NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO ATTN OF: GP

APR 10 1974

TO: KSI/Scientific & Technical Information Division
Attn: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,800,224

Government or Corporate Employee : Auburn Univ. Auburn, AL.

Supplementary Corporate Source (if applicable) : ——

NASA Patent Case No. : MFS-21,540-1

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

YES [X] NO [ ]

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words "...with respect to an invention of ..."

Bonnie L. Woerner

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Enclosure

United States Patent [19]

Fletcher et al.

[11] **3,800,224**

[45] **Mar. 26, 1974**

[54] **AUTOMATIC FREQUENCY CONTROL FOR F. M. TRANSMITTER**

[76] Inventors: **James C. Fletcher,** Administrator of the National Aeronautics and Space Administration with respect to an invention of; **Martial A. Honnell,** Auburn, Ala.

[22] Filed: **Feb. 20, 1973**

[21] Appl. No.: **333,912**

[52] **U.S. Cl.** **325/148,** 178/7.1

[51] **Int. Cl.** **H04b 1/04**

[58] **Field of Search** .... 179/69.5 TV; 325/45, 148, 325/159, 184, 187; 178/5.8 AF, 7.1, 7.2

[56] **References Cited**

UNITED STATES PATENTS

3,137,816 6/1964 McLin et al. 325/148

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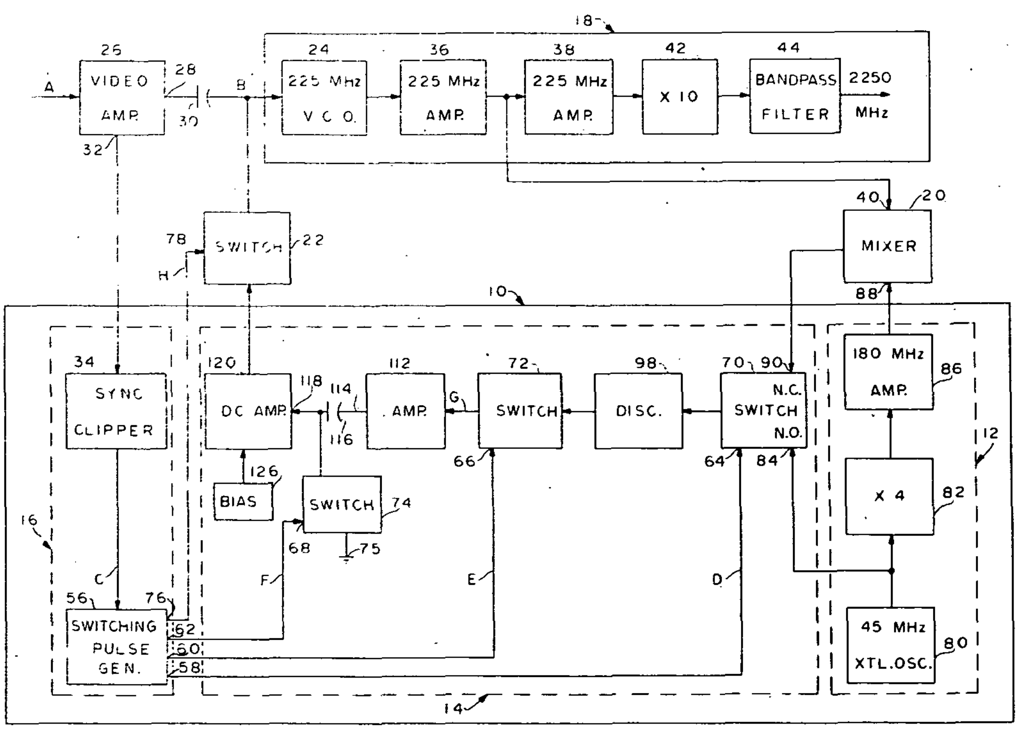
[57] **ABSTRACT**

An automatic frequency control circuit for an F.M. television transmitter in which the frequency of the transmitter is sampled during what is termed the "back porch" portion of the horizontal synchronizing pulse which occurs during the retrace interval, the frequency sample compared with the frequency of a reference oscillator, and a correction applied to the frequency of the transmitter during this portion of the retrace interval.

