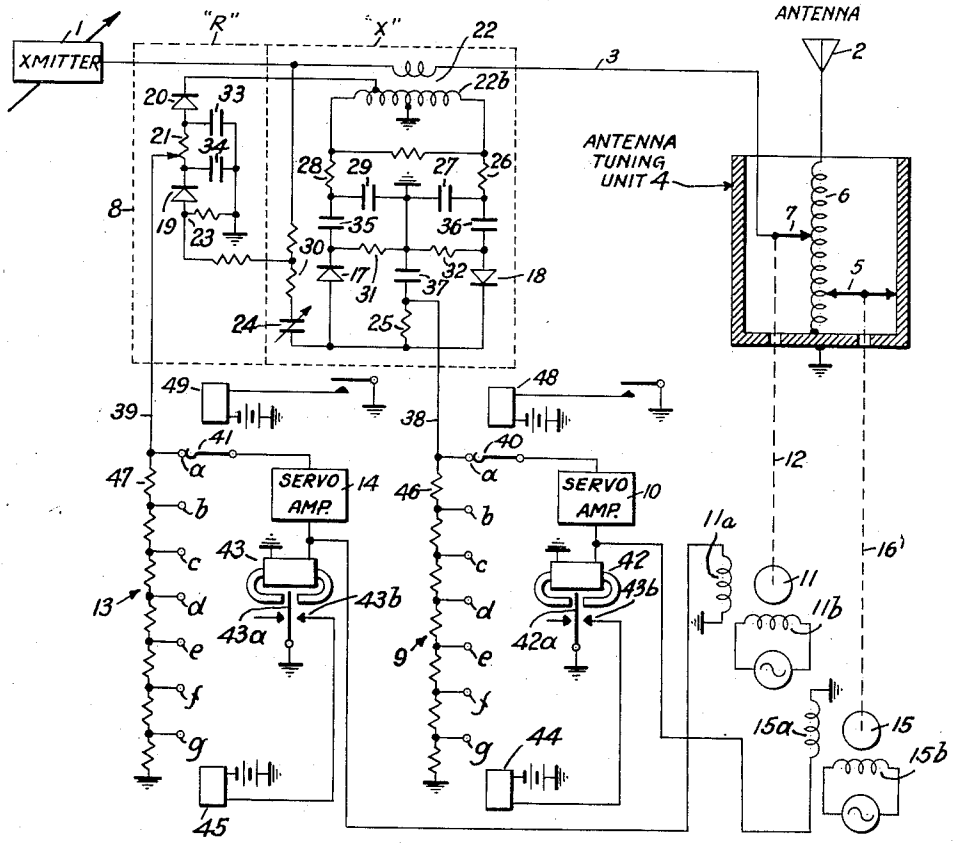
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AUTOMATIC TUNING SYSTEM

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AUTOMATIC TUNING SYSTEM

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This invention relates to automatic control circuits, and more particularly to an automatic antenna tuning control system.

In order to obtain optimum radiated power and transmitter performance from a communication system, it is essential that the antenna impedance be matched to the transmitter output. It is, of course, well known that over a predetermined range of frequencies any given antenna presents a variety of impedances which can be expressed in terms of a reactance and a resistance component at any specified frequency. In order to tune the antenna and match the input feedline to the antenna a sensing circuit is required which measures the input impedance over a wide frequency range. The information received from such a measurement is utilized to control one or more adjustment mechanisms through well-known servo mechanism principles. The antenna tuning equipment adjusts a matching section between the transmitter and the antenna at any selected frequency within the transmitter range to provide a satisfactory impedance match and such automatic adjustment of the matching section can be obtained through the use of a servo loop.

In any automatic control circuit it is desirable to have a rapid response. In order to achieve a rapid response a high initial gain is required in the servo loop. However a high gain in the servo loop tends to cause the servo motor to overshoot the desired position and hunting results. Many prior art systems have been developed to overcome this problem but most of the prior art systems decreased the initial gain of the servo loop.

One of the objects of this invention, therefore, is to provide an antenna tuning system automatically controlled in response to a servo loop having a high initial gain and which rapidly reaches a steady state condition.

Another object of this invention is to provide an automatic antenna tuning system which rapidly adjusts a matching section between a transmitter and antenna to provide a satisfactory impedance match.

Still another object of this invention is to provide an automatic control circuit which rapidly positions a mechanism to a predetermined point without an excess of hunting.

A further object of this invention is to provide an automatic antenna tuning unit which rapidly positions its input coupling means and its antenna resonating means to positions providing a satisfactory impedance match over a wide range of frequencies in a minimum period of time.

