March 24, 1936. H. S. BLACK 2,034,856

CARRIER WAVE TRANSMISSION SYSTEM

Filed Nov. 16, 1932 3 Sheets-Sheet 1

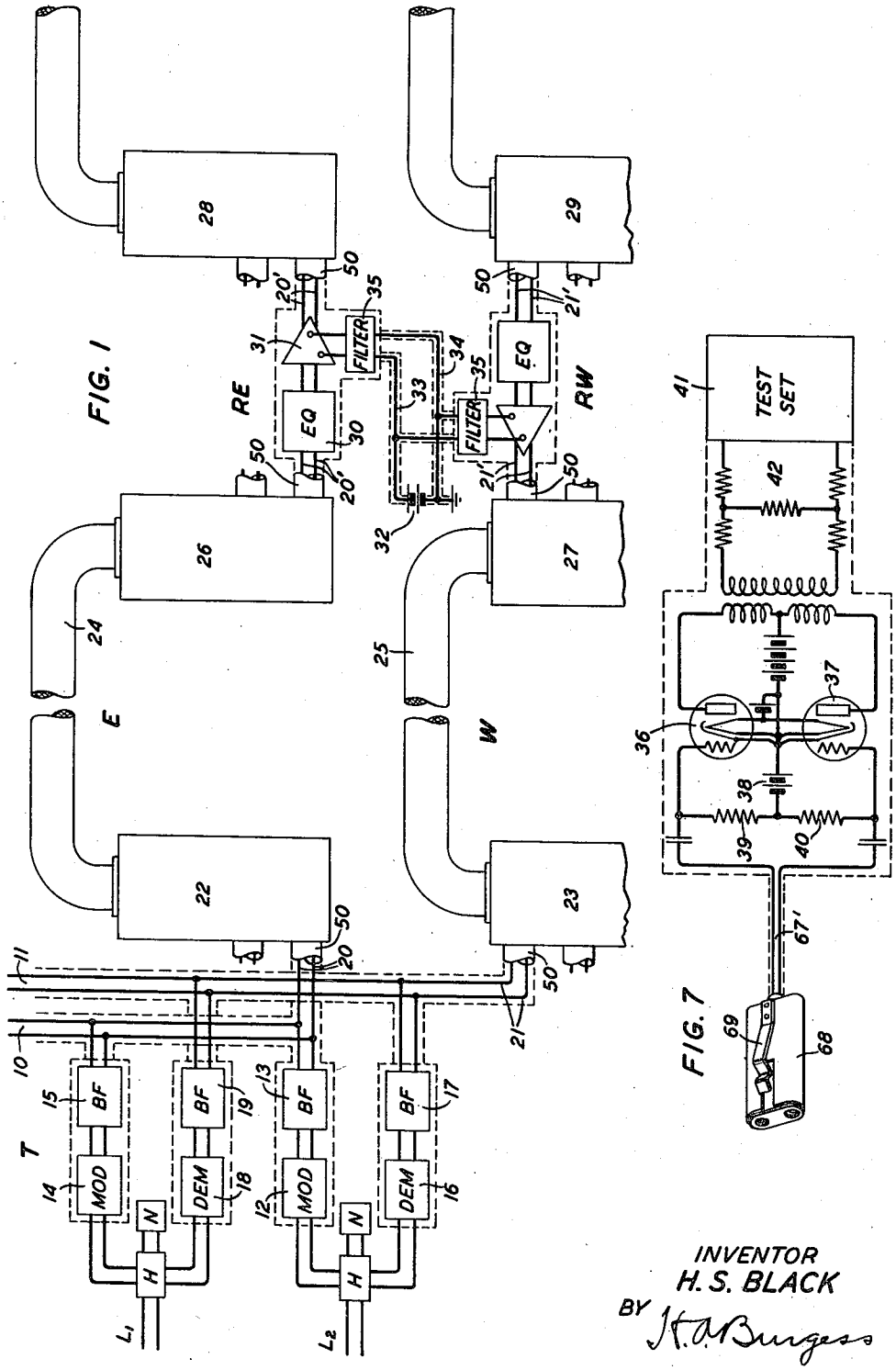


FIG. 1

FIG. 7

INVENTOR
H. S. BLACK
BY H. A. Burgess
ATTORNEY

March 24, 1936. H. S. BLACK 2,034,856

