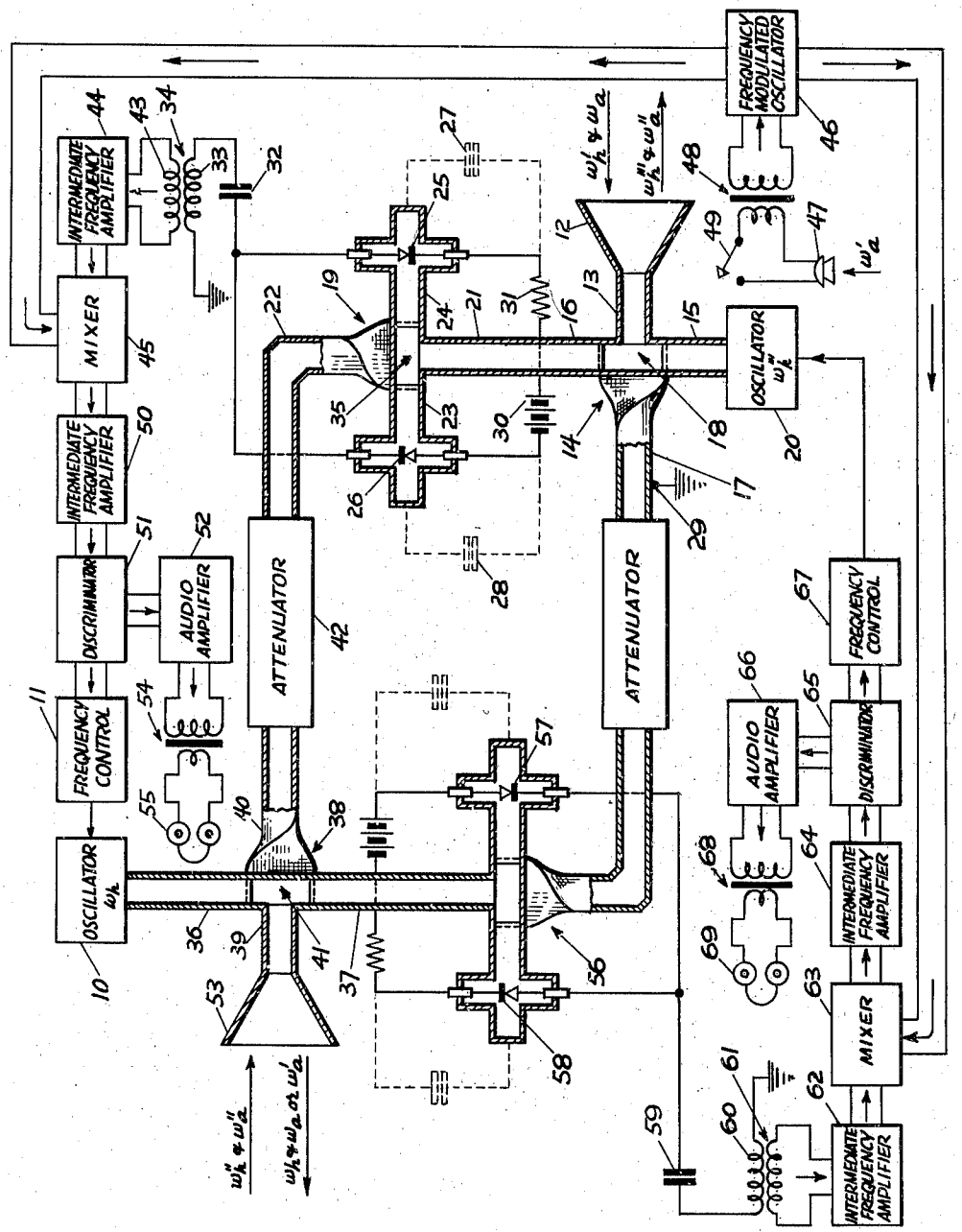
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COMMUNICATION RELAY STATION

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## COMMUNICATION RELAY STATION

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This invention relates to radio communication systems, and more particularly to an intermediate relay station for a frequency-modulated, radio communication system comprising, for example, two widely separated terminal stations and a plurality of intermediate relay stations, all operating on different mean carrier frequencies, or each station operating on two different carriers alternately, the system permitting two-way transmission of intelligence between any and all of the stations included therein, with the carrier wave emanating from one of the terminal stations, hereinafter referred to as the slave station, and from each intermediate relay station under the control of the carrier wave received at each such station, and all under the control of the carrier wave originating at the remaining terminal station, hereinafter referred to as the master station.

It is, therefore, one of the main objects of the present invention to provide an intermediate relay station capable of relaying intelligence received from two widely separated terminal stations.

