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MIXING APPARATUS

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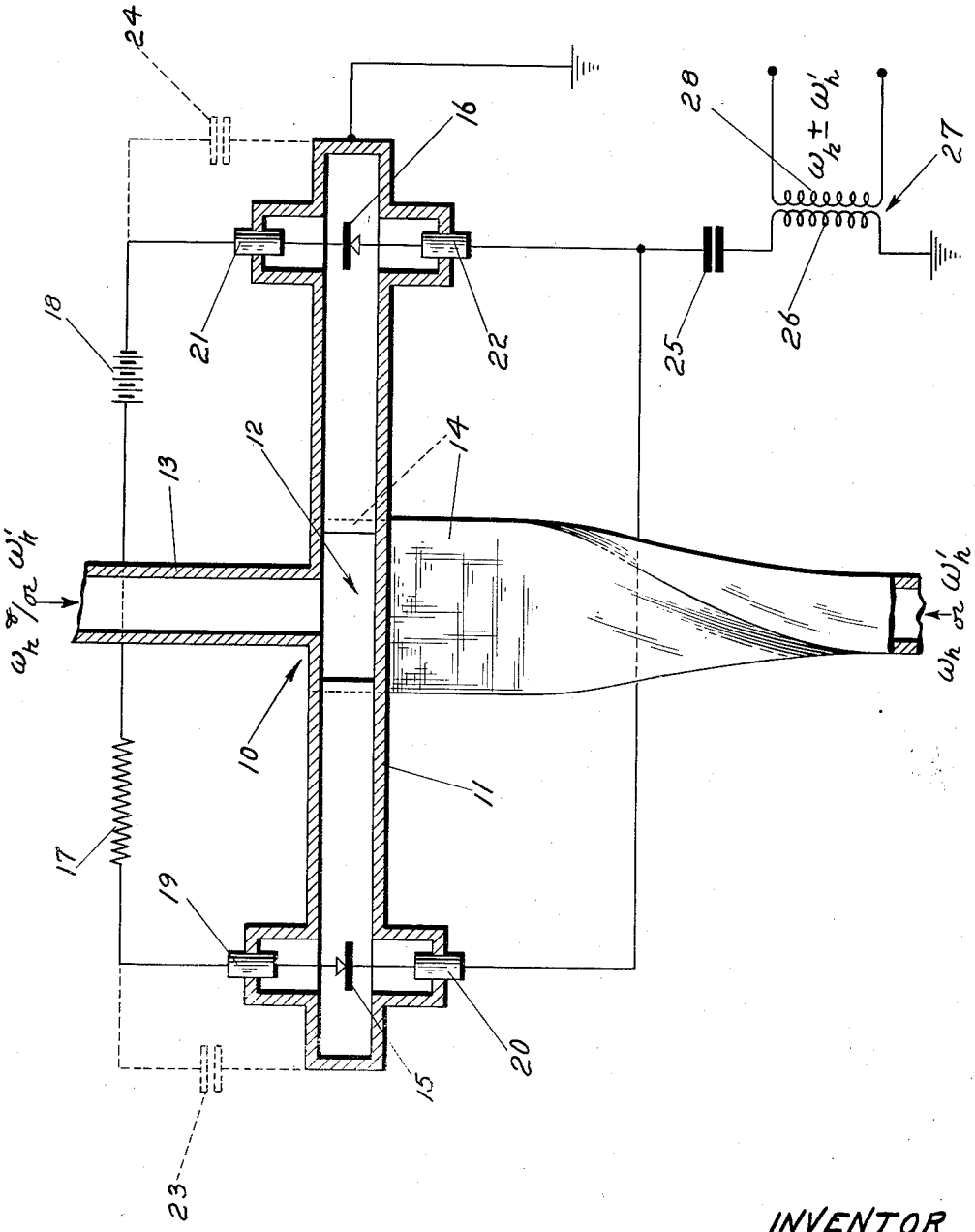

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MIXING APPARATUS

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This invention relates to mixing apparatus, and more particularly to mixing apparatus for combining periodic waves, especially, but not necessarily, electromagnetic waves having different frequencies in the microwave region of the spectrum, to produce a resultant wave whose frequency is an arithmetic function, for example, the sum of or difference between the frequencies of the initial waves.

