CHARACTERIZED FAST TUNING CONTROL FOR A TELEVISION SYSTEM

The fast tuning subsystem for switching television channels includes a tuner (124) having a VCO (130) responsive to voltage applied to its control input for determining the channel frequency the tuner (124) selectively receives. Predictive means (128, 140) supplies a selected predicted voltage signal, corresponding to a signal stored in memory (138), to the control input to slew the channel frequency rapidly to the corresponding selected frequency. An error detector (146, 148) generates a tuning error signal indicative of the error of the tuner with respect to the selected channel frequency. Feedback means (i.e., the phase locked loop (144)) combines the tuning error signal with the selected predicted voltage signal to provide a control signal to the VCO (130). The predictive means is substantially decoupled from the feedback means to prevent the slew mode from substantially perturbing the feedback mode. A method for predicting control voltages for slew control is also directed, preferably utilizing a combination binary and linear search.
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CHARACTERIZED FAST TUNING
CONTROL FOR A TELEVISION SYSTEM

The present invention relates to television systems and more particularly to a fast tuning subsystem for switching channels in a television system. Still more particularly it relates to such subsystem in which a selected substitute television signal in a substitute channel can be indistinguishably substituted for one or more normal television signal in respective normal channels, as for market research purposes.

Background of the Invention

Marketing research techniques have been developed in which a substitute television signal channel, containing a commercial the effectiveness of which is to be assessed, is substituted for a normal television channel in homes of selected test viewers, and the effectiveness of the commercial evaluated. This allows the promoter of a service or product to have the reaction of a small, demographically controlled panel of test viewers assessed before the wide airing of an ineffective commercial.

One example of such a television signal substitution system is disclosed in United States Patent No. 4,404,589. As there disclosed, substitute television program signals are transmitted in at least one substitute channel along with signal substitution control signals. A control box at each test viewer receiving station responds to the signal substitution control signals by selectively switching a substitute television program into a normal channel. The signal substitution control signals include a number of different terminal command signals and a number of different event command signals. Each of the terminal command signals includes a respective test viewer address signal for identifying a respective test viewer receiving station and a number of event identification signals identifying respective signal substitution
events in which this terminal is participating. Each of
the event command signals includes a respective event
address signal corresponding to a respective event, an
appropriate substitution control command; a substitute
channel identification signal, and one or more normal
channel identification signals for identifying a normal
channels into which a substitute television program is
to be switched. The current event command signals
corresponding to each allowable event address are stored
in the terminal for latter correlation to the terminal's
participation event list and to the viewer's selected
channel signal. When the viewer selected channel
corresponds to a normal channel identification signal
associated with a current event command whose event
address signal corresponds to an event in which this
terminal is participating, a substitute channel is
substituted for the channel selected by the viewer for a
period determined by the event command signals. The
subsequent responses, such as purchases, of the
respective viewers are then individually tabulated and
analyzed against the responses of viewers receiving the
normal signals.

When a viewer changes channels on a modern
television set, the channel change is carried out in,
for example, about a quarter of a second. The change is
accompanied by momentary disruption of the picture and a
sound pop or a period of sound muting. When a market
research company causes a channel substitution, it is
desirable that the substitution be carried out so
quickly and unobtrusively as to be imperceptible to the
normal test viewer. If the substitution were
distinguishable, it could, at least subconsciously,
influence the response of the test viewer to the
commercial. That is, were the viewer to know or suspect
he was receiving a test commercial, he might react in a
manner in which he believes he is expected to react,
rather than acting normally, skewing the test of his
normal response. Therefore, it is desirable that the tuning be accomplished extremely rapidly so as to be indistinguishable. More specifically, the transition time between channels should be kept well under 100 microseconds to prevent an audible pop due to loss of the television signal's frequency modulated intercarrier sound subcarrier. The normal and substitute channel tuning should be very accurately matched to ensure no shift in picture quality, particularly that of the chroma signal. The transition should be timed to occur during the vertical blanking interval between picture fields so that the change is not seen by the viewer.