This, and other objects of the present invention, which will become more apparent as the detailed description thereof progresses, are attained briefly, in the following manner:

Throughout this specification it will be assumed that the device of the present invention operates in conjunction with a radio communication system comprising two widely separated terminal stations, and that said device is, preferably, disposed between said terminal stations.

Each station includes means for locally generating a carrier wave, preferably, in the microwave region of the electromagnetic spectrum, and means for frequency modulating said carrier waves with locally-generated intelligence. Normally, there is a predetermined difference between the frequencies of the carrier waves generated at each station, i. e., the master and slave stations and the intermediate relay stations therebetween. For example, the frequency of the locally-generated carrier wave at the master station may be 8,000 megacycles, while the relay station, in this particular embodiment, will have means for locally generating two carrier waves of 8010 megacycles, and 8020 megacycles, and the slave station will have means for locally generating a carrier wave having a frequency of 8030 megacycles.

A portion of the locally-generated carrier wave at the master station is radiated into space, and a portion of the locally-generated carrier wave

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of the relay station, received at the master station, is mixed to derive therefrom an intermediate-frequency wave whose frequency normally corresponds to the aforesaid frequency difference between said carrier waves. For example, if the locally-generated carrier wave at the master station has a frequency of 8000 megacycles, and it is mixed with the remotely-generated carrier wave of the relay station, whose frequency is 8010 megacycles, the intermediate frequency wave will have a frequency difference of 10 megacycles.

The intermediate-frequency wave thus derived is passed through a system, of the type described in the copending application of George G. Bruck, Philip E. Volz, Paul J. Pontecorvo and Malcolm C. Vosburgh, entitled "Radio communication system," Ser. No. 650,716, filed February 27, 1946, now Patent No. 2,475,474, issued July 5, 1949, and serves to adjust the frequency of the local carrier wave to compensate for any deviation from the desired mean frequency thereof. Now, as will hereinafter be pointed out, the remotely-generated carrier wave, emanating from the relay station and received at the master station, is frequency stabilized within very close limits, and inasmuch as the apparatus, described in said pending application, assures the maintenance of a constant frequency difference between the remotely and locally-generated carrier waves, the locally-generated carrier wave at the relay station, likewise, becomes frequency stabilized. At the relay station, as pointed out before, there are employed two local carrier wave generators whose frequencies are, respectively, for example, 8010 megacycles, and 8020 megacycles. The remotely-generated carrier wave, which has, for example, a frequency of 8000 megacycles, transmitted from the master station, is received by the relay station and mixed with the locally generated carrier wave of 8010 megacycles, to produce an intermediate frequency of 10 megacycles. This frequency difference controls the stability of the locally-generated carrier wave at the relay station and is locked in with the remotely-generated wave at the master station. Thus, any drift from the desired mean frequency is always corrected.

Intelligence transmitted via the 8000 megacycle carrier wave, for example, from the master station is extracted from said carrier wave at the relay station and impressed on the locally-generated 8010 megacycle carrier wave of said relay station and is in turn transmitted from

said relay station to the other terminal or slave station.

At the slave station, the locally-generated carrier wave, which has for example a frequency of 8030 megacycles, is mixed with the remotely-generated carrier wave of the relay station, which has a frequency of 8010 megacycles, to produce a difference frequency for controlling the local generator of said slave station. Thus far, the transmission has been from the master station via the relay station to the slave station. The locally-generated carrier wave at said slave station, whose frequency, for example, is 8030 megacycles, is received by the relay station and mixes with a second locally-generated carrier wave in said relay station, which has a frequency, for example, of 8020 megacycles, to produce an intermediate frequency of 10 megacycles, said last-named frequency difference controlling the frequency stability of said 8020 megacycle carrier wave at the relay station, as described in the aforesaid pending application. Now, the intelligence from the slave station is extracted, at the relay station, from the remotely-generated carrier wave at said slave station and transmitted back to the master station via the carrier wave of 8020 megacycles, the frequency of the second locally-generated carrier wave at said relay station. At said master station the last-named carrier wave of 8020 megacycles, generated at the relay station, mixes with the locally-generated carrier wave of the master station and the intelligence is extracted, as described in the aforementioned pending application.

In the accompanying specification there shall be described, and in the annexed drawing shown, an illustrative embodiment of the relay station of the present invention. It is, however, to be clearly understood that the present invention is not to be limited to the details herein shown and described for purposes of illustration only, inasmuch as changes therein may be made without the exercise of invention, and within the true spirit and scope of the claims hereto appended.

In said drawing, the single figure is a partial block, partial schematic diagram of the relay station of the present invention.

Referring now more in detail to the aforesaid illustrative embodiment of the present invention, with particular reference to the single figure of the drawing, the numeral **10** designates an oscillator for locally generating, at a relay station, a carrier wave $\omega_h$, preferably in the microwave region of the electromagnetic spectrum. It is the mean frequency of this carrier wave that it is desired to stabilize, either under the control of a stabilized, remotely-generated carrier wave received from a master station, or by means incorporated in the local station itself.

