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F. W. McKOWN ET AL

TELEPHONE SUBSTATION CIRCUITS

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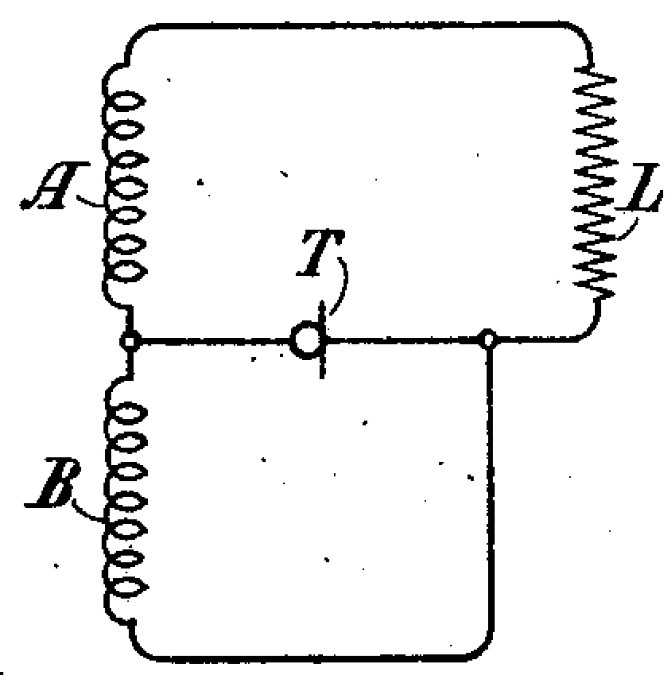