Switching channels may require a large frequency charge in the tuner. For example, if the normal channel is a low VHF channel (wherein Channel 2 has a picture carrier frequency of 55.25 MHz) and the substitution channel is a high UHF channel (wherein Channel 70 has a picture carrier frequency of 807.25 MHz), the tuner might have to slew through more than 700 MHz. The vertical blanking interval of standard NTSC video, during which the substitution is to be effected, takes 1.3 milliseconds. The factor that is most critical in making the substitution indistinguishable is the sound. The audio frequency modulation receiver is not tuned to the sound carrier, but is tuned to the 4.5 MHz intercarrier beat generated between the picture carrier and the sound carrier in each VHF and UHF channel. When the tuner tunes between channels the intercarrier beat disappears because both the picture and sound carriers are no longer simultaneously present in the IF bandpass. When the sound FM receiver has no signal applied, its internal limiter amplifier amplifies noise up to the full amplitude level. This causes the pop heard during viewer controlled channel changing. This presents no problem when the viewer changes channels, for it is expected. However, when produced during signal substitution, it alerts the viewer to the fact of substitution.
In order to avoid the effect of noise during signal substitution, the channel change should be sufficiently fast that the human ear cannot distinguish it. The total energy of the noise burst is the integral of power over time. The human ear is essentially logarithmic in perception and can hear extremely low energy noise pulses. To make the noise attendant a channel change unobtrusive, the change should be accomplished in less than about 60 microseconds. Not only is extremely fast tuning required, but also the tuning must be extremely accurate to recover the 4.5 MHz intercarrier beat. Due to the close proximity of the sound carrier in an adjacent channel, a maximum error of about $\pm$ 500 KHz is required for both the picture and sound subcarriers of the substitute channel to be within the television bandpass.

A modern television tuner employs a voltage controlled local oscillator which determines the input frequency to which the tuner is tuned. Previous signal substitution systems have employed a cable television distribution system with a control box for channel switching located at each test viewer's home. A voltage divider network was established based upon predicted tuning voltages necessary to cause the local oscillator to translate each individual channel's frequency to that of the television receiver. The tuner was made to select a particular channel very quickly by jamming the appropriate control voltage into the local oscillator. This is known as jam tuning. Thus, by directing an electronic switch in the local oscillator control circuit to change from a normal channel voltage to the substitute channel voltage, the substitution could be made. This prior art tuner controller system was predictive in nature in that the channel tuning control voltages corresponding to the desired input channels were determined by testing prior to or during installation of the tuner at the home of the test
viewer. A problem encountered was that with time the correct tuning voltages tended to drift. Drifting results in frequency errors which cause loss of picture definition, and color, hue or saturation changes. The automatic fine tuning circuitry in the television set of the test viewer may correct the error, but it would correct the error in a visible manner due to its slower operating speed. With time, the drifting became so extreme as to require the controller boxes be removed from test viewer homes for recalibration.

**Brief Summary of the Invention**

The present invention provides an improved fast tuning subsystem combining accurate jam tuning with feedback to take care of long term drift. A phase-locked loop feedback system samples the output of the local oscillator in the tuner to determine if a frequency error is present. The frequencies of the channels are generally very accurately maintained, but significant frequency error could arise from the tuner in the controller box. If such an error were present, the phase detector would provide an error signal for combination with the predicted voltage signal and application of the resultant voltage signal to the voltage controlled local oscillator of the tuner thereby causing the tuner to provide the desired frequency output. In this controller system, the predicted or characterization voltages for each frequency is stored in a look-up table in a memory associated with a microprocessor. Each of the predicted voltage signals is predetermined for the respective channels for a particular tuner to be substantially equal at the time of characterization to the voltage applied to the voltage controlled oscillator that provides a null tuning error signal. In the predictive, feed forward portion of the control operation, the microprocessor, upon selection of a substitute channel, applies a signal
representative of that characterization voltage to a precision digital to analog converter which applies its analog output to the voltage controlled oscillator. With time, due to aging of the components, the voltage values for the various frequencies stored in the look-up table become somewhat erroneous. This results in the voltages applied during the feed forward mode becoming incorrect for the various channels, and the relatively slow operating phase locked loop adding a corrective offset to assure accurate tuning to the desired frequency. The response time of the feedback mode is made substantially slower than that of the predictive mode so as to decouple the one control from the other.

