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AUTOMATIC CIRCUIT-TUNING APPARATUS

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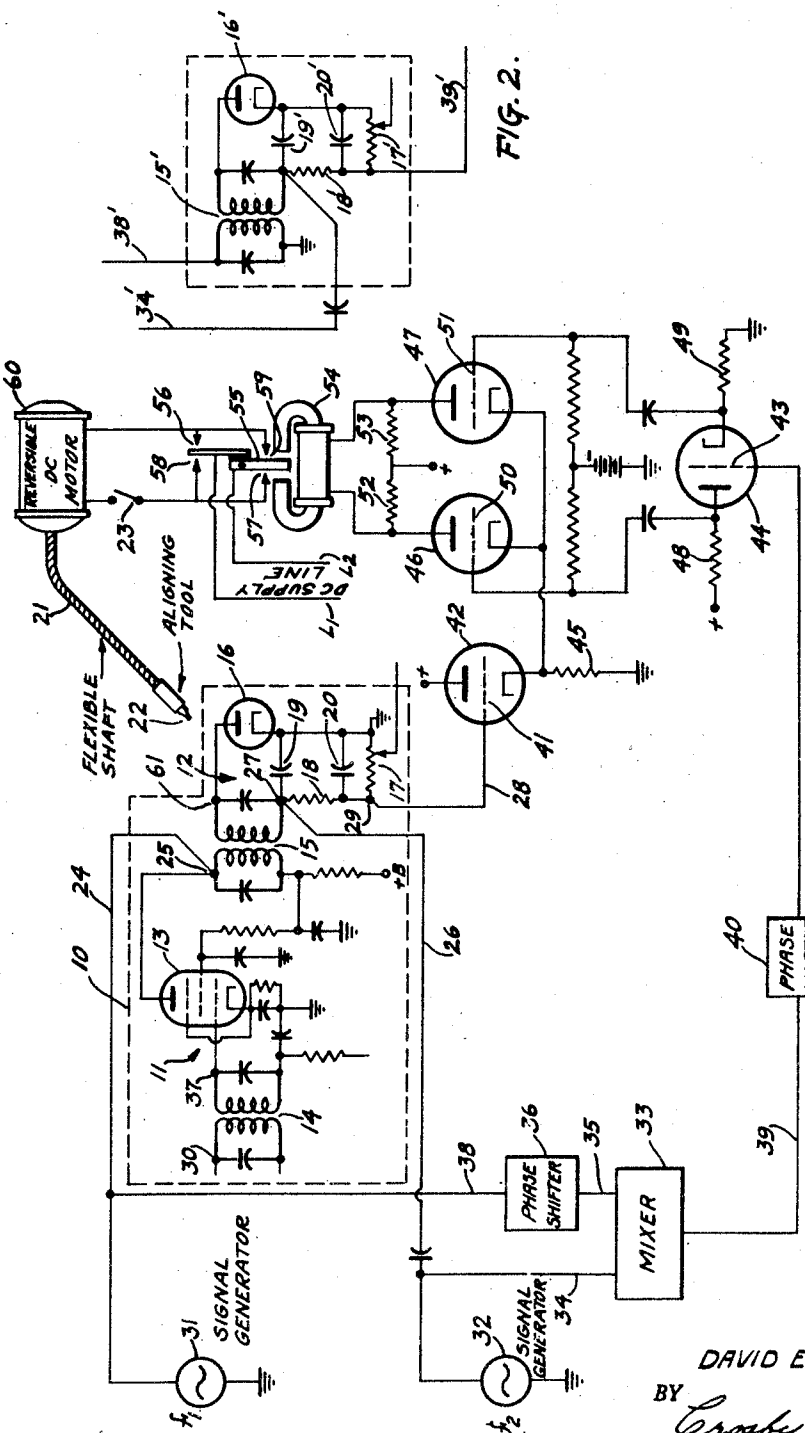


FIG. 2.

FIG. 1.

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AUTOMATIC CIRCUIT-TUNING APPARATUS

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This invention relates to the art of tuning resonant circuits to prescribed frequencies. It is particularly useful as an adjunct to factory production of radio and television receivers and the like, but is not limited to any such special purpose.