7 Claims, 2 Drawing Figures



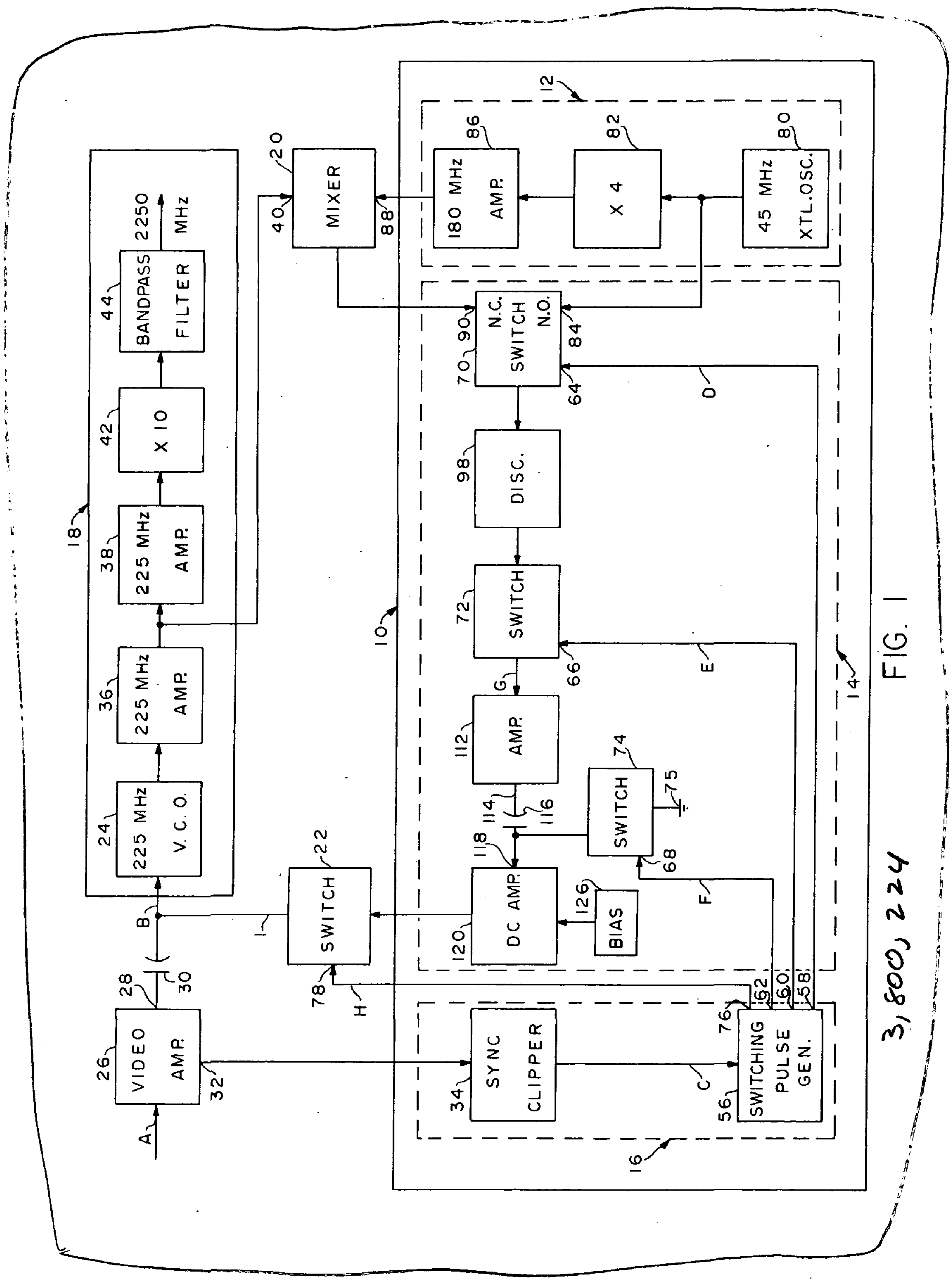

MIXER
180 MHz AMP.
X 4
45 MHz XTL. OSC.
BANDPASS FILTER
2250 MHz
X 10
225 MHz AMP.
225 MHz AMP.
225 MHz V. C. O.
N.C. SWITCH N.O.
DISC.
SWITCH
AMP.
SWITCH
DC AMP.
BIAS
SWITCH
VIDEO AMP.
SYNC CLIPPER
SWITCHING PULSE GEN.
3,800,224

