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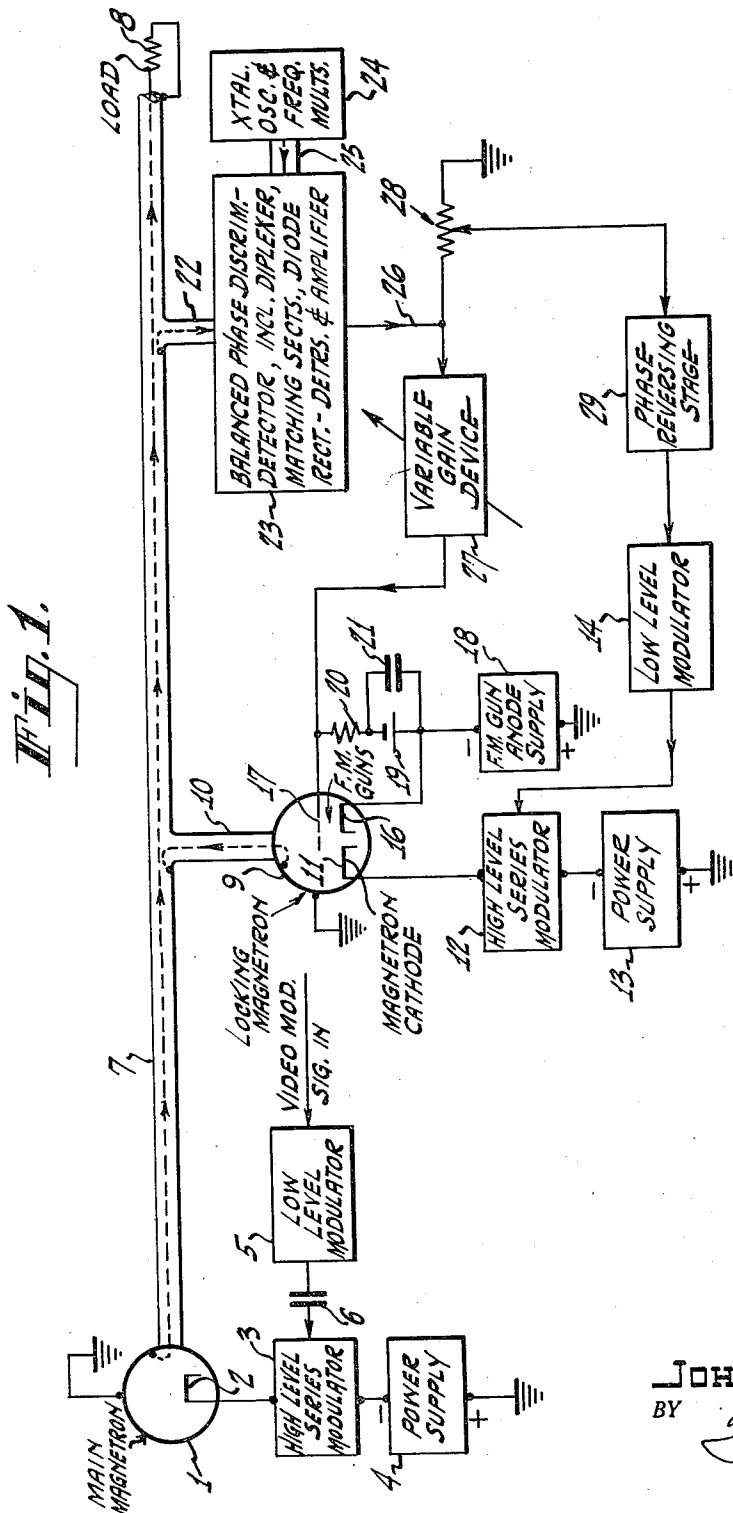
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2,820,197

MAGNETRON FREQUENCY CONTROL SYSTEM

Filed March 11, 1954

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

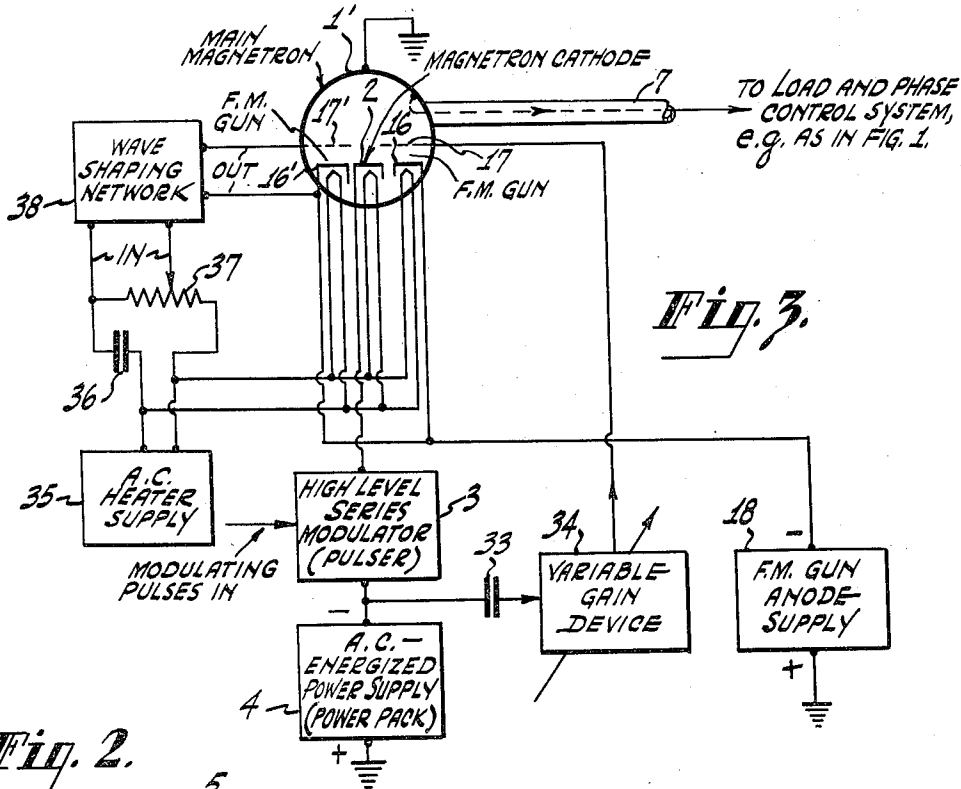
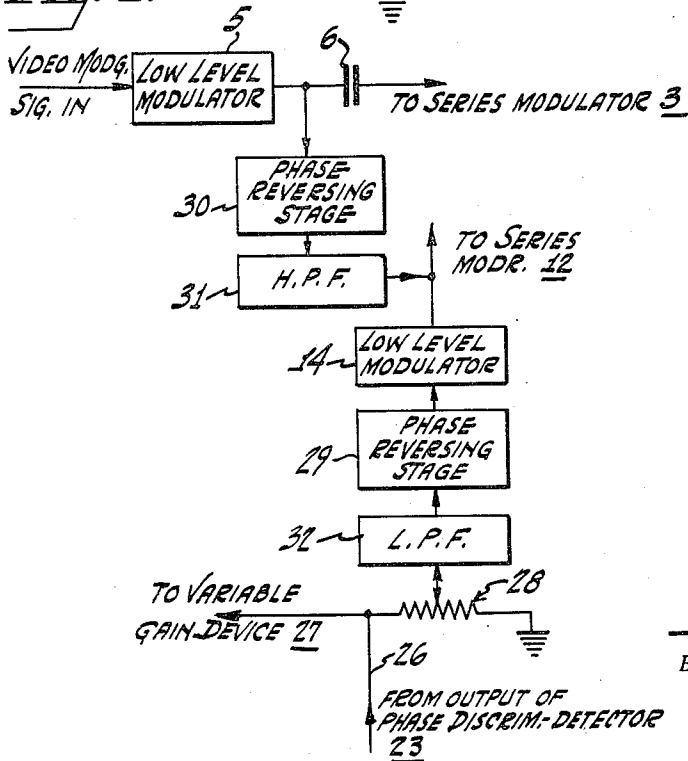