According to one aspect of the invention a fast tuning subsystem is used in switching from a current channel to a selected channel of a television system. The tuning subsystem includes a tuner for selecting a channel to be received, the tuner including a voltage controlled oscillator having a control input for determining, in response to voltage applied to its control input, the channel frequency the tuner selectively receives. Predictive means supplies a selected predicted voltage signal to the control input of said oscillator, the predictive means including an associated memory in which is stored signals corresponding to respective voltage signals predicted for applying to the oscillator to tune the tuner to receive the channel frequencies of the respective channels. The oscillator is responsive to a selected predicted voltage signal to slew the channel frequency at a rapid slew rate to the frequency corresponding to said selected predicted voltage signal. An error detector generates a tuning error signal indicative of the frequency error of the tuner off the frequency for the selected channel. A feedback circuit combines the tuning error signal with the selected predicted voltage signal to provide a control signal at the control input
for adjusting the channel frequency to reduce said tuning error. The operation of the predictive means is substantially decoupled from the operation of the feedback circuit to prevent transients in the slew mode of the predictive means from substantially perturbing the feedback mode.

It is an aspect of the invention that the channel frequency is slewed sufficiently fast that the total spurious intercarrier sound energy detected during the slew mode is sufficiently small as to be inaudible to a viewer, and where transients occasioned by operation of the predictive means do not perturb the operation of the feedback circuit so as to cause transient visible degradation of picture as observed by a viewer.

In another aspect the response time of the feedback circuit is made sufficiently slower than the response time of the predictive means as to result in substantial decoupling. Preferably, the response time of said feedback circuit be at least four orders of magnitude slower than the response time of said predictive means. In another aspect the error detector means includes means for limiting the error signal in magnitude during the interchannel slewing, preferably a phase-error detector limiting the error signal to $\pm \omega$ radians during interchannel slewing.

According to another aspect, the error detector compares the frequency of the voltage controlled oscillator with the reference to generate the tuning error signal. According to another aspect, such an error detector comprises a reference oscillator for generating a reference signal at a frequency that is $1/N$ times the frequency of the voltage controlled oscillator at the frequency at which the tuner selectively receives respective channels, where $N$ is a different respective integer for each channel. The error detector further includes divide by $N$ means for dividing the output
frequency of the voltage controlled oscillator by N and means for comparing the divided by N signal with the reference signal to produce the tuning error signal. Preferably, the means for decoupling includes a loop filter in circuit with the feedback means.

Another important aspect is the characterizing of the predictive control signal. This must be done accurately and rapidly in the course of manufacture or the cost of characterization of a large number of channels could well become excessive. According to the present invention, the control signals for each tuner are characterized by, for each channel, applying a respective preliminary control voltage signal estimate to the respective control input, utilizing the resulting tuning error signal from the error detecting means to determine the control voltage signal at the control input so as to reduce the tuning error signal to less than a predetermined magnitude, and storing in the memory means a signal corresponding to the determined control voltage as a signal corresponding to a respective predicted control voltage signal.

In another aspect the error detector and the feedback means comprise a phase-locked loop generating a tuning error signal indicative of phase error, the derivative of the tuning error signal is utilized to determine successive incremental updates to the preliminary control voltage signal so as to reduce the tuning error signal to less than a predetermined magnitude, and a signal corresponding to the then characterized preliminary control voltage signal is stored in memory as corresponding to the determined control voltage signal.

In another aspect the determination of the characterized control voltage signal is made for each channel by applying a respective preliminary control voltage signal to the control input, utilizing the resulting tuning error signal to modify the preliminary
control voltage signal by a predetermined amount to produce a modified preliminary control voltage signal, applying the modified preliminary control voltage signal to said control input, and repeating the steps until the resulting tuning error signal is less than the predetermined magnitude.

In another aspect each predetermined amount is in accordance with a binary search process wherein successive predetermined amounts decrease by half. In another aspect each predetermined amount is substantially the same in accordance with a linear search process. In still another aspect each predetermined amount is in accordance with a binary search process for a number of steps wherein successive predetermined amounts decrease by half and is thereafter in accordance with a linear search process wherein each said predetermined amount is substantially the same.

Other aspects, objects and advantages of the invention will become apparent from the following detailed description, particularly when taken in conjunction with the accompanying drawings.