One of the features of this invention is the use of an antenna tuning system having a matching section in which a helical center conductor transmission line of variable length has its length varied to provide a zero reactance or, in other words, to provide an antenna at a quarter wavelength or odd multiple thereof at the operating frequency. Adjustable input coupling means are provided which can be adjusted to a point of coupling to maintain a given impedance level. A sensing circuit provides an error signal to a servo mechanism control circuit

dependent upon the match or mismatch of the antenna tuning means. This signal is amplified and drives each of the respective adjustable mechanisms in the antenna tuning unit. In order to provide an extremely rapid response of the automatic control unit the servo loop has a high initial gain which is successively decreased each time the servo motor changes its direction by the addition of resistances in series with the servo amplifier, thus reducing the amount of oscillations, reducing hunting and still providing a high initial torque to the servo motors.

The above-mentioned and other features and objects of this invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawings, in which:

The figure of the drawing is a schematic circuit diagram partly in block form of one embodiment of an automatic control circuit in accordance with the principles of our invention.

Referring to the drawing, it is seen that a transmitter **1** is coupled to an antenna **2** by a transmission line **3** through an antenna tuning unit or matching section **4**. As the frequency of the output of the transmitter **1** is varied, the sliding short circuit **5** is varied along the length of the helical center conductor **6** to resonate the antenna by making the equivalent electrical length equal to a quarter wavelength or odd multiple thereof, providing a zero reactance. An adjustable input coupling **7** is utilized to adjust the point of coupling maintaining a given resistance level input for a zero reactance component of input impedance. Any mismatch in the input to the antenna **2** is detected by a sensing circuit **8** which develops two error voltages, one to control the adjustable input coupling **7** and the other to adjust the sliding short **5**. The first error voltage is coupled through a gain control mechanism **9** to a servo amplifier **10** whose output controls a servo motor **15** which is mechanically geared through train **16** to the sliding short **5**. The other output of the sensing circuit **8** is coupled to gain control mechanism **13** and then to the servo amplifier **14** whose output controls the servo motor **11**. The servo motor **11** is mechanically geared through train **12** to adjust the input coupling **7**.

In order to develop the control voltages for the servo motors **11** and **15**, the sensing circuit **8** is provided. The most sensitive type of circuit for measuring small deviations or differences from a predetermined or desired value is, in general, a bridge. When used in the measurement of radio frequency it is most convenient to use the output of an R.-F. detector as an indication of the unbalance. Since such an indication would not give direction of unbalance, it becomes necessary to use two bridges in conjunction with each other so that when each bridge is unbalanced in opposite directions by the same amount the outputs of the two detectors remain balanced. Deviations from the predetermined or desired value then increase the output of one detector as the output of the other detector decreases and the resultant indicates a direction of deviation, as well as a deviation in amplitude.

The sensing circuit **8** comprises two portions, an "R" or resistance level sensing circuit and an "X" or reactance sensing circuit. The "R" sensing circuit consists essentially of a double detector bridge circuit in which the outputs are balanced providing a simple comparison of two in-phase voltages; one taken from a voltage divider and the other, twice the amplitude of the first, taken from the secondary of a current transformer are compared.

The "X" sensing circuit or bridges comprises a plurality of phase shifting combinations, one of which acts as a common side to two phase detecting bridges. The common portion or common phase shifting network comprises capacitor **24** in series with the resistor **25**. This

common side forms one bridge with resistor 26 and condenser 27 and the common side forms a second bridge with resistor 28 and condenser 29. The variation of each of the two phase detecting bridges from a balanced condition is indicated by the outputs of the detectors 17 and 18. The voltage for the common side of each phase detecting bridge is taken from the voltage divider formed by resistances 30 and 25 across the line. The other two voltages opposite in phase are taken from the center tap secondary 22*b* of the current transformer 22. The circuit components are so selected that all voltages are made equal in magnitude at the center frequency of the transmitter's operating range. When the load, in this case the antenna, has an inductive reactance the line or load current will lag the voltage, but at balance the two are in phase. The sensitivity of the double bridge sensing circuit varies with frequency or, in other words, the difference between the outputs of detectors 17 and 18 is not constant for a given phase difference at any frequency. A single current transformer 22 is used for both the "R" and "X" bridges, and detectors 17 and 18 of the "X" sensing circuit are biased to a predetermined resistive impedance by inserting resistors 31 and 32 in the direct current path. A resistor 21 is inserted between the detectors 19 and 20 in the "R" bridge to equalize the detector impedance. In the "R" bridge R.-F. bypass and D.-C. blocking capacitors 33 and 34 are utilized, whereas D.-C. and R.-F. bypass condensers 35, 36 and 37 are utilized in the "X" sensing bridge circuit. The values of the resistors and condensers forming the phase shifting networks across the current transformer 22 in the sensing circuit 8 should be as low as possible to prevent the detectors 17 and 18 from loading these circuits. In the "R" bridge the voltage tap point from the secondary winding 22*b* of current transformer 22 is selected so that the voltage at that point is equal to the voltage at point 23 when the phase angle is not considered. The independence of the series reactance is lost and the dependence upon the "X" bridges is introduced which is not disadvantageous as long as the "X" and "R" circuits are used together.

