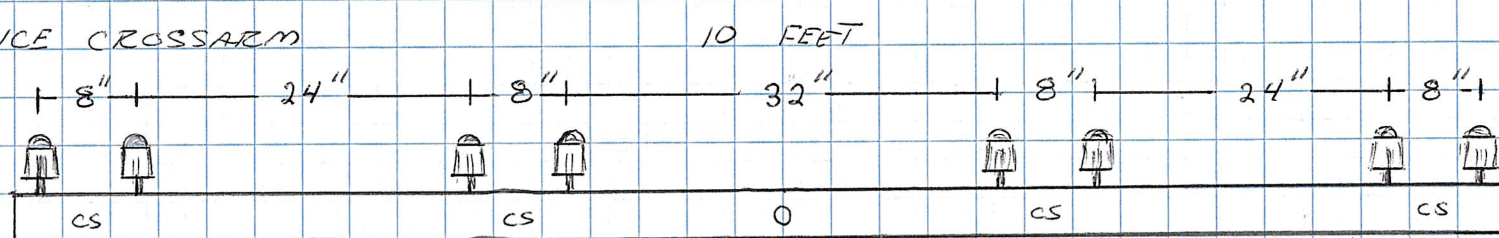
POLE PAIR CROSSARM



TRANSMISSION CROSSARM



ENTRANCE CROSSARM



SCALE APPROXIMATE