

March 31, 1936.

E. I. GREEN

2,035,545

COAXIAL CONDUCTOR TRANSMISSION SYSTEM

Filed June 18, 1932

3 Sheets-Sheet 1

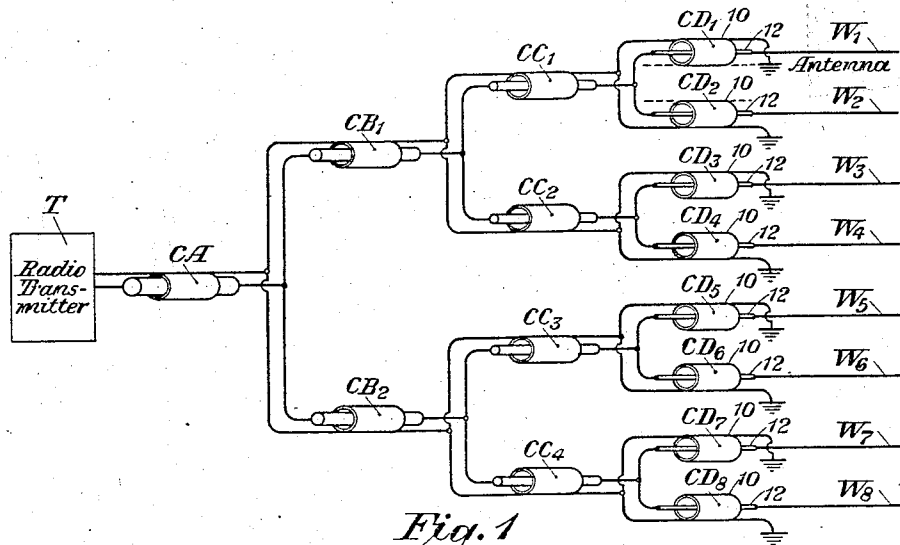


Fig. 1

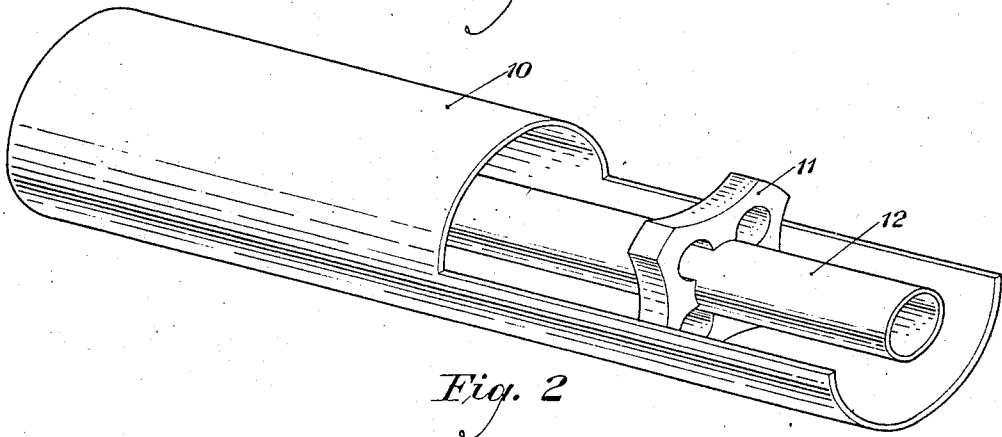


Fig. 2

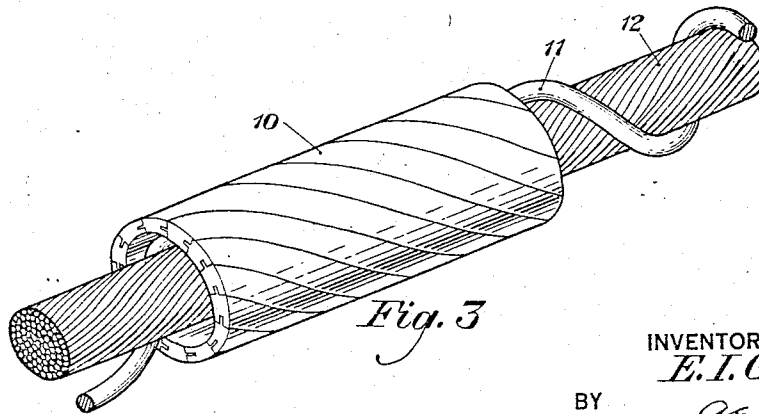


Fig. 3

INVENTOR
E. I. Green

BY

J. G. 402
ATTORNEY

March 31, 1936.