Referring to the servo loop circuit comprising the gain adjustment devices 9 and 13, servo amplifiers 10 and 14 and servomotors 11 and 15, it is seen that the "X" and "R" error voltages are coupled over lines 38 and 39, respectively, to the gain adjustment devices 9 and 13. The gain adjusted error signals are then coupled to servo amplifiers 10 and 14 whose output is coupled to one field winding of servomotors 11 and 15. The mechanical output of servomotors 11 and 15 are utilized to move the input coupling and tuning portions 7 and 5 of the antenna tuning unit 4.

Initially, the contact arms 40 and 41 of the gain adjustment devices 9 and 13 are coupled to the contacts "A" and thus no resistance elements are connected in series between the output of the error sensing circuit and the input to the servo amplifiers 10 and 14. As a result, a maximum initial gain is derived in the servo loop circuits and the output of the servo amplifiers 10 and 14 coupled to the field windings 15*a* and 11*a* is at a maximum causing a high initial torque in motors 15 and 11 and a very rapid adjustment of mechanisms 5 and 7. As is quite natural in servo loops, the mechanisms 5 and 7 will "overshoot" causing a reversal in the polarity of the error signal which is coupled to the field windings 11*a* and 15*a* after amplification, to result in a reversal of rotation of motors 11 and 15. This reversal in direction in the output of servo amplifiers 10 and 14 is detected by the polarity switches 42 and 43, causing the armatures 42*a* and 43*a* to make contact with contacts 42*b* and 43*b*, and a pulse of current is coupled to the relays 44 and 45. The pulses in relays 44 and 45 cause the armatures 40 and 41 of the stepping switches or gain adjustment devices 9 and 13 to make contact with terminals B, causing one of the resistance elements 46 and 47, respectively, to be coupled in series between the output of the sensing circuits 8 and the servo amplifiers 10 and 14. The introduction of the resistance elements 46 and 47 in the servo loop reduces the gain of the servo loop causing the output of servo amplifiers 10 and 14 coupled to field windings 15*a* and 11*a* to result in a lowering of the torque output of motors 11 and 15 coupled to mechanisms 5 and 7. The stepping switches 9 and 13 continue to advance from the initial position to the succeeding positions where additional resistance elements are introduced into the circuit of the servo amplifiers 10 and 14 via wipers 40 and 41. The additional resistance in each servo loop reduces the gain of the amplifiers which in turn decreases the magnitude of power applied to the motors 11 and 15, with a corresponding decrease in speed. For each reversal of polarity the polar relays 42 and 43 respond causing the stepping switches 9 and 13 to advance from one terminal to another thus successively introducing additional resistance elements into the servo loop circuit. The introduction of additional resistance elements reduces the gain of the servo loop from an initial value which is usually excessive and hence unstable to the maximum value consistent with servo loop stability. This adjustment of loop gain results in maximum speed of response. Thus a high initial gain alignment is quickly reached while oscillations or hunting is reduced by attenuation of the gain. In addition to the normal decrease in the magnitude of the error signal, the reduction in the gain of the servo signal causes the mechanisms 5 and 7 to come to rest much sooner with a decrease in hunting and an increase in the rapidity of time of adjustment. After a number of error signal polarity reversals, switches 48 and 49 are normally depressed to cause a resetting to occur in the stepping switches 9 and 13, and the contacts 40 and 41 are again connected to terminal A, thus restoring the original sensitivity to the servo loop preparing it for its next automatic operation.

While we have described above the principles of our invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of our invention as set forth in the objects thereof and in the accompanying claims.