**Brief Description of the Drawings**

FIG. 1 is a diagram, partly schematic and partly block in nature, illustrating a prior art fast tuning subsystem having predictive tuning voltage control;

FIG. 2 is a block diagram illustrating a fast tuning subsystem according to the present invention having not only predictive tuning voltage control but also a slowly operating phase-locked loop for improving the accuracy of the tuned frequency over time; and

FIG. 3 is a block diagram illustrating the characterizing of the subsystem in the course of its production.

Corresponding reference characters indicate corresponding components throughout the several figures.
Detailed Description of the Preferred Embodiments

A control box is used in a television system for switching between substitute channels and normal channels. A control box is located, for example, at the home of each test viewer and provides the signal input to the television set of the test viewer. Each box is under the control of a remote supervisory controller which selects, for example, commercials in a substitute channel for insertion into a selected normal channel for the purpose of, for example, testing the effectiveness of each commercial using an appropriately selected panel of viewers. An example of a television system with multi-event signal substitution is shown and discussed in the above-mentioned United States Patent No. 4,404,589.

As mentioned above, it is desirable that a test viewer not know when a substitute commercial is inserted in place of a commercial of a normal television channel. The judgment of the test viewer could be influenced, if only subconsciously, if the substitution were distinguishable. One way the test viewer could distinguish a substitution is interference with or disruption of the picture or sound. Such interference typically occurs when a television viewer changes normal channels because the electronic tuner of conventional television sets usually takes a fraction of a second to tune to the chosen channel. During this time the 4.5 MHz intercarrier sound signal disappears resulting in a popping noise because the limiter amplifier in the audio FM receiver of the television set 22 amplifies random thermal noise and intervening spurious signals up to the full amplitude level. One aspect of the present invention is the ability to switch between channels so swiftly that the act of signal substitution is indistinguishable to the test viewer.

A previously used predictive tuning system is shown in FIG. 1. A control box 100 as previously
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employed in fast tuning a cable system is there shown. A voltage divider 102 is formed by a number of potentiometers 104 each of which is factory calibrated for the estimated tuning voltage of a respective one of the normal and substitute channels (shown as normal channels 2-13 and substitute channels A and B, respectively). A switch SW3 permits the test viewer to select a normal channel. An electronic switch SW4 is under the control of a signal from a substitute control circuit 106 as provided by way of a data receiver 107 which extracts the control signals from signals received over a cable 108 from a testing facility. The switch SW4 switches among the viewer selected normal channel and the two substitute channels to apply the respective estimated control voltage to a tuner or frequency converter 110. The tuner 110 includes a local oscillator (L.O) 112 and a mixer 114. The local oscillator 112 is a voltage controlled oscillator oscillating at a frequency determined by the control voltage applied to its control input terminal from the switch SW4. The output of the local oscillator 112 is mixed in the mixer 114 with the signal on the cable 108 to produce beat frequencies. A beat frequency for the channel to be detected is at an intermediate frequency which is later converted by a second converter 115 to the frequency to which the viewer's television set 116 is tuned, such as that of a channel not used in the local broadcast area, usually channel 3 or channel 4. Upon operation of the switch SW4 during a vertical blanking interval, the predetermined control voltage for tuning to the desired channel is jammed into the tuner 110. Among the shortcomings of this system are that potentiometers are difficult to adjust precisely during factory calibration, and the system offers no provision for compensation for drift due to the aging of components. With time, the frequency errors of this predictive system became so intolerable that the various
channels could not be properly tuned, necessitating the return of the boxes 100 to the factory for recalibration.

A fast-tuning control subsystem according to the present invention is illustrated in FIG. 2. The subsystem includes a box 120 for receiving signals over a signal transmission medium, which includes a cable 122 in this embodiment. The signals are received by a fast tuner or frequency converter 124 and a data receiver 126. The tuner 124 separates the television signals; whereas the data receiver detects and separates the control signals received from the supervisory testing facility. The fast tuner 124 is under the control of a microprocessor 128 and has two phases or modes of operation, a jam phase and a feedback phase.