This description will be addressed to the case where the carrier wave which is locally generated at a relay station is to be stabilized under the control of a carrier wave which is remotely generated at a master station.

The oscillator **10** is adapted to be frequency modulated, by any preferred frequency control **11**, as will be presently explained. An electromagnetic horn **12** is receptive, from a first predetermined direction, of a remotely-generated carrier wave of a frequency $\omega'_h$, which may be frequency modulated with intelligence $\omega_a$, and which emanates from a terminal station, in the case under consideration, a master station, the master and relay carrier waves normally differing, as hereinbefore stated, by a predetermined frequency $\omega_d$. The remotely-generated carrier wave $\omega'_h$ and the intelligence $\omega_a$ travel along a so-called E arm **13** of a wave guide assembly **14**, known as a "magic T." Such a wave-guide assembly comprises, in addition to the E arm **13**, oppositely-disposed side branches **15** and **16** extending in the same direction and at right angles to the E arm **13**, and a so-called H arm **17**, extending outwardly from said side branches **15** and **16**, and being mutually perpendicular to said side branches and said E arm, said side branches, said E arm, and said H arm all extending from a common junction **18**. As shown in the drawing, the H arm **17** recedes from the observer for a short distance from the common junction **18**, then bends away from the branches **15** and **16**, and is then twisted through an angle of 90°.

As the energy travelling along the E arm **13** from the horn **12** reaches the junction **18**, it splits, part travelling along the side branch **16** to a second T **19** and the other part along the side branch **15** to a second local oscillator **20** where this part of the energy is lost. That portion of the energy travelling along the side branch **16** enters an E arm **21** of the second T **19**.

The second-named T **19**, the operation and construction of which is fully disclosed in the copending application of George G. Bruck, entitled "Mixing apparatus," Ser. No. 652,628, filed March 7, 1946, now Patent No. 2,468,166, granted April 26, 1949, comprises, in addition to an H arm **22**, oppositely-disposed side branches **23** and **24**, said side branches being terminated in oppositely-disposed crystals **25** and **26**, between one side of each of which and the T itself capacitances **27** and **28** exist, said T being grounded as shown at point **29**, and said crystals being connected in series with a source **30** of direct current and a resistor **31**, to provide parallel outputs to ground through a capacitor **32** and the primary winding **33** of a radio-frequency transformer **34**. The source **30** of direct current is for the purpose of operating the crystals **25** and **26** at a favorable point along their characteristic curve, and the series circuit is for the purpose of passing equal currents through said crystals to assure their similar action even though they be mismatched to the wave-guide system.

Now, as the energy of the carrier wave $\omega'_h$ and the intelligence $\omega_a$ travelling along the side branch **16** and the E arm **21** reaches a junction **35** of the wave-guide assembly **19**, assuming the electric vector of said carrier wave is pointing to the right in the E arm **21**, it splits into two constituent waves containing $\omega'_h$ and $\omega_a$, travelling along the side branches **23** and **24**, each constituent wave, respectively, travelling toward the crystals **25** and **26**. The wave travelling toward the crystal **25** will have its electric vector pointing downwardly and the wave travelling toward the crystal **26** will have its electric vector pointing upwardly. In other words, these two constituent waves will be of equal amplitude but of opposite phase.

Digressing for the moment and referring back to the local oscillator **10**, it was pointed out that said oscillator provides a locally-generated carrier wave $\omega_h$. The output from said oscillator is applied to one branch **36** of a pair of oppositely-disposed branches **36** and **37** of a third "magic T" **38**, said T comprising an E arm **39**, an H arm **40** and a junction **41**, all of which are disposed in a manner hereinbefore described in connection with the first and second-named T's.

As the energy travelling along the branch 36 reaches the junction 41, it splits, part travelling along the H arm 40 to an attenuator 42 and the other part being radiated from an electromagnetic horn 53, as will be explained below. The attenuator permits just enough of said partial energy from said local oscillator 10 to travel along the H arm 22 to the junction 35 where said energy again splits into two constituent waves $\omega$ the waves traveling along the side branches 23 and 24, respectively, toward the crystals 25 and 26. Assuming that the electric vector of the wave $\omega_h$ travelling along the H arm 22 is pointing upwardly at the junction 35, the constituent waves thereof travelling along the side branches 23 and 24 will have their electric vectors, likewise, pointing upwardly. In other words, these constituent waves will be of equal amplitude and like phase.