It is also related to the art of determining whether a transformer or other coupling network is in tune or off tune and, in the latter event, the direction in which it is off tune.

One of the routine operations in the manufacture of radio receivers, television receivers, tuned amplifiers, etc. consists in adjusting each of several resonant circuits to a prescribed frequency. This is commonly referred to as aligning the receiver or amplifier. For example, the primary and secondary windings of the intermediate frequency transformers of a superheterodyne receiver must each be tuned to the intermediate frequency; and the radio frequency transformers, when these are ganged, must likewise be adjusted so that they are all resonant to the same frequency when the variable tuning condensers are set at some predetermined point at the high frequency end of the reception band.

Heretofore, the stated operation has involved close attention and the exercise of a certain amount of skill and judgment on the part of the adjuster and has, largely for that reason, entailed the expenditure of an inordinate amount of time per unit. But what is even more important, the job is a tedious one when carried on as a production line operation, and, in consequence, it has been found that too often the work has not been accurately done.

One of the primary objects of the present invention is to ensure, as far as possible, against faulty performance in the carrying out of the above-described operation and, with that end in view, to eliminate the need for more than elementary skill.

Another important object is to decrease the man-hours per unit required to perform an aligning operation.

Still another object is to achieve even more accurate alignment of the tuned circuits than could generally be realized with the prior procedure even though the operator exercised all the skill and care that could be expected of him.

A further object is to provide means which will afford an instantaneous indication as to the fact that a transformer or other coupling network is off resonance with respect to a specified frequency and, at the same time, an indication as to the direction of its disparity from resonance.

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The alignment of a receiver or amplifier has heretofore been accomplished by manually adjusting, one at a time, the capacities of several padding condensers until, in each instance, a meter showed maximum response. This demanded close and continued attention and, after many consecutive repetitions, caused the adjuster considerable nervous strain which was apt to be reflected in either poor workmanship or a substantial reduction of output, or both.

The present invention provides equipment which reduces the alignment of a receiver or amplifier to almost a purely manual operation by relieving the adjuster of the necessity of watching a meter and of exercising skill and judgment in determining when the adjustment is optimum.

A characteristic feature of this invention is that use is made of the phase-shifting properties of the transformer or other coupling network under tuning adjustment. For example, if a simple high Q, loosely coupled transformer is precisely tuned to the frequency of the voltage impressed upon its primary, the secondary voltage will be substantially 90° out of phase with the primary voltage; but if the transformer is not so tuned the phase shift will be something more or less than 90°. The invention makes use of this phase varying phenomenon to produce two signal waves which have a given mutual phase relation when the transformer or other coupling network is properly tuned, but which acquire a different mutual phase relation when said transformer or network is off tune. According to one preferred embodiment, the invention makes use of the aforementioned phenomenon to produce a phase difference between two beat waves of common origin as a result of the transformer or other network under adjustment being out of tune and to cause said beat waves to be brought into phase as a result of said network having been correctly adjusted. The equipment employed includes means responsive to the two beat waves jointly to cause energization of a reversible motor which drives a tool used to adjust a tuning element (e. g. a padding condenser). If the network under tuning adjustment is out of tune in one direction said motor is caused to rotate its shaft in the direction which is appropriate to correct the misadjustment, and if the tuning is off in the other direction, the motor shaft is caused to rotate oppositely, which, likewise, is appropriate to effect the desired correction. All the operator is required to do is to make certain simple electrical connections to the receiver or amplifier under adjustment and apply the motor driven tool to

the adjustable tuning element and turn on the motor current. The motor will then run in the proper direction until the coupling network is brought into tune and will then stop. This procedure is repeated for each tuned circuit until the receiver or amplifier, as the case may be, is completely aligned.

Alternatively, the invention herein described can be utilized simply to inform the operator as to the facts that a transformer or other coupling network is off tune, and of the direction in which it is off tune.

In the drawing:

Fig. 1 is a schematic diagram of a complete system according to a preferred embodiment of the invention;

Fig. 2 is a schematic diagram illustrating how a portion of a receiver can be utilized as a phase shifter, whereby to establish substantially complete identity between two parallel branches of an electrical network forming a part of the system as a whole.