While not limited thereto, the present invention is admirably adapted for use in a communication system, such as is disclosed in the copending application of George G. Bruck, Philip E. Volz, Paul J. Pontecorvo and Malcolm C. Vosburgh, entitled "Radio communication system," Serial No. 650,716, filed February 27, 1946, for heterodyning microwave carriers to produce a beat-frequency wave.

One of the objects of the present invention is to provide mixing apparatus of the general character indicated in which impedance-matching problems, normally difficult of solution, are held to a minimum.

Another object of the present invention is to provide mixing apparatus which is so designed that should one of the input waves include undesirable amplitude variations, the effect thereof on the final output can be eliminated.

These, 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:

The invention contemplates the provision of means, for example, a double T-shaped waveguide assembly including a cross-arm common to both T's and a pair of branch arms perpendicular to said cross-arm and to each other, for dividing a pair of periodic waves applied thereto into two oppositely-phased pairs of similarly-phased constituent waves, and two additional pairs of constituent waves, the waves of one of said additional pairs being of like phase and the waves of the other additional pair being of opposite phase. The constituent waves of each of said first-named pairs, and the constituent waves of each of said second-named pairs are combined in means, for example, a pair of oppositely-disposed, series-connected, non-linear impedances terminating the outer ends of the above referred to waveguide cross-arm, to derive therefrom, respectively, two resultant waves of like phase and two resultant waves of opposite phase. All of said resultant waves are combined in means, for example, an inductive impedance connected in parallel with the above referred to non-linear impedances, whereby said first-named resultant waves cancel each other to produce a zero output, while said second-named resultant waves add to each other to produce a final output whose frequency is an arithmetic function of the frequencies of the initial waves.

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In the accompanying specification there shall be described, and in the annexed drawing shown, an illustrative embodiment of the mixing apparatus 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 schematic diagram of a mixing device assembled in accordance with the principles of the present invention.

Referring now more in detail to the aforesaid illustrative embodiment of the present invention, with particular reference to the drawing illustrating the same, the numeral 10 generally designates what may be termed a double T-shaped wave-guide assembly. Such an assembly includes a cross-arm 11 from the center of which, or from what will hereinafter be called a common junction 12, extends two branch arms 13 and 14, said cross-arm being common to both T's, and said branch arms being perpendicular to said cross-arm, and to each other. As herein shown, the branch arm 14 recedes from the observer for a short distance from the common junction 12, then bends downwardly, and is then twisted through an angle of 90°

The opposite ends of the cross-arm terminate, respectively, in non-linear impedances, for example, rectifying crystals 15 and 16, said crystals being oppositely disposed with respect to each other, and connected in series through a resistor 17 and a source 18 of direct current. The conductors connecting said crystals pass through insulators 19 to 22, inclusive mounted in the cross-arm 11, the insulators 19 and 21 being of such construction (not specifically shown) as to present capacitances 23 and 24 between one side of each of said crystals and the cross-arm itself, the latter being grounded as shown. The crystals 15 and 16 are further connected to provide parallel outputs to ground through a capacitor 25 and the primary winding 26 of an output transformer 27 having a secondary winding 28.

The source 18 of direct current constitutes a bias for the purpose of enabling operation of the crystals at favorable points along their charac-

teristic curves, and the series circuit is for the purpose of passing equal currents through said crystals to assure their similar behavior even though both be mismatched to the wave guide assembly.