The first phase is the jam phase where a predicted control voltage for the desired channel is applied to the local oscillator (L.O.) 130 of the tuner 124. The local oscillator 130 is a voltage controlled oscillator oscillating at a frequency determined by the control voltage applied to its control input terminal. The output of the local oscillator 130 is mixed in a mixer 132 with the signals received on the cable 122 to produce a beat frequency that for the selected channel corresponds to a fixed intermediate frequency. The signals at the intermediate frequency are then converted by a second converter 133 to a frequency to which the viewer's television set 134 is tuned. Signals corresponding to respective control voltages for tuning the various channels, both substitute and normal, are contained in a channel table 138 in an addressable read only memory associated with the microprocessor 128. The various voltages are predetermined as part of a characterization process performed as a last step of the manufacture of the control box, 120 as will be explained further below in connection with FIG. 3. The corresponding signals are stored in the memory table 138 at respective addresses where they are addressed in
accordance with an appropriate channel selection algorithm 136 of the microprocessor 128 under the control of a substitution controller 137 of the microprocessor, acting under instructions from the data receiver 126. The microprocessor 128 also receives a signal indicating the channel selection made by the television viewer, as from a selector switch, not shown. Upon channel selection, the microprocessor 128 calls up the corresponding control signal from the memory table 138 and applies the corresponding predetermined, estimated or predicted voltage signal (in digital form) to a precision digital to analog converter (DAC) 140 having 12-14 bit accuracy. The DAC 140 converts the signal to analog form and applies it to the local oscillator 130 by way of a summing circuit 142. The memory table 138 used to store the predicted signal is an erasable programmable read only memory such as an EPROM or an EEPROM. These programmable devices contain a channel table 138 custom programmed to contain signals corresponding to accurate estimates of the frequency control voltage required for each individual frequency converter module 124.

The second phase of tuning is the feedback mode employing an error detection system to determine the difference between the desired frequency output of the local oscillator 130 and actual frequency output. It can usually be safely assumed that the input signal has a reasonably accurate and stable frequency and that significant frequency error results only from the local oscillator 130 in the tuner 124. Thus any frequency error of the tuner output can be accurately assessed by measuring the frequency output of the local oscillator 130. The output of the local oscillator serves as an input to a phase-locked loop (PLL) 144 including a divide by N divider 146 controlled by the microprocessor 128 for selecting an integer N by which the tuner output frequency is divided to reduce it to a frequency that is
supposed to match that of a crystal reference oscillator 148. By comparing the phase of the reference oscillator 148 and the phase of the output of the divider 146 using a phase detector 150, an error signal is established for feeding back through a loop filter 152 to the summer 142 for combining with the output of the DAC 140 to bring the local oscillator precisely on the frequency for tuning in the desired channel.

This second or feedback mode of operation is substantially decoupled from the first or jam mode of operation in order that the two modes not interfere with one another. It would be counterproductive for the phase-locked loop to be trying to synchronize the oscillator frequency with the reference while the predicted control voltage is slewing the frequency. More specifically, the act of slewing or jamming provides a random unbalance of the phase-locked loop 144 which the phase-locked loop seeks to reduce. By making the response time of the phase-locked loop 144 sufficiently long relative to the response time of the predictive jamming mode, the two modes may be substantially decoupled. Specifically, the response time must be sufficiently long so that the rate of correction of the random phase unbalance be sufficiently slow so that the resulting transient local oscillator frequency offset be bounded to prevent significant transient visible picture degradation. The response time of the jamming mode is made sufficiently rapid as to slew the tuner to the new channel so fast that the total intercarrier sound noise energy detected during the slew mode is so small as to be inaudible to the viewer. The transients generated as the tuner slews through intervening channel frequencies do not perturb the operation of the feedback means so much as to cause transient visible degradation of the picture observed by a viewer immediately after the jam mode. A response time for the jam mode of less than 60 microseconds has
been found appropriate and is readily achieved by appropriate choice of a common local oscillator 130 and a common DAC 140. A response time for the phase-locked loop 144 four orders of magnitude slower than the response time of the predictive slewing circuit has proven effective in providing adequate decoupling. In the specific embodiment actually used, a settling time of the order of three seconds for the phase-locked loop 144 provided effective decoupling. Such settling time for the phase-locked loop 144 is provided by the filter constants of the loop filter 152. The error detector 150 includes means for limiting the error signal during interchannel slewing to further limit the error that must be corrected. This is an inherent property of a phase-locked loop, which limits the error signal to less than \( \pm \pi \).