CARRIER WAVE TRANSMISSION SYSTEM

Filed Nov. 16, 1932 3 Sheets-Sheet 2

FIG. 6

FIG. 2

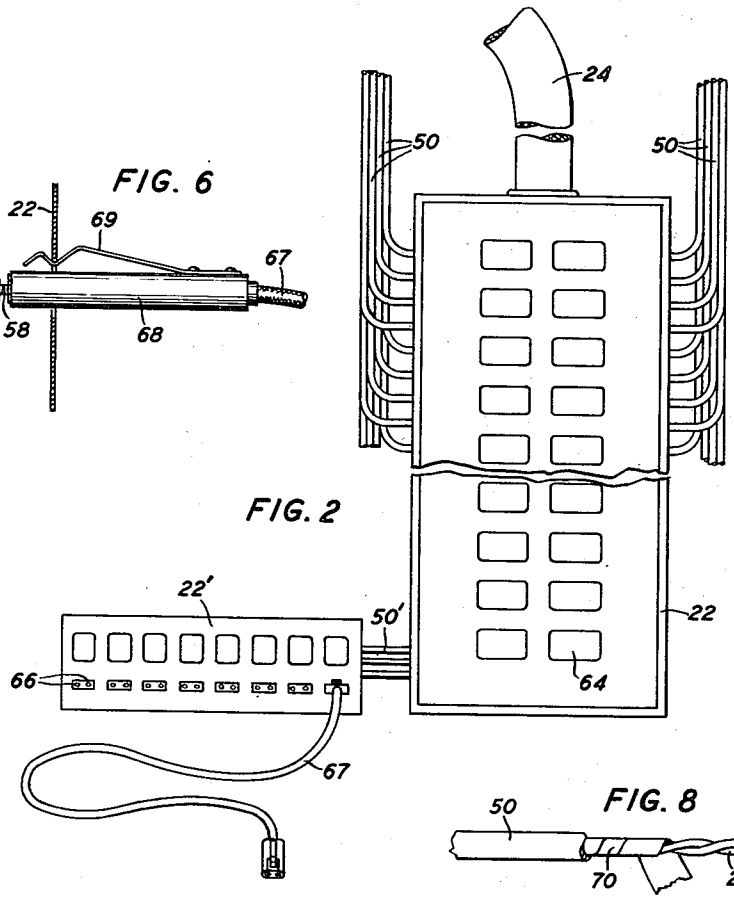


FIG. 8

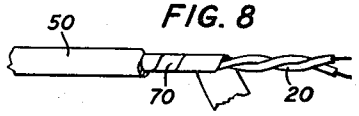
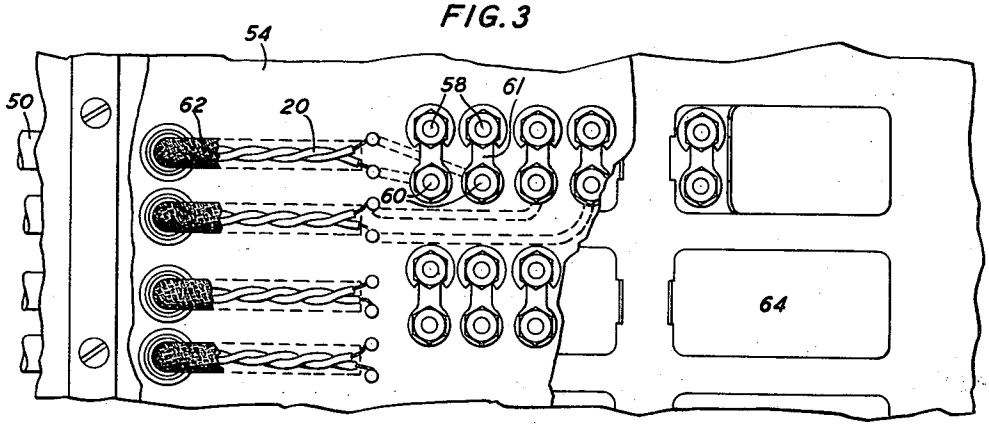