For an understanding of the operation of the device, assume that two input waves of different frequencies ω_h and ω'_h are both traveling down the branch arm 13 toward the common junction 12 with their electric vectors pointing in the same direction, arbitrarily, to the right. As these waves reach the junction 12, each splits into two constituent waves, the waves traveling along the cross-arm 11 toward the crystal 15 having their electric vectors pointing in the same direction, namely, downwardly; and the waves traveling along said cross-arm toward the crystal 16 having their electric vectors, likewise, pointing in the same direction, namely, upwardly. Thus, there arrives at the crystal 15, two similarly-phased constituent waves, and there arrives at the crystal 16, two also similarly-phased constituent waves, although it is to be noted that the two pairs of waves are oppositely phased. At the crystal 15, resultant waves, whose frequencies correspond to the sum of and difference between the frequencies of the initial waves, and whose phases may be considered positive because there component waves are in phase, are produced; and at the crystal 16, additional resultant waves, having the same frequencies as said first-named resultant waves, and having phases which may also be considered positive because their component waves are also in phase, are produced. However, as to each other, the resultant waves obtained, respectively, at the two crystals are 180° out of phase, and set up equal voltages of opposite polarities across said crystals. Inasmuch as parallel outputs are taken from these crystals, cancellation occurs and no output appears across the primary winding 26 of the transformer 27.

Now assume that the input to the branch 13 includes at least one of the waves ω_h, ω'_h, and further assume that the other of these waves, having its electric vector pointing, for example, upwardly at the junction 12, is applied to the branch arm 14. As before, the wave ω_h or ω'_h traveling along the branch arm 13 will split at the junction 12, the wave traveling along the cross-arm 11 toward the crystal 15 having its electric vector pointing downwardly, and the wave traveling along said cross-arm toward the crystal 16 having its electric vector pointing upwardly. When the wave traveling along the branch arm 14 reaches the junction 12, it, too, splits into two waves, one traveling along the cross-arm 11 toward the crystal 15 and one traveling along said cross-arm toward the crystal 16, with both having their electric vectors pointing in the same direction, namely, upwardly. Thus, there arrives at the crystal 15, two constituent waves which are out of phase, and there arrives at the crystal 16 two constituent waves which are in phase. Therefore, there are produced at the crystal 15, two resultant waves whose frequencies corresponds to the sum of and difference between the frequencies of the initial waves, and whose phases may be considered negative because their component waves are out of phase; while at the crystal 16, there are produced two resultant waves having the same frequencies as said first-named resultant waves, and having phases which may be considered positive because their component waves are in phase.

As to each other, the resultant waves obtained, respectively, at the two crystals are in phase, and set up equal voltages of like polarities across said crystals. Inasmuch as parallel outputs are taken from these crystals, addition occurs, and constant-amplitude, sum and difference output waves appear across the primary winding 26 of the transformer 27. Either of these waves may be finally selected by appropriately tuning the output circuit.

This completes the description of the aforesaid illustrative embodiment of the present invention. Objects and advantages thereof, in addition to those set forth in earlier portions of this specification, will readily occur to those skilled in the art to which the same relates.

What is claimed is:

1. Apparatus for mixing periodic waves having different frequencies comprising: a double T-shaped wave-guide assembly, having a cross-arm common to both T's and a pair of branch arms perpendicular to said cross-arm and to each other, receptive of said waves, for deriving from one, two constituent waves of opposite phase, and from another, two constituent waves of like phase; and means, receptive of all of said constituent waves, for deriving therefrom an output wave whose frequency is an arithmetic function of the frequencies of the initial waves.

2. Apparatus for mixing periodic waves having different frequencies comprising: means, receptive of said waves, for deriving from one, two constituent waves of opposite phase, and from another, two constituent waves of like phase; and means, including a pair of series-connected, nonlinear impedances and an inductive impedance in parallel therewith, receptive of all of said constituent waves, for deriving therefrom an output wave whose frequency is an arithmetic function of the frequencies of the initial waves.