At the crystals 25 and 26, there are now present in-phase portions of the locally-generated carrier wave $\omega_h$, out-of-phase portions of the remotely-generated carrier wave $\omega'_h$ and the intelligence $\omega_a$. Therefore, at the crystals 25 and 26 there are produced two waves having a beat frequency, whose frequency corresponds to the frequency difference $\omega_d$ between the carrier waves. At the crystal 26, the resultant wave is produced by two in-phase components and the phase of said resultant wave may thus be considered positive. At the crystal 26, the resultant wave is produced by two out-of-phase components and the phase of said last-named resultant wave may thus be considered negative. However, inasmuch as parallel outputs are taken from the crystals 25 and 26, the two resultant waves are in-phase with respect to each other and addition occurs, and a constant-amplitude intermediate-frequency wave appears across the primary winding 33 of the transformer 34.

Through a secondary winding 43 of the transformer 34 this intermediate frequency wave is applied to a broad-band amplifier 44 whose center frequency corresponds to the normal difference $\omega_d$ between the frequencies of the locally and remotely-generated carrier waves $\omega_h$ and $\omega'_h$. The output of the amplifier 44, consisting of the difference frequency $\omega_d$ and any audio-frequency modulation or intelligence $\omega_a$, originating at the master station, is applied to a mixer 45. Also applied to said mixer is a frequency-modulated signal $\omega_m$ from a monitoring oscillator 46. This last-named monitoring unit enables the relay station operator to break in on the transmission being relayed in the event of emergencies, etc. The locally-generated intelligence $\omega'_a$ is applied to said monitoring oscillator 46 through a microphone 47 and an audio-frequency transformer 48, the operation of the microphone 47 being controlled by a switch 49.

At the mixer 45 the frequencies $\omega_d$ and $\omega_m$ are combined to produce a second difference frequency $\omega'_d$, the output from said mixer being applied to a second broadband amplifier 50, whose center-frequency corresponds to the difference frequency $\omega'_d$. The output of the amplifier 50, consisting of the second difference frequency $\omega'_d$ and any audio-frequency modulation $\omega_a$ and $\omega'_a$ originating, respectively, at the master station or relay station, is applied to a frequency discriminator 51 whose center frequency corresponds to the difference frequency $\omega'_d$. The discriminator extracts the intelligence $\omega_a$ or $\omega'_a$ impressed upon the difference frequency $\omega'_d$ input applied thereto, which intelligence is then conveyed simultaneously to an



audio-frequency amplifier 52 and the frequency control 11.

The output from the frequency control 11 frequency modulates the local oscillator 10 and the energy from said oscillator travels along the branch arm 36 and thence to the junction 41 where it splits, part travelling along the H arm 40 as explained hereinbefore, the other part travelling along the E arm 39 to the electromagnetic horn 53 which is adapted to directionally radiate the carrier $\omega_h$ containing $\omega_a$ or $\omega'_a$.

Regarding the intelligence conveyed to the audio-frequency amplifier 52, the output of said amplifier is applied to an audio-frequency transformer 54 and thence to phones 55. The function of said last-named components serves as a monitoring unit to supervise the relayed transmission by an operator at the relay station.

As long as the mean frequency of the intermediate-frequency wave derived from the heterodyning of the remotely and locally-generated carrier waves corresponds to the predetermined difference $\omega_d$ therebetween, the only output from the discriminator 51 is an audio-frequency output corresponding to the intelligence $\omega_a$ or $\omega'_a$. However should the oscillator 10 drift, resulting in a deviation of the frequency of the intermediate-frequency wave from the difference frequency $\omega_d$ between the carrier-wave frequencies, the discriminator 51 will have an output including, in addition to that resulting from the intelligence applied thereto, a D.-C. or unidirectional component whose sense and magnitude will depend, respectively, on the sense and magnitude of any such deviation. Therefore, the output of the discriminator is applied to the frequency control 11 to adjust the oscillator 10 and compensate for any frequency deviation from the mean frequency desired of said oscillator.

Thus far there has been described that portion of the relay station of the present invention when said station is relaying the transmission, represented by $\omega'_h$ and $\omega_a$, received from the master station at the electromagnetic horn 12. Under these conditions the system performs like a single repeater relay station. However, the relay station of the present invention is capable of relaying, in two different directions, two different remotely-generated carrier waves simultaneously, the components and the operational functions being the same when the other terminal or slave station transmits toward the electromagnetic horn 53 a remotely-generated carrier wave $\omega''_h$ containing intelligence $\omega''_a$.

A locally-generated carrier $\omega'''_h$ produced by a local oscillator 20 combines with the remotely-generated carrier wave $\omega''_h$ to produce a difference frequency $\omega''_d$ in a fourth "magic T" 56 in the same manner described in connection with the first-named local oscillator 10. The output of a pair of oppositely-disposed crystals 57 and 58 is applied, as explained hereinbefore in connection with the "magic T" 19, through a capacitor 59 and thence to the primary 60 of a radio-frequency transformer 61. As explained previously, the output of the radio-frequency transformer is applied to a series of stages, 62, 63, 64, 65, 66, 67, 68 and 69 and to the local oscillator 20 in the same manner in connection with the stages 44—45 and stage 11.