Fig. 1

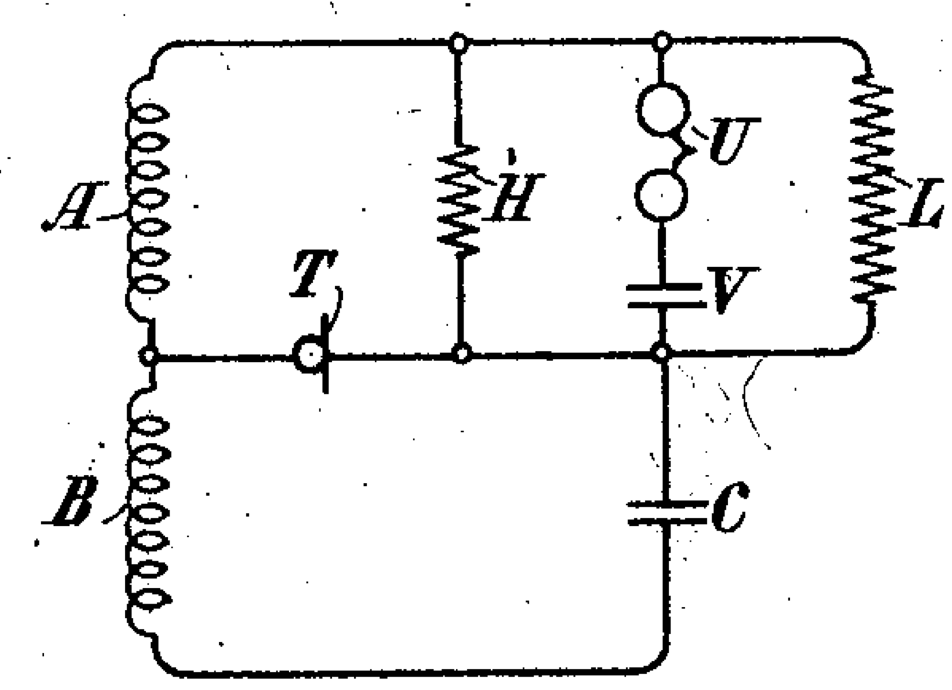

Fig. 3

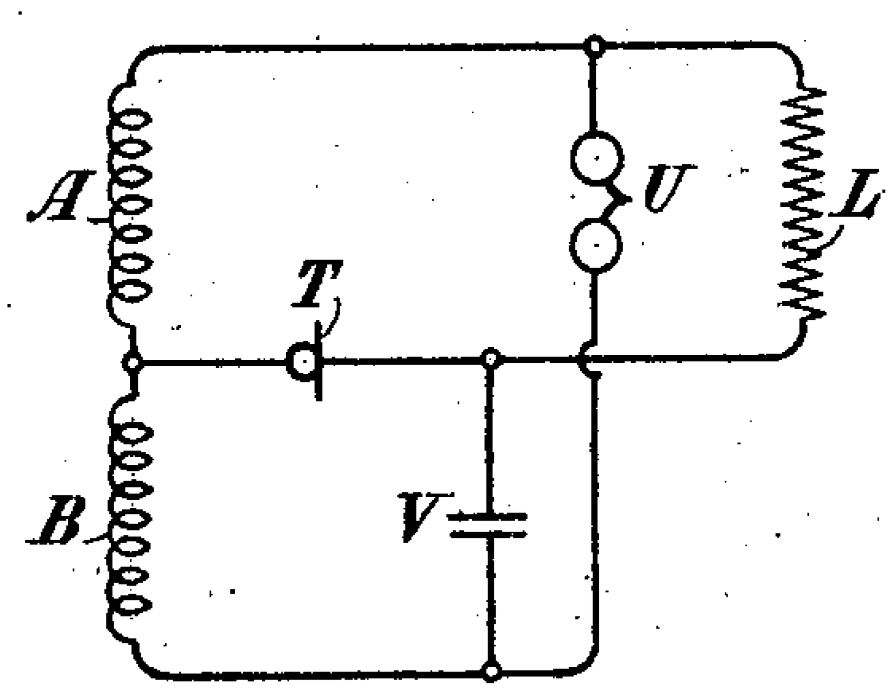

Fig. 2

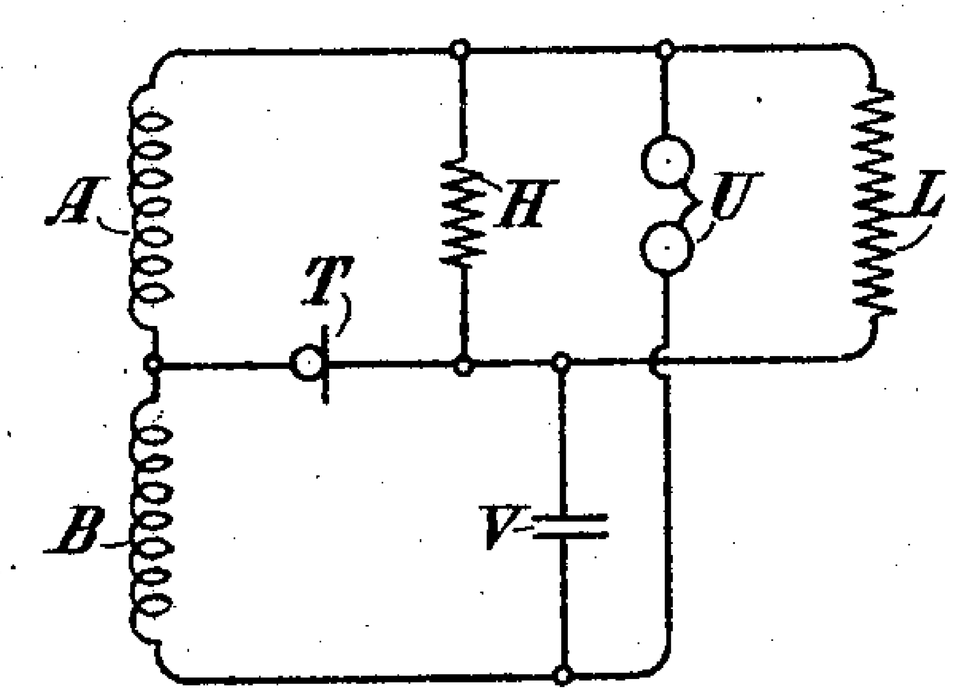

Fig. 4

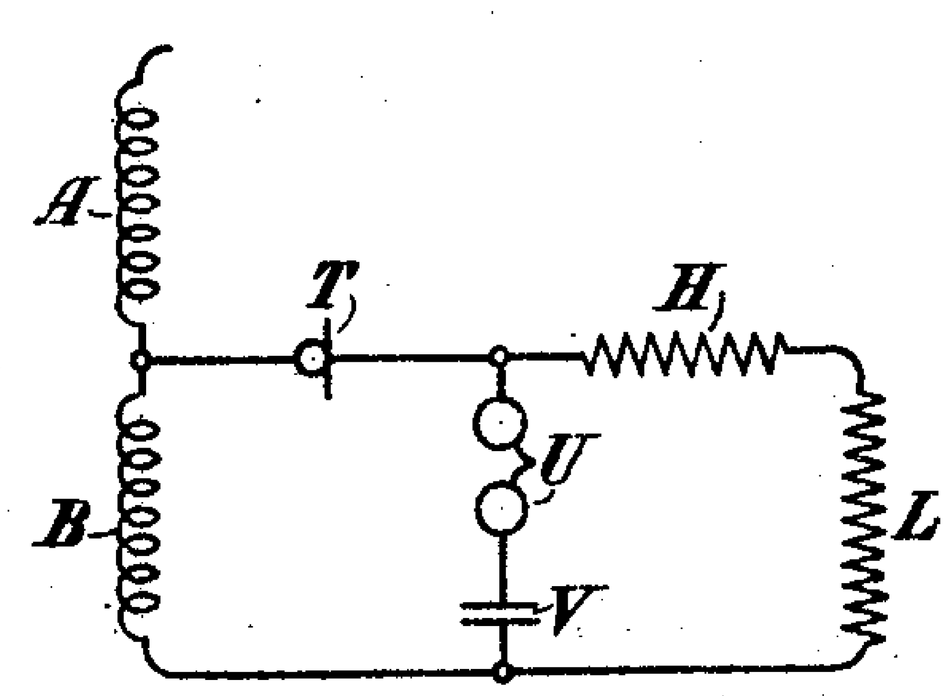

Fig. 5

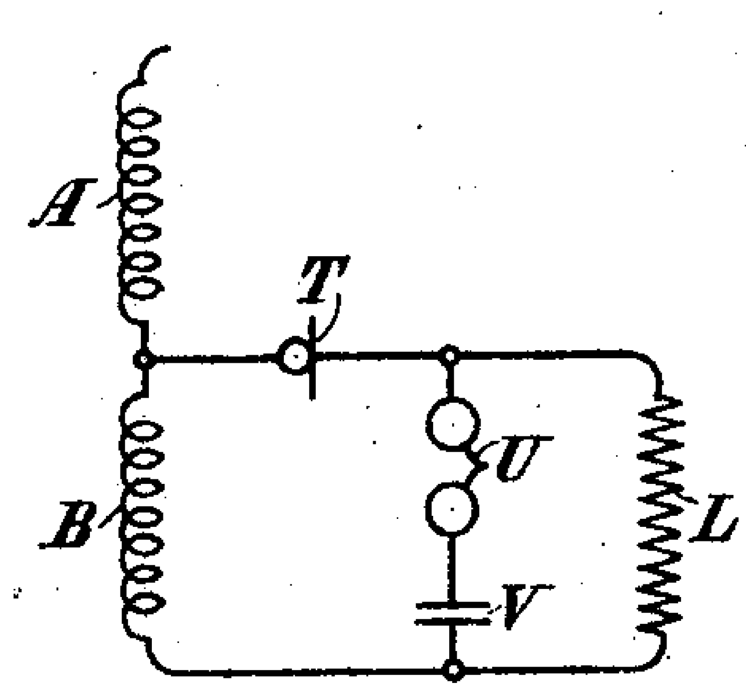

Fig. 6

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UNITED STATES PATENT OFFICE.

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TELEPHONE SUBSTATION CIRCUITS.

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This invention relates to circuit arrangements for signaling systems wherein signals may be either transmitted from or received at the same station. In its more specific aspect this invention is embodied in a subscriber's telephone station hereinafter termed, in accordance with common usage, a substation, and more particularly in the combination of a substation and a telephone set.

The object of this invention is to provide an economical signaling circuit arrangement which in co-operative combination with a similar and equal signaling circuit arrangement at the distant end of a telephone line, shall deliver a large proportion of energy to the receiving apparatus of said signaling circuit arrangement at the distant end of the line.

A further object is to provide a substation consisting of a transmitter and a receiver of the electromagnetic type, having a plurality of windings and arranged for invariable two-way communication over a line having given impedance and length. In other words, the object of the invention is to provide signaling means characterized by a minimum number of elements.

