March 19, 1929. G. WUCKEL 1,706,339

CABLE CIRCUITS

Filed June 6, 1927

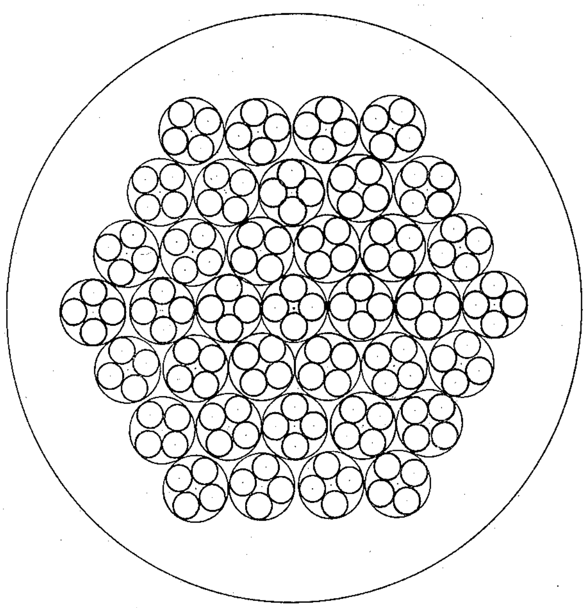

Fig. 1

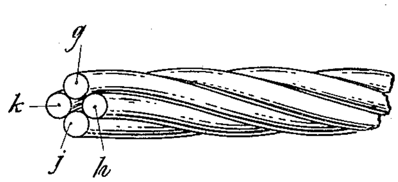

Fig. 2

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Patented Mar. 19, 1929. 1,706,339

UNITED STATES PATENT OFFICE.

GÜNTER WUCKEL, OF KARLSHORST-BERLIN, GERMANY, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

CABLE CIRCUITS.

Application filed June 6, 1927, Serial No. 197,002, and in Germany June 19, 1926.

This invention relates to cable circuits, and particularly to cable circuits of high cut-off frequencies for the transmission of signals over long distances.

With the development of modern cable systems it has been found that it is necessary to use circuits having high cut-off frequencies for transmission over the longer distances while circuits having lower cut-off frequencies are satisfactory for the shorter distances. Moreover, repeaters must be grouped together in repeater stations at definite points where suitable sources of power are available and the necessary supervision can be carried on. As repeaters must be inserted in long cable circuits at approximately equal intervals, it is desirable that the transmission losses per mile of the various classes of cable circuits be multiples of some common value. The repeater stations are then so located along the route that circuits having the greatest loss will require repeaters at each repeater station, while circuits having lesser losses will require repeaters only at every second station or every third station, etc. In practice, repeater stations are located at approximately equal distances of about 50 miles from each other.

In the multiple-twin type of construction, the insulated wires forming a cable are taken, two at a time, and twisted together to form "pairs". The pairs are next taken, two at a time, and twisted together to form quads. The quads in turn are arranged in layers around a central quad to form the cable. The four wires forming any quad all have the time diameter or gauge, but different quads in the same cable may have wires of different sizes. The two wires of each pair are the conductors which are used for a "side circuit", while the two pairs of a quad are used as conductors for a phantom circuit. Each quad thus provides for two side circuits and one phantom circuit. In this type of construction, the capacity per unit length of the phantom is so related to that of the sides, that when they are loaded to have the same transmission loss the cut-off frequency of the phantom is higher than that of the side circuits. Each quad thus provides two side circuits suitable for transmission over a certain distance and one phantom circuit suitable, because of its higher cut-off frequency, for transmission over longer distances.

In the star type of construction, four insulated wires are twisted around a common axis to form a quad and these quads are assembled to form a cable. Two wires which lie diametrically opposite to each other in the quad are used for one side circuit, and the two remaining wires are used for the second side circuit. The wires of the two side circuits form the conductors for the phantom. The four wires of any quad are all of the same diameter, but different quads may have wires of different diameters. The capacity per unit length of the phantom in this type of construction is so great compared with the capacity of the side circuits that even when they are loaded to give the same transmission loss the cut-off frequency of the phantom is lower than that of the side circuits, which, of course, is undesirable.

On the other hand, the space required for a star quad is much less than that required for a multiple-twin quad, hence it is possible to put as many good circuits within a cable sheath of a given size by using the star construction as by using the multiple-twin construction, without using the phantoms of the star quads. This arrangement obviates many of the disadvantages connected with the utilization of phantom circuits, but it has one disadvantage, namely, it does not provide circuits of high cut-off frequency such as are available in the phantoms of the multiple-twin system. Side circuits of high cut-off frequency could be provided in star quadded cable by increasing the diameters of some of the quads to reduce their capacity, but this makes the construction of the cable more difficult. Side circuits of high cut-off frequency may also be provided, by changing the spacing of the loading coils or by departing from the requirement that the transmission losses of various kinds of circuits shall be multiples of a certain value. All of these methods for increasing the cut-off frequency are, however, uneconomical.