FIG. 3



INVENTOR
H. S. BLACK
BY H. A. Burgess
ATTORNEY

March 24, 1936. H. S. BLACK 2,034,856

CARRIER WAVE TRANSMISSION SYSTEM

Filed Nov. 16, 1932 3 Sheets-Sheet 3

FIG. 4

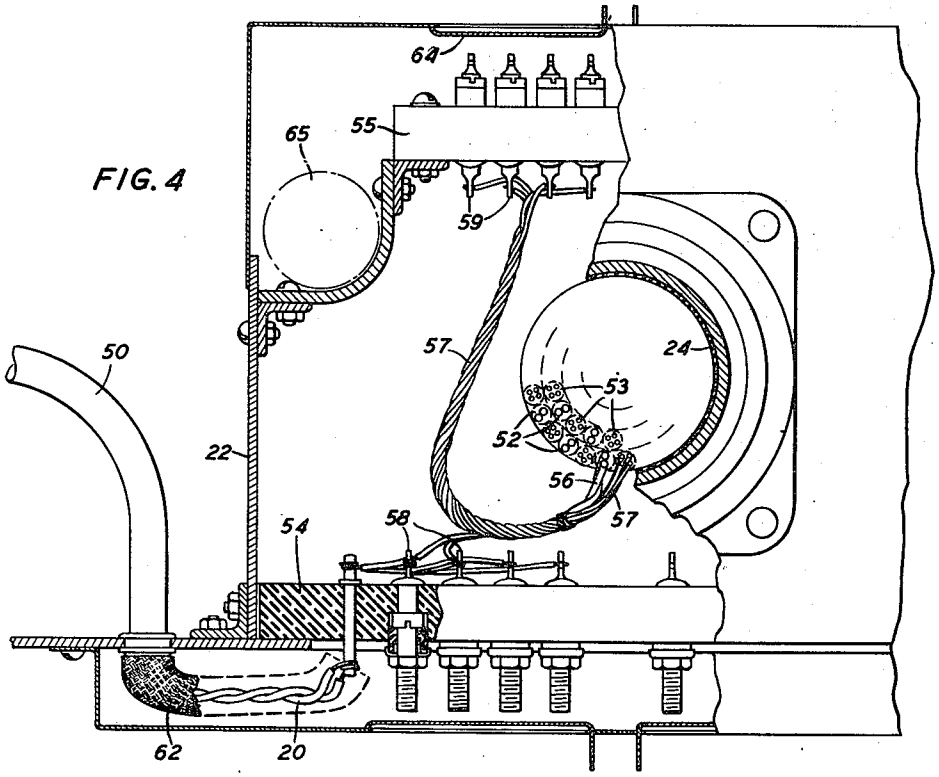
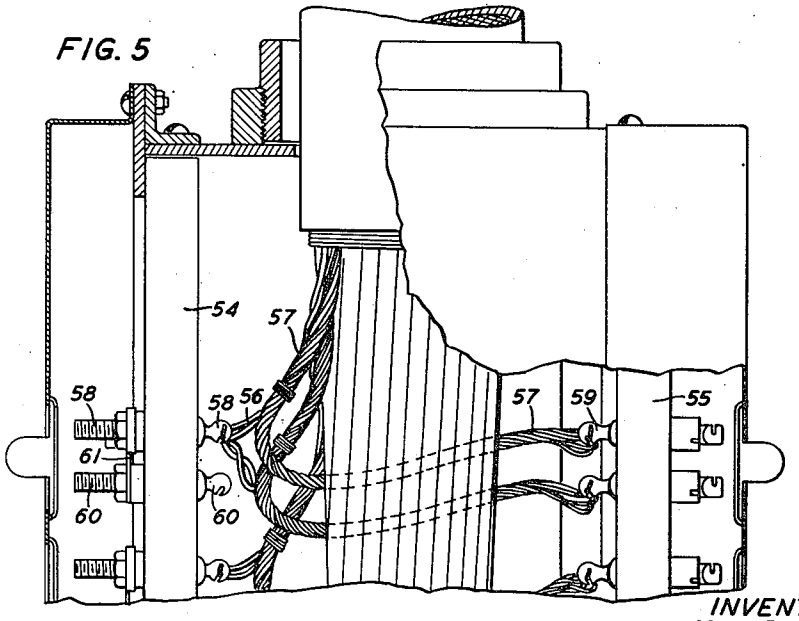