Characterization

Characterization is a process performed at the end of the production cycle of each control box 120, or during the recalibration of each control box 120, in which the table of predictive tuning voltages for each normal and substitute channel, called the channel table, is determined and entered in the memory 138. It is these tuning voltages which are jammed into the local oscillator 130 of the tuner 124 to cause the tuner to slew quickly to the chosen channel. These voltages are predetermined with high accuracy because the tuner must arrive promptly within a narrow range of the desired channel in order to prevent a correction in the feedback mode of an initial frequency error sufficient to cause visible picture degradation. Within 100 kHz has proven adequate. In order to realize the desired accuracy, which may approach one part in 10,000, a digital to analog converter having 12 to 14 bit accuracy is provided.

A problem with this factory characterization is that it is a very extensive operation because each
individual box 120 must be individually characterized for each of up to about 70 channels. Up to 1000 decisions may be necessary to characterize each box 120. The phase-locked loop 144 settles to equilibrium relatively slowly, taking at least several seconds. This is much too slow to be able to use the equilibrium condition in making these characterization decisions in a low cost manner. As will be explained in greater detail below, these decisions are each more efficiently made in a fraction of a second using a process based upon the derivative of the output of the phase detector 150. The process depends upon the fact that frequency is the instantaneous derivative of phase.

There are numerous considerations in obtaining the desired accuracy. A first consideration is that all critical components of a control box 120 must be used in the characterization of that box. That is, at least the digital to analog converter 140, the frequency converter 124 and the phase-lock loop 144 of the control box 120 are actually used in its characterization. This is because the required accuracy is so high that minute differences which could occur due to the use of different groupings of components cannot be tolerated. A second accuracy consideration is burn in and stabilization. To achieve the required accuracy, the control box 120 is brought up to its final operating temperature and allowed to operate in at that temperature until the components reach thermal equilibrium. A third area of concern where extreme accuracy is required relates to the linearity and hysteresis of the components, such as resistors and capacitors.

In order to achieve high speed and at the same time remove the effects of hysteresis, the characterization search for the estimated tuning voltage for each channel is divided into two parts. The first part is a high speed binary search. A crude estimate of
the channel tuning voltage is mode initially, but
typically an eight bit binary search is carried out to
get a more accurate estimate of the tuning voltage for
the channel. Binary or dichotomizing searches are well
known to those of skill in the art and need not be
further discussed herein. Such a search involves
stepping the test signal in the proper direction by
amounts successively decreasing by half to narrow the
error. To the extent that components in the circuit
exhibit hysteresis or any degree of thermal memory, the
result of the binary search is not accurate even when
carried to small steps.

The second part of the characterization search
involves backing off in the test value some small extent
and then proceeding to sweep up through the estimated
value (resulting from the binary search) using a linear
and constant velocity sweep. Through the use of a
linear and constant velocity sweep, all hysteresis
effects are aligned in a common direction for all the
channels characterized. Any residual hysteresis error
is reduced to a constant error term, like the error due
to characterizing the box in a temperature environment
slightly different than ambient temperature of a test
viewer's home, and can readily be removed by the PLL
control loop 144.

To implement the characterization process, a
characterization test jig 154 is used. The test jig 154
is connected between the output of the phase detector
150 and the microprocessor 128. The test jig includes a
differentiator 156 and a polarity discriminator 158 for
detecting the sense of tuning error and an EPROM
programmer 160 and a characterization control computer
162 for carrying out the test sequence. An incremental
weighting algorithm 164 is included in the
microprocessor 128 itself. A switch SW5 switches the
input of the loop filter 152 to ground from its
connection to the phase detector 150 to assure that the
phase-lock loop 144 does not simultaneously try to correct incremental tuning voltage steps introduced during the characterization process. The phase detector thus senses only the error of the control voltage applied to the summer 142 by the DAC 140.

The characterization control computer 162 puts the test jig 154 through its program sequence. The incremental weighting algorithm responds to the sense of the error as determined by the polarity discriminator 162. It responds by putting out an incremental signal corresponding to an increment or decrement in the control signal to the local oscillator 130. This signal is summed by a summer 166 with a tentative predicted voltage signal from the channel table 138. The initial tentative predicted voltage signals are stored in a test read only memory (ROM) which is plugged into the microprocessor 128 for test purposes to provide initial tentative predicted voltage signals for each channel. As each incremental signal is added to a tentative predicted voltage signal, the sum is stored in a random access memory as a current tentative predicted voltage signal. When the test program is completed for all channels, the EPROM programmer is enabled to put the final predicted voltage signals in an EPROM. The EPROM is then physically inserted in the microprocessor 128 in lieu of the test ROM.

