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MAGNETIC WAVE AMPLIFYING REPEATER

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FIG. 1

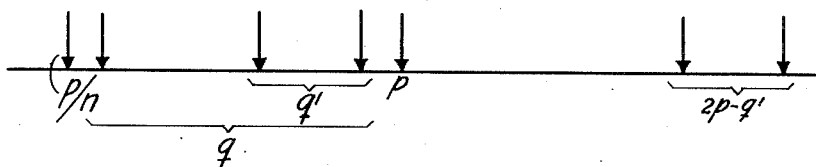


FIG. 2.

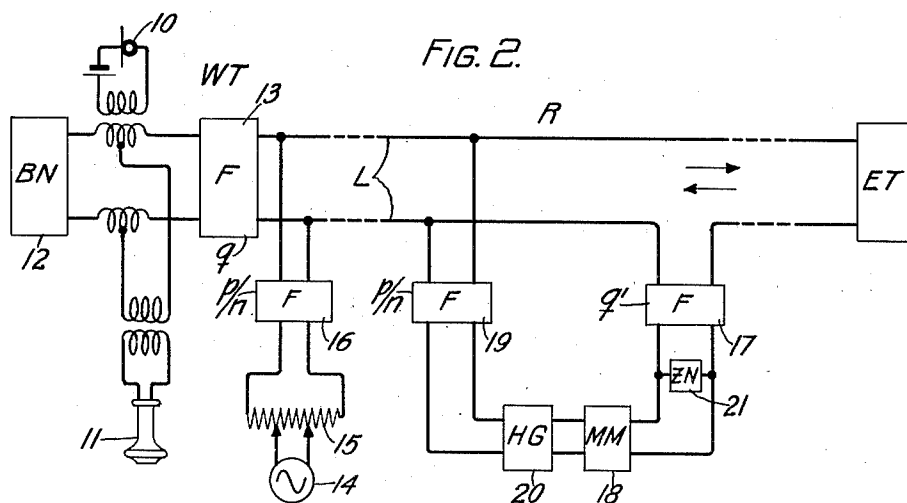
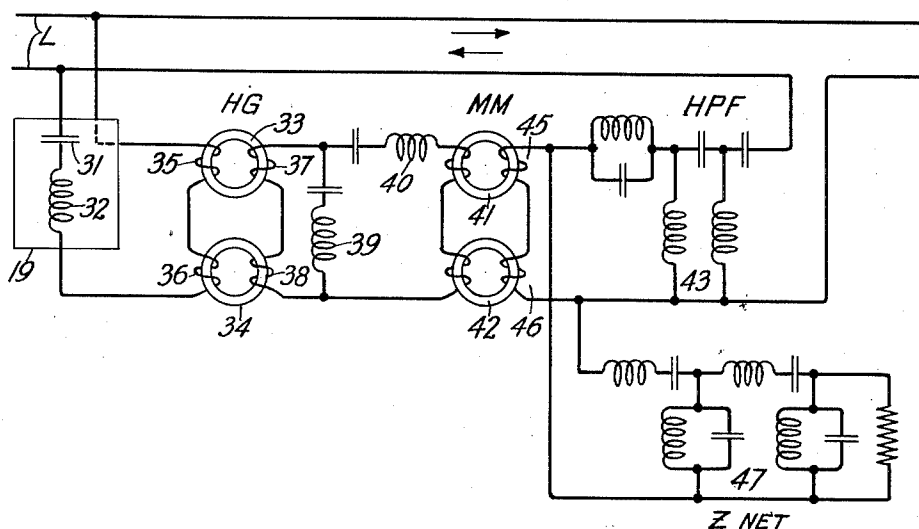


FIG. 3.



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## MAGNETIC WAVE-AMPLIFYING REPEATER

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The present invention relates to amplifying or reinforcing repeaters particularly designed for use in a submarine cable although capable of other uses as well.

5 An object of the invention is an amplifying repeater which, when once installed, requires no attention, replacements or adjustments and which, therefore, is particularly suited to inaccessible situations, as in the case of a submarine cable.