FIG. 5



INVENTOR
H. S. BLACK
BY H. A. Burgess
ATTORNEY

Patented Mar. 24, 1936 2,034,856

UNITED STATES PATENT OFFICE

2,034,856

CARRIER WAVE TRANSMISSION SYSTEM

Harold S. Black, New York, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application November 16, 1932, Serial No. 642,870

5 Claims. (Cl. 179—78)

The present invention relates to a high frequency signaling system such as a multiplex carrier wave transmission system. More particularly, the invention relates to the transmission of high frequency waves over the conductors of a telephone cable and involves features appertaining to the construction of terminal, line and repeater equipment.

One of the main limiting factors in the design of satisfactory transmission systems of the type indicated is the noise level. Noise is of two kinds, namely, (1) inherent noise including resistance noise due to thermal agitation and (2) interference in the form either of cross-talk from neighboring lines or noise picked up from extraneous sources. The amount of amplification and the distance between amplifiers in the line must be such that the signals are at all times kept sufficiently above the noise level. It is desirable for economy reasons to be able to space the repeaters far apart but this means that the signals are attenuated to very low levels before the next repeater point is reached and they must not be allowed to fall to the resistance noise level. If an attempt be made to prevent this by increasing the amount of amplification, a limiting factor is the cross-talk which increases as the level difference increases between adjacent lines. Thus it is seen that the maximum permissible signal level is fixed by cross-talk (a form of noise) and the minimum permissible level is also fixed by noise. Also, since cross-talk varies with frequency, the upper limit of frequency is determined by the cross-talk factor.

An object of the invention is to keep noises of all forms at such low levels as to permit the use of high frequencies over closely adjacent lines, as, for example, pairs in the same cable, and to permit efficient and economical design of the plant by effectively reducing the limitation imposed by noise on signal amplitude.

The invention, in the specific form to be described, comprises a system with its parts so disposed as to reduce in large measure cross-talk, so thoroughly shielded against interference noise that the lower limit of signal amplitude is fixed substantially by inherent noise generated within the system and so constructed that the inherent noise is substantially only that due to resistance noise or thermal agitation.

The various features and objects of the invention will appear more fully from the following detailed description of a preferred embodiment or illustrated in the accompanying drawings, in which:

Fig. 1 is a schematic diagram of a terminal and a repeater station embodying the invention;

Figs. 2 to 6 and 8 show details of the system of Fig. 1; and

Fig. 7 is a circuit diagram of a voltage test apparatus adapted for use in the system of Fig. 1.

In Fig. 1 the terminal station T is shown connected by an eastward cable E and a westward cable W with the two-way repeater station, comprising eastward repeaters RE and westward repeaters RW. It should be understood that while only one repeater for each direction is shown, there would be one per line for each direction.