The simplest form of substation for invariable two-way communication is that in which the receiver and transmitter are connected in series with each other across a telephone line, the transmitter and receiver each having a resistance which is equal to one-half of the line impedance. In such an arrangement the over-all efficiency is a maximum for an invariable set, even though 50 per cent of the energy delivered by the line to the substation is wasted in the transmitter and only 50 per cent of the energy available at the transmitter reaches the line. Further, such an arrangement labors under the disadvantage of full side tone.

In the types of substation circuits now in use, the transmitter has a resistance which is about one-twelfth of the line impedance. Such a transmitter cannot be employed in the simple series circuit if the conditions for maximum energy transfer are to be satisfied. To improve the efficiency of the substation it has been customary to employ a transformer or induction coil in the substation circuit in order to step up the transmitter resistance. In the arrangements of the present invention, however, the induction coil has been eliminated and its function has been relegated to the receiver.

The invention will be more fully understood by reference to the accompanying drawing, in which Figure 1 is a substation having a minimum number of elements, Fig. 2 is a modification of Fig. 1 showing the ringing circuit, Figs. 3 and 4 are further modifications of Figs. 1 and 2 designed for side tone reduction on short loops, and Figs. 5 and 6 are other modifications arranged to effect lower side tone or short loops.

In order to illustrate the scope of the invention and elucidate the principles on which the embodiments rest, a general theoretical discussion will now be given which applies to the substation shown in the drawing of this specification. In this discussion anc the equations and formulæ included in the specification, the subscripts T, L and R will refer to transmitter, line and receiver respectively. Thus, I_T, I_L and I_R will denote the currents flowing in the transmitter, line and receiver, respectively, while Z_T will denote the impedance of the transmitter, Z_L the impedance of the line, etc.

Consider the substation, illustrated in Fig. 1, consisting of a transmitter and receiver connected to a line of given impedance. In practice, the line connects two similar and equal substations between which communication is established. For transmitting, consider the transmitter as having a voltage E in series therewith. By Kirchoff's laws,

$$I_L(Z_A+Z_L+Z_T)+I_B(Z_M-Z_T)=E$$

and

$$I_L(Z_M-Z_T)+I_B(Z_B+Z_T)=-E$$

In the foregoing expressions A and B refer to the two windings of the electromagnetic receiver used in the substation, Z_A and Z_B refer to the self-impedances of said windings, and Z_M refers to the mutual impedance of said windings. Solving these equations simultaneously, (bearing in mind that the impedance of a receiver having two windings, A and B, which are series aiding is $Z_A+Z_B+2Z_M$) the current in the line, I_L, is

$$\frac{E(Z_B+Z_M)}{(Z_A+Z_L+Z_T)\,(Z_B+Z_T)-(Z_M-Z_T)^2}$$

and the current in winding B, I_B, is

$$\frac{-E(Z_A+Z_L+Z_M)}{(Z_A+Z_L+Z_T)\,(Z_B+Z_T)-(Z_M-Z_T)^2}$$

In deriving the values of the currents in the respective branches when signals are being received at the substation, consider a voltage e to be in series with the line L, then

$$I_L(Z_A+Z_L+Z_T)+I_B(Z_M-Z_T)=e$$

and

$$I_L(Z_M-Z_T)+I_B(Z_B+Z_T)=o$$

The expression for the value of the current in the line L, I_L, when signals are being received at the substation is

$$\frac{e\,(Z_B+Z_T)}{(Z_A+Z_L+Z_T)\,(Z_B+Z_T)-(Z_M-Z_T)^2}$$

The current I_B in the lower branch, which includes the winding B of the receiver of the substation is

$$\frac{e\,(Z_T-Z_M)}{(Z_A+Z_L+Z_T)\,(Z_B+Z_T)-(Z_M-Z_T)^2}$$

The transmitting efficiency of the substation may be expressed as the square root of the ratio of the power actually sent into the line by the transmitter of the substation to the maximum power that could be sent into the line by the transmitter of the ideal invariable substation. The transmitting efficiency may be determined from the expression