Fig. 3.

Fig. 2.



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MAGNETRON FREQUENCY CONTROL SYSTEM

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12 Claims. (Cl. 332—5)

This invention relates to a frequency control or stabilization system for magnetrons, and more particularly to a frequency stabilization system of the injection-locking type.

This invention is concerned with a system generally similar to that disclosed, for example, in the copending but now abandoned Koros application, Serial No. 177,455, filed August 3, 1950. Such a system is known as an injection-locking type of frequency stabilization system, wherein output from a main high power magnetron oscillator is coupled by means of a transmission line to a load, and wherein a lower power stable frequency source injects power into the transmission line (thereby coupling such injected power also into the main magnetron) to stabilize the frequency of the main magnetron. This frequency stabilization of the main magnetron is particularly desirable and useful in magnetron anode modulation (for amplitude modulation) systems, wherein "pushing" frequency changes normally tend to occur as the anode voltage of the main magnetron is varied for amplitude modulation of the output thereof.

If it is desired to injection-lock a very high-power magnetron to stabilize its frequency, the only injection locking tube available may be another (smaller) magnetron, since in this case the injection power required (at a frequency equal to the desired operating frequency of the main magnetron) may be beyond the capabilities of tubes of other types. The necessity for the use of a magnetron as an injection locking tube, while present for main magnetrons operating C. W., is even greater for pulsed magnetrons, wherein the power of the main magnetron during the pulse is extremely high, and wherein the injection power must be proportionately high.

However, the use of a magnetron as an injection-locking tube involves some additional difficulties, which the present invention satisfactorily overcomes or counteracts. The smaller, locking magnetron is ordinarily phase-locked to a crystal-controlled (stable frequency) source, in order to cause such locking magnetron to serve in turn as a stable frequency locking source for the main magnetron. Despite this phase-locking of the small or locking magnetron, the same may be phase modulated in an undesirable direction or to an undesirable degree (thus producing corresponding undesired system phase modulation, or phase modulation at the load) by the large or main magnetron. This comes about by reason of the following. During the amplitude modulation cycle, the large magnetron inherently presents (due to the modulation thereof) a varying admittance at the junction of the main transmission line (extending between the main magnetron and the useful load) and the branch transmission line (extending between the locking magnetron and the main transmission line). This varying admittance is transformed to some other value at the terminals of the small locking magnetron. Due to the phenomenon known as "pulling" (changes of magnetron frequency resulting from changes in the load on the magnetron), this varying admittance at the terminals of the locking magnetron

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causes phase modulation of the latter. This phase modulation of the small magnetron by the large magnetron is undesirable because it produces incidental, undesired system phase modulation.

An object of this invention is to provide a novel injection-locking frequency stabilization system for magnetrons, wherein the system phase modulation is decreased.

Another object is to devise an injection-locking system for magnetrons, wherein a magnetron is used as a locking tube and wherein this locking magnetron is itself stabilized in frequency.

A further object is to provide, in an injection-locking frequency stabilization system utilizing a magnetron as the locking tube, an arrangement for counteracting undesirable phase modulation of the locking magnetron.

A still further object is to utilize the phenomenon known as "pushing" of a magnetron in a novel way, to decrease the system phase modulation in an injection-locked magnetron system.

In a transmitter utilizing a pulsed magnetron, the pulse-to-pulse frequency variation of the transmitted pulses, even when the (envelope) flat-top portions of a plurality of spaced pulses are compared, may be severe. This is a result of several causes, among which may be mentioned the "pushing" frequency change due to ripple on the power-pack-derived anode voltage applied to the magnetron and the frequency change due to the alternating magnetic field inside the magnetron as a result of the use of alternating current for the magnetron heater. In an injection-locked magnetron frequency stabilization system, of course, the elimination of this pulse-to-pulse frequency variation is attempted by the action of the injection-locking system. However, the necessity for the elimination of this said frequency variation calls for an extremely accurate and fine-acting injection-locking system.

Therefore, another object of this invention is to devise an arrangement for minimizing the pulse-to-pulse frequency variation of a pulsed magnetron on which a phase control system is operative, thereby rendering less exacting the required performance of the phase control system.