At the terminal T are shown ordinary voice frequency telephone lines L_1 and L_2, representative of a much larger number, say nine lines, connected through suitable carrier terminal apparatus to the bus conductors 10 and 11 which lead to pairs in the respective cables. The carrier terminal apparatus comprises a transmitting branch and a receiving branch per line, connected to the line through the usual hybrid coil H and balancing network N. The transmitting branches comprise a modulator 12, 14, etc., and a band filter 13, 15, etc., respectively. The receiving branches comprise a demodulator 16, 18, etc., and a band filter 17, 19, etc., respectively. The modulators and demodulators are preferably of the balanced type which suppress the unmodulated carrier component, and it is assumed in the drawings that each modulator and demodulator incorporates a carrier source. The band filters transmit one of the two side bands of the respective modulated carrier wave and suppress the other. The outputs of all the transmitting band filters 13, 15, etc., connect to bus conductors 10 which connect to a pair 20 leading to the cable E. The inputs of the receiving filters 17, 19, etc., all connect to bus conductors 11 which connect to a pair 21 leading from the cable W. In other words, the nine lines L_1, L_2, etc., are arranged for two-way repeating with a single eastward pair 20 and a single westward pair 21 extending from pairs in respective cables E and W. A second pair in cable E and a second pair in cable W would be similarly arranged for two-way repeating with a second group of nine telephone lines (not shown), and other pairs in the cables would be similarly arranged to repeat into and from still other groups of lines.

If, as assumed, there are nine lines in each group L_1, L_2, etc. the range of frequencies employed by each cable pair may be from about 4 kilocycles to 40 kilocycles. If a still larger number of

lines than nine is used in each group, a correspondingly wider frequency range is necessary on each cable pair. For example, with 24 lines in each group, the 24 channels on each cable pair might occupy the range 8 to 100 kilocycles.

The dotted lines in the terminal station T indicate individual shielding enclosures for each carrier sending and each carrier receiving apparatus and for each line connecting the carrier apparatus with the pairs **20**, **21**, etc. The character of this shielding will be described more fully later on.

The pairs **20**, **21**, etc. are connected to corresponding cable pairs by means of terminal or junction boxes **22**, **23**, to be described more fully later on. Similar junction boxes **26**, **27**, **28** and **29** are provided at the repeater station for bringing out pairs **20'** and **21'** so that the repeaters RE and RW can be inserted into the respective lines. Junction boxes **22** and **26** are metallically continuous with the cable sheath **24** of cable E, and the same is true of junction boxes **23** and **27** with respect to sheath **25**.

The repeaters RE and RW may comprise any suitable apparatus and are shown as including an equalizer network **30** and an amplifier **31**. The repeater must be capable of amplifying the entire range of carrier waves employed on a line, such as 4 to 40 kilocycles or 8 to 100 kilocycles. A suitable amplifier for such purpose is disclosed in my prior application, Serial No. 606,871, filed April 22, 1932, for example, Fig. 57 or Fig. 65.

The shielding enclosure of the terminal boxes **26**, **28** is continuous over the repeater apparatus RE so that pair **20** between the points where it emerges from box **26** and enters box **28**, including all apparatus connected in the pair, is completely shielded against extraneous fields.

Operating voltages for the amplifier **31** are supplied from station batteries or other sources, one of which is shown at **32**, in the form of an anode battery, over shielded conductors **33**, **34**, leading inside the shielded enclosures for the repeaters, and there connecting to filters **35** which pass substantially only direct current. Cathode-heating current would be similarly supplied over shielded conductors and through filters, it not being thought necessary to show these in detail.

A better understanding can be gained of the terminal box construction and manner of connecting the cable conductors and station apparatus, by referring to Figs. 2, 3, 4 and 5.