E. I. GREEN

2,035,545

COAXIAL CONDUCTOR TRANSMISSION SYSTEM

Filed June 18, 1932

3 Sheets-Sheet 2

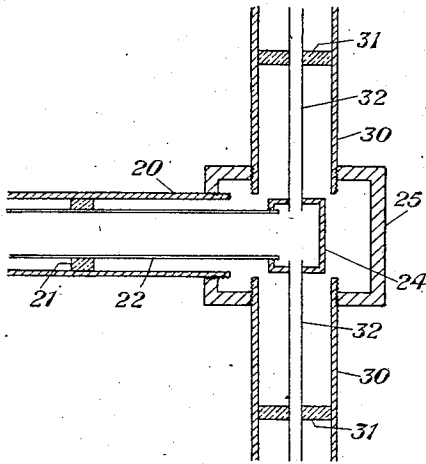


Fig. 4

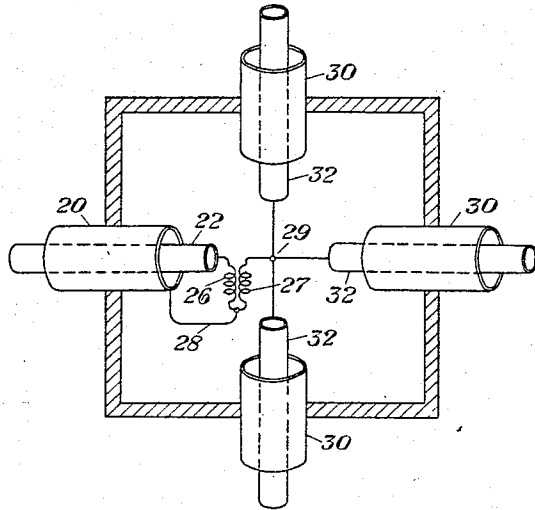


Fig. 5

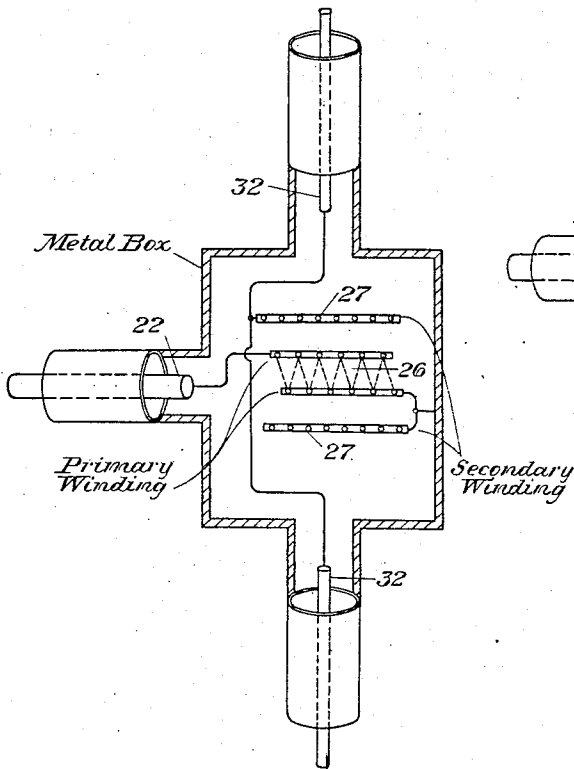


Fig. 7

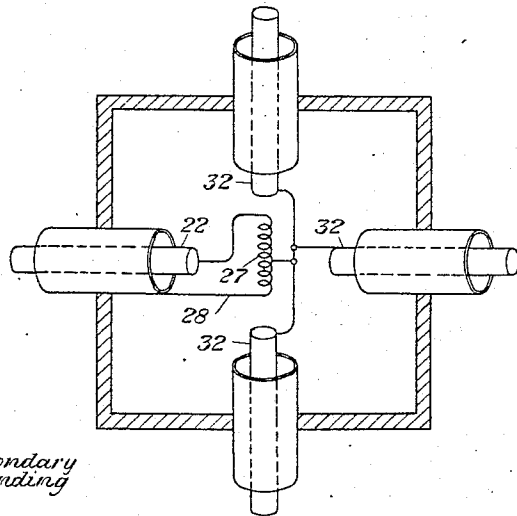


Fig. 6

INVENTOR
E. I. Green
BY *g w f o r c*
ATTORNEY

March 31, 1936.