The objects of this invention are accomplished, briefly, in the following manner: In an injection-locking frequency stabilization system for a main magnetron, a smaller magnetron is used as the injection locking tube. A sample of the oscillatory energy in the load is compared in a phase discriminator with oscillatory energy from a crystal-controlled source, and the output of this discriminator is used to anode modulate the small locking magnetron in such a direction as to decrease the system phase modulation. The locking magnetron may be phase-locked by means of a feedback loop operating on FM guns inside the magnetron, in addition. In certain cases, a portion of the modulating signal acting on the main magnetron may be also applied to anode modulate the small locking magnetron. In addition, to counteract certain pulse-to-pulse frequency variations of a pulsed magnetron, a counteracting voltage may be applied to an FM gun in the magnetron, this voltage being derived from the voltage responsible for producing the said pulse-to-pulse frequency variations.

The foregoing and other objects of this invention will be better understood from the following description of some exemplifications thereof, reference being had to the accompanying drawings, wherein:

Fig. 1 is a combined detailed schematic and block diagram of an arrangement according to this invention;

Fig. 2 is a partial block diagram of a modified embodiment;

Fig. 3 is a combined detailed schematic and block diagram of another arrangement according to this invention.

Now referring to Fig. 1, a main high power magnetron oscillator 1 is the oscillator whose frequency is to be stabilized by an injection-locking system according to this invention. Magnetron 1 has a cathode 2 (the outer shell or anode of the magnetron being grounded as shown) which is connected through a high level series modulator 3 to the negative terminal of a high voltage unidirectional power supply 4 the positive terminal of which is grounded as indicated. A modulating signal, for example a television video signal, is fed into a low level modulator 5 which is essentially an amplifier, and is then fed through a coupling capacitor 6 to the high level modulator 3 the output of which is coupled to cathode 2. Thus, it may be seen that the modulator 3 is connected in series in the cathode circuit of magnetron 1, so that such magnetron is anode-modulated by the modulating signal fed into modulator 5. The modulator 3 is, in effect, in the anode-cathode circuit of magnetron 1.

Magnetron 1 is connected to act as an oscillator, developing therein oscillatory energy in the R. F. range (for example, about 800 mc.), and this energy is amplitude modulated by the modulating signal fed to modulator 5, which modulating signal varies the magnetron anode-cathode voltage and thereby the amplitude of the R. F. output of the magnetron.

A main transmission line 7 serves as the main magnetron output line and is coupled to feed output energy from magnetron 1 to a useful load 8 which may, for example, be a transmitting antenna. Line 7 may be a coaxial line, as illustrated. The oscillatory energy appearing in the load 8 is amplitude modulated in the manner described.

As the result of several different causes, undesired phase modulation or (FM) of the oscillatory energy in the load may tend to occur, and this undesired system phase modulation is what is reduced by the present invention. This phase modulation may occur at very slow rates (being the result of temperature variations in the magnetron, for example) or it may occur at modulation frequency rates (being the result of frequency "pushing" due to amplitude modulation of the magnetron).

To stabilize the frequency of the magnetron 1 and to substantially eliminate the system phase modulation, an injection-locking frequency stabilization system is utilized. A locking magnetron oscillator 9, of smaller output power rating than the main magnetron 1, is coupled by means of a branch transmission line 10 (which may be a coaxial line, as illustrated) to inject power of quite stable frequency into transmission line 7, and thereby also into magnetron 1, to lock the frequency of the main magnetron 1 to the frequency of the "standard" or "reference" magnetron 9, which latter operates at a frequency equal to the desired frequency of operation of magnetron 1. Transmission line 10 is coupled between the output of magnetron 9 and the transmission line 10. Magnetron 9 has a cathode 11 (the outer shell or anode of the magnetron being grounded as shown) which is connected through a high level series modulator 12 to the negative terminal of a high voltage unidirectional power supply 13 the positive terminal of which is grounded as indicated. The output of a low level modulator 14 (which latter is essentially an amplifier) is fed to the high level modulator 12 the output of which is coupled to cathode 11. The modulator 12 is connected in series in the cathode circuit of magnetron 9, so that such magnetron is anode-modulated by the modulating signal fed into modulator 14. What the said modulating signal is and from whence it is derived, will be explained hereinafter.

The injection of a small amount of locking power (small as compared to the power output of the main magnetron 1) from magnetron 9 into the main transmission line 7, and thereby also into the main magnetron 1, serves to lock the frequency of magnetron 1 to the frequency of magnetron 9, in the manner described in detail in the aforementioned Koros application. Thus, the frequency

of magnetron 1 is stabilized by the locking magnetron 9, by means of an injection-locking arrangement.

In order for the main magnetron 1 to be stabilized in this manner, it is of course essential that the locking magnetron 9 provide locking power which is stable in frequency. To stabilize the frequency of the locking magnetron 9, this (smaller) magnetron may be phase-locked to a crystal-controlled oscillatory source by means of a feedback loop operating on FM guns in magnetron 9, if this magnetron has such guns. Thus, the magnetron 9 may have embodied therein a plurality of frequency control means known as "FM guns," only one of which is illustrated in Fig. 1, but each of which may consist of an electron-emitting cathode 16 and an electron flow control element or grid 17. The electron beams from these guns are projected by means of a gun anode supply 18 the negative terminal of which is connected to cathode 16 and the positive terminal of which is grounded, through cavity resonators which are integral with the cavity resonators of the magnetron 9. In order to suitably bias grids 17 negatively with respect to cathodes 16, a bias potential source 19, illustrated for simplicity as a battery, is connected between cathodes 16 and grids 17 through a resistor 20. The source 19 is bypassed for high frequencies by a capacitor 21. Variable control of the intensity of the electron beams from cathodes 16, by the application of a suitable varying voltage between cathodes 16 and grids 17, provides variable shunt reactance for the frequency-determining parameters of the magnetron; in this way the output frequency of magnetron 9 may be controlled. These FM guns may be used to phase-lock the tube 9 to a reference crystal-controlled source, by means of a feedback loop now to be described.