Fig. 2 shows the front of any one of the junction boxes, say box **22**. The cable sheath **24** is shown coming in at the top and making a metallically continuous joint with the top of the box **22**, as by soldering, screw threading, or the like. The side of the box shown in Fig. 2 is the front or carrier frequency side. The rear side is of similar appearance but is the low or voice frequency side, meaning that the low frequency conductors in cable E have their terminals on the rear of the box while the high frequency pairs terminate on the front side. The shielded high frequency pairs which distribute to the terminal apparatus are shown leading from the junction box at **50**, **50**.

Fig. 4 shows a top view, partly in section, of Fig. 2 and shows the arrangement of conductors within cable sheath **24** and the manner of connecting them to terminals. The cable is made up of carrier pairs **52** and voice quads **53**, positioned so that the quads afford a considerable amount of shielding between carrier pairs. This cable may be of the type disclosed and claimed in A. G. Chapman Patent No. 1,931,601, granted Oct. 24, 1933, and twisting, transposition, rotation and spacing of the various conductors within the cable, together with suitable cross-talk reducing agencies, as disclosed in this and in A. G. Chapman Patent 1,863,651, granted June 21, 1932 may be employed to maintain the cross-talk within tolerable limits.

The carrier pairs are brought to terminals on the front panel **54** and the voice quads are led to terminals on the rear panel **55**. In making these connections, a pair **56** and an adjacent quad **57** are brought out of the cable core within the junction box so that the quad lies around the carrier pair or lies between it and adjacent carrier pairs, and thus continues within the junction box the shielding effects that the quads offer between the carrier pairs within the cable sheath. The carrier pair and its shielding quads are brought downward within the junction box (Fig. 5) as part of the cable core and at the proper level are brought first to the front panel where the carrier pair is connected to terminal pins **58**. The quad **57** is then carried to the rear panel and connected to terminals **59** for eventual connection to other low frequency circuits, not shown.

The terminal pins **58** are arranged in horizontal rows, and are paired with similar pins **60** immediately below. These extend through the panel **54** and may be joined by lugs **61** on the exterior of the panel. The pins **60** are connected directly to the pairs **20** leading to terminal or other carrier apparatus. The sheaths **50** over pairs **20** are in each instance continued as a braid or other metallic sheath **62** (Figs. 3 and 4) to a point closely adjacent the panel terminals. Lugs **61** are clamped down by threaded nuts on the threaded terminal pins **58** and **60** and the contact surface is large enough and of sufficiently accurate fit to offer negligibly low resistance and negligibly low contact noise.

The metal shield or housing making up the box enclosure **22** is continuous over the exterior of all of the conductors **56**, **57** where they emerge from the cable sheath, and over all contact pins and lugs **58**, **60**, **61**, etc. so as to shield all of these elements from the influence of stray fields. Slides **64** cover openings in the metal face of box **22** and may be pushed aside to permit access to any set of terminals for connection or test purposes. In case not all of the voice conductors in cable **24** are to be terminated on box **22**, the ones that are carried on may be grouped and brought out near the bottom of box **22** into a small cable **65** (Fig. 4) extending to a desired location.

In Fig. 2, certain individual pair shielded cables are shown leading to a small junction box **22'**. These cables **50'** contain carrier pairs connected to certain of the pins such as **58** within box **22** and at their other ends to pins **66** in box **22'**, thus in effect extending cable pairs from cable **24** by shielded connections to terminals **66**. A patching cord **67** may then be used to extend the connections to other similar junction boxes like box **22'** or to boxes having their pin terminals connected to repeaters, modulators, demodulators, testing equipment or any apparatus desired.

For this purpose, a special plug and cord are provided (Figs. 2, 6 and 7) comprising a flexible pair cord **67** enclosed in a metallic braided shield which is continuous with the metal casing of the plug and a spring **69** adapted, when inserted in an aperture in box **22** or **22'**, to make contact

with the metal of the box thus grounding the metal braid of the cord 67. Plug 68 has a metal exterior conductively joined to the braid or cord 67, but within is made of insulation with sleeves embedded in it and permanently connected to the wires in cord 67. These sleeves fit snugly over pins 58 or 60 or 66 (as the case may be) when the plug is used to extend connection.