E. I. GREEN

2,035,545

COAXIAL CONDUCTOR TRANSMISSION SYSTEM

Filed June 18, 1932

3 Sheets-Sheet 3

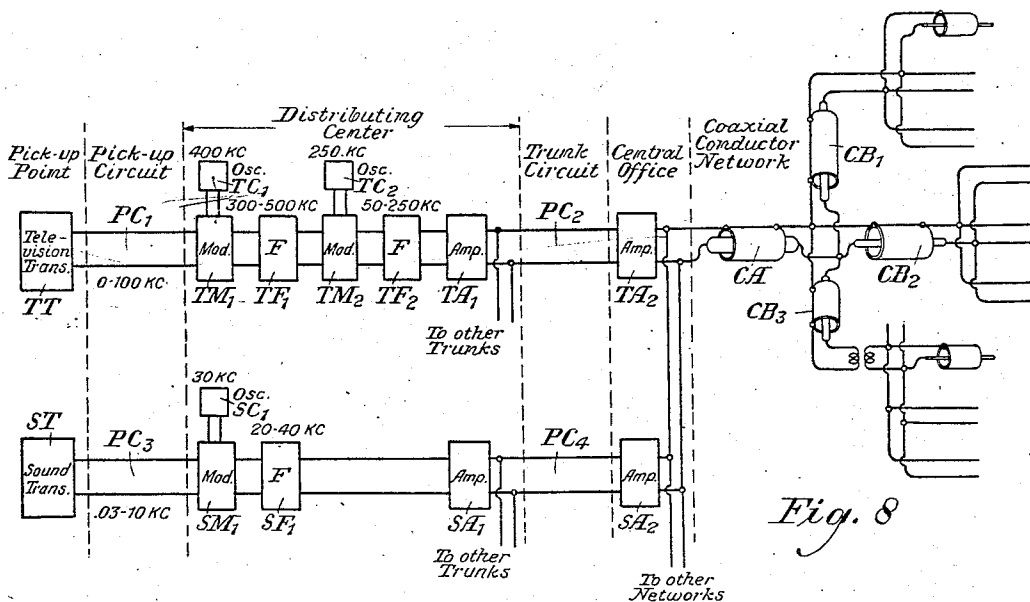


Fig. 8

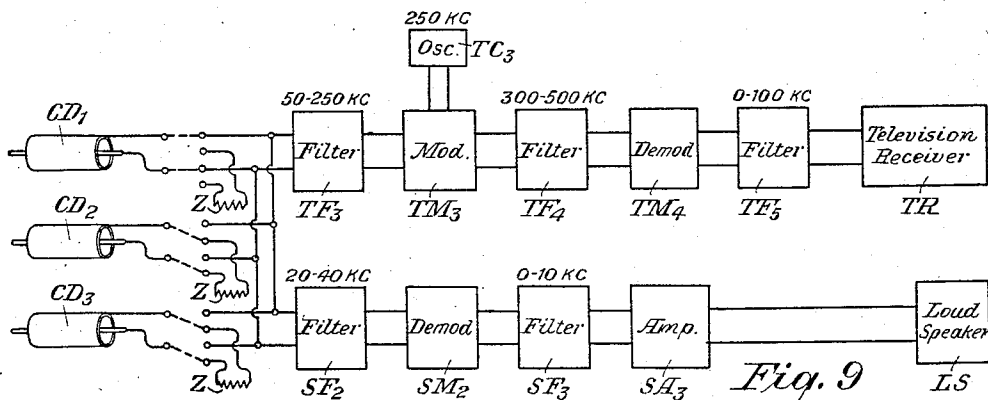


Fig. 9

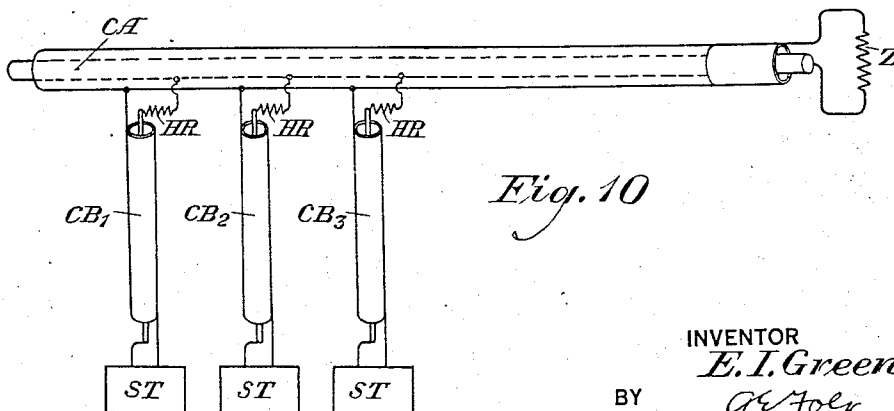


Fig. 10

INVENTOR
E. I. Green
BY *gr 706*
ATTORNEY

UNITED STATES PATENT OFFICE

2,035,545

COAXIAL CONDUCTOR TRANSMISSION
SYSTEM

Estill I. Green, East Orange, N. J., assignor to
American Telephone and Telegraph Company,
a corporation of New York

Application June 18, 1932, Serial No. 618,075

9 Claims. (Cl. 178-44)

This invention is concerned with transmission systems in which one-way transmission is effected from a single transmitting point to a plurality of receiving points, a branching network of conductors being used for this purpose. One of the principal objects of the invention is the provision of means whereby, in progressing outwardly from the transmitting terminal to the receiving terminals over such a branching network, undesirable reflection effects may be avoided.

In accordance with the invention one-way transmission between a single transmitting terminal and a plurality of receiving terminals may be accomplished over a branching network which comprises in succession a main trunk which divides into branches, each branch then splitting into further branches, and this process of subdivision being repeated to any desired degree. A particular object of the invention is the provision of means whereby in such a network smooth impedance relations may be obtained at each point of branching for energy passing from the transmitting terminal toward the receiving terminals.