In the drawing, Figure 1 shows a quad located centrally and including four conductors, each of which may comprise a wire of copper or of other conducting material covered by a strip of paper or of other insulating material. Six quads are shown in a layer about the central quad, twelve quads in the next layer, and so on. It will be clearly understood that these quads may be of similar construction and of similar cross-sectional area, as shown. All of the quads are covered by a sheath which may be made of lead, as is well known. It will also be understood that any number of layers may be provided and that each layer may have any desired number of quads and that each quad may or may not be wrapped separately.

Fig. 2 shows a perspective of one of the quads to which the principles of this invention may be applied. Here, conductors g, h, j and k are wound spirally about a common axis. Conductors g and j represent one side circuit and conductors h and k the other side circuit. It will be shown hereinafter how the cut-off frequencies of these side circuits may be increased to equal or exceed those obtainable with the phantom circuits of the multiple-twin type of cable construction.

In accordance with the present invention a novel arrangement is provided for increasing the cut-off frequency of any desired number of quads without affecting the normal cut-off frequencies of the other quads of the cable, all of which may be accomplished without changing the spacing of the loading coils or of the repeaters and without any change in the general construction of the cable. In order to more clearly understand the principles underlying this invention, a mathematical analysis will be resorted to. The attenuation constant of a coil loaded circuit is given approximately, within the transmitting range, by the following expression:

$$\beta=\frac{R_0+R_1}{2}\sqrt{\frac{C}{L}}+\frac{A}{2}\sqrt{\frac{L}{C}} \quad (1)$$

In this expression, R_0 is the resistance of the conductor, R. is the resistance of the loading coil, C and L are the capacity and inductance, respectively, per unit of length, of the circuit and A is a factor dependent upon leakage. The attenuation constant may also be expressed in the following manner:

$$\beta=\frac{R_0C}{4}s\omega_0+\frac{R_1}{L}\frac{1}{\omega_0 s}+\frac{A}{C}\frac{1}{s\omega_0} \quad (2)$$

in which

$$\omega_0=\frac{2}{s\sqrt{LC}} \quad (3)$$

ω_0 representing the cut-off frequency while s represents the distance between loading coils. It readily follows that the equation may be rewritten in the following form:

$$\beta=\frac{s}{4}R_0C\omega_0+\frac{1}{\omega_0 s}\left[\frac{R_1}{L}+\frac{A}{C}\right] \quad (4)$$

On examination of Equation (4) it will be seen than there are two terms on the right-hand side of the sign of equality. The first term gives the attenuation factor approximately and the second term is a small correction factor. It will be apparent from Equation (4) that if two circuits having conductors of different diameters and in which the loading coils are spaced at substantially equal distances apart, be compared, their attenuations will be substantially equal when the product of R_0, C and ω_0 is the same for both circuits.

One of the features of this invention is to provide a method of design by which the cut-off frequency of any group of circuits may be increased without requiring any change in the diameter of the quads. In practicing this method, use is made of an empirical curve (not shown). Using primed symbols for the group of circuits having the higher cut-off frequency, then

$$\beta'=\frac{s}{4}R'_0C'\omega'_0+\frac{1}{\omega'_0 s}\left[\frac{R'_1}{L'}+\frac{A'}{C'}\right] \quad (5)$$

If we make

$$R'_0C'=R_0C\frac{\omega_0}{\omega'_0} \quad (6)$$

then the first terms on the right of Equations (4) and (5) are equal and, since the second terms are small,

$$\beta'=\beta \text{ approximately.} \quad (7)$$

In cases where the difference between the second terms of Equations (4) and (5) are not negligible a correction may be made in the design of the loading coil in which the factor $\frac{R'_1}{L'}$ is important.

As an example, assume the following data relating to a group of circuits of low cut-off frequency:

R_0=57.8 ohms per kilometer
R_1= 9 ohms per kilometer
L = 0.1 henries per kilometer
C = 0.0335 microfarads per kilometer
A = 0.8 micromhos per kilometer
ω_0=17300 radians (equivalent to 2760 cycles per second)
s =2 kilometers

It follows, then, that

$$R_0.C=1.935. \quad (8)$$

Assuming that the side circuits of a multiple-twin quad have the constants listed above, the phantoms would have a cut-off frequency of 22,000 radians (3500 cycles). To obtain this frequency in the group of circuits of high cut-off frequency in a star quadded cable, we have the relation:

$$R'_0C'=1.935\,\frac{17300}{22000}=1.52 \quad (9)$$

The empirically derived curve mentioned hereinbefore in which R_0 is plotted against C, shows that in a cable in which the quads are of equal diameter, the requirements of the circuits of high cut-off frequency will be met by using conductors 1.3 millimeters in diameter (27 ohms per kilometer), which have a capacity of 0.055 microfarads per kilometer.