It will be observed from the foregoing, that substantially continuous metallic shielding extends over all of the high frequency apparatus and circuits from one end of the system to the other. Thus, in Fig. 1, the shielding encloses the modulators, demodulators, filters and carrier sources, these being the end portions of the high frequency circuits, and continues to the junction box 22 without interruption, thence to cable sheath 24 and junction box 26, then over all of the repeater equipment to junction box 28 and so on to other repeaters and to the other terminal which may be identical with that shown. The same method of shielding is also used for the westward lines and apparatus.

The repeaters, modulators, filters, etc. are enclosed in heavy copper boxes with tight fitting covers and the tubes are operated without ventilation. This means that apparatus inside these boxes must be capable of operation at fairly high temperature.

Let it be assumed that the cross-talk within a cable (E, for example) is reduced to such a point that a voltage applied to one pair at station T is received at repeater station RE on the next adjacent pair 86 decibels weaker than on the pair to which it was applied. This gives a measure of the cross-talk within the cable, and the methods of the Chapman disclosures above referred to were effective in one example in reducing the cross talk to this extent. Since cable E near repeater RE carries currents that have been highly attentuated and are at low level while cable W at the same point carries currents that have just been amplified by repeater RW, the maximum level difference between currents in the two cables is substantially equal to the repeater gain which may be taken as 75 decibels, by way of example. Now, at the repeater point, the individual pairs 20' and 21' are taken out and distributed in individual cables 50 to repeater racks, etc. and may run near each other. It is important, therefore, to maintain at least as high protection against cross-talk between these conductor pairs as between pairs within the cables so as not to degrade the standard of quality set for the cables themselves, which, incidentally, are the main structure of the system and represent by far the greatest expenditure of capital cost. Cables 50 are, therefore, designed to provide a cross-talk reduction from pair to pair of 86 decibels plus 75 decibels (the repeater gain) plus a safety factor of, say, 15 decibels to allow for flexibility in repeater gain, etc., or a total of 176 decibels. This is an excessively high figure and can only be realized by taking extraordinary precautions. This figure applies not only to the cables 50 but to the repeater apparatus itself, junction boxes and all points of the system from one cable section to the next. In order to provide this high shielding and at the same time keep cables 50 flexible, the construction shown in Fig. 8 is employed, consisting of a spiral copper strip 70 around the rubber-insulated pair 20, and a lead sheath 50 pressed over the shield 70. As already explained, as nearly as possible complete enclosures are used for the repeater and terminal apparatus, of heavy copper. It was found sufficient to use copper braid to insulate power leads 33 and 34 and to supplement this shielding by filters 35 enclosed within the repeater shield themselves.

The cable sheaths 24 and 25 each give a protection of the order of 80 decibels against interference sources outside the cable. This margin should, therefore, be maintained in the design of the terminal boxes 26, etc. The figure of 176 decibels given above for cross-talk protection from circuit 20 to circuit 21, for example, is high enough to equal or exceed the shielding protection of the cable sheath against extraneous fields.

It will be observed that the usual testing and patching jacks have been omitted and that all the through circuits are free of loose contacts that might develop noise. All joints, where practicable, are soldered. The only joints not soldered are those between lugs 61 and pins 58 or 60, or in case patching cord 67 is used in certain circuits, the contacts between pins 58 or 60 or 66, etc. as the case may be and sleeves of the plug.