A small portion of the output of magnetron 1 is taken off by means of a coaxial transmission line 22 which is coupled to the main transmission line 7 and is fed as one input to a balanced phase discriminator-detector 23. A reference crystal-controlled source 24, which comprises a crystal oscillator feeding one or more frequency multiplier stages, supplies the other input to unit 23, by way of a transmission line 25. Unit 23 includes a diplexer, impedance matching sections, diode rectifier-detectors and an amplifier. In the unit 23, the frequency and phase of the main magnetron output (the system output, in the load 8) are compared with the frequency and phase of the reference crystal-controlled source 24, and an amplified voltage appears on the phase discriminator output lead 26 whenever the main magnetron frequency differs from the reference crystal-controlled source and/or whenever the relative phase of the main magnetron output has other than a predetermined value. Since the injection locking arrangement operates to lock the frequency of the main magnetron 1 to that of the locking magnetron 9, the frequency of the locking magnetron is essentially the same as that of the system (which latter is what is sensed by unit 23), so that the frequency and phase of the locking magnetron 9 may be sensed by unit 23 and said locking magnetron may be phase-locked to the crystal-controlled source 24. The output of phase discriminator-detector 23 may contain energy from zero frequency (D. C.) on up through a high video frequency, and thus may be responsive to slow drifts (due to temperature changes, etc.) or changes at modulation rates (e. g., due to magnetron "pushing," etc. and which may be termed system phase modulation) in the system or load frequency. For a more detailed description of the arrangement comprising units 23 and 24, reference is made to the copending Bond et al. application, Serial No. 130,964, filed December 3, 1949, now Patent No. 2,676,260, dated April 20, 1954.

The discriminator output which may operate on the FM guns of the locking magnetron 9 (if this magnetron has such guns therein) may be passed through a variable gain device 27 (e. g., an attenuator), to adjust the relative amplitude of the signal to a desired value, and then

applied directly to the control elements or grids 17 of the FM guns in magnetron 9, so that such signal is effectively applied between the cathodes 16 and control elements 17 of such guns as a variable or controllable bias voltage for such guns, to produce controllable changes in the output frequency of magnetron 9. The output of discriminator 23 thus may control, by means of the FM guns, the output frequency of locking oscillator 9 to bring it back to exactly the frequency of reference source 24, if it has drifted away therefrom. The arrangement just described, including elements 22 through 27, thus may constitute a first feedback loop operating on the FM guns of magnetron 9, which phase-locks the locking magnetron 9 to the crystal-controlled source 24.

If desired, a coupling circuit such as that described in my prior Patent No. 2,620,467 may be used between the output of device 27 and the FM gun grids.

As previously stated, for frequency stabilization of the main magnetron 1 by injection locking it is essential that the frequency of the locking magnetron 9 be held substantially fixed or constant. However, during the amplitude modulation cycle of the main magnetron, such magnetron presents a varying admittance to the locking magnetron, so that due to "pulling," phase modulation of the locking magnetron tends to be produced. This, of course, is detrimental to the necessary constancy of frequency of the locking magnetron, if it occurs in an undesirable direction (with respect to the system phase modulation) or to an undesirable degree. According to this invention, incidental phase modulation of the locking magnetron is purposely caused to occur (by anode modulation of this magnetron), but in such a direction as to decrease the "pulling" phase modulation of this magnetron, and thereby to decrease the system phase modulation, also.

As previously described, a sample of the load power is compared as to phase with that from the crystal-controlled source 24, in the phase discriminator 23. The output of discriminator 23 is coupled through a potentiometric adjustable attenuating device or gain controlling device 28 (to adjust the relative amplitude of the signal to a desired value) to the input of a phase reversing stage 29, and the output side of this stage is coupled to the input side of the low level modulator 14. In this way, the output of discriminator 23 is attenuated, reversed in phase, and applied as a modulating signal to modulator 14, thereby to produce anode modulation of the locking magnetron 9 through the series modulator 12. Thus, the locking magnetron is anode modulated by the output of phase discriminator 23.

Due to the action of phase discriminator 23, any system phase modulation (which could result from phase modulation of the locking magnetron by the main magnetron) is detected and appears in the discriminator output lead 26 as a corresponding modulating voltage which is used to anode modulate the locking magnetron 9, and to serve as a correcting control voltage on the FM gun grids. Due to the frequency "pushings" action characteristic of any magnetron, anode modulation of the locking magnetron 9 in the manner aforesaid causes incidental phase modulation of the output thereof. According to one aspect of this invention, the output of the phase discriminator 23 is applied to the modulator 14, 12 to anode modulate the locking magnetron 9 in such a direction that the incidental phase modulation produced as a result decreases the system phase modulation. As the system phase modulation tends to go in a particular direction, the phase modulation which is caused to occur at the output of the locking magnetron is in the opposite direction. The FM guns, also, can be considered to produce incidental phase modulation of the locking magnetron 9 which decreases the system phase modulation.

The elements 23, 26, 28, 29, 14, 12, etc. constitute a second feedback loop which operates on the anode modulator for locking magnetron 9, to produce phase modulation thereof in opposition to the system phase modulation

and in such a direction as to counteract phase modulation of the locking magnetron by the main magnetron.

The necessity for the phase reversing stage 29 will now be explained. It may be seen that there are two separate feedback loops, both excited by the output of the phase discriminator 23, and it will be assumed that there are an even number of stages in the low level modulator (amplifier) 14, so that there is no reversal of phase in modulator 14. Magnetrons operate in such a way that, when the modulating signal applied to main magnetron 1 is such as to increase its output amplitude, the output frequency tends to rise, advancing the phase of the oscillator energy in the load 8. This advance of phase (with respect to the crystal-controlled source 24) causes a positive-going voltage to appear at the output of the phase discriminator 23, no matter how such discriminator is connected. This is true because the FM guns ordinarily operate to decrease the magnetron frequency in response to a positive voltage applied to their grids; if a negative voltage tends to appear at the phase discriminator output in response to an advance of system phase, the magnetron frequency would tend to further increase because of the FM gun action, resulting in instability or "running away" and a consequent "jumping" to a stable condition wherein the system frequency becomes such that a positive-going voltage appears at the phase discriminator output. Therefore, it is always true that when the main magnetron 1 is modulated up in amplitude, the system frequency tends to rise, and a positive voltage appears at the phase discriminator output, to be applied to the FM gun grids to thereby lower the frequency of the locking magnetron 9. If at this time (to wit, when the magnetron 1 is modulated up in amplitude) the voltage on the grid of amplifier tube 14 is positive, the voltage applied to the grids of modulator 12 would be positive and would bias these grids to conduct more strongly, decreasing the voltage drop thereacross and causing the cathode 11 to become more negative, thus modulating the magnetron 9 up in amplitude, and due to "pushing" causing its output frequency to increase. This is in the wrong direction, since what is needed is a decrease in output frequency of locking magnetron 9 to counteract the increase in system output frequency when main magnetron 9 is modulated up in amplitude. Therefore, a phase reversing stage 29 must be inserted in the connection between discriminator 23 and modulator 14, so that when the voltage on the FM gun grids is positive (in response to the modulation of magnetron 1 up in amplitude), the voltage on the grid of amplifier tube 14 and on the grids of modulator 12 is negative, and vice versa. In this way, the anode modulation of the locking magnetron 9 is made to be in such a direction as to decrease the system phase modulation, since when the main magnetron 1 is modulated up in amplitude, tending to increase the system frequency, both the FM gun action and the anode modulation of locking magnetron 9 tend to decrease the system frequency, and vice versa.