In accordance with the invention a branching network may be employed which is constituted of circuits, each of which consists of two conductors arranged in concentric or coaxial relation to one another. Methods are described whereby an impedance match may be obtained for one direction of transmission from a single coaxial circuit to a plurality of coaxial circuits branching away therefrom, and whereby similar impedance matching may be secured as the process of subdividing the circuit is repeated.

Another object of the invention is the provision of transmission systems employing a branching network of coaxial conductors capable of transmitting a wide band of frequencies.

The invention will now be more readily understood from the following description when read in connection with the accompanying drawings, in which Figure 1 represents a system in which a radio transmitter is connected by a branching network of conductors to a plurality of transmitting antennas; Figs. 2 and 3 illustrate a type of coaxial circuit structure which may be used for such a network; Figs. 4, 5, 6 and 7 show different arrangements for obtaining smooth impedance relations at junctions of coaxial circuits; Figs. 8 and 9 illustrate a system for the combined broadcasting of sound and television programs over a branching network to a plurality of receiving points; and Fig. 10 shows an alterna-

tive form of network which may be used instead of that shown in Fig. 8.

In radio transmission it may be found advantageous to employ a transmitting antenna system comprising a plurality of individual antennas disposed in some symmetrical arrangement. For greatest effectiveness in such an arrangement it may be desirable that substantially identical transmission be secured between the radio transmitter and each antenna, so that energy of substantially the same magnitude and phase will be applied to each antenna. In some cases it may be required to transmit a single frequency from the transmitter to the antenna system, while in other cases multiple frequencies or bands of frequencies may be used. Generally a low attenuation between the transmitter antenna system will be essential in order to obtain the highest standard of performance with the greatest economy of apparatus.

One method of effecting transmission from the radio transmitter to such an antenna system might be to provide a separate transmission circuit between the transmitter and each antenna, compensating for any differences in the distance to the various antennas by building out all circuits to the same length. With such an arrangement, however, the total length of circuit required is very much greater than that necessary when using a branching network of the type illustrated in Fig. 1. Here it is assumed that it is desired to feed from a single radio transmitter T a system consisting of eight different antennas designated W_1 , W_2 , W_3 , etc. To accomplish this result there is provided a network of coaxial circuits, consisting of a main circuit CA, which is divided into two main branches CB_1 and CB_2 , each of these branches being divided in turn into two secondary branches marked CC_1 , CC_2 , etc., and each secondary branch being divided into two final branches, denoted as CD_1 , CD_2 , etc., which lead to the antennas. The outer conductor 10 of each final coaxial branch is grounded, while the inner conductor 12 is connected to the antenna. It will be seen that the network system is perfectly symmetrical so that the energy is propagated to all antennas in identical manner.

The various branches forming the network of Fig. 1 may each consist of a structure comprising two coaxial conductors as illustrated in Fig. 2. Here the inner conductor 12 is supported concentrically with respect to the outer conductor 10, the two conductors being separated by insulating discs or beads 11. Obviously, many other forms

of coaxial construction might be employed instead of that shown in Fig. 2. For example, either the inner or outer conducting path of the coaxial circuit might be formed, not of a single conductor, but of a cylindrical assembly of conducting wires, strips, tapes, ribbons or the like. For the insulation between the two conductors any of various forms or shapes could be employed for members spaced at intervals or a continuous spirally applied string or strip of dielectric material might be used. One such type of construction is illustrated in Fig. 3. This figure shows the outer conductor composed of spirally wound interlocking strips of conducting material and the inner conductor composed of a bundle of stranded wires which may be insulated from one another and interwoven as desired. Insulation between the two conductors is effected by means of a spirally applied string. Such forms of construction would be particularly advantageous where a flexible structure is desired. Generally, it will be desirable that the amount of insulating material employed be a minimum in order that the dielectric between the two conductors may be largely gaseous. In some instances, however, it may be found advantageous to use a dielectric which is partly or wholly non-gaseous as, for example, rubber insulation.

The coaxial type of circuit is peculiarly adapted to the transmission of high frequencies or a wide range of frequencies without excessive attenuation and without the possibility of interference from external sources. These properties are due primarily to the phenomenon of skin effect in the conductors, in accordance with which the transmitted currents tend to flow on the inner surface of the outer conductor and the outer surface of the inner conductor. Hence the conducting material is used more effectively than is the case with ordinary construction in which a pair of solid conductors forms the transmission circuit. Since the interfering currents tend to flow on the outer surface of the outer conductor of the coaxial circuit, this conductor acts as a highly effective shield against induction from external sources. In contrast to the ordinary unshielded circuit, in which balance is relied upon to reduce the external induction, and for which as a result the susceptibility to external influences increases as the frequency is increased, the coaxial circuit possesses a shield whose effectiveness increases with increasing frequency. Consequently, when circumstances make it desirable, the energy transmitted over the coaxial circuit may be attenuated to a minimum level which is limited only by the noise occasioned by thermal agitation of electricity in the conductors themselves.