10 Among the requirements of such a repeater are: absence of moving parts and of parts which deteriorate appreciably with time, constancy of operating characteristics, rugged mechanical construction and ability to withstand excessively high compressional forces. Furthermore, the energy employed in amplifying or reinforcing the signal must be supplied independent of local sources which would need replenishing from time to time.

15 The foregoing requirements are realized, according to the present invention, in a magnetic structure capable of being incorporated in or suitably associated with the cable sheath and occupying small dimensions. Assuming a submarine telephone cable which is to transmit frequencies embracing the range 300 to 2000 cycles per second, a low frequency wave is supplied to the repeating point or points and is there converted into a wave of suitably high frequency to enable the magnetic structure to introduce into the cable circuit a negative resistance effect in accordance with a magnetic modulator action which of itself is well understood in the art. The negative resistance effect results in amplification of the speech wave traversing the cable. Since the attenuation of the cable is greatest for the upper frequencies of the transmitted band, it may be necessary to reinforce only the upper portion of the frequency range, say the frequencies 1500 to 2000 cycles per second, although it is within the invention to amplify some other portion or the entire speech band that is being transmitted. The amount of amplification and the range over which it is effected is determined by design and control of the system in a

manner that will be clear from the description to follow.

The nature of the invention as a whole and its various aspects and objects will appear more fully from the following detailed description, with reference to the accompanying drawing, in which Fig. 1 is a diagram illustrating certain frequency relations which may be utilized in a system in accordance with the invention, Fig. 2 is a schematic diagram in simplified form of a complete system with a single repeater illustrated and Fig. 3 is a detailed circuit diagram of a repeater such as is indicated more generally in Fig. 2.

25 The invention is based on the known principle that if two fundamental frequencies are applied to a magnetic modulator a negative impedance to the lower of the two fundamental frequencies is produced when the impedance of the system is low to the lower side band and high to the upper side band frequencies. The magnitude of this negative resistance depends upon the amplitude of the fundamental wave of the higher frequency when the amplitude of this wave is large, and upon the impedances offered to the side bands. The negative resistance to the lower fundamental frequency may be utilized to effect amplification of this component. The energy of the amplification is derived from the higher frequency fundamental wave.

30 In Fig. 1 the horizontal axis represents frequencies for which the zero of the scale is at the left. The range indicated as  $q$  is assumed to be the range of essential speech frequencies to be transmitted. The range  $q'$  represents a portion of the higher frequencies of this range and corresponds to the lower of the two fundamental frequencies mentioned in the general example of the preceding paragraph. The upper fundamental frequency, which for convenience, will be referred to as the carrier, is indicated at  $p$ . The range  $2p - q'$  represents the frequencies comprising the lower side band based upon double the carrier frequency, this side band being produced by third order modulation. From the general example given above it will be ap-

parent that when the frequencies  $q'$  and  $p$  are applied to a magnetic modulator and when the system is made to present low impedance to the range  $2p-q'$  and high impedance to the upper side band frequencies  $(2p+q')$  a negative resistance effect will be introduced for the range  $q'$ .

If instead of the range  $q'$  the entire range  $q$  were applied to the modulator together with the frequency  $p$  and if low impedance were provided for the range  $2p-q$  and high impedance for the range  $2p+q$  then a negative resistance would be produced for the entire range  $q$ .

The invention contemplates producing a negative resistance effect in series in the signaling circuit for the entire speech band, or for a portion of the band such as the range  $q'$  comprising the uppermost frequencies. The effect of the negative resistance is, of course, to amplify the signal.

In the frequency diagram of Fig. 1 the carrier frequency  $p$  is observed to be above the upper limit of the speech range. In the case of a submarine cable the attenuation would be quite high to a frequency of this order so that it is preferable to provide the frequency  $p$  at the various repeater points by transmitting over the line a low fre-

quency indicated in Fig 1 as  $\frac{p}{n}$  lower than the lower limit of the speech band. This frequency may be any convenient low frequency of which  $p$  is an integral multiple (i. e.  $n$  is an integer). Suitable values for the frequencies illustrated in Fig. 1 may

be as follows:  $\frac{p}{n}$ , 250 cycles per second;

the range  $q$ , from 300 cycles per second to 2000 cycles per second; the range  $q'$ , from 1500 to 2000 cycles per second;  $p$ , 2500 cycles per second. These values are to be taken as merely illustrative, of course, and not as limiting the invention.