Within the area enclosed by the dash-line 10 there is illustrated a portion of a superheterodyne radio receiver including an intermediate frequency amplifier 11 and a second detector 12. Said amplifier comprises a pentode 13 having an input transformer 14 and output transformer 15. The primary and secondary of each of those transformers is to be tuned to the intermediate center frequency, and the tuning must, of course, be broad enough to pass without excessive attenuation the prescribed intermediate frequency band—which generally takes in about 5 kc. on either side of the center frequency. Each winding of each transformer is shunted by a tuning condenser, and it is to be understood that each tuning condenser may be supplemented by a padding condenser, not shown, which is adjustable by means of a screw driver or similar tool. Alternatively, the intermediate frequency transformer windings may be tunable by adjusting their inductances, as in the case of powdered iron core transformers. In either case the tuning adjustment is accomplished by turning a screw or in some analogous manner which is adaptable to the present invention.

Second detector 12 comprises a diode 16 connected across the secondary terminals of transformer 15 in series with a load resistor 17 and filter resistor 18, which is shunted by by-pass condensers 19 and 20, the latter of which is directly in shunt to load resistor 17.

The principal function of the invention is to effect tuning, one at a time, of the primaries and secondaries of transformers 14 and 15, and such additional intermediate frequency transformers as the receiver includes; and also, if desired, to tune each of the radio frequency amplifier transformers by adjusting, in each case, a padding condenser or some analogous tuning element. At 60 there is indicated a direct current electric motor which is reversible in response to reversal of the voltage applied to its armature or field from the direct current line L_1L_2 by way of the reversing relay 54 referred to hereinafter. The motor 60 is shown provided with a flexible shaft 21 at the end of which is a screw driver or similar attachment 22, designed to engage, one at a time, the padding condenser adjusting screws, or such other adjustable tuning elements as may be employed. When the equipment of this invention is suitably connected to the receiver under adjustment, all the adjuster has to do is apply tool 22 to one of the padder adjusting screws and

turn on the current, as for instance, by closing switch 23. The screw driver or other tool is then automatically rotated in the appropriate direction until the adjustment is accomplished—whereupon the motor stops. The first step in the operation consists in tuning the secondary of the last transformer in the series, which in this case is the secondary of transformer 15. Thereafter, the primary of transformer 15 is tuned and then, in turn, the secondary and primary of transformer 14, and so on toward the input end of the receiver or amplifier as the case may be. Thus, as the adjuster moves forward, step by step, all transformers to the rear have previously been adjusted and each is, therefore, operative to produce a phase shift of predetermined value between its primary and secondary terminal voltages—which, as will later be seen, is an indispensable aspect of the invention.

The equipment is shown set up for tuning the secondary of transformer 15 to the intermediate frequency. This involves connecting a lead 24 to terminal 25, a second lead 26 to terminal 27, and a third lead 28 to terminal 29. Preferably, these are quick detachable connections which may conveniently be effected by means of connector clips. As the operation progresses from winding to winding and transformer to transformer, leads 26 and 28 remain connected as shown, but lead 24 is transferred from terminal to terminal. Thus, for adjusting the primary of transformer 15, lead 24 is detached from terminal 25 and attached to terminal 37 of transformer 14. Thereafter, for adjusting the secondary of transformer 14, lead 24 is connected to terminal 30, and so on until the entire alignment operation is completed. There may, of course, be one or more additional stages of intermediate frequency amplification, and there may be one or several stages of radio frequency amplification preceding the intermediate frequency amplifier; but the procedure remains generally the same. The remaining elements shown within area 10 are conventional receiver parts which require no description and, accordingly, are not identified by reference numerals.