Referring to the network of coaxial conductors illustrated in Fig. 1, it will be apparent that in order to avoid unwanted reflection effects for currents passing from the transmitting apparatus to the antenna system, the impedances should be matched at each junction point. It is clear that if such matching is not provided, the reflections occurring at frequencies for which the circuits have appreciable electric length will result in an irregular transmission-frequency characteristic and likewise an irregular impedance-frequency characteristic. In order to match impedances for one direction of transmission at each point where a stem divides into two branches, the impedance of each branch should be twice the impedance of the stem. Thus, if Z is the characteristic impedance of the main circuit CA, the characteristic impedance of each branch CB₁, CB₂, etc., should be

2Z, that of each branch CC₁, CC₂, etc., should be 4Z, that of each final branch CD₁, CD₂, etc., should be 8Z, and the terminating impedance should also be 8Z.

Considering the more general case where a stem divides into n branches, the characteristic impedance of each branch should evidently be n times that of the stem.

Now the characteristic impedance at high frequencies of the coaxial conductor circuit is

$$Z_0 = \sqrt{\frac{L}{C}} \quad (1)$$

where the inductance L per unit length is given by

$$L = 0.3219 \log_e \frac{c}{b} \times 10^{-3} \text{ henries per mile} \quad (2)$$

and the capacity C per unit length is

$$C = \frac{0.0894K}{\log_e \frac{c}{b}} \times 10^{-6} \text{ farads per mile} \quad (3)$$

In these formulas c is the inner radius of the outer conductor, b is the outer radius of the inner conductor, and K is the effective dielectric constant of the material between conductors. Formulas (2) and (3) may be obtained by analogy with formula (55), page 109, and formula (56), page 72, respectively, of "Calculation of Alternating-Current Problems," by L. Cohen.

Substituting the values for C and L in formula (1), we have

$$Z_0 = 60 \cdot \frac{1}{\sqrt{K}} \log_e \frac{c}{b} \quad (4)$$

It is evident from Equation (4) that with any given insulating material the characteristic impedance of the circuit at high frequencies is determined by the ratio of the radii (or diameters) of the conductors, i. e.,

$$\frac{c}{b}$$

When the dielectric between the conductors of the coaxial circuit consists largely of air, the high-frequency impedance becomes

$$Z_0 = 60 \cdot \log_e \frac{c}{b} \quad (5)$$

Hence, if a coaxial circuit which may be designated as No. 2 is to have a high-frequency characteristic impedance equal to n times that of another coaxial circuit which may be designated as No. 1, the two circuits having the same dielectric constants, the diameter ratios should be related as follows:

$$\log_e \frac{c_2}{b_2} = n \log_e \frac{c_1}{b_1} \quad (6)$$

This reduces to:

$$\frac{c_2}{b_2} = \left[\frac{c_1}{b_1} \right]^n \quad (7)$$

$$\frac{c_1}{b_1}$$

and

$$\frac{c_2}{b_2}$$

being the diameter ratios for circuits Nos. 1 and 2, respectively.

Thus, in a network arrangement such as that of Fig. 1, it is possible within reasonable limits to obtain the impedance desired at each end of the system and to match the impedance at all

junctions for transmission toward the antennas. Suppose, for example, that in the case shown on the drawings it is desired to secure an impedance of 167 ohms at each antenna. The branch leading to each antenna may be given such an impedance by using a coaxial circuit with a diameter ratio of about 16, a ratio which might be secured, for example, by making the diameter of the outer conductor about 2 inches and the diameter of the inner conductor about $\frac{1}{8}$ inch. The branches feeding the 167-ohm circuits may each be given an impedance of about 83 ohms by using a diameter ratio of about 4. The branches leading to the 83-ohm circuits would have an impedance of about 42 ohms and a diameter ratio of about 2, while the characteristic impedance of the main circuit would be about 21 ohms and the diameter ratio of this circuit about 1.4. Since reflection effects are avoided the impedance looking from the transmitting end into the main circuit will be the same for the entire high-frequency range.

It is fairly evident that the process of matching impedances by changing the diameter ratios cannot be continued indefinitely as the number of subdivisions is increased. The limit in this regard may be set either by the increased attenuation or the mechanical difficulties which would be obtained if very small or very large diameter ratios were used.

A possible method of joining the coaxial conductors in such a network is illustrated in Fig. 4, where the impedance looking from the stem toward the two branches is matched to the impedance of the stem by making the diameter ratio for each branch four times that of the stem. As shown in this figure, the outer conductor 20 of the stem may be joined to the outer conductor 30 of each branch through the medium of a junction box 25, which may be considered as an enlargement of the outer conductor and to which the outer conductors are connected by means of screwed or soldered joints. The inner conductor 22 of the stem may be similarly joined through the connector 24 to the inner conductor 32 of each branch. Insulators 21 and 31 may be used to support the inner conductors in proper concentric relation. Obviously other ways of effecting the physical junction between the circuits might be used instead of that shown.