FIG. 1

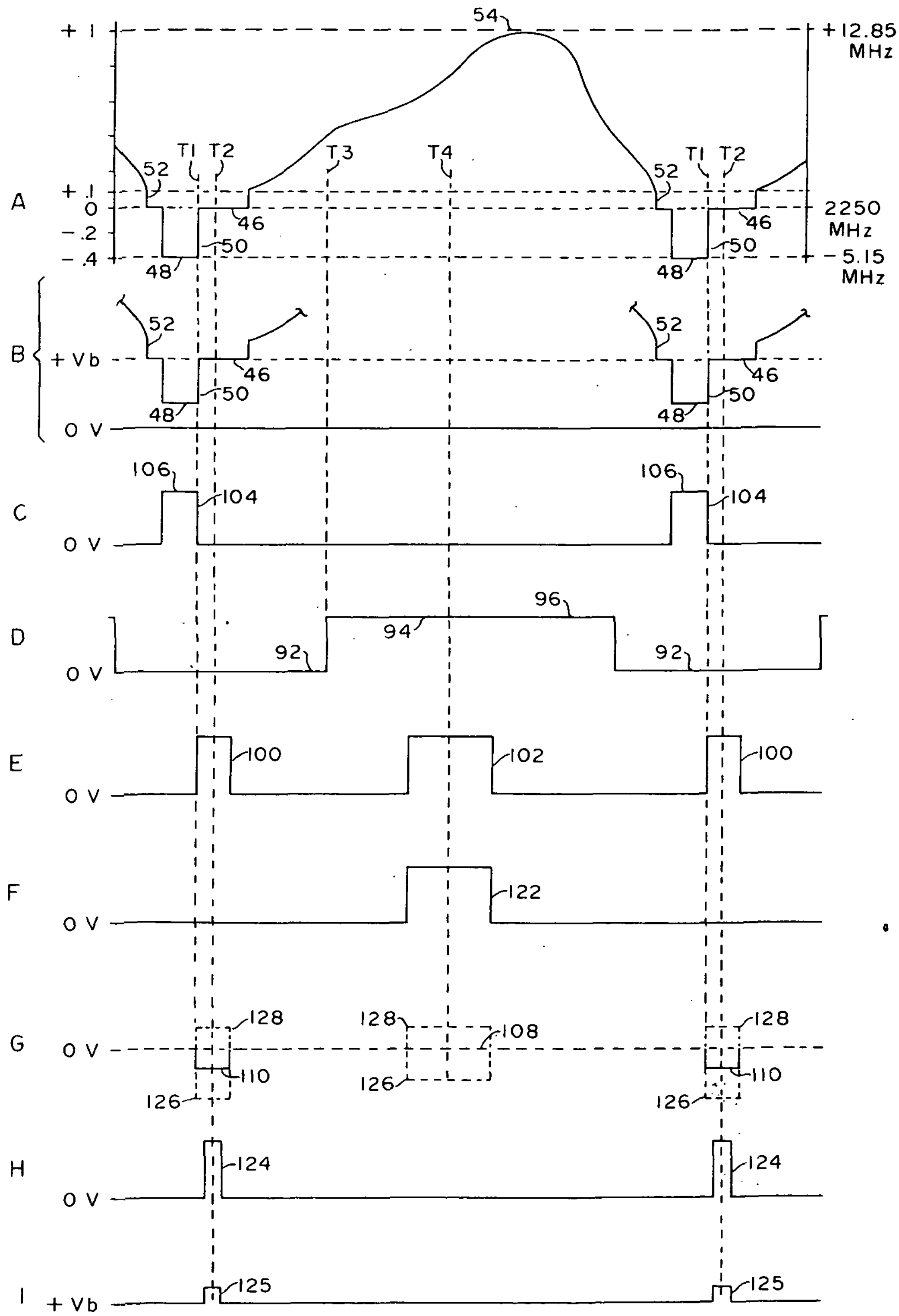

54
+1
+12.85 MHz
T1 T2
T3
T4
52
+.1
0
-.2
-.4
46
50
48
2250 MHz
-5.15 MHz
A
B
+Vb
0 V
C
106
104
D
92
94
96
E
100
102
F
122
G
128
108
110
126
H
124
I
125