At 31 and 32 are indicated, symbolically, two continuous wave sources. These may be crystal-controlled vacuum tube oscillators. For aligning the intermediate frequency amplifier the output frequency of source 31 must be equal or substantially equal to the intermediate frequency—assuming that all stages are to be tuned to the same frequency. The output frequency of source 32 differs from that of source 31 by an amount corresponding to some convenient difference frequency. This is usually but not necessarily a relatively low audio frequency. For broadcast receivers the intermediate frequency is, commonly, 455 kc. For aligning radio frequency stages of a broadcast receiver the output frequency of source 31 would usually be of the order of 1400 kc. In either case the difference frequency preferably is rather low, which means that the output frequency of source 32 is close to that of source 31.

It will be observed that there are impressed upon second detector 12 a signal from source 31 via transformer 15 and conductor 24, and a signal from source 32 via conductor 26. Detector 12 functions as a mixer and in consequence a difference frequency beat voltage is developed across load resistor 17. The higher frequency components are by-passed by filter condensers 19 and 20.

Another mixer 33 is connected to source 32 via conductor 34, and to source 31 via conductor 35, phase shifter 36 and conductor 38.

If the secondary of transformer 15 is precisely tuned to the intermediate frequency that transformer will produce a given voltage phase shift; and if phase shifter 36 also produces the same amount of phase shift, the difference frequency beat voltage across load resistor 17 will be precisely in phase with the difference frequency output voltage of mixer 33. But if the secondary of transformer 15 is not precisely tuned to the intermediate frequency, the phase shift produced by that transformer will be something other than the aforementioned given amount, and there will result a phase difference between the difference frequency beat voltage across load resistor 17 and the difference frequency beat voltage output of mixer 33. If the tuning of the secondary of transformer 15 is off resonance in one direction with respect to the intermediate frequency, the difference frequency voltage developed across resistor 17 will lead the corresponding output voltage of mixer 33; but if the tuning of said secondary is off resonance in the opposite direction the difference frequency voltage developed across resistor 17 will lag the corresponding output voltage of mixer 33. It is this characteristic upon which the operativeness of the described embodiment of the present invention depends and which determines the direction of rotation of the shaft of motor 60. The extent of lead or lag will be proportional to the disparity between the frequency of source 31 and the frequency to which said secondary is actually resonant.

The output of mixer 33 is passed via conductor 39 through a 90° phase shifter 40 and, as a result, the beat frequency voltage impressed on grid 43 of triode 44 is in 90° phase quadrature to the beat frequency voltage impressed on grid 41 of triode 42—provided the secondary of transformer 15 is precisely tuned to the intermediate frequency. But if said secondary is not resonant to the intermediate frequency there will result something other than a 90° phase difference between said grid voltages.

Triode 42 is an impedance transforming tube having a cathode load resistor 45. Triode 44 is an input tube for the push-pull phase detector comprising triodes 46 and 47. Triode 44 is provided with a plate load resistor 48 and a cathode load resistor 49. Grids 50 and 51 of triodes 46 and 47 are connected respectively to the plate and cathode of triode 44. In place of the latter there can be substituted a push-pull input transformer, and a similar substitution could be made in place of triode 42. The cathodes of triodes 46 and 47 are connected in parallel to the cathode of triode 42 and have impressed upon them a low frequency voltage corresponding in frequency and phase to the beat voltage developed across load resistor 17.

Phase detectors similar to that illustrated are well known in the art and it need only be stated that with triodes 46 and 47 biased to operate class B or, at any rate, other than class A, a 90° phase difference between the voltages impressed on grids 41 and 43 will not produce any D. C. component of voltage across the terminals of combined plate load resistors 52 and 53. But any phase difference other than 90° between the signal voltages on grids 41 and 43 will give rise to a D. C. component of voltage across said combined plate load resistors, the polarity of which voltage is dependent upon whether the

signal voltage on grid 41 is displaced from the signal voltage on grid 43 by more or less than 90°. Thus if the secondary of transformer 15 is off resonance in one direction the resultant D. C. potential component developed across combined load resistors 52 and 53 will have a certain polarity whereas if said secondary is off resonance in the other direction the opposite polarity will obtain as respects said resultant D. C. potential component.

Phase detectors functioning according to the same principle as that illustrated, but employing diodes instead of triodes are well known to the art and could be substituted in place of the phase detector here shown. It is, however, preferable to employ triodes rather than diodes because of the voltage gain which can be realized.