The empirically derived curves mentioned above are obtained by tests of experimental cables. They show the relation between R_0 and C for star quads of various diameters.

These curves vary widely depending upon the insulation used. But, trying various curves it is possible to select a construction for the required quads which is most advantageous from a manufacturing standpoint. Then, also, the accuracy with which the value of the product $R_0' C'$ is attained need not be very great since, in accordance with the calculations given hereinbefore, there is still a correction factor which may be applied and any correction deemed necessary may be obtained by an appropriate selection of a loading coil having a suitable $\frac{R'_1}{L'}$ factor. The proper selection of the loading coil, its proportions, etc., may be made in its manufacture. One of the essential features of this invention is based on the recognition of a fundamental proposition that if the diameters of any quad are kept constant, a higher cut-off frequency may be attained by a suitable selection of the magnitudes R' and C'. If the cut-off frequency required is of such large value as to render the fulfilment of the condition given by expression (6) hereinabove practically impossible, assuming, of course, that the quad diameters remain the same, then, in accordance with a further feature of this invention, the conductor diameters may be determined from the expression

$$R'_0C' = nR_0C\frac{\omega_0}{\omega'_0} \quad (10)$$

in which n is an integer. In the latter case the groups of circuits having a higher cut-off frequency will not have the same attenuation factor as heretofore, but rather an attenuation factor n times as great as those of the remaining circuits. The separation between the repeaters or amplifying means in the latter case will be $\frac{1}{n\text{th}}$ as great as the corresponding repeaters or amplifying means discussed heretofore. In the case under consideration, however, n may be, for example, two, for groups of conductors having double the cut-off frequency. In the normal German long distance cable circuits, conductors of one diameter are used and loading coils having one-quarter of the normal inductance are used for the circuits of high cut-off frequency. The attenuation is twice normal and the distance between repeaters is one-half normal. Yet, in accordance with the present invention, the assembly and construction of the cable is exactly the same as in the case in which all of the groups of conductors have the same cut-off frequency.

In contrast with the multiple-twin cable system in which the phantoms are utilized this invention has great advantages since any desired number of talking circuits may be given high cut-off frequencies. In the ordinary multiple-twin cable system, only one-third of the circuits may be so arranged, irrespective of the percentage required or desired with higher cut-off frequencies.

Furthermore, in accordance with the present invention a further advantage results from the fact that the quads having higher cut-off frequencies may be arranged in any desired way within the cable so that, for example, two quads having higher cut-off frequencies will never be situated next to each other. In the ordinary multiple-twin cable system, however, one talking circuit having a higher cut-off frequency is found in every quad. This fact is of considerable importance in the familiar four-wire circuits, in which two wires are employed for transmission direction and the two others for transmission in the opposite direction. In connection with the four-wire circuits, it is necessary because of the large gains that are used, to separate the pairs used for transmission in one direction from the pairs used for transmission in the opposite direction so as to minimize the possibility of cross-talk.

While this invention has been pointed out in particular arrangements merely for the purpose of illustration, it is to be distinctly understood that the general principles of this invention may be applied to other and widely varied organizations without departing from the spirit of the invention or the scope of the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States, is,—

1. In a cable for the transmission of speech currents, the combination of a plurality of quads of substantially equal diameters loaded at equal intervals, some of the circuits of which are to have higher cut-off frequencies than others, the constants of the circuits of high cut-off frequency being related to the constants of the circuits of low cut-off frequency by the formula

$$R'_0C' = R_0C\frac{\omega_0}{\omega'_0}$$

in which R_0 is the conductor resistance, C in the capacity of the circuit per unit length and ω_0 is the cut-off frequency, the primed characters relating to the properties of the conductors of higher cut-off frequencies.

2. In a cable for the transmission of currents such as speech currents, the combination of a plurality of quads of equal diameter loaded at equal intervals, some of which are to have higher cut-off frequencies than others, said quads being proportioned such that the product of the resistance, capacity and cut-off frequency of each circuit intended to have a higher cut-off frequency shall equal the product of the resistance, capacity and cut-off frequency of each circuit of low cut-off frequency.

In witness whereof, I have hereunto set my hand this 19th day of May, 1927.

GÜNTER WUCKEL.

4.

CERTIFICATE OF CORRECTION.

Patent No. 1,706,339. Granted March 19, 1929, to

GUNTER WUCKEL.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 3, line 111, claim 1, after the letter "C" for the word "in" read "is"; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 23rd day of April, A. D. 1929.

(Seal)

M. J. Moore,
Acting Commissioner of Patents.

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