In the previous discussion it was assumed that the dielectric constant is the same for all the circuits in the network. Use might be made, however, of circuits having different dielectric material, in order to cut down the amount of change in diameter ratio required at a junction. The higher dielectric constant would be employed for the circuit which is to have the lower impedance. Thus, referring to Equation (4) it is found that the general condition for securing in circuit No. 2 an impedance n times that of circuit No. 1 is:

$$\frac{1}{\sqrt{K_2}} \log \frac{c_2}{b_2} = n \frac{1}{\sqrt{K_1}} \log \frac{c_1}{b_1} \quad (8)$$

which may be reduced to:

$$\frac{c_2}{b_2} = \left[\frac{c_1}{b_1} \right]^n \sqrt{\frac{K_2}{K_1}} \quad (9)$$

It will be seen from (4) that a circuit having a solid dielectric with a dielectric constant of 4 has a characteristic impedance equal to half that of a circuit of the same diameter ratio having air dielectric. Hence, in matching impedances when passing, for example, from a stem to two

branches, the diameter ratio might be increased by a factor of 4, the dielectric constant might be increased by a factor of 4, or both diameter ratio and dielectric constant might be changed in accordance with the relation of Equation (9).

It would also be possible to match impedances by using a transformer at each junction, leaving the diameter ratios and dielectric constants unchanged. Such a scheme is illustrated in Figs. 5, 6 and 7. With this scheme it would be possible to employ for all the coaxial circuits in the network the diameter ratio which gives minimum attenuation. Letting the outer radius of the inner conductor and the inner radius of the outer conductor be expressed by b and c , respectively, and expressing the attenuation in terms of these and other proper parameters, then setting up the expression for attenuation as a function of the ratio $c/b=x$; then differentiating and equating to zero according to the well-known procedure for ascertaining a maximum or minimum value, it can readily be shown that the Napierian logarithm of x is equal to $(x+1)/x$; when $x=3.6$ approximately. This relation holds under a considerable variety of conditions and is well checked experimentally.

The transformer at the junction point may be mounted inside the outer coaxial conductor or in a box which represents an enlargement of the outer conductor. It may be designed so that the windings are symmetrically arranged with reference to the conductors. Fig. 5 shows an ordinary transformer arrangement in which the outer conductor 20 of the stem is directly connected to the outer conductors 30 of three branches. The transformer for matching impedances has a primary winding 26 connected between the inner conductor 22 of the stem and the common outer conductor connection 23, and a secondary winding 27 connected between the common junction 29 of the inner conductors 32 of the branches and the common outer conductor connection. Assuming that the characteristic impedance of each branch is equal to that of the stem, the transformer should provide an impedance step-down ratio of approximately 3:1 in going from the stem to the three branches in parallel. This is accomplished by giving the primary approximately nine times the number of turns used in the secondary.

Fig. 6 shows an arrangement employing an auto-transformer 27 for matching the impedance of a stem to three branches. The entire winding of the transformer is connected between the inner conductor 22 of the stem and the common connection of outer conductors, while the junction of the inner conductors 32 of the branches is brought to an intermediate point of the winding.

Fig. 7 shows a physical arrangement whereby a transformer for connecting a stem and two branches may be symmetrically disposed with reference to the interconnected circuits. A primary winding 26 arranged in the form of a helix is connected between the inner conductor 22 of the stem and a box representing a common connection of the outer conductors of the stem and branches. This primary winding is supported concentrically within a secondary winding 27, which is connected between the junction of the inner conductors 32 of the branches and the box to which the outer conductors are connected.

Another possible method for matching impedances would consist of a combination of a

transformer together with a change of diameter ratio or a transformer together with different dielectric material for the conductors or a combination of all three. Equation (8) gives the general condition for matching the impedance of two coaxial circuits. If a transformer is also used this equation becomes

$$\frac{1}{\sqrt{K_2}} \log_e \frac{c_2}{b_2} = \frac{1}{R} n \frac{1}{\sqrt{K_1}} \log_e \frac{c_1}{b_1} \quad (9)$$

where R is the impedance ratio between the primary and secondary windings of the transformer connected between a main circuit having a diameter ratio

$$\frac{c_1}{b_1}$$

and a dielectric constant K_1 , and n branching circuits each having a diameter ratio

$$\frac{c_2}{b_2}$$

and a dielectric constant K_2 . Equation (9) may be reduced to

$$\frac{c_2}{b_2} = \left[\frac{c_1}{b_1} \right]^{\frac{n}{r}} \sqrt{\frac{K_1}{K_2}} \quad (10)$$

Any combination of the various components which approximately satisfies the relations of this equation may be employed for matching impedances between circuits.

Fig. 8 illustrates another type of system in which a branching coaxial network may be utilized. In this case the network is incorporated in a party line system in which sound and television signals are transmitted from a single transmitting point to a plurality of receiving points. At the place where the sound and television signals originate (for example, a studio or pick-up point), there is located a television transmitting apparatus TT of any well-known type, as, for example, that disclosed in a copending application of Frank Gray, Serial No. 227,649, filed October 21, 1927. This apparatus may include a suitable mechanism for scanning the image, photoelectric cells for converting the resulting light variations into electric signals, and means for amplifying these signals. The width of the band of signals obtained in the output of the television transmitter will depend upon the degree of image definition provided. In the present instance it will be assumed that this band extends from 0 to 100 kc.