It is desirable, in the system of this invention, that the length of line 10 (between the locking magnetron 9 and the junction of the main and branch transmission lines) be adjusted for minimum phase modulation of the locking magnetron by the main magnetron.

All of the circuits in the anode modulation feedback loop should be designed to have a minimum phase delay, so that the anode modulation scheme of this invention will have its maximum effectiveness, in the reduction of system phase modulation.

The two feedback loops described work together in parallel to reduce the system phase modulation. The use of both of these loops extends the overall frequency range of reduction of system phase modulation, and also increases the accuracy (in the sense of more nearly perfect compensation) of such reduction. As disclosed, both loops work in parallel for system phase modulation of all frequencies. Alternatively, a low pass filter could

be inserted in the first feedback loop (that leading to the FM guns), so that this loop would be operative for only a range of low frequencies (or zero frequency, D. C.) of system phase modulation, and a high pass filter could be inserted in the second feedback loop (that leading to the amplitude modulator 14), so that this loop would be operative for only a range of high frequencies of system phase modulation.

If the locking magnetron 9 has no FM guns therein, the first described feedback loop would be omitted and the anode-modulation loop used by itself. The anode-modulation feedback loop then acts by itself to reduce or decrease the system phase modulation, in the same manner as previously described. The phase-reversing stage 29 might not be necessary in this case, since the FM gun feedback loop is no longer present to be excited by the output of phase discriminator 23.

The foregoing description has been set forth with particular reference to a main magnetron operating C. W., with video modulation. However, this invention is also applicable to pulsed main magnetrons. In this case, the C. W. level of the small, locking magnetron can be altered (that is, its output can be amplitude modulated) during the pulses of the large, main magnetron, the arrangement again being such that the locking magnetron is anode modulated in such a direction as to decrease the system phase modulation, during the pulses of the main magnetron. With pulsed-output main magnetrons, the locking magnetron may be prepulsed, to save power or to make high locking power available without undue increase in the size of the locking magnetron that is required. In other words, the locking magnetron may be pulsed, with its longer pulses overlapping those of the main magnetron. In the case of a prepulsed locking magnetron, the pulsed amplitude level thereof can be modulated during the pulses of the main magnetron, by the arrangement of this invention, to correct the system phase modulation during the main magnetron pulses.

There is evidence that, at least for certain types of magnetrons, the "pushing" frequency modulation of the magnetron (which is the incidental frequency modulation of the magnetron output resulting from the amplitude modulation of the magnetron) shifts phase with respect to the amplitude modulation as the modulation frequency is increased. This is true for either locked or unlocked magnetrons, although the aforementioned shift of phase may differ in these two cases. When magnetrons of this type are used for the main magnetron, if the phase modulation of the locking magnetron (which, it will be remembered, is carried out in such a direction as to decrease the system phase modulation) is effected in some other way than by anode modulation thereof, for example by a video modulating signal derived from the main modulator 5 and applied to the FM guns of the locking magnetron 9, the resulting (correcting) phase modulation would have to be shifted in phase as the modulation frequency is increased, in order to substantially completely cancel or correct the system phase modulation, as is desired. However, if the phase modulation of the locking magnetron is brought about by anode modulation thereof, this correcting phase modulation will shift phase automatically, to follow the phase shift (for the main magnetron) of the incidental frequency modulation (or phase modulation) with respect to the amplitude modulation; thus, there is an additional advantage, in certain cases or when employing magnetrons of certain types, to using anode modulation of the locking magnetron to decrease the system phase modulation. In such cases, though, a modification of the Fig. 1 circuit is necessary to obtain the desired results, and such modification is illustrated in Fig. 2, which will now be described.

Fig. 2 is a block diagram of a portion of Fig. 1, illustrating the modification referred to, and in Fig. 2 elements the same as those of Fig. 1 are denoted by the same reference numerals. In Fig. 2, a portion of the

amplified video modulating signal appearing at the output of low level modulator 5 is taken off and fed through a phase reversing stage 30 and a high pass filter 31 to the output of low level modulator 14 for the locking magnetron 9, so that the signal appearing at the output of filter 31 is used to anode modulate the locking magnetron 9. In Fig. 2, a low pass filter 32 is inserted between the adjustable attenuator 28 (to which the output signal of phase discriminator-detector 23 is applied, by means of output lead 26) and the phase reversing stage 29. As in Fig. 1, the output of phase reversing stage 29 is applied to the low level modulator 14, to provide a modulating signal for the anode modulation of locking magnetron 9.

The units 30 and 31, by means of which a portion of the main modulating signal is used to anode modulate the locking magnetron 9, serve as a means for causing the incidental but purposeful and correcting phase modulation of the locking magnetron to shift phase automatically to follow the phase shift of system phase modulation with respect to amplitude modulation. Since the phase shift of system phase modulation or frequency modulation with respect to amplitude modulation takes place only as the modulation frequency is increased, the phase shift of the correcting phase modulation needs to take place only at higher modulation frequencies. For this reason, the high pass filter 31 is utilized to pass only the higher modulation frequencies on to the series modulator for the locking magnetron. Also, since the phase shift of the correcting phase modulation (which phase modulation is the phase modulation of the locking magnetron) needs to be, for proper correction, in a direction opposite to the phase shift of the system phase modulation or frequency modulation with respect to amplitude modulation, the phase reversing stage 30 is utilized to reverse the phase of the modulating voltage which reaches the series modulator 12 for the locking magnetron.