The intelligence $\omega''_a$ having been extracted in the same manner as the intelligence $\omega_a$ and $\omega'_a$, said intelligence frequency modulates the local oscillator 20, whereby the locally-generated carrier wave $\omega'''_h$ containing the remotely-gen-

erated intelligence $\omega''_a$ is radiated from the horn 12 in the direction of the master station. As explained before, it is possible to inject the locally-generated intelligence $\omega'_a$ from the oscillator 46 into the mixer 63 of the system for supervisory purposes.

This completes the description of the aforesaid illustrative embodiment of the present invention, including the mode of operation thereof either as a one-way or two-way relay station in a communication system having the characteristics set forth in the opening paragraphs of this specification.

The flexibility of the system of the present device provides excellent means for relaying transmission of intelligence in that portion of the radio frequency spectrum which depends on line-of-sight installations such as frequency-modulated radio communication and television broadcasting. With the system of the present invention it is possible to disregard topographical obstructions by skirting such obstructions with a chain of relay systems as presented in this specification.

What is claimed is:

1. In a relay station for a communication system: means for locally generating a carrier wave; means for receiving a remotely-generated carrier wave, said carrier waves normally having a predetermined frequency difference therebetween; means, receptive of portions of both said carrier waves, for deriving from one, two constituent waves of equal amplitude and opposite phase, and from the other, two constituent waves of equal amplitude and like phase; means for deriving from all of said constituent waves an intermediate-frequency wave whose frequency normally corresponds to said predetermined difference between the frequencies of said carrier waves; means, receptive of said intermediate-frequency wave, for deriving therefrom a unidirectional output whose sense and magnitude are functions, respectively, of the sense and magnitude of any deviations of the frequency of said intermediate-frequency wave from said predetermined difference between the frequencies of said carrier waves; means, receptive of said unidirectional output, for so controlling the frequency of said locally-generated carrier wave in response thereto as to maintain substantially constant said predetermined difference between the frequencies of said carrier waves; and means for transmitting said locally-generated carrier wave.

2. In a relay station for a communication system: means for locally generating a carrier wave; means for receiving a remotely-generated carrier wave, said carrier waves normally having a predetermined frequency difference therebetween; means, receptive of a portion of one of said carrier waves, for dividing the same into two constituent waves of equal amplitude and opposite phase; means, receptive of a portion of the remaining carrier wave, for dividing the same into two constituent waves of equal amplitude and like phase; means for mixing said first-named constituent waves, respectively, with said second-named constituent waves to derive therefrom two beat-frequency waves of equal amplitude and opposite phase; means for so combining said beat-frequency waves as to produce a single intermediate-frequency wave whose frequency normally corresponds to said predetermined difference between the frequencies of said carrier waves; means, receptive of said intermediate-frequency wave, for deriving therefrom a unidirectional output whose sense and magnitude are functions, respectively, of the sense and magnitude of any deviations of the frequency of said intermediate-frequency wave from said predetermined difference between the frequencies of said carrier waves; means, receptive of said unidirectional output, for so controlling the frequency of said locally-generated carrier wave in response thereto as to maintain substantially constant said predetermined difference between the frequencies of said carrier waves; and means for transmitting said locally-generated carrier wave.

3. In a relay station for a communication system: means for locally generating a carrier wave; means for receiving a remotely-generated carrier wave, said carrier waves normally having a predetermined frequency difference therebetween; means, receptive of portions of both said carrier waves, for deriving from one, two constituent waves of equal amplitude and opposite phase, and from the other, two constituent waves of equal amplitude and like phase; means for deriving from all of said constituent waves an intermediate-frequency wave whose frequency normally corresponds to said predetermined difference between the frequencies of said carrier waves; means, receptive of said intermediate-frequency wave, for driving therefrom an output for so controlling the frequency of said locally-generated carrier wave as to maintain substantially constant said predetermined difference between the frequencies of said carrier waves; and means for transmitting said locally-generated carrier wave.

4. In a relay station for a communication system: means for locally generating a carrier wave; means for receiving a remotely-generated carrier wave, said carrier waves normally having a predetermined frequency difference therebetween; means, receptive of a portion of one of said carrier waves, for dividing the same into two constituent waves of equal amplitude and opposite phase; means, receptive of a portion of the remaining carrier wave, for dividing same into two constituent waves of equal amplitude and like phase; means for mixing said first-named constituent waves, respectively, with said second-named constituent waves to derive therefrom two beat-frequency waves of equal amplitude and opposite phase; means for so combining said beat-frequency waves as to produce a single intermediate-frequency wave whose frequency normally corresponds to said predetermined difference between the frequencies of said carrier waves; means, receptive of said intermediate-frequency wave, for deriving therefrom an output for so controlling the frequency of said locally-generated carrier wave as to maintain substantially constant said predetermined difference between the frequencies of said carrier waves; and means for transmitting said locally-generated carrier wave.