FIG. 2

AUTOMATIC FREQUENCY CONTROL FOR F. M. TRANSMITTER

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 U.S.C. 2457).

BACKGROUND OF THE INVENTION

This invention relates to automatic frequency control systems for radio transmitters and particularly to a system adapted to control the frequency of a frequency modulation, F.M., transmitter employed to transmit television or other signals having recurring periods of fixed frequency operation.

GENERAL DESCRIPTION OF THE PRIOR ART

Commercial television transmitters generally employ amplitude modulation to apply the picture information to the carrier and since in such systems the carrier signal is generated by a very accurately controlled crystal oscillator, carrier frequency control is not a substantial problem. On the other hand there are applications, particularly in microwave television links and in industrial, space and military fields wherein it is sometimes desirable to employ frequency modulation for the transmission of video signals. In such cases, since the frequency determing oscillator must necessarily be variable in frequency and thus not inherently stable, there exists the problem of controlling the frequency of the F.M. carrier in some manner which will assure that a given modulation signal will always produce the same output frequency. The problem becomes particularly difficult for television signals and where transmission frequencies are in or above the ultra-high-frequency range.

The well-known techniques used to control the frequency of frequency modulated transmitters modulated with audio frequency signals compare the average frequency of the transmitter with a stable frequency produced by a crystal oscillator. A correction signal derived from the difference between the average frequency of the transmitter and that of the crystal oscillator is used to correct the frequency of the transmitter. This can be done because the average value of the modulating audio frequency signal is zero, that is, the audio frequency signal does not contain a DC component.

A television, or video, signal contains a varying DC component proportional to the brightness information in the scene televised. The difficulty of transmitting the DC component and, at the same time, maintaining the frequency of the transmitter within its assigned channel has, in the prior art, led to the design of FM television transmitters without direct crystal control of the frequency.

These transmitters used open-loop systems with voltage-controlled oscillators carefully temperature-compensated for the required frequency stability. This compensation process is slow, and the open-loop system provides no protection against frequency drift caused by aging effects. Another scheme used is to upconvert the output signal of the frequency modulated oscillator by mixing it with a crystal-controlled high-frequency signal. This system reduces the percent error in the output frequency, but it is subject to aging drifts and presents modulation linearity problems when wide frequency deviation is required.

SUMMARY OF THE INVENTION

Accordingly, it is the object of this invention to provide an automatic frequency control capable of very closely regulating the frequency of an F.M. television transmitter employing a stable reference source.

In accordance with this invention the frequency of a transmitter which generates a signal having a known recurring reference frequency, such as a video signal, is sampled during the recurring frequency portion of the signal. This signal, or as converted to a selected lower frequency signal, is fed to a discriminator together with a fixed reference frequency from a crystal-controlled oscillator with respect to which the transmitter is to be controlled in frequency. The transmitter signal and fixed reference signal are alternately processed by the discriminator by an electronic switch which causes the transmitter signal to be sampled during periods of the recurring reference frequency signal and the fixed reference signal to be sampled between such periods. During the discrimination of one of the two signals, the discriminator output is stored. Thereafter, and during the discrimination of the other signal, the discriminator output is connected in series with the previously stored output in such a manner that a voltage representative of the difference of the discriminator output is obtained. This difference is representative of the error in transmitter frequency and is applied back to the transmitter during the reference frequency period and employed to correct the frequency of the transmitter. The result is that the frequency of the transmitter is held to a very small percentage of error.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an electrical block diagram of an embodiment of the invention.