We claim:

1. In a circuit for automatically controlling the position of a radio frequency circuit tuning device responsive to a control signal, means to produce said control signal including a network of bridge circuits coupled to said radio-frequency circuit by means of a voltage divider circuit and a current transformer, said control signal having a magnitude and polarity responsive to the impedance components of said radio frequency circuit as sensed from the voltage developed across said voltage divider circuit and current induced in said current transformer, means to detect successive changes in the polarity of said control signal, means to couple said control signal to said device to adjust the position thereof including amplifier means and stepping means, said control signal being coupled to said amplifier means through said stepping means, said stepping means being responsive to successive changes in the polarity of said control signal to reduce to ineffectivity in successive steps the magnitude of said control signal thus terminating the amplified control signal.

2. In a circuit for automatically controlling the position of a radio frequency circuit tuning device responsive to a control signal, means to produce said control signal including a network of bridge circuits coupled to said radio-frequency circuit by means of a voltage divider circuit and a current transformer, said control signal having a magnitude and polarity responsive to the impedance components of said radio frequency circuit as sensed from the voltage developed across said voltage divider circuit and current induced in said current transformer, means to detect successive changes in the polarity of said control

signal, a motor drive for said device, means to couple said control signal to said motor drive to adjust the position of said device including amplifier means and stepping means, said control signal being coupled to said amplifier means through said stepping means, said stepping means being responsive to successive changes in the polarity of said control signal to reduce to ineffectivity in successive steps the magnitude of said control signal to terminate the amplified control signal and thus terminate the motor operation.

3. In a circuit for automatically controlling the position of a radio frequency circuit tuning device responsive to a control signal, means to produce said control signal including a network of bridge circuits coupled to said radio frequency circuit by means of a voltage divider circuit and a current transformer, said control signal having a magnitude and polarity responsive to the impedance components of said radio frequency circuit as sensed from the voltage developed across said voltage divider circuit and current induced in said current transformer, means to detect successive changes in the polarity of said control signal, motor means for adjusting the position of said device, a plurality of resistance elements, means to couple said control signal in series through some portion of said plurality of resistance elements to said motor means, means to increase said portion of resistance responsive to changes in the polarity of said control signal to reduce to ineffectivity in successive steps the magnitude of said control signal.

4. An antenna tuning system to automatically match the input impedance of a given antenna to a transmission line coupling radio frequency energy over a wide band of frequencies from a transmitter to said antenna, comprising an antenna tuning unit including an input connection, a first motor means to adjust the positioning of said input connection along a length of said antenna to vary the input impedance to said antenna and a second motor means to adjust the electrical length of said antenna to vary the phase of said input impedance to said antenna, a sensing circuit, first and second means coupling said sensing circuit to said transmission line to form respectively a voltage reference and a current reference including means to produce a first control signal of a magnitude and polarity indicative of the real component of said input impedance and another means to produce a second control signal proportional to the phase angle of said input impedance, means to couple said first and second control signals to said first and second motor means respectively, said first and second motor means being responsive to the magnitude and polarity of said first and second control signals respectively to position said input connection and said antenna length adjusting means respectively, first and second detector means to detect respectively a change in direction of operation of said first and second motor means, a first signal control means responsive to the output of said first detector means to reduce toward ineffectivity the magnitude of said first control signal and a second signal control means responsive to the output of said second detector means to reduce toward ineffectivity the magnitude of said second control signal.

5. An antenna tuning system to automatically match the input impedance of a given antenna to an input transmission line coupling energy from a transmitter over a wide band of frequencies to said antenna, comprising an antenna tuning unit including an input connection, first motor means to adjust the position of said input connection to match the reactance of the antenna over the band of frequencies, second motor means to adjust the electrical length of said antenna to vary the phase of said input impedance to said antenna, means coupled to said transmission line through a voltage divider circuit and a current transformer for sensing the real and imaginary components of the input impedance to said antenna, means

responsive to said real component of input impedance for producing a first control signal, means responsive to said imaginary component of input impedance for producing a second control signal, first and second means to amplify each of said first and second control signals, a first and second stepping switch, said first and second motor means coupled respectively to said control signals through said amplification means and said stepping switches, first and second detector means responsive to a change in direction of said first and second motors and associated with said stepping switches respectively to reduce toward ineffectivity the respective magnitudes of the said first and second control signals to subsequently terminate the respective control signal amplifications.