5. In a relay station for a radio communication system: means for locally generating a carrier wave; means for receiving a remotely-generated, frequency-modulated carrier wave, said carrier waves having a predetermined frequency difference therebetween; means, receptive of said locally-generated carrier wave and said remotely-generated, frequency-modulated carrier wave, for deriving from one, two constituent waves of equal amplitude and opposite phase, and from the other, two constituent waves of equal amplitude and like phase; means for deriving from all of said constituent waves a frequency-modulated, intermediate-frequency wave whose mean frequency

corresponds to the difference between the frequency of said locally-generated carrier wave and the mean frequency of said remotely-generated carrier wave; means, receptive of said intermediate-frequency wave, for extracting therefrom the intelligence incorporated therein; means, receptive of said intelligence, for altering the frequency of said locally-generated carrier wave in accordance therewith; and means for transmitting the resulting frequency-modulated, locally-generated carrier wave.

6. In a relay station for a radio communication system: means for locally generating a carrier wave; means for receiving a remotely-generated, frequency-modulated carrier wave, said carrier waves having a predetermined frequency difference therebetween; means, receptive of a portion of one of said carrier waves, for dividing the same into two constituent waves of equal amplitude and opposite phase; means, receptive of a portion of the remaining carrier wave, for dividing the same into two constituent waves of equal amplitude and like phase; means for mixing said first-named constituent waves, respectively, with said second-named constituent waves to derive therefrom two beat-frequency waves of equal amplitude and opposite phase; means for so combining said beat-frequency waves as to produce a single intermediate-frequency wave whose frequency normally corresponds to the difference between the frequency of said locally-generated carrier wave and the mean frequency of said remotely-generated carrier wave; means, receptive of said intermediate frequency wave, for extracting therefrom the intelligence incorporated therein; means, receptive of said intelligence, for altering the frequency of said locally-generated carrier wave in accordance therewith; and means for transmitting the resulting frequency-modulated, locally-generated carrier wave.

7. In a relay station for a radio communication system: means for locally generating a carrier wave; means for receiving a remotely-generated, frequency-modulated carrier wave, said carrier waves having a predetermined frequency difference therebetween; means, receptive of said locally-generated carrier wave and said remotely-generated, frequency-modulated carrier wave, for deriving from one, two constituent waves of equal amplitude and opposite phase, and from the other, two constituent waves of equal amplitude and like phase; means for deriving from all of said constituent waves a frequency-modulated, intermediate-frequency wave whose mean frequency corresponds to the difference between the frequency of said locally-generated carrier wave and the mean frequency of said remotely-generated carrier wave; means, receptive of said intermediate-frequency wave, for extracting therefrom the intelligence incorporated therein; means, receptive of said intelligence, for altering the frequency of said locally-generated carrier wave in accordance therewith; and means for transmitting the resulting frequency-modulated, locally-generated carrier wave.

8. In a relay station for a radio communication system: means for locally generating a carrier wave; means for receiving a remotely-generated, frequency-modulated carrier wave, said carrier waves having a predetermined frequency difference therebetween; means, receptive of a portion of one of said carrier waves, for dividing the same into two constituent waves of equal amplitude and opposite phase; means, receptive of a portion of the remaining carrier wave, for dividing same into two constituent waves of equal amplitude and like phase; means for mixing said first-named constituent waves, respectively, with said second-named constituent waves to derive therefrom two beat-frequency waves of equal amplitude and opposite phase; means for so combining said beat-frequency waves as to produce a single intermediate-frequency wave whose mean frequency corresponds to the difference between the frequency of said locally-generated carrier wave and the mean frequency of said remotely-generated carrier wave; means, receptive of said intermediate frequency wave, for extracting therefrom the intelligence incorporated therein; means, receptive of said intelligence, for altering the frequency of said locally-generated carrier wave in accordance therewith; and means for transmitting the resulting frequency-modulated, locally-generated carrier wave.

9. In a relay station for a communication system: means for locally generating a carrier wave; means for receiving a remotely-generated, frequency-modulated carried wave, said carrier waves normally having a predetermined frequency difference therebetween; means for combining said locally-generated carrier wave with said remotely-generated, frequency-modulated carrier wave, for deriving from one, two constituent waves of equal amplitude and opposite phase, and from the other two constituent waves of equal amplitude and like phase; means for deriving from all of said constituent waves a frequency-modulated, intermediate-frequency wave whose mean frequency corresponds to the difference between the frequency of said locally-generated carrier wave and the mean frequency of said remotely-generated carrier wave; means receptive of said intermediate-frequency wave, for deriving therefrom an output wave, the magnitude and sense of which corresponds to the magnitude and sense of the deviation of the frequency of said intermediate frequency wave from its mean frequency and for extracting therefrom the intelligence incorporated therein; means, receptive of said output wave and said intelligence, for controlling the frequency of said locally-generated carrier wave as to maintain substantially constant said predetermined difference between the mean frequency of said remotely-generated carrier wave and the frequency of said local carrier wave and to incorporate in the latter said intelligence; and means for transmitting the resulting frequency-modulated, locally-generated carrier wave.