$$\sqrt{\frac{P_A}{P_i}},$$

in which P_A is the power actually delivered to the line, or

$$\sqrt{P_A}=I_L\sqrt{R_L};$$

and P_i, the power in the ideal invariable substation circuit, is determined from the expression

$$\sqrt{P_i}=\frac{1}{\sqrt{2}}\cdot\frac{E}{2\sqrt{Z_T}}.$$

Substituting the value of the current in the line, I_L, derived hereinbefore, and bearing in mind that

$$Z_M=\sqrt{Z_AZ_B}$$

approximately, the transmitting efficiency becomes

$$\frac{2\sqrt{2Z_TR_L}\,(Z_B+\sqrt{Z_AZ_B})}{(Z_A+Z_L+Z_T)\,(Z_B+Z_T)-(Z_M-Z_T)^2}$$

The receiving efficiency of the substation may be expressed as the square root of the ratio of the power actually sent into the receiver of the substation from the line to the maximum power that could be sent into the receiver of the ideal invariable substation from the line. The receiving efficiency of the substation may be written as

$$\sqrt{\frac{P_A}{P_i}},$$

in which P_A is the energy actually delivered to the receiver, or

$$\sqrt{P_A}=I_R\sqrt{R_R},$$

and

$$\sqrt{P_i}\ \text{is}\ \frac{1}{\sqrt{2}}\cdot\frac{e}{2\sqrt{R_L}}.$$

Defining the effective current in the receiver as the quotient of the ampere turns and the turns of the receiver, the receiving efficiency may be determined from the expression

$$\frac{2Z_T\sqrt{2R_LR_R}}{(Z_A+Z_L+Z_T)\,(Z_B+Z_T)-(Z_M-Z_T)^2}$$

The power in the receiver of an invariable substation circuit when a voltage is acting in series with the transmitter at the same substation is known as side tone. The side tone efficiency is

$$\sqrt{\frac{P_A}{P_i}},$$

in which P_A is the power actually delivered to the receiver at the same substation, and P_i is the value obtained from the expression

$$\sqrt{P_i}=1/2\cdot\frac{E}{2\sqrt{Z_T}},$$

the impedance of the transmitter, Z_T, being merely a resistance at normal telephonic frequencies. The value of the current in the receiver I_R, having been determined hereinbefore, the side tone efficiency will then be found to be

$$\frac{Z_L\sqrt{Z_B}}{\sqrt{Z_A}+\sqrt{Z_B}}\cdot\frac{4\sqrt{Z_TR_R}}{(Z_A+Z_L+Z_T)\,(Z_B+Z_T)-(Z_M-Z_T)^2}$$

The transmitter may be considered a generator having a fixed internal resistance which sends current through the receiver at the same substation and through the line in series therewith. While transmitting, the energy in the receiver is wasted so far as transmission to the substation at the distant end of the line is concerned. Also, while receiving, the power delivered to the transmitter is wasted. In order to have the maximum energy transfer between the line and the substation the generator element should be equal to the element to which power is being delivered. Therefore, in order to obtain the miximum energy transfer between the line and the substation while transmitting, the line should have the same impedance as the transmitter, and while receiving, the receiver should have the same impedance as the line. From the equations given hereinbefore the maximum energy transfer between the line and the substation may be obtained when the impedance of the substation, Z_S, has the magnitude.

$$\frac{Z_T Z_R}{Z_B + Z_T}$$

The energy ratio Y_R is known in the art as

$$\left(\frac{\text{transmitting efficiency}}{\text{receiving efficiency}}\right)^2.$$

Substituting the values for the transmitting and receiving efficiencies, respectively, the energy ratio Y_R will be found to equal

$$\frac{Z_B}{Z_T \cos \Theta}$$

in which Θ is the receiver angle, the tangent Θ being the ratio of the reactance component to the resistance component of a single winding of the electromagnetic receiver, Θ being of substantially equal magnitude for both of the windings.

The embodiments of this invention disclose arrangements in which the transmitter, receiver and line are effectively in parallel. Side tone may become objectionable on short loops because noises at the substation, which excite the transmitter, will produce sounds in the receiver. Furthermore, the operator talks in his own ear, and if he talks very loudly the effect of side tone may make it very uncomfortable for him. It is therefore important that on short loops the side tone be kept very low.