Referring to Fig. 2 the line L extends between a west terminal WT and an east terminal ET and may include a number of repeater points along the line, one only of these being designated at R. The line L may be an ordinary telephone line, telephone cable, or a submarine telephone cable although the invention is not limited to the transmission of speech, but is suitable for other types of signals. The west terminal comprises a speech transmitter 10 and a receiver 11 suitably coupled to the line through a conjugate connection for enabling transmission and reception in anti-side tone relation, or with any desired degree of side tone. The balancing network 12 accurately or approximately balances the line depending upon the degree of conjugacy desired between the circuits 10 and 11. The filter 13 passes the frequency range to be transmitted over the line L and preferably excludes frequen-

cies outside of this range, which in the present case is assumed to comprise the band 300 to 2000 cycles per second. This and the other wave filters shown throughout the system may be designed in accordance with the principles disclosed in U. S. patent to Campbell, No. 1,227,113, May 22, 1917.

There is also located at the west terminal a source of sustained waves 14 of a frequency of 250 cycles per second although it will be understood that this source may have any convenient or suitable frequency. The waves from source 14 are applied through the potentiometer 15 and filter 16 to the line L, the filter 16 passing waves of this frequency

$$\left(\frac{p}{n}\right)$$

and excluding waves of higher and lower frequencies.

The speech waves traversing the line, upon arriving at a repeater point R pass in part through the filter 17 and into the output of the magnetic modulator 18. It is assumed that the filter 17 passes the range  $q'$  but excludes the remaining portion of the speech range. Filter 19 allows the frequency

$$\frac{p}{n}$$

(i. e., 250 cycles per second), to pass into the harmonic generator 20 in which the carrier frequency  $p$ , (i. e., 2500 cycles per second) is produced. This carrier frequency is applied to the input of the modulator 18 and a number of new components are produced as a result of the interaction in the magnetic modulator of the waves of frequency  $p$  and the range  $q'$ . The impedance network 21 offers a low impedance to the range  $2p-q'$  and the circuit as a whole offers high impedance to the range  $2p+q'$ . As a result of this effect, as described more generally above, there is produced in series with the line L a negative resistance for the frequency range  $q'$  so that amplification of the range of the frequency  $q'$  is produced in the line L at the repeater point R. In a similar manner this action may be produced at any desired number of repeater points along the line L.

In Figs. 2 and 3 the line is indicated as a two wire line. In the case of a submarine cable it will be understood that a single conductor with a ground return and with suitable terminal duplex or other connections for enabling two-way conversation will be used. In this case the filter 19, shown in shunt of the line, would be connected across from the cable core to the cable sheath, the sheath forming the return for this wave. That is, in Fig. 3 the upper line conductor may be the cable sheath. An alternative manner of supplying this low frequency

wave at the repeater points is to connect filter 19 in series with the cable in the same manner as the filter 17 is connected in the cable.

The waves of amplified form after traversing the length of the line are received at the east terminal which may be of the same type as the west terminal WT. It is only necessary to provide a source 14 at one of the stations, although in practice this low frequency wave may be sent out from both terminals.

Speech waves originating in the east terminal traverse the line L and when arriving at the repeater point R pass in part through the filter 17 to the modulator 18 where they combine with the waves of the carrier frequency produced in the harmonic generator 20 as a result of the waves of frequency

$$\frac{p}{n}$$

arriving from the west terminal. Amplification is produced at each repeater point for these westwardly transmitted speech waves in the same manner as described above for the eastward transmission.

It will be clear from what was said above that the filter 17, if desired, may pass the entire speech frequency band and so produce amplification over the whole band. In a similar manner any portion other than  $q'$  may be selectively amplified.

