COMMUNICATION CABLES

Standard Telephones and Cables Limited
A British Company of **ITT**

Loading of Telephone Cable Circuits

Introduction

This leaflet is intended as a brief guide to the selection and application of 'loading' (the insertion, of coils as 'lumped' inductance) to telephone circuits to meet specified transmission requirements of attenuation, impedance and frequency band.

The guide is sufficient only to illustrate the effect of the amount of inductance added per unit length of circuit in conjunction with the distance between loading coils, variation of circuit capacitance, etc. Loading is, in general, confined to voice-frequency circuits and the information in this leaflet applies to these. However, special loading is sometimes applied to carrier entrance cables, to broadcast music circuits and to intermediate cables in open wire routes.

STC's Telephone Cable Division will be glad to give further information and to advise on suitable loading for any specific scheme.

Loading is normally applied for one or more of three reasons.

- To reduce the circuit attenuation.
- To match a given impedance.
- To equalise the attenuation over a specified frequency band.

Loading will also affect the circuit crosstalk (due to changed impedance as well as by possible coil to coil crosstalk) and will limit the transmitted frequency band by lowering the cut-off frequency. The loading applied to a circuit is, therefore, often a compromise in order to attain the desired improvement in one characteristic whilst maintaining others at acceptable values.

Nowadays, and particularly with star-quad cables, it is usual to load only the 'side' or physical circuits, employing one coil for each pair. If 'phantom' loading is required (generally applied only to the phantom of a Dieselhorst-Martin multiple-twin quad) the loading unit consists of two side circuit coils and one phantom circuit coil.

Attenuation (transmission loss) is a function of the four primary parameters of a cable, Resistance (R), Capacitance (C), Inductance (L) and Leakance (G), all per unit length.

In a modern cable, L and G are so small that they can usually be considered negligible. R and C are large, and are responsible for the major portion of the attenuation. They are generally determined by the economics of the system and for any particular cable design a reduction of R can only be attained by increase in conductor size, and reduction of C by increasing the conductor spacing resulting in a larger and more expensive cable.

For a loaded cable, where G is very small, the attenuation may be expressed approximately as

$$\text{Attenuation} = \sqrt{\frac{R^2C}{4L}} = \frac{R}{2}\sqrt{\frac{C}{L}}$$

It is often impracticable to lower the attenuation by reducing R or C and simpler to increase the inductance (L) by the insertion of loading coils at intervals. Although this is 'lumped loading' (and theoretically the inductance should be evenly distributed along the line), in practice it is found that coil loading gives quite acceptable overall circuit characteristics provided that the inductances and the spacing of the coils are constant within close limits.

It should be noted that a cable having a poor dielectric, or with water in the cable in any quantity, will have a high mutual capacitance and probably also a high leakance. Thus, not only is C high but G is no longer negligible, resulting in a high attenuation. In such circumstances loading may not be advantageous and G will have a very marked effect as the cut-off frequency is approached.

Fig. 2 illustrates the characteristics of two normal cables, typical in their values of R and C with values of L, and the various curves indicate the effect on attenuation of altering each of these characteristics. Fig. 3 shows the attenuation of a non-loaded circuit and the improvement obtained by loading with 66 and 88 mH coils at a spacing of 1830 metres, these being the most common loading system for new installations.

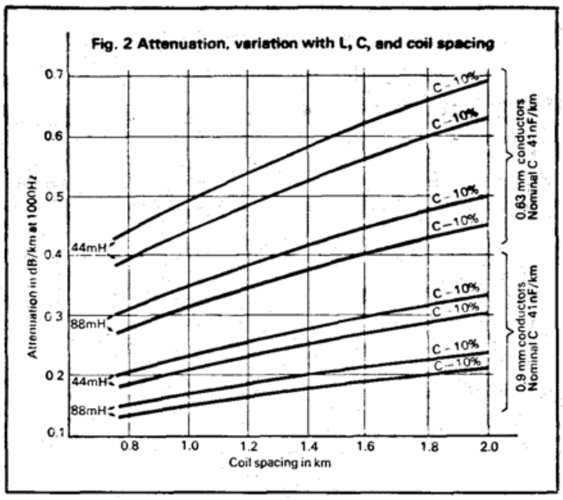
Cut-off Frequency

An effect of coil loading is to reduce the attenuation at low frequencies and to equalise the loss over most of the voice frequency band. At the top end of this band the approximate formula for attenuation is no longer valid and the effect of the loading coils is that the attenuation rises steeply to the so-called 'cut-off' frequency where transmission over the circuit becomes impracticable. This effect is shown in Fig. 3, as well as the advantage at the lower frequencies of loading.