In the system of Fig. 2, the modulating signal is used for anode modulation (amplitude modulation) of both magnetrons, but in opposite phases. Since magnetrons are generally similar in their behavior, at higher modulation frequencies (such as can pass through the high pass filter 31) the phase modulation of the locking magnetron shifts phase automatically (and in the opposite direction from that of the main magnetron, due to phase reverser 30) to follow the phase shift of the system phase modulation or frequency modulation with respect to amplitude modulation.

The feedback loop from the phase discriminator output to the modulator 14 is effectively broken at high modulation frequencies, this being done by inserting the low pass filter 32 between the phase discriminator output and the modulator 14. Filter 32 passes only low modulation frequencies and cuts out high modulation frequencies, so that at high modulation frequencies the phase discriminator output is rendered ineffective to anode modulate the locking magnetron. This is necessary because the extra phase shift (due to the system phase modulation shifting phase with respect to the amplitude modulation) forces the feedback loop to be narrow band and low gain, in order for the loop gain to be zero at the frequency at which the total phase shift around the loop is 180° (the "Nyquist criterion"). Actually, if this "extra" phase shift is 90° , the total phase shift around the loop would be 180° at zero frequency, since there is another 90° phase shift already present (the conversion of frequency modulation to phase modulation in the loop, by discriminator 23). In this case, the anode-modulation feedback loop would be entirely impractical and one would have to go entirely to the Fig. 2 system but omitting the feedback loop (from discriminator 23).

Filter 32, when present and in use, should be adjusted so that the anode-modulation feedback loop is used to as high a frequency as possible, without the loop "singing." In the system of Fig. 2, a low pass filter should be

used in the FM-gun feedback loop. This should not be used to cut out the FM-gun loop off arbitrarily, however, but again (as with filter 32) should be adjusted to use this loop to as high as possible a frequency, but to cut it off to satisfy the previously-mentioned "Nyquist criterion."

The only practical way to obtain the D. C. input or energizing power for the magnetron is from an A. C.-operated transformer-rectifier-filter combination, that is, from a power pack. In other words, the power supplies 4 and 13 in Fig. 1 are always A. C.-energized power packs. Even with the best filtering, a certain ripple voltage, known as "power pack ripple," is unavoidably present at the D. C. output terminals of these power packs. This ripple voltage ordinarily is of double the A. C. supply frequency. In a transmitter employing a pulsed magnetron oscillator for producing short pulses of oscillatory energy, the pulse-to-pulse frequency variation, even in the flat-top portion of the pulse envelope, may be severe. This pulse-to-pulse frequency variation may come about due to the fact that the magnetron is pulsed on at different times in the ripple voltage cycle of the anode voltage, so that different anode voltages are effective on the magnetron during these different pulses; thus, the magnetron "pushing" frequency changes are different from pulse to pulse because of the different effective anode voltages on the magnetron. In order to eliminate such pulse-to-pulse frequency variations in a phase-controlled or frequency-stabilized pulse magnetron transmission system, the phase control system has to perform in an extremely exact manner, with a very close tolerance or degree of error. According to another aspect of this invention, the pulse-to-pulse frequency variation is minimized and the required performance of the phase control system is thereby made less exacting, by a scheme to be presently described. Also, quite often in systems of this type, alternating current is used for the magnetron heater. This produces an alternating magnetic field inside the magnetron which, combined with the steady magnetic field applied to the magnetron, produces a resultant periodically-varying magnetic field which will produce corresponding periodic variations in the output frequency of the magnetron. The scheme now to be described in connection with Fig. 3 minimizes frequency variations arising from this cause also.

Now referring to Fig. 3, the main magnetron 1' has a main cathode 2 which is suitably energized to produce pulses of oscillatory energy. For this purpose, said cathode is connected to the negative terminal of an A. C.-energized unidirectional power supply 4 through a high level series modulator 3 which acts as a pulser for the magnetron and is in effect opened or closed by a series of modulating pulses fed thereto from a suitable source (not shown). The positive terminal of power pack 4 is grounded, as is the anode (shell) of the magnetron 1', so that this power pack serves as the main anode supply for such magnetron. The D. C. or unidirectional voltage output of power pack 4 contains a ripple component (e. g., of 120-cycle frequency) which is effective on the anode voltage applied to magnetron 1', causing such anode voltage to ripple or fluctuate periodically. Due to frequency "pushing," this fluctuating magnetron anode voltage causes corresponding fluctuating frequency modulation of the magnetron, so that there tends to be produced a pulse-to-pulse frequency variation in the magnetron output.

Magnetron 1' has coupled thereto an output transmission line 7 which extends to a useful load and also to a phase control or frequency stabilization system which latter may be, for example, of the injection-locking type disclosed in detail in Fig. 1 and previously described herein. In order to counteract the pulse-to-pulse frequency variation previously described, the frequency stabilization system would have to perform with a high degree of accuracy. By means of the Fig. 3 system, the

pulse-to-pulse frequency variation is minimized and the phase control system is not required to perform as accurately.

By means of a coupling and D. C. isolation capacitor 33 connected to the negative terminal of power supply 4, a signal derived from the ripple component of the anode power pack voltage and corresponding to this alternating ripple component is applied to the input side of a variable gain device 34, which may be either an attenuator or an amplifier, as required. The main magnetron 1' in Fig. 3 has embodied therein a plurality (at least two, though there may be more) of FM guns, similar in construction and operation to the FM guns of locking magnetron 9 in Fig. 1. One of these guns includes an electron-emitting cathode 16 and an electron flow control electrode or grid 17, while another gun includes an electron-emitting cathode 16' and an electron flow control electrode or grid 17'. As in Fig. 1, an FM gun anode supply 18 coacts with the two FM guns referred to, the negative terminal of this anode supply being connected to cathodes 16 and 16' and the positive terminal of this supply being grounded.