10. In a relay station for a communication system: means for locally generating a carrier wave; means for receiving a remotely-generated, frequency-modulated carrier wave, said carrier waves normally having a predetermined frequency difference therebetween; means, receptive of a portion of one of said carrier waves, for dividing the same into two constituent waves of equal amplitude and opposite phase; means, receptive of a portion of the remaining carrier wave, for dividing the same into two constituent waves of equal amplitude and like phase; means for mixing said first-named constituent waves, respectively, with said second-named constituent waves to derive therefrom two beat-frequency waves of equal amplitude and opposite phase; means for so combining said beat-frequency waves as to produce a single intermediate-frequency wave whose mean frequency corresponds to the difference between the frequency of said locally-generated carrier wave and the mean frequency of said remotely-generated carrier wave; means, receptive of said intermediate frequency wave, for extracting therefrom the intelligence incorporated therein; means, receptive of said intelligence, for altering the frequency of said locally-generated carrier wave in accordance therewith; and means for transmitting the resulting frequency-modulated, locally-generated carrier wave.

of said locally-generated carrier wave and the mean frequency of said remotely-generated carrier wave; means, receptive of said intermediate frequency wave, for deriving therefrom an output wave, the magnitude and sense of which corresponds to the magnitude and sense of the deviation of the frequency of said intermediate frequency wave from its mean frequency and for extracting therefrom the intelligence incorporated therein; means, receptive of said output wave and said intelligence, for controlling the frequency of said locally-generated carrier wave as to maintain substantially constant said predetermined difference between the mean frequency of said remotely-generated carrier wave and the frequency of said local carrier wave and to incorporate in the latter said intelligence; and means for transmitting the resulting frequency-modulated, locally-generated carrier wave.

11. In a relay station for a communication system: means for locally generating a carrier wave; means for receiving a remotely-generated, frequency-modulated carrier wave, said carrier waves normally having a predetermined frequency difference therebetween; means for combining said locally-generated carrier wave with said remotely-generated, frequency-modulated carrier wave to derive from one, two constituent waves of equal amplitude and opposite phase, and from the other, two constituent waves of equal amplitude and like phase; means for deriving from all of said constituent waves a frequency-modulated, intermediate-frequency wave whose mean frequency corresponds to the difference between the frequency of said locally-generated carrier wave and the mean frequency of said remotely-generated carrier wave; means receptive of said intermediate-frequency wave, for deriving therefrom an output wave, the magnitude and sense of which corresponds to the magnitude and sense of the deviation of the frequency of said intermediate-frequency wave from its mean frequency and for extracting therefrom the intelligence incorporated therein; means, receptive of said output wave and said intelligence, for controlling the frequency of said locally-generated carrier wave as to maintain substantially constant said predetermined difference between the mean frequency of said remotely-generated carrier wave and the frequency of said local carrier wave and to incorporate in the latter said intelligence; and means for transmitting the resulting frequency-modulated, locally-generated carrier wave.

12. In a relay station for a communication system: means for locally generating a carrier wave; means for receiving a remotely-generated, frequency-modulated carrier wave, said carrier waves normally having a predetermined frequency difference therebetween; means, receptive of a portion of one of said carrier waves, for dividing the same into two constituent waves of equal amplitude and opposite phase; means, receptive of a portion of the remaining carrier wave, for dividing same into two constituent waves of equal amplitude and like phase; means for mixing said first-named constituent waves, respectively, with said second-named constituent waves to derive therefrom two beat-frequency waves of equal amplitude and opposite phase; means for so combining said beat-frequency waves as to produce a frequency-modulated, intermediate-frequency wave whose mean frequency corresponds to the difference between the frequency of said locally-generated carrier wave and the mean frequency of said remotely-generated carrier wave; means receptive of said intermediate-frequency wave, for deriving therefrom an output wave, the magnitude and sense of which corresponds to the magnitude and sense of the deviation of the frequency of said intermediate-frequency wave from its mean frequency and for extracting therefrom the intelligence incorporated therein; means, receptive of said output wave and said intelligence, for controlling the frequency of said locally-generated carrier wave as to maintain substantially constant said predetermined difference between the mean frequency of said remotely-generated carrier wave and the frequency of said local carrier wave and to incorporate in the latter said intelligence; and means for transmitting the resulting frequency-modulated, locally-generated carrier wave.