On inspection of the formula for the side tone efficiency it will be noted that the side tone efficiency varies in accordance with the impedance of the line, the side tone increasing as the impedance of the line increases. In arrangements of the parallel type, the side tone may be reduced by making the impedance of the substation set higher than the impedance of the line.

Fig. 2 shows an arrangement of the parallel type, in which a condenser V is placed in series with winding B of the receiver in order to confine direct current to a path through the transmitter. Condenser V is also employed in the ringing circuit in series with ringer U. Fig. 3 shows an arrangement for short loops in which an equalizing resistance H is placed in shunt with the line L. This causes a diminution in the line current, and a still greater diminution in the side tone. Also, in this arrangement a condenser V, other than the condenser C in series with winding B, is employed in series with ringer U for ringing purposes. Fig. 4 shows a modification of Fig. 2 for short loops in which the equalizing resistance H is placed in shunt with the line L, thus limiting the transmitted and received currents to a predetermined maximum value. Figs. 5 and 6 show modifications of the invention which are arranged to reduce side tone on short loops. In Fig. 5, one of the windings, A, is disconnected so that the transmitter, the line, and the equalizing resistance H are in series with winding B of the receiver at the substation. The presence of the equalizing resistance H in series with the line L effects a lowering of the line current, and therefore a reduction in the side tone. In Fig. 6 no equalizing resistance is employed.

The accompanying formulæ give satisfactory results and the methods by which they are derived enable one skilled in the art to compute the substation constants when desired.

It will be understood that while certain embodiments have been specifically illustrated and described as embodied in a telephone substation, it is capable of many and varied embodiments which render it applicable to other kinds of signaling systems. Consequently, the invention is not to be limited to the particular form and use herein disclosed but is to be limited only by the appended claims. It will be further understood that in this specification the word "substation" is employed in its generic sense, and that consequently, its significance is not limited to a subscriber's telephone station but embraces broadly a telephone station including a repeater station for relaying telephonic signals.

What is claimed is:

1. A substation circuit comprising a transmitter and a receiver of the electromagnetic type having two windings each of substantially low resistance, said instruments being connected effectively in parallel with each other with respect to signaling currents from a telephone line, the windings of said receiver being closely coupled and being so arranged with respect to said transmitter as to step-up the resistance of said transmitter to a predetermined value.

2. A substation circuit comprising a transmitter, and an electromagnetic receiver having two windings each of substantially low resistance, said instruments being associated with a line over which signals may be transmitted and received, said transmitter being connected to the midpoint of the two windings of said receiver, the windings of said

receiver being closely coupled and arranged to step-up the transmitter resistance to a predetermined value.

3. A substation circuit comprising a transmitter, an electromagnetic receiver having two windings which have a high mutual impedance, said transmitter and receiver being connected to a line over which signals are transmitted and received, and a resistance, said resistance being placed in shunt across said line at the substation in order to diminish the side tone, the windings of said receiver being related to the transmitter so as to step-up the transmitter resistance to a predetermined value.

4. In a substation circuit, in combination, means for transmitting signals, means for receiving signals, and a line to which said transmitting and receiving means are connected, said receiving means comprising two windings having a high mutual impedance and arranged so as to attract a diaphragm in accordance with signals that are received at said substation, said windings being of substantially low resistance and being so located with respect to said transmitting means as to step-up the resistance of said transmitting means to a predetermined value.

5. In a substation circuit, in combination, transmitting means, receiving means, a line, said receiving means consisting of two windings each of substantially low resistance having a high mutual impedance and arranged so as to step-up the resistance of said transmitting means to a predetermined value, means consisting of a resistance to balance said line, ringing means, and means to confine direct current to a path through said transmitting means.

6. A substation circuit comprising two branches, a receiver having a plurality of windings, one of said windings being included in each of said branches, one of said branches being adapted to be connected to a telephone line, the other of said branches forming a separate circuit having a condenser serially connected thereto, and a transmitter differentially arranged with said branches, the condenser being employed to confine direct current to a path through said transmitter, the windings of said receiver being of substantially low resistance, being closely coupled and being arranged so as to step-up the resistance of said transmitter to a predetermined value.

In testimony whereof, we have signed our names to this specification this 27th day of May 1925.

FREDERICK W. McKOWN.
EGINHARD DIETZE.