A balanced polarized relay 54 has its winding connected across combined load resistors 52, 53 and is operative to actuate its armature 55 in opposite directions from center depending upon the polarity of the D. C. voltage impressed upon its winding; but it will not respond to the A. C. voltage across said load resistors. When said relay is actuated in one direction it will close contacts 56 and 57, thus completing a circuit between motor 60 and supply lines L_1, L_2 to cause the motor shaft to rotate in one direction. When armature 55 is actuated to close contacts 58 and 59 the current flow through motor 60 is reversed and its shaft will rotate in the opposite direction.

When the adjustment of the secondary of transformer 15 is completed the motor stops and the operator transiers the connection of lead 24 from terminal 25 to terminal 29 and then proceeds to tune the primary of transformer 15. This, however, involves an additional phase shift of approximately 180° produced by pentode 13 and necessitates a commensurate change in the phase shift effected by shifter 36. For this purpose phase shifter 36 is preferably made adjustable to predetermined fixed values.

When the adjustment of the primary of transformer 15 has been completed lead 24 is transferred to terminal 30 for the purpose of adjusting the secondary of transformer 14. Transformer 14 introduces a further phase shift of approximately 90° for which compensation has to be made in order to realize the desired phase relationship between grids 41 and 43. This can be done by again adjusting phase shifter 36 to the appropriate predetermined value.

In the system illustrated it will be apparent that the phase shift produced by shifter 36 is a counterpart of the phase shift produced by the transformer or transformers of the receiver undergoing alignment when the latter are tuned to the frequency of source 31 and that mixer 33 is likewise a counterpart of the mixer comprising second detector 12. Consequently, as shown in Fig. 2, phase shifter 36 and mixer 33 may consist of elements of a properly tuned radio receiver otherwise identical with that undergoing alignment, as indicated within the area 10. In Fig. 2 I have shown the necessary elements including a transformer 15', diode 16' etc. The primed reference notations on Fig. 2 conform numerically to corresponding notations on Fig. 1.

Since the direction of rotation of the shaft of motor 60 is determined by the direction in which the contemporaneous resonant frequency of transformer 15 differs from that of source 31; it will be apparent that the system described could be utilized merely to indicate that the

transformer is not in tune and the direction in which it is off tune. In employing the system only for the latter purpose the motor 60 may be omitted and the polarized relay 54 employed simply as an indicator.

What is claimed is:

1. A system of the class described comprising a first wave source having a prescribed output frequency, a mixer, a coupling network interposed between said first source and said mixer, a second wave source having an output frequency different from the aforesaid prescribed frequency by an amount equal to a desired difference frequency, said mixer being connected to said second wave source independently of said coupling network, another mixer connected to both said wave sources, means interposed between said last mentioned mixer and at least one of said wave sources for producing a phase shift, each of said mixers being operative to combine waves from both said sources to produce a beat wave of said difference frequency, the arrangement above defined being such that when said coupling network is tuned to the frequency of said first source the beat wave outputs of said mixers are mutually in phase, but when said network is not tuned to the frequency of said first source said beat waves are mutually out of phase, additional phase shifting means for shifting at least one of said beat waves, the effect of which is to bring into being two coexisting beat voltages of identical frequency which are mutually phase displaced by 90° when said network is tuned to the frequency of said first source, but are mutually phase displaced by an amount more or less than 90° when said network is not tuned to the frequency of said source, phase detection means operative in response to said last mentioned beat voltages, jointly, to produce a D. C. potential only when said voltages are otherwise than 90° phase displaced, said phase detector being characterised in that the polarity of the aforesaid D. C. potential is determined by the direction in which said network is off tune, and means responsive to said D. C. potential for indicating the polarity thereof.