FIG. 2 is a series of waveforms illustrative of the operation of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings, automatic frequency control **10**, as shown in FIG. **1**, includes crystal oscillator reference **12**, error corrector **14** and control **16**, which are interconnected to sample the quiescent carrier frequency of FM transmitter **18**, through mixer stage **20**, and apply an appropriate correction, through switch **22**, to voltage controlled oscillator **24** of transmitter **18**.

A source of video, having scanning rate and sync standards similar to those required for commercial broadcasting, is coupled to the input of video amplifier **26**. One output **28** of video amplifier **26** is coupled through capacitor **30** to the input of 225 MHz voltage controlled oscillator **24** of transmitter **18**, and to the output of switch **22**. A second output **32** of video amplifier **26** is coupled to the input of sync clipper **34** of control **16**.

The output of voltage controlled oscillator, or V.C.O., **24** of transmitter **18** is connected as an input to a first 225 MHz buffer amplifier **36**, in turn having an output coupled to the input of second 225 MHz amplifier **38**, and to input **40** of mixer **20**. The output of amplifier **38** is, in turn, connected as an input to timesten frequency multiplier **42** which outputs a carrier frequency of 2,250 MHz. This 2,250 MHz carrier is then fed through band-pass filter **44**, which reduces the spurious, or undesired, sideband frequencies present at the output of frequency multiplier **42** to provide a clean transmitter output. Waveform A of FIG. **2** is a plot of time versus voltage at the input of video amplifier **26** and the resultant deviation in carrier frequency of transmitter **18** during any one horizontal scanning period. The back porch **46** of the composite video signal is clamped to a zero volt reference which also represents a quiescent carrier output frequency of **2250** MHz. The negative peak **48** of sync pulses **50** is 0.4 volts which results in a negative shift of 5.15 MHz of the 2,250 MHz carrier.

Blanking pedestal **52** occurs between an input of +0.1 and zero volts which is the black or blanking level of the input video, also designated as the retrace interval. A +1 volt input is required for a maximum white level **54** and results in a +12.85 MHz shift of the carrier.

The input of voltage controlled oscillator **24** is clamped by frequency corrector **14**, in a manner to be further described, to a voltage which corrects for deviations of oscillator **24** from the desired frequency of 225 MHz (the output frequency 2,250 MHz divided by 10) when the video input is 0 volts, and during an interval coincident with the back porch **46** of the video signal.

Sync clipper **34** of control **16** strips the horizontal and vertical synchronizing pulses from the incoming video signal which are then coupled as clocking pulses to the input of switching pulse generator **56**, having outputs **58, 60** and **62** coupled to control inputs **64, 66** and **68** of switches **70, 72** and **74**, respectively, or corrector **14**, and having output **76** coupled to control input **78** of sample and clamp switch **22**.

Reference standard **12** includes **45** MHz crystal oscillator **80**, the output of which is coupled to times-four multiplier **82**, and to the normally open input **84** of switch **70** of frequency corrector **14**. The output of multiplifer **82** is, in turn, amplified by 180 MHz amplifier **86** and coupled to a second input **88** of mixer **20**.

The resultant output frequency of mixer **20** is thus the difference between the 180 MHz reference frequency and the output of 225 MHz amplifier **36**. This output is also 45 MHz, assuming that the output of V.C.O. **24** is 225 MHz. Any deviation of voltage controlled oscillator **24** from 225 MHz produces a proportional change in the 45 MHz output of mixer **20**, which is coupled to the normally closed input **90** of R.F. type switch **70**, of corrector **14**.

This signal and the 45 MHz signal from reference crystal oscillator **80** are alternately sampled for approximately one-half of each horizontal scanning period, by switch **70**, having control input **64** connected to output **58** of pulse generator **56**. With 0 volts applied to control input **64**, (Waveform D), switch **70** samples the output of mixer **20**, through normally closed input **90**, for approximately a half horizontal sweep period, that is, a 32 microsecond interval **92**, centered about back porch **46** of the video signal. During the intermediate 32 microsecond interval **94** (Waveform D) centered about the midpoint of each horizontal sync period, designated T_4, a positive pulse **96** from output **58** of pulse generator **56** enables switch **70** to sample the output of reference oscillator **80** through normally open input **84**.