The television signals from the transmitter TT may be transmitted to a central distributing point over a trunk circuit PC₁, which may be either an ordinary cable pair or a coaxial circuit of the type illustrated in Fig. 2. At the distributing center the television signal band is first applied to a modulator TM₁, which is supplied by an oscillator TC₁ with a carrier frequency assumed to be 400 kc. In the output of this modulator the upper and lower sidebands of modulation, namely, 300-400 kc. and 400-500 kc., together with the carrier frequency, are selected by the filter TF₁, which suppresses other unwanted modulation products and the input frequencies. The output of this filter is applied to a second modulator TM₂, which is provided by the oscillator TC₂ with a carrier frequency assumed to be 250 kc. In the output of this modulator the lower sideband components, comprising the twin television sidebands extending from 50 to 250 kc. and a carrier frequency of 150 kc., are selected by the filter TF₂, which excludes the various

undesired frequencies. The output of this filter is passed through the amplifier TA₁ and transmitted over a trunk circuit PC₂ to an intermediate amplifying point which may be a telephone central office. Here the signals, after passing through the amplifier TA₂, are applied to the distribution network.

The sound signals accompanying the television signals are picked up and amplified in the apparatus ST. For good quality these signals may extend from about 30 cycles to 10,000 cycles. The signals are then transmitted over a trunk circuit PC₃ to the central distributing point. Here they are applied to the modulator SM₁, which is provided by the oscillator SC₁ with a carrier supply assumed to be 30 kc. The two sidebands of modulation, extending from 20 to 40 kc. and the carrier frequency are selected by the filter SF₁. After passing through the amplifier SA₁, these frequencies are transmitted from the trunk circuit PC₄ to the intermediate point where they are amplified in the sound amplifier SA₂ and combined with the television signals for application to the distribution network.

The distribution network may consist of a main coaxial conductor circuit CA, which divides into three branches CB₁, CB₂ and CB₃, these branches being further subdivided and re-subdivided until the various receiving points are reached. At each junction point the impedances may be matched in accordance with the methods already described. If the coaxial circuits comprising the network are made small and flexible, they may be included inside a lead sheath in combination with ordinary cable pairs. Additional networks for reaching other receiving points may, of course, be connected at the intermediate amplifying point in parallel with the one illustrated.

At any one receiving point such as that illustrated in Fig. 9 the television signals may be selected by the filter TF₃ and applied to the modulator TM₃ which is furnished with a carrier frequency of 250 kc. by the oscillator TC₃. In the output of this modulator the twin sidebands, extending from 300 to 500 kc. accompanied by a carrier frequency of 400 kc., are selected by the filter TF₄. The original television band is then obtained through the demodulator TM₄ with a filter TF₅ serving to eliminate undesired frequencies in the output. The signals are applied to a television receiver TR which reproduces the original image. This receiver may be of any suitable type, as, for example, that described in the application of Gray previously referred to.

The sound signals are selected at the receiving point by the filter SF₂ and are restored to their original frequency position by the demodulator SM₂. After passing through the filter SF₃ which eliminates undesired modulation products, they are amplified in the amplifier SA₃ and applied to the loud-speaker LS.

The received sound and television signals may be reproduced at the residences of individual subscribers or they may be brought to theatres or other places where they may be reproduced for the benefit of audiences.

If it is desired to have more than one program at the receiving point, additional transmitting apparatus and distributing networks may be provided, while the receiving apparatus may be switched to any desired program by means of a switching arrangement such as that illustrated in Fig. 9, so arranged that when the sound and television apparatus is not connected

to an incoming network branch, this branch is terminated in a resistance Z approximating the characteristic impedance of the branch.

In Fig. 10 there is illustrated an alternative form of distributing network which may be employed in place of that shown in Fig. 8. In this case the main circuit CA which may be of the coaxial type, after dropping off the various branches CB₁, CB₂, etc., each of which leads to a receiving point, is terminated in a resistance Z approximately equal to its characteristic impedance. At each point of branching, reflection effects are avoided by inserting in series with the inner conductor of the branch a resistance H_R, which is high in comparison with the impedance of the main circuit. The branch then extends to the sound and television apparatus ST where the loss due to the high resistance may be overcome by suitable amplification.

While the invention has been disclosed for purposes of illustration in certain specific forms, it will be obvious that its basic principles as defined in the appended claims are such as to permit its incorporation in many widely different organizations.

I claim:

1. In an electrical transmission system, a circuit network designed to transmit a wide band of frequencies, said network extending between a single transmitting point and a plurality of receiving points, said network being constituted of a plurality of circuits each of which has a length at least as great as several wave lengths of the lowest frequency to be transmitted, so that the impedance as seen from one end is independent of what is connected at the other end, said circuits comprising two conductors arranged in coaxial relation to and having such diameter ratios as to produce minimum attenuation, a plurality of points where several circuits are interconnected being included in said network, and means at each point of interconnection for avoiding reflection effects for energy transmitted toward the receiving points, said means being effective over a wide range of frequencies.