Circuits for carrying out the actions at the repeater point R as above described are shown in detail in Fig. 3. The filter 19 may comprise simply a series tuned circuit comprising condenser 31 and inductance 32. The harmonic generator may comprise a single toroidal core with suitable windings, but has been shown as comprising a pair of toroidal cores 33 and 34 to form a balanced circuit. These cores have input windings 35 and 36 and output windings 37 and 38. Either the pair of windings 35 and 36, or the pair of windings 37 and 38 are wound in respectively opposite sense on the two cores 33 and 34. This produces a differential action and prevents the frequencies from passing in either direction between the circuit containing the windings 35 and 36 and the circuit containing the windings 37 and 38.

Due to the non-linear B—H characteristic of the cores 33 and 34, when the frequency

$$\frac{p}{n}$$

is applied to the windings 35 and 36, multiples of these frequencies appear in the circuits containing windings 37 and 38 one of which is, of course the frequency  $p$ . The balanced relationship of the coils prevents to a large extent the harmonic frequencies in the secondary circuit from passing back into the primary circuit and also prevents the input

frequencies in the primary circuit from passing across to the secondary circuit. This eases the requirements on the tuned circuits. The circuit comprising the shunt arm 39 and the series arm 40 aids in producing a large component of the 10th harmonic, i. e., the frequency  $p$ , assumed to be 2500 cycles per second, and in applying this frequency to the input windings of the magnetic modulator comprising the toroidal cores 41 and 42. For this purpose the shunt 39 may be tuned to the frequency

$$\frac{2p}{n}$$

and the series circuit 40 to the frequency  $p$ .

The upper portion of the frequency band, i. e.,  $q'$  is selectively transmitted through the high pass filter 43 to the windings 45 and 46 of the magnetic modulator. Modulation takes place between waves of the frequency  $p$  and the wave components of the signal contained in the range  $q'$  both of which are applied to the magnetic modulator as has been described. The impedance network 47 is designed to present across the outer terminals of the magnetic windings 45 and 46 a low impedance to the range  $2p - q'$  in this case extending from 3000 to 3500 cycles per second and to present high impedance to frequencies both higher and lower than this range. The impedance network 47 may be designed in accordance with well known filter theory to possess the proper impedance within the required frequency limits.

It is preferable to construct the cores of the harmonic generator and the magnetic modulator of some magnetic alloy possessing high permeability at low magnetizing forces such as is characteristic of certain of the nickel-iron alloys, examples of which are disclosed in U. S. patent to G. W. Elmen, No. 1,586,884, granted June 1, 1926. One advantage of using such alloys is that the required magnetic effects may be obtained by the use of cores and windings which occupy a relatively small space. This fact adapts the coils for mounting inside a submarine cable sheath. The various other inductances shown in Fig. 3 may likewise be wound on nickel-iron alloy cores of suitable configuration to provide the requisite inductances in a small space. The condensers required are of relatively small capacity and may be designed to accommodate the space within the sheath of a submarine cable such, for example, as by being made long relative to the width, or being curved around the cable.

It was stated above that the amount of amplification produced in the signal waves is a function of the impedances afforded to the side bands and to the amplitude of the carrier. The impedance characteristic of the network 47 may be made to bear such a relation to frequency that the higher frequencies

in the range  $q'$  are more strongly amplified than the lower. This is desirable because of the increasingly high attenuation afforded by the cable or transmission line at the higher frequencies. The invention therefore contemplates designing the impedance of the network 47 with reference to the attenuation characteristic of the line L so that the amount of amplification provided for each frequency component of the signal is related to the attenuation produced in the corresponding components by the line in such a way as to effect equal transmission of all frequencies over the line, or to emphasize the higher frequencies as the case may be.

As was stated above, the filter 43 may be designed to pass the entire speech range and the impedance network may then be designed to have such an impedance characteristic over the frequency range  $2p-q$  as to produce resultant amplification of the entire speech band by either a constant factor or a variable factor related to the attenuation characteristic of the line.