The output of switch **70** is coupled through 45 MHz discriminator stage **98** to the input of a second R.F. type, normally open switch **72**. Switch **72** is closed for two intervals during each horizontal scan by positive pulses **100** and **102** from pulse generator **56**, (Waveform E).

Pulse **100**, of 3.5 microseconds duration, is initiated by the trailing edge **104** of each sync pulse **106** at time T_1 (Waveform C).

The second pulse, pulse **102**, is 7.5 microseconds in width, and is centered about the midpoint of 32 microseconds sampling interval **94** (Waveform D).

Switch **72** provides sampled outputs **108** and **110** (Waveform G), being outputs of discriminator **98** responsive to the frequency of reference oscillator **80** and mixer **20**, respectively. These sampled outputs are coupled as inputs to amplifier **112**. Output **114** is connected across holding capacitor **116** during pulse **96**, and output **114** is connected in series with capacitor **116** to input **118** of DC amplifier **120** during sampling interval **92**. These alternate circuits, which enable the subtraction of the mixer derived output from the referenced signal derived output, are achieved by the operation of clamp switch **74** which grounds to circuit ground **75** the output side of capacitor **116** responsive to 7.5 microsecond pulse **122** (Waveform F) coincidence with similar pulse **102** applied to sample switch **70** (Waveform E). At other times, the output side of capacitor **116** is connected to input **118** of amplifier **120**.

The output of D.C. amplifier **120** is sampled by sample switch **22**, being closed by 1.5 microsecond pulse **124** (Waveform H) centered about the midpoint (T_2) of 3.5 microsecond discriminator sample pulse **100** (Waveform E). Sample switch **22** feeds the output of amplifier **120** representing the transmitter error to capacitor **30** from which it is applied to the frequency control input of V.C.O. **24**.

OPERATION

Initially, the frequency of transmitter **18** is calibrated to 2,250 MHz, as follows.

First, the video signal is removed from the inout of video amplifier **26**. Then sample switch **22** and clamp switch **74** of error corrector **14** are enabled by means provided internally of switching pulse generator **56**.

Under these conditions, the input of D.C. amplifier **120** is referenced to zero volts through clamp switch **74**. The output of amplifier **120** is connected, through sample switch **22**, to the input of voltage controlled oscillator **24**. Bias adjust **126** of amplifier **120** is then adjusted in the appropriate direction to calibrate oscillator **24** to a frequency of 225 MHz, or the output of transmitter **18** at 2,250 MHz.

Since the output of mixer **20** is now 45 MHz and is coupled through the normally closed input **90** of switch **70** to limiter-discriminator **98**, the discriminator may be adjusted for an approximate 0 volt output.

If preferred, switch **70** may be operated in order to connect 45 MHz oscillator **80** to discriminator **98**, and then the discriminator is adjusted for zero output.

Once the calibration is complete, each of switches **74, 70** and **22** is returned to a normal operating position, and the video input signal is reconnected.

It is assumed, for the purpose of illustration, that the calibration of voltage controlled oscillator **24** as described above, results in a positive bias voltage (V_b) at the otuput of D.C. amplifier **120** as shown in (Waveform B). Accordingly, holding capacitor **30** is charged to this value and holds the charge within very close limits during each horizontal scan interval, since the decay time of capacitor **30** is selected to be about **30** scanning periods.

Since the back porch **46** of the video signal at the input of V.C.O. **24** is referenced to this bias level, the carrier during any back porch interval is unmodulated, or at a frequency of 2,250 MHz.