In order to be able to test the circuits without opening them or interrupting service, a voltage test is used. The circuit of Fig. 7 is adapted for this purpose. Plug 68 may be used to connect cord 67' across a pair of pins 58 or 68, for example, to derive a voltage from across the circuit, such as the input or output of a repeater, modulator, etc. The conductors of cord 67' lead to the grids of push-pull tubes 36 and 37, the cathodes of which are connected together and to bias battery 38. Stopping condensers may be desirable, as shown, to keep voltage from this battery from getting back into the circuit that is under test. Bridged across the grids are resistances 39 and 40 in series, each amounting to the order of 100,000 ohms. Since the grids are maintained highly negative by battery 38, the tubes 36 and 37 have high grid-to-cathode resistance, in view of which and of the size of resistances 39 and 40 this circuit produces but negligible current drain on the circuit under test. The voltage impressed across the grids of tubes 36 and 37 is amplified and may be impressed on any suitable test set 41 of the type commonly used in a current testing method. The entire apparatus is shielded, as indicated, to protect both the test set and the system under test from extraneous fields. The tubes 36 and 37 serve, in effect, as a voltage to current converter. They take a negligible amount of power from the circuit being tested and amplify it to a proper value for the test set 41 to measure. Pad 42 may be used to control attenuation or match impedances.

The invention is not to be construed as limited to the details disclosed or to the quantitative figures that have been given, but by the scope of the claims.

What is claimed is:

1. A signal transmission system comprising a number of lines closely adjacent one another and all transmitting in the same direction, means for transmitting over said lines waves of high frequencies of the order used for multiplex carrier telephone transmission, said lines as a group being shielded from extraneous interference, and comprising transposed and spaced conductors whereby line-to-line cross-talk within the group is reduced by a given factor, an amplifying repeater per line at intervals in said lines for amplifying said waves of high frequencies, individual line shielding for said lines where they con-

nect to said repeaters and shielding over said repeaters, whereby said lines are at all points either shielded as a group or individually against external interference, the reduction in interference due to said shielding at said high frequencies being of the same order of magnitude as the gain introduced by each of said repeaters plus the cross-talk reduction factor between lines within said cable.

2. In a carrier telephone system, a lead covered cable, pairs within the cable being shielded by the sheath from extraneous interference and certain individual pairs being separated by other pairs and transposed to reduce cross-talk between such individual pairs, a terminal box of conductive material continuous with said lead sheath at its end, terminals therein, said individual pairs and said other pairs extending into said terminal box and connected to respective terminals therein, the individual pairs within said terminal box being still separated by said other pairs, terminal apparatus, conductive shielding therefor, and shielded pairs connecting said apparatus respectively to the terminals to which said individual pairs are connected, the shielding on said shielded pairs being as effective in reducing interference and cross-talk between pairs as the cable sheath together with the transposition and the separating of the pairs within the cable.

3. A system, according to claim 2, in which said shielded pairs comprise pairs covered by one or more layers of copper tape covered with a lead sheath whereby said shielded pairs are flexible but have high effective shielding.

4. In a carrier signaling system, oppositely transmitting cables adjacent each other, each comprising a group of lines covered by a lead sheath, means for transmitting speech-modulated carrier waves of high frequency over said lines, means for reducing cross-talk between the lines in a cable, repeaters inserted in the individual lines, input and output connections between said repeaters and said respective lines, said connections being included in individual-pair shields, the shielding of which for said high frequencies is as effective in decibels in reducing interference in the pairs from external sources as the gain of each of said repeaters in decibels plus the cross-talk reduction in decibels between lines in the same cable.

5. In combination, a lead covered telephone cable comprising a multiplicity of pairs of conductors, means to transmit a plurality of speech-modulated carrier waves simultaneously over each of a plurality of said pairs, means shielding said plurality of pairs from each other within said cable, terminal and intermediate repeater points for said cable including apparatus to be connected to said plurality of pairs carrying high frequency currents, said repeater points being so far apart and so far from the terminals that the signaling energy in said plurality of pairs falls to a value limited principally by the resistance noise generated within the conductors, and shielding completely covering the said apparatus and the leads connecting it to said pairs, the degree of shielding for individual pairs including their said connected apparatus being so complete that the noise present in the pairs is substantially only the resistance noise generated in the conductors.

HAROLD S. BLACK.