A formula for the theoretical cut-off frequency (f_c) for a high quality loaded telephone cable is

$$f_c = \frac{1}{\pi\sqrt{LC}}$$

The effective transmission band is usually taken as up to 0.75 of the cut-off frequency.



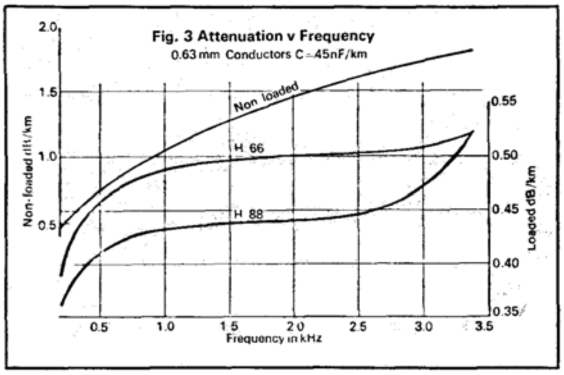
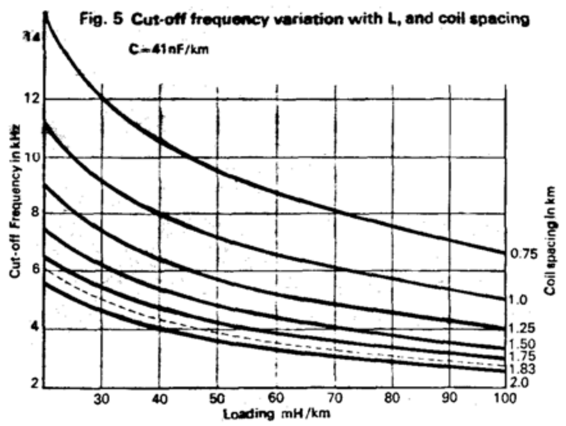


Fig. 4 gives examples of the variation of cut-off frequency with the cable mutual capacitance, the inductance of loading coils and the coil spacing. Fig. 5 shows a convenient method of relating loading inductance, loading spacing and cut-off frequency for a given circuit capacitance.



Impedance

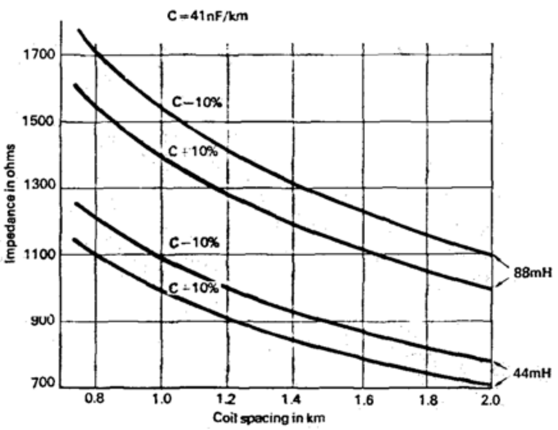
Loading of a telephone line will normally increase its characteristic impedance and, assuming a loaded line of infinite length, the characteristic impedance (Z_0) is given approximately by the following formula

$$Z_0 = \sqrt{\frac{L}{C}}$$

where L and C represent the coil inductance and pair capacitance per unit length of line (e.g. for one loading section).

The cable impedance for various values of L and C are given in Fig. 6 with 44 and 88 mH being shown as examples of the many inductances that may be used.

Fig 6 Nominal impedance variation with L, C and coil spacing



Because the loading is 'lumped' rather than the ideal of being continuously distributed along the cable length, the impedance frequency characteristic, as measured from the cable end, will vary in shape (in both resistive and reactive curves) according to the length of the section at the end being considered.

It may therefore be necessary to consider the end section when determining what impedance shape is required and this is studied further under 'Spacing'.

Spacing

In determining the spacing to be employed (the distance between loading coils on any pair), several factors must be considered, i.e.

- Attenuation
- Cut-off frequency
- Impedance
- Crosstalk
- Cost

As already explained, attenuation will generally decrease with added inductance, but the amount added is limited by cut-off considerations. A higher cut-off with the same attenuation may be attained by adding half-value loading coils at half spacing, but this will affect impedance, crosstalk and cost.