Regarding the necessary speed of the decision making during both the binary search mode and the linear sweep mode of the characterization process for each channel, there may be as many as 1000 decisions necessary to fully characterize each tuner. For the sake of economy, each decision must be made within a small fraction of a second. This speed cannot be obtained by allowing the phase locked loop 144 to settle to accurate values because the time constant of the phase-locked loop itself is many seconds. On the other hand, frequency is the instantaneous derivative of
phase. In a search process, all that is required for each decision is a determination of the sense of any error; that may be determined by observing whether a currently observed phase error is increasing or decreasing. This is determined from the slope of the instantaneous derivative of phase by the differentiator 156 which determines the derivative and the polarity discriminator 158 which determines sense. Put more basically, the output of the differentiation is proportional to the rate of change of the phase. If the slope is downward, it means the current value is above the proper value. On the other hand, if the slope is upward, the present value is below the proper value. In this way simple binary decisions can be made rapidly.

In the binary search mode, the incremental weighting algorithm 164 puts out incremental signals wherein each signal after the first is half the value of the preceding incremental signal and of sense determined by the signal from the polarity discriminator 158. The binary search is programmed for eight jumps or tests. After the binary search the linear search continues by fixed increments until the sense changes. That determines the final predicted voltage signal. Thus, the resulting table of tuning voltages is a merge of the invariant field and the accumulated increments to create a channel table, custom to each control box 120. This table is burned into a nonvolatile read only memory, EPROM, and assembled into the memory 138 of each of the microprocessor assembly 128. As critical components age, the control boxes 120 may be returned occasionally for recalibration.

Although a preferred embodiment of the invention has been disclosed in some detail, various modifications may be made therein within the scope of the invention. For example, although in the preferred embodiment the system has been designed for operation over cable, the invention may also be used with over-the-air signals.
What Is Claimed Is:

1. A fast tuning subsystem for use in switching from a current channel to a selected channel of a television system, said tuning subsystem comprising a tuner for selecting a channel to be received, said tuner including a voltage controlled oscillator having a control input for determining, in response to voltage applied to said control input, the channel frequency said tuner selectively receives, and predictive means for supplying a selected predicted voltage signal to said control input of said oscillator, said predictive means including an associated memory means in which is stored signals corresponding to respective voltage signals predicted for applying to said oscillator to tune said tuner to receive the channel frequencies of the respective channels, and further including means interconnected between said memory means and said control input of said oscillator for applying one of said respective predicted voltage signals as said selected predicted voltage signal to said control input of said oscillator, said oscillator being responsive to said selected predicted voltage signal to slew the channel frequency at a rapid slew rate to the frequency corresponding to said selected predicted voltage signal, characterized by error detecting means, including a reference, for generating a tuning error signal indicative of the tuning error of the tuner off the frequency for the selected channel; feedback means for combining said tuning error signal with said selected predicted voltage signal to provide a control signal at said control input for adjusting said channel frequency to reduce said tuning error; and means for substantially decoupling the operation of said predictive means from the operation of said feedback means to prevent transients in the slew mode of said predictive means from substantially perturbing the feedback mode of said feedback means.
2. A fast tuning subsystem according to Claim 1 characterized in that said means for substantially decoupling causes the rate at which the channel frequency is slewed by said predictive means to be sufficiently fast that the total intercarrier sound noise energy detected during the slew mode is sufficiently small as to be inaudible to a viewer, whereby transients occasioned by operation of said predictive means do not perturb the operation of said feedback means as to cause transient visible or audible degradation of picture or sound as observed or heard by a viewer.

3. A fast tuning subsystem according to either one of Claims 1 and 2 characterized in that said means for substantially decoupling makes the response time of said feedback means sufficiently slower than the response time of said predictive means as to result in said substantially decoupling.

4. A fast tuning subsystem according to Claim 3 characterized in that said means for substantially decoupling makes the response time of said feedback means at least four orders of magnitude slower than the response time of said predictive means.