6. An antenna tuning system to automatically match the input impedance of a given antenna to a transmission line coupling radio frequency energy over a wide band of frequencies from a transmitter to said antenna, comprising an antenna tuning unit including an input connection, motor means to adjust the positioning of said input connection along a length of said antenna to vary the input impedance to said antenna and to adjust the electrical length of said antenna to vary the phase of said input impedance to said antenna, a sensing circuit coupled to said transmission line by first and second means to form respectively a voltage reference and a current reference to produce at least one control signal having a magnitude and polarity responsive to a characteristic of said input impedance, means to couple said control signal to said motor means including means to detect a change in polarity of said control signal and means to amplify said control signal, said motor means responsive to the magnitude and polarity of said amplified control signal to adjust said antenna tuning means to vary said input impedance and means coupled to said amplifier means responsive to a change of polarity of said control signal to reduce to ineffectivity the magnitude of said control signal.

7. An antenna tuning system to automatically match the input impedance of a given antenna to an input transmission line coupling energy from a transmitter over a wide band of frequencies, comprising a tuning unit including an input connection, first adjusting means to adjust the position of said input connection to match the reactance of the antenna over the band of frequencies, second adjusting means to adjust said input coupling means along a length of said antenna, first and second reference means coupled to said transmission line to form respectively a voltage reference and a current reference for sensing the real and imaginary components of the input impedance to said antenna, first means coupled to said reference means responsive to said real component of said input impedance for producing a first control signal, second means coupled to said reference means to produce a second control signal responsive to the difference in phase between the input transmission line voltage and line current, means to couple respectively said first and second control signal to said first and second adjusting means including means to amplify each of said first and second control signals and first and second motor means, said first motor means responsive to said first control signal to actuate said first adjusting means, said second motor means responsive to said second control signal to actuate said second adjusting means, means coupled to said amplifier, means to detect respectively a change in the direction of movement of said first and second motor means and responsive to said detected change in direction respectively to reduce to ineffectivity the magnitude of said control signal.

8. An arrangement for automatically matching the impedance of a load to a radio frequency input circuit to minimize any reflected energy comprising a load including first and second varying means to respectively vary the resistance component and reactance component of the load impedance, first and second reference means

coupled to said radio frequency circuit to provide respectively a voltage and current reference, a first bridge circuit coupled to said first and second reference means to determine a mismatch of the resistance component of said impedance and to produce a signal having a magnitude and polarity in response thereto, a second bridge circuit to determine a mismatch of the reactance component of said impedance and produce a signal having a magnitude and polarity in response thereto, first and second motor means respectively coupled to said first and second load varying means, first circuitry means coupling said first bridge circuit control signal to said first motor means to vary the resistance component of said impedance in accordance with said signal, second circuitry means coupling said second bridge circuit control signal to said second motor means to vary the reactance component of said impedance in accordance with said signal, first anti-hunt means coupled between said first motor means and said bridge circuit, second anti-hunt means coupled between said second motor means and said second bridge circuit, each of said anti-hunt means responsive to successive changes in the polarity of said control signal to reduce to ineffectivity in successive steps the magnitude of the respective control signals.

9. In a circuit for automatically controlling the position of a radio frequency circuit tuning device responsive to a control signal, sensing means to produce said control signal including a network of bridge circuits coupled to said radio frequency circuit by means of a voltage divider circuit and a current transformer, said control signal having a magnitude and polarity responsive to the impedance components of said radio frequency circuit as sensed from the voltage developed across said voltage divider circuit and current induced in said current transformer, a plurality of resistance elements each having a tap and coupled in series, said series connected resistance elements coupled to said sensing means to receive said control signal therefrom, a stepping switch having an operating contact disposed to engage sequentially each of said taps, an amplifier coupled to said operating contact to amplify the control signal received therethrough, motor means coupled to said tuning device for adjusting

the position of said device and coupled to said amplifier to receive said control signal therefrom, and polarity detecting means coupled to said amplifier to detect successive changes in the polarity of said control signal and coupled to said stepping switch, said stepping switch being operative to step upon each change in polarity of said control signal to sequentially add said resistance elements into said amplifier input circuit whereby said control signal is reduced toward ineffectivity.

10. An anti-hunt means to be used with a servo loop comprising a source of error control signal for said servo loop, a signal attenuation means having a plurality of taps and coupled to said error control signal source, each of said taps disposed along said attenuating means to provide at each tap a different degree of attenuation for a signal passing therethrough, a stepping switch having an operating contact disposed to engage sequentially each of said taps in response to change in polarity of said signal to said stepping switch, a servo amplifier coupled to said operating contact to receive the attenuated error control signal therefrom, a servo motor coupled to said amplifier means, a variable control means for said error signal source coupled to said motor to be driven thereby in accordance with the polarity sense of the error control signal and to be driven by lesser amounts as there are reversals of this error control signal polarity in accordance with the introduction of greater attenuation steps through said attenuating means and said stepping switch.

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