3. Apparatus for mixing periodic waves having different frequencies comprising: a double T-shaped wave-guide assembly, having a cross-arm common to both T's and a pair of branch arms perpendicular to said cross-arm and to each other, receptive of said waves, for deriving from one, two constituent waves of opposite phase, and from another, two constituent waves of like phase; and means, including a pair of series-connected, nonlinear impedances and an inductive impedance in parallel therewith, receptive of all of said constituent waves, for deriving therefrom an output wave whose frequency is an arithmetic function of the frequencies of the initial waves.

4. Apparatus for mixing periodic waves having different frequencies comprising: a double T-shaped wave-guide assembly, having a cross-arm common to both T's and a pair of branch arms perpendicular to said cross-arm and to each other, receptive of said waves, for deriving from one, two constituent waves of opposite phase, and from another, two constituent waves of like phase; means, terminating said cross-arm, for combining said first-named constituent waves, respectively, with said second-named constituent waves to derive therefrom two resultant waves of opposite phase; and means for combining said resultant waves to derive therefrom an output wave whose frequency is an arithmetic function of the frequencies of the initial waves.

5. Apparatus for mixing periodic waves having different frequencies comprising: a double T-shaped wave-guide assembly, having a cross-arm common to both T's and a pair of branch arms perpendicular to said cross-arm and to each

other, receptive of said waves, for deriving from one, two constituent waves of opposite phase, and from another, two constituent waves of like phase; a pair of oppositely-disposed, series-connected, non-linear impedances terminating said cross-arm for combining said first-named constituent waves, respectively, with said second-named constituent waves to derive therefrom two resultant waves of opposite phase; and means for combining said resultant waves to derive therefrom an output wave whose frequency is an arithmetic function of the frequencies of the initial waves.

6. Apparatus for mixing periodic waves having different frequencies comprising: a double T-shaped wave-guide assembly, having a cross-arm common to both T's and a pair of branch arms perpendicular to said cross-arm and to each other, receptive of said waves, for deriving from one, two constituent waves of opposite phase, and from another, two constituent waves of like phase; a pair of oppositely-disposed, series-connected, non-linear impedances terminating said cross-arm for combining said first-named constituent waves, respectively, with said second-named constituent waves to derive therefrom two resultant waves of opposite phase; and an inductive impedance connected in parallel with said non-linear impedances for combining said resultant waves to derive therefrom an output wave whose frequency is an arithmetic function of the frequencies of the initial waves.

7. Apparatus for mixing periodic waves having different frequencies comprising: means, receptive of said waves, for dividing the same into two oppositely-phased pairs of similarly-phased constituent waves, and two additional pairs of constituent waves, the waves of one of said additional pairs being of like phase and the waves of the other additional pair being of opposite phase; means for combining the constituent waves of each of said first-named pairs to derive therefrom two resultant waves of like phase, and for combining the constituent waves of each of said second-named pairs to derive therefrom two resultant waves of opposite phase; and means for so combining said first-named resultant waves as to produce a zero output, and for so combining said second-named resultant waves as to produce an output wave whose frequency is an arithmetic function of the frequencies of the initial waves.

8. Apparatus for mixing periodic waves having different frequencies comprising: a double T-shaped wave-guide assembly, having a cross-arm common to both T's and a pair of branch arms perpendicular to said cross-arm and to each other, receptive of said waves, for dividing the same into two oppositely-phased pairs of similarly-phased constituent waves, and two additional pairs of constituent waves, the waves of one of said additional pairs being of like phase and the waves of the other additional pair being of opposite phase; means for combining the constituent waves of each of said first-named pairs to derive therefrom two resultant waves of like phase, and for combining the constituent waves of each of said second-named pairs to derive therefrom two resultant waves of opposite phase; and means for so combining said first-named resultant waves as to produce a zero output, and for so combining said second-named resultant waves as to produce an output wave whose frequency is an arithmetic function of the frequencies of the initial waves.