This ripple-component signal at the output side of variable gain device 34 is applied to the grid 17 of one FM gun in the magnetron 1', in such a way as to act as a signal voltage on grid 17 with respect to cathode 16. By the FM gun action previously described, the ripple signal thus applied to grid 17 frequency modulates or phase modulates the magnetron 1' at the frequency of the ripple. Since when the ripple component of the anode voltage is positive the effective magnetron anode voltage goes up and the output frequency of the magnetron tends to increase, and since a positive voltage applied to the FM guns decreases the magnetron output frequency, no phase reversing is necessary in the circuit which applies the ripple signal to the FM guns, in order for such signal to act to correct the magnetron frequency to the proper value and to counteract the tendency of the magnetron frequency to vary as a result of the ripple on the anode voltage applied thereto. The ripple-component signal is present on the FM gun at all times (even when the magnetron is quiescent or not pulsed on, since this signal is obtained from the continuously-energized power supply 4), and therefore there is no delay or time lag (in the application of this signal to the FM gun) such as would be associated with a feedback loop. The system of Fig. 3 then operates in such a manner that the main magnetron 1' is already automatically tuned to the correct output frequency as the pulse is applied to pulser 3 and the magnetron is pulsed on. The variable gain device 34 is so adjusted that the voltage applied to FM gun grid 17 makes the frequency variation of the magnetron output, during the ripple voltage cycle, as small as possible.

Since ripple components are of low frequency (e. g., 120 C. P. S.) and reasonably constant waveform, no complex phasing or shaping circuits are required in the coupling between power pack 4 and the FM gun grid 17. If desired, a very simple shaping circuit could be used in the aforesaid coupling.

An A. C. heater supply 35 supplies 60-C. P. S. energy to the heaters for all of the magnetron cathodes 2, 16 and 16'. Such alternating current sets up an alternating magnetic field inside the magnetron which, added to the steady magnetic field of the magnetron, may cause undesired periodic or alternating variations in the output frequency of the magnetron. It is well-known to those skilled in the magnetron art that the magnetron output frequency varies as the magnetic field inside the magnetron varies. It is also within the scope of this invention to reduce the magnetron output frequency variations arising due to the use of alternating current for the magnetron heaters.

A 60-cycle voltage is derived from the heater supply 35, passed through a D. C. isolating capacitor 36, and applied to a potentiometric variable attenuator 37. A portion

of the voltage across the potentiometer 37 is taken off and applied to the input side of a suitable wave-shaping network 38. The output of network 38 is applied as a modulating voltage between grid 17' and cathode 16' of the second FM gun in magnetron 1'. Elements 37 and 38 are so designed and adjusted that the 60-cycle voltage wave obtained from the heater supply 35, attenuated and shaped by these elements, and then applied to FM gun grid 17' makes the frequency variation of the magnetron output due to this FM gun such as to exactly cancel the magnetron output frequency variations tending to occur as a result of the use of alternating current for the magnetron heaters. In other words, the 60-cycle voltage is applied to the FM gun grid 17' with such a relative polarity as to oppose the magnetron output frequency variations tending to occur because of the use of alternating current for the magnetron heaters.

What is claimed is:

1. In combination, a high power magnetron oscillator the frequency of which is to be stabilized, a transmission line coupling the output of said magnetron to a load, a magnetron oscillator of lower power than said first-named magnetron coupled to inject power into said line to lock the frequency of said high power magnetron to the frequency of said low power magnetron, means for detecting undesired phase modulation present at said load, and means for utilizing the voltage output of said detecting means to amplitude modulate said low power magnetron by variation of its anode voltage, to thereby incidentally phase modulate said low power magnetron oppositely to the undesired phase modulation present at said load.
2. In combination, a high power magnetron oscillator the frequency of which is to be stabilized, a transmission line coupling the output of said magnetron to a load, a magnetron oscillator of lower power than said first-named magnetron coupled to inject power into said line to lock the frequency of said high power magnetron to the frequency of said low power magnetron, means for stabilizing the frequency of said low power magnetron, means for amplitude modulating the output of said high power magnetron, thereby causing it to present a varying admittance to said low power magnetron and producing undesired phase modulation of said low power magnetron, means for detecting phase modulation present at said load, and means for utilizing the voltage output of said detecting means to amplitude modulate said low power magnetron by variation of its anode voltage, to thereby incidentally decrease the phase modulation of said low power magnetron and consequently to decrease also the phase modulation present at said load.
3. In combination, a high power magnetron oscillator the frequency of which is to be stabilized, a transmission line coupling the output of said magnetron to a load, a magnetron oscillator of lower power than said first-named magnetron coupled to inject power into said line to lock the frequency of said high power magnetron to the frequency of said low power magnetron, voltage-responsive frequency controlling means in said low power magnetron, a modulator connected in series in the anode-cathode circuit of said low power magnetron, means for detecting phase modulation present at said load, means for coupling the voltage output of said detecting means to said frequency controlling means to control the frequency of said low power magnetron, and means for coupling the voltage output of said detecting means also to said modulator to amplitude modulate said low power magnetron by variation of its anode voltage.
4. In combination, a high power magnetron oscillator the frequency of which is to be stabilized, a transmission line coupling the output of said magnetron to a load, a magnetron oscillator of lower power than said first-named magnetron coupled to inject power into said line to lock the frequency of said high power magnetron to the frequency of said low power magnetron, a source of

modulating signals operative to amplitude modulate the output of said high power magnetron, means for detecting phase modulation present at said load, means for utilizing the voltage output of said detecting means to amplitude modulate said low power magnetron by variation of its anode voltage, to thereby incidentally phase modulate said low power magnetron oppositely to the phase modulation present at said load, and means for utilizing modulating signals from said source to amplitude modulate said low power magnetron by modulation of its anode voltage.

5. In combination, a high power magnetron oscillator the frequency of which is to be stabilized, a transmission line coupling the output of said magnetron to a load, a magnetron oscillator of lower power than said first-named magnetron coupled to inject power into said line to lock the frequency of said high power magnetron to the frequency of said low power magnetron, means for detecting undesired phase modulation present at said load, means for utilizing the voltage output of said detecting means to amplitude modulate said low power magnetron by variation of its anode voltage, to thereby incidentally phase modulate said low power magnetron oppositely to the undesired phase modulation present at said load, and means for utilizing the voltage output of said detecting means also to stabilize the frequency of said low power magnetron.