2. A system of the class described comprising: a first wave source having a prescribed output frequency, a mixer, a coupling network interposed between said first source and said mixer, a second wave source having an output frequency different from the aforesaid prescribed frequency by an amount equal to a desired difference frequency, said mixer being connected to said second wave source independently of said network, another mixer connected to both said wave sources, means interposed between said last mentioned mixer and at least one of said wave sources for producing a phase shift, each of said mixers being operative to combine waves from both said sources to produce a beat wave of said difference frequency, the arrangement above defined being such that when said network is tuned to the frequency of said first source the beat wave outputs of said mixers are mutually in phase, but, when said network is not tuned to the frequency of said first source, said beat waves are mutually out of phase, additional phase shifting means for shifting at least one of said beat waves, the effect of which is to bring into being two coexisting beat voltages of identical frequency which are mutually phase displaced by 90° when said network is tuned to the frequency of said first source, but are mutually phase displaced by an amount more or less than 90° when said network is not tuned to the frequency of said first source, phase

detection means comprising a pair of rectifiers arranged in push-pull relation with reference to one of said last mentioned beat waves and in parallel relation with reference to the other of said last mentioned beat waves, a pair of load impedances connected in series and individual to said rectifiers, and means responsive to D. C. potential components developed across the combined series-connected load impedances for indicating the polarities of said D. C. potential components.

3. A system for tuning to a prescribed frequency a resonant coupling network having a variable reactance, said reactance having mechanically adjustable means for varying the resonant frequency of said network, said system including a first wave source of said prescribed frequency and a second wave source having an output frequency different from the aforesaid prescribed frequency by an amount equal to a desired difference frequency, a mixer, said first source being coupled to said mixer through said network, said second source being connected to said mixer independently of said network, said mixer being operative to combine waves from both said sources to produce a first beat wave the frequency of which is equal to said difference frequency, another mixer connected to both said sources, a phase shifter interposed between said last-mentioned mixer and one of said sources, said second mixer being operative to combine waves from both said sources to produce a second beat wave of said difference frequency, a power-operated device having a moving element engageable with said adjustable means to tune said network, said device being directionally reversible in operation, and means for initiating actuation of said device in response to a phase difference between said beat waves, said means being operative to control the direction of operation of said device in conformity with the direction in which said network is out of tune whereby to correct the tuning error.

4. A system for tuning to a prescribed frequency a coupling network having an adjustable tuning element, said system including a first wave source of said prescribed frequency and a second wave source having an output frequency different from the aforesaid prescribed frequency by an amount equal to a desired difference frequency, a mixer, said first source being coupled to said mixer through a path including said network, said second source being coupled to said mixer independently of said network, said mixer being operative to combine waves from both said sources to produce a first beat wave the frequency of which is equal to said difference frequency, another mixer connected to both said sources and operative to combine wave energy therefrom to produce a second beat wave of said difference frequency, phase shifting means operative to cause said two beat waves to be mutually phase displaced by 90° when said network is tuned to said prescribed frequency, there being a phase difference other than 90° between said beat waves when said network is off tune, means for indicating phase displacement, and phase detecting means operative to actuate said indicating means to indicate the direction of the deviation from 90° of the phase difference between said beat waves.

5. A system for tuning to a prescribed frequency a coupling network having an adjustable tuning element, said system including a first wave source of said prescribed frequency and a second

wave source having an output frequency different from the aforesaid prescribed frequency by an amount equal to a desired different frequency, a mixer, said first source being coupled to said mixer through a path including said network, said second source being coupled to said mixer through a path exclusive of said network, said mixer being operative to combine waves from both said sources to produce a first beat wave the frequency of which is equal to said different frequency, another mixer, a path connecting said last mentioned mixer to said first source, a path connecting said last mentioned mixer to said second source, said second mixer being operative to combine waves from both said sources to produce a second beat wave the frequency of which is equal to said difference frequency, phase shifting means included in one of said paths and operative to cause said beat waves to be in phase when said network is tuned to said prescribed frequency, means for indicating the direction of any phase difference between said beat waves, and phase detection means responsive to said beat waves jointly, said phase detection means being operative to actuate said indicating means in conformity with the direction of any phase difference which may obtain between said beat waves.