To examine the operation of automatic frequency control **10**, assume initially that discriminator **98** is properly adjusted to provide an output of 0 volts upon receiving a precise 45 MHz signal from reference oscillator **80** (Waveform G). Assume further that the output frequency of V.C.O. **24** has drifted lower in frequency and therefore that the output of mixer **20** has drifted below 45 MHz. During interval **94** (Waveform D) switch **70** is operated to pass the reference signal from oscillator **80** to discriminator **98**. There will, accordingly, result a 0 voltage output **108** (Waveform G) of discriminator **98** which will be passed during interval **94** (Waveform D) by switch **72** (Waveform G) to amplifier **112** which in turn applies this potential across capacitor **116** which is at this time connected across the output of amplifier **112** by clamp switch **72**. Thereafter the output terminal of capacitor **116** is disconnected from ground **75** and during interval **92** (Waveform D), discriminator **98** is responsive to the assumed "off" frequency output of mixer **20** and thus there is applied to D.C. amplifier **120** the difference between the capacitor voltage being 0 at this time as described above, and output voltage of discriminator **98**, being a negative pulse **110**, representative of the "off" frequency output of mixer **20**. Thus the reference derived. capacitor voltage of 0 volts is simply subtracted from the mixer derived discriminator voltage, negative in this case, and the difference voltage is applied to D.C. amplifier **120**. Amplifier **120** amplifies the error **110** and reverses its polarity, applying an error correcting pulse **125**, Waveform I, through switch **22** to holding capacitor **30**. This sequence of sampling of error **110** occurs once for each sync cycle and the voltage thus derived is cyclically fed from amplifier **120** by switch **22** to capacitor **30** and thus to the control input of V.C.O. **24**, which causes its frequency to be raised to a correct value of 225 MHz.

If V.C.O. **24** tends to drift higher in frequency, the output of mixer **20** tends to become higher than 45 MHz, resulting in a positive error signal to amplifier **120**. Then each time the output is sampled by switch **22**, during back porch **46** of video input (Waveform A), a discrete negative pulse, would be applied to holding capacitor **30** to thus cause the frequency of V.C.O. **24** to lower to a correct frequency.

If there is no error in frequency and thus the outputs of discriminator **98** responsive to both the signal from oscillator **80** and mixer **20** are zero, no corrective voltage will be applied by automatic frequency control **10** to V.C.O. **24**.

If due to environmental or other effects, the discriminator output should drift, for example in a negative direction, shown by dashed lines **126** (Waveform G), this will, of course, cause a negative voltage to be applied to capacitor **110** during the sampling of reference oscillator **80**. Since, however, the same negative drift voltage will also be applied to the discriminator output during the sampling of mixer **20**, and the two voltages are subtracted by virtue of the switching of the output terminal of capacitor **110**, no net error is introduced by discriminator drift. This is true whether the drift be negative as shown by dashed line **126** or positive as shown by dashed line **128**. Thus for example, if it were assumed that discriminator **98** produced a minus 1 volt at a "on" frequency of 45 MHz and the transmitter were "on" frequency there would be a minus 1 volt across capacitor **116** during the effective sampling of referenced oscillator **80** and thereafter with a correct 45 MHz signal from mixer **20**, discriminator **98** would also output a minus 1 volt. Since the capacitor voltage is placed in series with the discriminator voltage during error sampling by D.C. amplifier **120** and the latter voltage thus subtracted from the former, a correct 0 volts, indicating a no error condition, is fed to amplifier **120**. The same process of elimination of discriminator drift as a factor is applicable when there is an actual error of voltage output representative of an "off" frequency signal from mixer **20**. In such case the voltage representative of discriminator drift appears identically in both the reference derived signal and mixer derived signal and are cancelled leaving only a voltage representative of the actual error.

The output frequency stability factor derived from a mathematical model of the FM TV transmitter is presented in the following equation.

$$d_0 = d_R + (dv/K_0) + (dL/5)\,(d_D - d_R) + (1/K_0)\,[K_C d_C + K_B d_B + K_S d_S]$$

Where

d_0 — OUTPUT FREQUENCY STABILITY FACTOR

K_0 — OPEN LOOP GAIN (K_0 1)

d_R — REFERENCE OSCILLATOR STABILITY FACTOR

d_V — VCO STABILITY FACTOR

d_L — LIMITING ERROR FACTOR

d_D — DISCRIMINATOR STABILITY FACTOR

$K_C d_C$ — CLAMPING ERROR FACTOR

$K_B d_B$ — FREQUENCY CONTROL BIAS DRIFT FACTOR

$K_S d_S$ — SAMPLING ERROR FACTOR

Thus it is seen that the steady-state frequency stability (d_0) is a function of the following factors:

1. The stability factor d_R of the reference oscillator;

2. The term dv/K_0 representing the stability factor of the V.C.O. divided by the open loop gain;

3. The disturbance term $(dL/5)\,(d_D - d_R)$ resulting from imperfect limiting which causes the discriminator zero drift to affect the stability, although this factor is reduced by the down conversion ratio;

4. The disturbance term, $(1/K_0)[K_C d_C + K_B d_B + K_S d_S]$, representing clamping inaccuracy, frequency control bias voltage drift and sampling error.