2. In an electrical transmission system, transmitting apparatus for supplying a band of frequencies extending from approximately zero to a frequency several times the upper limit of audibility, a circuit for transmitting the band of frequencies supplied formed of two coaxial conductors extending from said transmitting apparatus, said circuit being divided into branching coaxial circuits, each of said branching circuits being further subdivided and resubdivided into coaxial circuit branches, each branching circuit having a length at least as great as several wave lengths of the lowest frequency to be transmitted, so that the impedance as seen from one end is independent of what is connected at the other end, the conductors of said coaxial circuits having such diameter ratios as to produce minimum attenuation, receiving apparatus connected to each final branch for receiving and utilizing the wide band of frequencies transmitted, and means at each point of division for avoiding the reflection of energy over the wide band of frequencies transmitted.

3. A main transmission circuit comprising two conductors arranged in coaxial relation to each other and having such diameter ratio as to produce minimum attenuation, a plurality of coaxial circuit branches, a transformer of substantially uniform transmission over a wide frequency range having a primary winding connected to said main circuit and a secondary winding to which said branches are connected in parallel.

4. A main transmission circuit comprising two conductors arranged in coaxial relation to each other and having such diameter ratio as to produce minimum attenuation, a plurality of coaxial circuit branches, each branching circuit having a length at least as great as several wave lengths of the lowest frequency to be transmitted, so that the impedance as seen from one end is independent of what is connected at the other end, a transformer of substantially uniform transmission over a wide frequency range having a primary winding connected to said main circuit and a secondary winding to which said branches are connected in parallel, the impedance ratio between said primary and secondary windings being equal to the ratio of the impedance of the main circuit to the impedance of the branches connected in parallel.

5. A main transmission circuit comprising two conductors arranged in coaxial relation to each other, a plurality of coaxial circuit branches, a transformer enclosed within a shielded metallic connection between the outer conductor of said main circuit and the outer conductors of said branches, the primary winding of said transformer being connected between the inner conductor of said main circuit and the common connection of outer conductors, and the secondary winding of said transformer being connected between a common junction of the inner conductors of said branches and the common connection of the outer conductors.

6. A main transmission circuit comprising two conductors arranged in coaxial relation to each other, a plurality of coaxial circuit branches, a transformer enclosed within a shielded metallic connection between the outer conductor of said main circuit and the outer conductors of said branches, said transformer having a primary winding connected between the inner conductor of said main circuit and the common connection of outer conductors, and a secondary winding connected between a common junction of the inner conductors of said branches and the common connection of the outer conductors, the impedance ratio between said primary and secondary windings being equal to the ratio of the impedance of the main circuit to the impedance of the branches connected in parallel.

7. A main circuit comprising two conductors arranged in coaxial relation to each other, a plurality of coaxial circuit branches connected thereto, a transformer enclosed within a shielded metallic connection between the outer conductor of said main circuit and the outer conductors of said branches, said transformer having a primary winding connected between the inner conductor of said main circuit and the common connection of outer conductors, and a secondary winding of said transformer being connected between a common junction of the inner conductors of said branches and the common connection of the outer conductors, the impedance ratio between the windings of said transformer and the diameter ratios for the conductors in the main circuit of the branches being such as to approximately satisfy the relation

$$\frac{c_2}{b_2} = \left[\frac{c_1}{b_1} \right]^{\frac{n}{R}} \sqrt{\frac{K_2}{K_1}}$$

where c_1 and b_1 represent, respectively, the inner

diameter of the outer conductor and the outer diameter of the inner conductor of the main circuit, c_2 and b_2 represent the corresponding dimensions of each of the branches, K_1 and K_2 represent, respectively, the effective dielectric constant for the main circuit and for each of the branches, n represents the number of branches, and R represents the impedance transformation ratio between the primary and secondary windings of the transformer.

8. In an electrical transmission system which includes a main circuit and a plurality of branching circuits, each comprising two conductors arranged in coaxial relation to each other and having such diameter ratio as to produce minimum attenuation, the method of avoiding reflection of energy which consists in connecting the circuits at each point of division to a transformer of substantially uniform transmission over a wide frequency range and having a ratio such as to equalize the impedances of the circuits, said main circuit being connected to the

primary winding and said branching circuits being connected in parallel to the secondary winding.

9. In an electrical transmission system which includes a main circuit and a plurality of branching circuits, each comprising two conductors arranged in coaxial relation to each other, means for avoiding reflection effects, said means including connections from the circuits at each point of division to a transformer enclosed within a shielded metallic connection between the outer conductor of said main circuit and the outer conductors of said branches, the primary winding of said transformer being connected between the inner conductor of said main circuit and the common connection of outer conductors and the secondary winding of said transformer being connected between a common junction of the inner conductors of said branches and the common connection of outer conductors.

ESTILL I. GREEN.