6. A system for tuning to a prescribed frequency a coupling network having an adjustable tuning element, said system including a first wave source of said prescribed frequency and a second wave source having an output frequency different from the aforesaid prescribed frequency by an amount equal to a desired difference frequency, a mixer, said first source being coupled to said mixer through said network, said second source being coupled to said mixer independently of said network, said mixer being operative to combine wave energy from both said sources to produce a first beat wave the frequency of which is equal to said difference frequency, another mixer coupled to both said sources independently of said network and operative to combine wave energy therefrom to produce a second beat wave the frequency of which is equal to said difference frequency, a phase detector, phase shifting means interposed between said phase detector and the output side of at least one of said mixers, and means for indicating the direction in which said network is off tune, said phase detector being operative in response to mutual phase differences between said beat waves to actuate said indicating means in accordance with the direction in which said network is off tune.

7. A system for tuning to a prescribed frequency a resonant transformer having a variable reactance, said reactance having mechanically adjustable means for varying the resonant frequency of said transformer, said system including a first wave source of said prescribed frequency and a second wave source having an output frequency different from the aforesaid prescribed frequency by an amount equal to a desired difference frequency, a mixer, said first source being coupled to said mixer through said transformer, said second source being connected to said mixer independently of said transformer, said mixer being operative to combine waves from both said sources to produce a first beat wave the frequency of which is equal to said difference frequency, another mixer connected to both said sources, a phase shifter interposed between said last mentioned mixer and one only of said sources, said second mixer being operative

to combine waves from both said sources to produce a second beat wave of said difference frequency, an electric motor having a rotating element engageable with said adjustable means, said motor being directionally reversible, and means for energizing said motor in response to a phase difference between said beat waves, said means being operative to control the direction of operation of said motor in accordance with which one of said beat waves leads the other in phase.

8. The method of determining the direction in which a coupling transformer is off tune with respect to a prescribed frequency, which method comprises: generating a first wave of said prescribed frequency, generating a second wave having a frequency different than said prescribed frequency, utilizing said transformer to phase-shift a portion of said first wave, mixing a portion of said second wave with the phase-shifted aforementioned portion of said first wave to produce a first beat frequency signal, phase-shifting an additional portion of one of said waves by utilizing phase-shifting means other than said transformer, mixing the phase-shifted additional wave portion with an additional portion of the other wave to produce a second beat frequency signal, and phase detecting said beat frequency signals, conjointly, to produce a D. C. potential the polarity of which is indicative of the direction in which said transformer is off tune.

9. The method of determining the direction in which a coupling network is off tune with respect to a prescribed frequency, which method comprises: generating a first wave of said prescribed frequency, generating a second wave having a frequency different than said prescribed frequency, utilizing said network to phase-shift a portion of said first wave, mixing a portion of said second wave with the phase-shifted aforementioned portion of said first wave to produce a first beat frequency signal, phase-shifting an additional portion of one of said waves by utilizing phase-shifting means other than said network, mixing the phase-shifted additional wave portion with an additional portion of the other wave to produce a second beat frequency signal, phase-shifting by 90° one only of said beat frequency signals, and phase detecting the phase-shifted beat frequency signal together with the non-shifted beat frequency signal to produce a D. C. potential the polarity of which is indicative of the direction in which said network is off tune.

10. The method of tuning a coupling network having a variable tuning element and means for physically adjusting said element, which method comprises: applying to said adjusting means an adjusting tool which is connected to a reversible electrically controlled motor, generating a first wave having a prescribed frequency to which said network is to be tuned, generating a second wave having a frequency different than said prescribed frequency, utilizing said network to phase-shift a portion of said first wave, mixing a portion of said second wave with the phase-shifted aforementioned portion of said first wave to produce a first beat frequency signal, phase-shifting an additional portion of one of said waves by utilizing phase-shifting means other than said network, mixing the phase-shifted additional wave portion with an additional portion of the other wave to produce a second beat frequency signal, phase shifting by 90° one only of said beat frequency signals, phase detecting the phase shifted beat frequency signal together with the non-shifted beat frequency signal to produce

a D. C. potential the polarity of which is indicative of the direction in which said network is off tune, and, utilizing said D. C. potential to control the actuation and direction of operation of said motor, whereby to cause said tool to be driven in the direction appropriate to bring said network into tune.

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