The actual effect of these factors is not large and in practice the carrier frequency of a transmitter controlled in frequency by the invention may be held to within less than 0.01 percent of the desired frequency.

What is claimed is:

1. An automatic frequency control for an F.M. radio frequency transmitter which transmits a signal having a periodically recurring period in which a constant frequency is generated, comprising:

reference frequency signal generating means for generating a stable signal at a selected frequency:

signal means responsive to the frequency of said transmitter for providing a frequency output corresponding to said selected frequency when said transmitter is "on" frequency:

discriminating means responsive to an input signal for providing a pulse output of a polarity representative of whether an input signal is above or below said selected frequency and of a magnitude proportional to the magnitude that the input signal deviates from said selected signal:

switching means for selectively feeding said output of said signal means to said discriminating means during said periodically recurring periods and for feeding the output of said reference frequency signal generating means to said discriminating means between said periods:

difference means, including means for temporarily storing the output of said discriminating means responsive to one of its signal inputs, for providing an error signal representative of the difference between outputs of said discriminating means responsive to successive signals from said reference frequency signal generating means and said signal means, respectively; and

coupling means responsive to said difference means for applying said error signal to said transmitter for correcting its frequency.

2. An automatic frequency control as set forth in claim 1 further comprising a long time-constant capacitor adapted to feed a video, frequency modulating, signal to said transmitter and said coupling means comprises means for feeding said error signal to the output side of said capacitor.

3. An automatic frequency control as set forth in claim 2 wherein said difference means comprising:

a second capacitor having an input terminal coupled to the output of said discriminating means and an output terminal connected to said coupling means; and

second switching means for connecting said output terminal of said second capacitor to ground for the said temporarily storing of the output of said discriminating means for a discrete period;

whereby said second capacitor is charged to a value of one of its signal inputs when said output terminal of said second capacitor is grounded, and thereafter with said output terminal ungrounded and with the occurrence of the other of the signal inputs to said discriminating means, the resulting signal output is combined with the stored voltage across said second capacitor as an error voltage to said coupling means and to said long time-constant capacitor.

4. An automatic frequency control as set forth in claim 3 wherein said voltage temporarily stored across said second capacitor is a voltage provided responsive to said reference frequency signal generating means.

5. An automatic frequency control as set forth in claim 4 further comprising:

a video signal source adapted to provide a video signal with periodic synchronizing pulse outputs during retrace intervals and its circuit output is connected to the input terminal of said long time-constant capacitor;

third switching means for selectively coupling the output of said discriminating means to the input of said second capacitor; and

switching control means responsive to said synchronizing pulse outputs of said video signal source for controlling said switching means, said second switching means, and said third switching means, whereby:

the signal output of said dicriminating means responsive to the output of said reference frequency signal generating means is applied through said third switching means across said capacitor to ground through said second switching means during a selected period between said periodically recurring periods; and

said signal from said signal means is connected through said switching means to said discriminating means and the responsive output of said discriminating means is connected through said third switching means in series with said second capacitor to said coupling means during said periodically recurring periods corresponding to a portion of each retrace interval of said video signal.

6. An automatic frequency control as set forth in claim 5 wherein said recurring periods correspond to the "back.porch" portion of the retrace interval portion of said video signal.

7. An automatic frequency control as set forth in claim 6 further comprising fourth switching means connected in circuit with said coupling means and said switching control means includes means coupled to said fourth switching means for operating said fourth switching means for selectively coupling the said error signal to the output side of said long time-constant capacitor only during a portion of each said "back porch" portion of said video signal.

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