Crosstalk from capacitance unbalances (between two circuits) is directly proportional to the circuit impedances. Adding loading coils will increase the impedance and therefore increase the cable crosstalk as well as the possibility of crosstalk between the coils themselves.

Cost, particularly where large numbers of coils are involved, can be a considerable factor if a short spacing between coils is used in order to attain a high cut-off or other particular characteristics. Obviously all factors must be considered if a truly economical loading is to be employed.

In laying out a route, consideration should be given to the possibility of future extension. It is desirable to make the two ends as near half sections (in length) as possible to give a convenient terminating end impedance, and allow extensions to be started also in half sections to give a complementary end impedance. To obtain these conditions the average spacing may be varied slightly throughout the route, but the length of any loading section should not differ by more than 1 % from (a) the average length of all full sections; (b) the length of any adjacent full section.

Where it is not possible to achieve half-section terminating conditions it is usual to consider each route, together with any equipment at the terminals and other cables into which circuits may be extended, and where necessary to fit building out capacitors and loading coils at the terminals. Some spacings have been coded for convenience and these are shown below

Code Letter	Coil Spacing		
	Yards	Ft	Metres
A	233	700	213
B	1000	3000	915
C	310	930	283
D	1500	4500	1372
E	1858	5575	1700
F	930	2790	850
H	2000	6000	1830
K	2470	7400	2256
M	3000	9000	2745
R	3870	11600	3536
W	13870	41600	12680

When referred to a loading system the spacing code letter is followed first by the inductance of the side circuit, in milli-Henrys and then that of the phantom circuit, if this is also loaded.

e.g.

H-66 denotes 66 mH side circuit coils at 1830 m spacing.

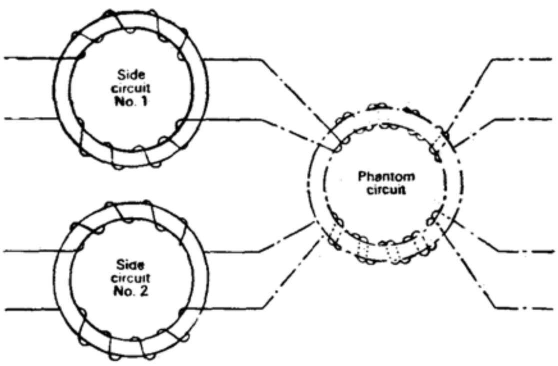
B-66-27 denotes 66 mH on side circuits, 27 mH on phantom circuits, both at 915 m spacing.

CE-5-12 denotes side circuit loading of 5 mH at 283 m and phantom circuit loading of 12 mH at 1700 m.

Phantom loading

Loading of the phantom circuit in addition to the two side circuits of a quad was a practice applied for many years to Multiple Twin quads, when all three circuits were employed directly for long distance speech. Although still employed in some areas, it is a practice which has been slowly dying since the introduction of the star-quad, where the mutual capacitance of the phantom circuit is high, and the phantom is often used for other purposes in its non-loaded state. However, where phantom loading is employed it takes the form of a three coil unit arranged as shown in Fig. 7.

Fig. 7



This is a specialised, and at times complex, problem, each project being considered for its several requirements. Coil spacings are often based on a capacitance rather than a physical distance and full particulars of each route are needed to enable a study to be made. Carrier loading is sometimes applied to entrance cables from open wire carrier systems, or on similar systems where a short intermediate cable replaces a section of open-wire route. These are instances where loading is primarily designed for impedance considerations rather than to attain a low attenuation.

Broadcast loading

On these circuits a light loading is normally employed with the object of attaining a degree of equalisation over a wide frequency band. Since the circuits have to cater for the transmission of both speech and music a high cut-off is required, necessitating both light loading and usually a close spacing of the loading coils.

Coil size

Although the electrical qualities of loading coils meet all the desired electrical characteristics, coil winding techniques and core materials are under constant development to achieve a physically smaller and more economic coil.

A loading coil case for installation in a manhole can contain up to 1040 voice-frequency coils, whilst up to 104 individual coils, fixed to a simple support frame, can be accommodated within the sleeve of a main cable joint.

STC anticipate that future loading coils will be even smaller enabling the same sized loading coil case, or cable joint, to house an even greater number of coils.

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