13. In a relay station for a communication system: a plurality of double T-shaped wave-guide assemblies, each including a cross arm common to both of its T's and a pair of branch arms perpendicular to said cross arm and to each other; means, connected to one of the branch arms of two of said wave-guide assemblies, for receiving and radiating electromagnetic carrier waves; a carrier-wave generator connected to one end of the cross arm of each of said last-named wave-guide assemblies; the other end of said last-named cross arms being connected to one of the branch arms of two other of said wave-guide assemblies; the remaining branch arms of said first two wave-guide assemblies being connected to the remaining branch arms of said second two wave-guide assemblies; said first two wave-guide assemblies being receptive, respectively, of remotely-generated carrier waves to divide the same, respectively, into two constituent waves, one of each of said constituent waves entering, respectively, said second two wave-guide assemblies to divide the same, respectively, into two sub-constituent waves of opposite phase; said first two wave-guide assemblies being also receptive of locally-generated carrier waves to divide the same, respectively, into two constituent waves, one of each of said last-named constituent waves entering, respectively, said second-named wave-guide assemblies and the other of each of said last-named constituent waves being transmitted in the respective directions from which said remotely-generated carrier waves were received, the first of said last-named constituent waves entering said second-named wave-guide assemblies and dividing into sub-constituent waves of like phase; a pair of series-connected, oppositely-disposed non-linear impedances terminating the opposite ends of the cross arms of said second two wave-guide assemblies for combining said locally and remotely-generated, sub-constituent waves to derive therefrom intermediate-frequency waves; an inductive impedance connected in parallel with each pair of said non-linear impedances for extracting said intermediate-frequency waves; and means, receptive of said intermediate-frequency waves, for so controlling the frequencies of said locally-generated carrier waves, respectively, as to maintain substantially constant predetermined differences between the frequencies of said locally and remotely-generated carrier waves.

14. In a relay station for a communication system; means for locally generating a carrier wave; means for receiving a remotely-generated carrier wave, said carrier waves normally having a predetermined frequency difference therebetween; means, receptive of portions of both of said car-

rier waves, for deriving therefrom a first intermediate-frequency wave whose frequency normally corresponds to said predetermined difference between the frequencies of said carrier waves; means for locally generating a monitoring wave; means, receptive of said first intermediate-frequency wave and said monitoring wave, for deriving therefrom a second intermediate-frequency wave; means, receptive of said second intermediate-frequency wave, for deriving therefrom a unidirectional output whose sense and magnitude are functions, respectively, of the sense and magnitude of any deviations of the frequency of said first intermediate-frequency wave from said predetermined difference between the frequency of said carrier waves; means, receptive of said unidirectional output, for so controlling the frequency of said locally-generated carrier wave as to maintain substantially constant said predetermined difference between the frequencies of said carrier waves; and means for transmitting said locally-generated carrier wave.

15. In a relay station for a communication system: means for locally generating a carrier wave; means for receiving a remotely-generated carrier wave; said carrier waves normally having a predetermined frequency difference therebetween; means, receptive of portions of both of said carrier waves, for deriving therefrom a first intermediate-frequency wave whose frequency normally corresponds to said predetermined difference between the frequencies of said carrier waves; means for locally generating a monitoring wave; means for frequency modulating said monitoring wave in accordance with locally-generated intelligence; means, receptive of said first intermediate-frequency wave and said monitoring wave, for deriving therefrom a sec-



ond frequency-modulated intermediate-frequency wave; means, receptive of said second intermediate-frequency wave, for deriving therefrom a unidirectional output whose sense and magnitude are functions, respectively, of the sense and magnitude of any deviations of the frequency of said first intermediate-frequency wave from said predetermined difference between the frequencies of said carrier waves and the sense and magnitude of the deviations of the frequency of said monitoring wave due to the frequency modulation of said monitoring wave; means, receptive of said unidirectional output, for so controlling the frequency of said locally-generated carrier wave as to maintain substantially constant said predetermined difference between the frequencies of said carrier waves and simultaneously to frequency modulate said locally-generated carrier wave in accordance with said locally-generated intelligence; and means for transmitting said locally-generated carrier wave.

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## REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

| Number | Name | Date |
|---|---|---|
| 2,148,532 | Chaffee | Feb. 28, 1939 |
| 2,369,268 | Trevor | Feb. 13, 1945 |
| 2,408,791 | Magnuski | Oct. 8, 1946 |

FOREIGN PATENTS

| Number | Country | Date |
|---|---|---|
| 116,110 | Australia | Nov. 4, 1942 |

## Certificate of Correction

Patent No. 2,477,428 July 26, 1949

ROBERT M. SPRAGUE ET AL.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows:

Column 10, line 24, claim 9, for the word "carried" read *carrier*;

and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 13th day of December, A. D. 1949.

[SEAL]

THOMAS F. MURPHY,
*Assistant Commissioner of Patents.*