9. Apparatus for mixing periodic waves having

different frequencies comprising: a double T-shaped wave-guide assembly, having a cross-arm common to both T's and a pair of branch arms perpendicular to said cross-arm and to each other, receptive of said waves, for dividing the same into two oppositely-phased pairs of similarly-phased constituent waves, and two additional pairs of constituent waves, the waves of one of said additional pairs being of like phase and the waves of the other additional pair being of opposite phase; a pair of oppositely-disposed, series-connected, non-linear impedances terminating said cross-arm for combining the constituent waves of each of said first-named pairs to derive therefrom two resultant waves of like phase, and for combining the constituent waves of each of said second-named pairs to derive therefrom two resultant waves of opposite phase; and means for so combining said first-named resultant waves as to produce a zero output, and for so combining said second-named resultant waves as to produce an output wave whose frequency is an arithmetic function of the frequencies of the initial waves.

10. Apparatus for mixing periodic waves having different frequencies comprising: a double T-shaped wave-guide assembly, having a cross-arm common to both T's and a pair of branch arms perpendicular to said cross-arm and to each other, receptive of said waves, for dividing the same into two oppositely-phased pairs of similarly-phased constituent waves, and two additional pairs of constituent waves, the waves of one of said additional pairs being of like phase and the waves of the other additional pair being of opposite phase; a pair of oppositely-disposed, series-connected, non-linear impedances terminating said cross-arm for combining the constituent waves of each of said first-named pairs to derive therefrom two resultant waves of like phase, and for combining the constituent waves of each of said second-named pairs to derive therefrom two resultant waves of opposite phase; and an inductive impedance connected in parallel with said non-linear impedances for so combining said first-named resultant waves as to produce a zero output, and for so combining said second-named resultant waves as to produce an output wave whose frequency is an arithmetic function of the frequencies of the initial waves.

11. A wave-guide assembly comprising: a main wave-guide section having a non-linear impedance at each of the opposite ends thereof; and a pair of branch wave-guide sections, perpendicular to said main wave-guide section and to each other, extending outwardly from said main wave-guide section.

12. A wave-guide assembly comprising: a main wave-guide section having a non-linear impedance at each of the opposite ends thereof; one side of each of said impedances being capacitively coupled to said main wave-guide section; and a pair of branch wave-guide sections, perpendicular to said main wave-guide section and to each other, extending outwardly from said main wave-guide section.

13. A wave-guide assembly comprising: a main wave-guide section having a crystal detector at each of the opposite ends thereof; and a pair of branch wave-guide sections, perpendicular to said main wave-guide section and to each other, extending outwardly from said wave-guide section.

14. A wave-guide assembly comprising: a main wave-guide section having a crystal detector at each of the opposite ends thereof; one side of each

of said crystal detectors being capacitively coupled to said main wave-guide section; and a pair of branch wave-guide section and to each other, extending outwardly from said main wave-guide section.

15. A wave-guide assembly comprising: a main wave-guide section having a pair of oppositely-disposed, series-connected, non-linear impedances at the opposite ends thereof; and a pair of branch wave-guide sections, perpendicular to said main wave-guide section and to each other, extending outwardly from said main wave-guide section.

16. A wave-guide assembly comprising: a main wave-guide section having a pair of oppositely-disposed, series-connected, non-linear impedances at the opposite ends thereof; one side of each of said impedances being capacitively coupled to said main-wave guide section; and a pair of branch wave-guide sections, perpendicular to said main wave-guide section and to each other, extending outwardly from said main wave-guide section.

17. A wave-guide assembly comprising: a main wave-guide section having a pair of oppositely-disposed, series-connected, crystal detectors at

the opposite ends thereof; and a pair of branch wave-guide sections, perpendicular to said main wave-guide section and to each other, extending outwardly from said main wave-guide section.

18. A wave-guide assembly comprising: a main wave-guide section having a pair of oppositely-disposed, series-connected, crystal detectors at the opposite ends thereof; one side of each of said crystal detectors being capacitively coupled to said main wave-guide section, and a pair of branch wave-guide sections, perpendicular to said main wave-guide section and to each other, extending outwardly from said main wave-guide section.

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