6. In combination, a high power magnetron oscillator the frequency of which is to be stabilized, a transmission line coupling the output of said magnetron to a load, a magnetron oscillator of lower power than said first-named magnetron coupled to inject power into said line to lock the frequency of said high power magnetron to the frequency of said low power magnetron, a phase discriminator having two input connections and an output connection; means for applying a sample of the voltage across said load to one of said input connections, means for applying a stable reference frequency voltage to the other of said input connections, means coupled to said output connection for amplitude modulating said low power magnetron by variation of its anode voltage in accordance with the voltage output of said phase discriminator, to thereby incidentally phase modulate said low power magnetron oppositely to the undesired phase modulation present at said load, and means also coupled to said output connection and operating to lock the frequency of said low power magnetron to said reference frequency.

7. In combination, a high power magnetron oscillator the frequency of which is to be stabilized, a transmission line coupling the output of said magnetron to a load, a magnetron oscillator of lower power than said first-named magnetron coupled to inject power into said line to lock the frequency of said high power magnetron to the frequency of said low power magnetron, means for stabilizing the frequency of said low power magnetron, means for amplitude modulating the output of said high power magnetron, thereby causing it to present a varying admittance to said low power magnetron and producing undesired phase modulation of said low power magnetron, a phase discriminator having two input connections and an output connection; means for applying a sample of the voltage across said load to one of said input connections, means for applying a stable reference frequency voltage to the other of said input connections, and means coupled to said output connection for amplitude modulating said low power magnetron by variation of its anode voltage in accordance with the voltage output of said phase discriminator, to thereby incidentally decrease the phase modulation of said low power magnetron and consequently to decrease also the phase modulation present at said load.

8. In combination, a high power magnetron oscillator the frequency of which is to be stabilized, a transmission

line coupling the output of said magnetron to a load, a magnetron oscillator of lower power than said first-named magnetron coupled to inject power into said line to lock the frequency of said high power magnetron to the frequency of said low power magnetron, means for amplitude modulating the output of said high power magnetron, thereby causing it to present a varying admittance to said low power magnetron and producing undesired phase modulation of said low power magnetron, a phase discriminator having two input connections and an output connection; means for applying a sample of the voltage across said load to one of said input connections, means for applying a stable reference frequency voltage to the other of said input connections, means coupled to said output connection for amplitude modulating said low power magnetron by variation of its anode voltage in accordance with the voltage output of said phase discriminator, to thereby incidentally decrease the phase modulation of said low power magnetron and consequently to decrease also the phase modulation present at said load, and means also coupled to said output connection for stabilizing the frequency of said low power magnetron.

9. In combination, a high power magnetron oscillator the frequency of which is to be stabilized, a transmission line coupling the output of said magnetron to a load, a magnetron oscillator of lower power than said first-named magnetron coupled to inject power into said line to lock the frequency of said high power magnetron to the frequency of said low power magnetron, voltage-responsive frequency controlling means in said low power magnetron, a modulator connected in series in the anode-cathode circuit of said low power magnetron, a phase discriminator having two input connections and an output connection; means for applying a sample of the voltage across said load to one of said input connections, means for applying a stable reference frequency voltage to the other of said input connections, means coupled to said output connection for applying the voltage output of said phase discriminator to said frequency controlling means to control the frequency of said low power magnetron, and means also coupled to said output connection for applying the voltage output of said phase discriminator to said modulator to amplitude modulate said low power magnetron by variation of its anode voltage.

10. In combination, a high power magnetron oscillator the frequency of which is to be stabilized, a transmission line coupling the output of said magnetron to a load, a magnetron oscillator of lower power than said first-named magnetron coupled to inject power into said line to lock the frequency of said high power magnetron to the frequency of said low power magnetron, a source of modulating signals operative to amplitude modulate the output of said high power magnetron, means for detecting phase modulation present at said load, means including a low pass filter for utilizing the voltage output of said detecting means to amplitude modulate said low power magnetron by variation of its anode voltage, to thereby incidentally phase modulate said low power magnetron oppo-

sitely to the phase modulation present at said load, and means including a phase reversing stage and a high pass filter for utilizing modulating signals from said source to amplitude modulate said low power magnetron by variation of its anode voltage.

11. In combination, a high power magnetron oscillator the frequency of which is to be stabilized, a transmission line coupling the output of said magnetron to a load, a magnetron oscillator of lower power than said first-named magnetron coupled to inject power into said line to lock the frequency of said high power magnetron to the frequency of said low power magnetron, a source of modulating signals operative to amplitude modulate the output of said high power magnetron, means for detecting phase modulation present at said load, means for utilizing the voltage output of said detecting means to amplitude modulate said low power magnetron by variation of its anode voltage, to thereby incidentally phase modulate said low power magnetron oppositely to the phase modulation present at said load, means for utilizing the voltage output of said detecting means also to stabilize the frequency of said low power magnetron, and means for utilizing modulating signals from said source to amplitude modulate said low power magnetron by variation of its anode voltage.

12. In combination, a high power magnetron oscillator the frequency of which is to be stabilized, a transmission line coupling the output of said magnetron to a load, a magnetron oscillator of lower power than said first-named magnetron coupled to inject power into said line to lock the frequency of said high power magnetron to the frequency of said low power magnetron, a source of modulating signals operative to amplitude modulate the output of said high power magnetron, a phase discriminator having two input connections and an output connection; means for applying a sample of the voltage across said load to one of said input connections, means for applying a stable reference frequency voltage to the other of said input connections, means including a low pass filter coupled to said output connection for utilizing the voltage output of said phase discriminator to amplitude modulate said low power magnetron by variation of its anode voltage, to thereby incidentally phase modulate said low power magnetron oppositely to the phase modulation present at said load, means including a phase reversing stage and a high pass filter for utilizing modulating signals from said source to amplitude modulate said low power magnetron by variation of its anode voltage, and means also coupled to said output connection and operating to lock the frequency of said low power magnetron to said reference frequency.

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