The dependence of the degree of amplification upon the amplitude of the carrier frequency  $p$  offers a convenient method of controlling from a terminal station the amount of amplification to be produced at the repeater stations along the line or cable. For example, in the circuit diagram of Fig. 2 where the low frequency wave

$$\frac{p}{n}$$

is shown as being transmitted from the west (or from each) terminal to all of the repeater stations, provision is made in the potentiometer 15 for varying the amplitude of the wave of this frequency transmitted to all of the repeaters. The amplitude of this wave, of course, determines the amplitude of the wave of frequency  $p$  generated at each of the repeater stations so that by controlling the potentiometer 15 the amplification factor may be controlled for each repeater. The preferred adjustment of the system is such an adjustment as will give a high degree of stability in each of the repeater circuits throughout a working range of amplitudes determined by the controlling wave sent from the terminal, thus permitting stable operation of the repeaters at different amplification factors within this range.

What is claimed is:

1. The combination with a submarine cable having a surrounding sheath, of a repeater wholly included inside said sheath, said repeater comprising magnetic modulator means for introducing a negative resistance effect into the cable conductor within the frequency range of the signals transmitted over said conductor, and means to supply to said modulator means from a distance the energy of a

sustained alternating current wave for enabling it to function.

2. A submarine telephone repeater for a submarine cable comprising wave-combining means whose action is wholly magnetic, and means to supply to said wave-combining means a signal to be amplified and another wave derived from an alternating current wave sent over the cable, of lower frequency than the signal.

3. An amplifying repeater comprising means wholly magnetic in action for deriving from a low frequency wave a wave of a high frequency suitable for combining with speech waves to reinforce them, and means wholly magnetic in action for causing interaction between the high frequency waves and the speech waves to produce amplified speech waves.

4. In a submarine cable system means to send signal waves and a lower frequency sustained wave over the cable, means at a point in the cable to select the sustained wave and produce from it a wave of higher frequency than the signal waves, a magnetic modulator, means to modulate therein said high frequency wave by the signal waves, means presenting to the modulated components a low impedance to the lower side band of the modulated waves whereby said signal waves will be amplified, and means to apply the resultant amplified signal waves to the cable.

5. In a submarine cable system means to send signal waves over the cable, means also to transmit from a terminal station of the cable to an intermediate point thereof a sustained wave of a lower frequency than the signal, a magnetic modulator system at said intermediate point, and means including said modulator system thereat for utilizing the energy of said low frequency wave to reinforce said signal waves traversing the cable.

6. A system as defined in claim 5 including means for varying the amplitude of the low frequency wave sent from the terminal station to control the degree to which the signal waves are reinforced at said intermediate point.

7. In a submarine cable telephone system, means at a terminal station to transmit over the cable speech waves and a sustained low frequency wave, a magnetic modulator system at a point in the cable distant from the terminal, means at said point for applying at least a portion of the speech waves to said magnetic modulator system, means for also selecting the wave of low frequency and generating from it a wave of higher frequency than the speech, a circuit for applying said higher frequency wave to said modulating system, the impedance and frequency relations of the modulator system being such as to produce amplification of the portion of the speech waves applied to said modulating system, whereby the speech waves traversing

the cable are, in part at least, amplified at a point in the cable.

8. A system as defined in claim 7 in which means is provided for varying the amplitude of the sustained low frequency wave sent  
5 from the terminal station, whereby the degree of amplification at the said point in the cable distant from the terminal is controlled.

9. In a signaling system, a line, means to send over said line a signal and a sustained  
10 wave of a different frequency from the signal, a magnetic modulator at a point in the line, means to apply to said modulator the signal and a sustained wave of higher frequency derived from the sustained wave sent  
15 over the line, whereby modulation products are generated in said modulator comprising upper and lower side bands means presenting low impedance to currents of said lower sideband frequency range whereby said signals are amplified, and means to apply the  
20 resultant amplified signals to said line.

In witness whereof, I hereunto subscribe my name this 29th day of March, 1929.

EUGENE PETERSON.

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