5. A fast tuning subsystem according to any one of Claims 1 to 4 characterized in that said error detecting means includes means for limiting the error signal in magnitude during said interchannel slewing.

6. A fast tuning subsystem according to Claim 5 characterized in that said error detecting means comprises a phase-error detector limiting said error signal to ±π radians during said interchannel slewing.

7. A fast tuning subsystem according to any one of Claims 1 to 6 characterized in that said memory means comprises an addressable memory storing at respective addresses therein a plurality of digital data signals corresponding to predicted voltage signals for respective channels that may be selected.
8. A fast tuning subsystem according to any one of Claims 1 to 7 characterized in that each of said predicted voltage signals is predetermined for the respective channels for the particular said tuner to be substantially equal at the time of predetermination to the voltage applied to said voltage controlled oscillator that provides a null tuning error signal.

9. A fast tuning subsystem according to any one of Claims 1 to 8 characterized in that said error detecting means includes means for comparing the frequency of said voltage controlled oscillator with said reference to generate said tuning error signal.

10. A fast tuning subsystem according to Claim 9 characterized in that said error detecting means comprises a reference oscillator for generating a reference signal at a frequency that is 1/N times the frequency of said voltage controlled oscillator at the frequency at which said tuner selectively receives respective channels, where N is a different respective integer for each channel, means responsive to said voltage controlled oscillator for dividing the output frequency thereof by N, comparison means for comparing the divided by N signal with said reference signal to produce said tuning error signal.

11. A fast tuning subsystem according to Claim 10 characterized in that said means for decoupling includes a loop filter in circuit with said feedback means.

12. A method for predicting control voltages for a slew control for a fast tuning subsystem for use in switching from a current channel to a selected channel of a television system, the tuning subsystem comprising a tuner for selecting a channel to be received, said tuner including a voltage controlled oscillator having a control input for determining, in response to a control voltage applied to said control input, the channel frequency said tuner selectively
receives, and a slew control for supplying a selected predicted control voltage signal to said control input of said oscillator, said slew control including an associated memory means for storing signals corresponding to respective control voltage signals predicted for applying to said oscillator to tune said tuner to receive the channel frequencies of the respective channels, and further including means interconnected between said memory means and said control input of said oscillator for applying one of said respective predicted control voltage signals as said selected predicted control voltage signal to said control input of said oscillator, said oscillator being responsive to said selected predicted control voltage signal to slew the channel frequency at a rapid slew rate to the frequency corresponding to said selected predicted control voltage signal, error detecting means, including a reference, for generating a tuning error signal indicative of the tuning error of the tuner off the frequency for the selected channel, and feedback means for combining said tuning error signal with said selected predicted control voltage signal to provide a control signal at said control input for adjusting said channel frequency to reduce said tuning error, characterized by, for each channel, applying a respective preliminary control voltage signal to said control input, utilizing the resulting tuning error signal from said error detecting means to determine the control voltage signal at said control input as reduces the tuning error signal to less than a predetermined magnitude, and storing in said memory means a signal corresponding to said determined control voltage as a signal corresponding to a respective predicted control voltage signal.

13. A method according to Claim 12 characterized in that the error detecting means and the feedback means comprise a phase-locked loop generating a
tuning error signal indicative of phase error, the
derivative of the tuning error signal is utilized to
modify the preliminary control voltage signal to produce
a modified preliminary control voltage signal, and a
signal corresponding to the then modified preliminary
control voltage signal is stored in memory as
Corresponding to said determined control voltage signal.

14. A method according to either one of
Claims 12 and 13 characterized in that said
determination of said determined control voltage signal
is made for each channel by applying a respective
preliminary control voltage signal to said control
input, utilizing the resulting tuning error signal to
modify the preliminary control voltage signal by a
predetermined amount to produce a modified preliminary
control voltage signal, applying the modified
preliminary control voltage signal to said control
input, and repeating the steps until the resulting
tuning error signal is less than said predetermined
magnitude.

15. A method according to Claim 14
characterized in that each said predetermined amount is
in accordance with a binary search process wherein
successive predetermined amounts decrease by half.

16. A method according to Claim 14
characterized in that each said predetermined amount is
substantially the same in accordance with a linear
search process.

17. A method according to Claim 14
characterized in that each said predetermined amount is
in accordance with a binary search process for a number
of steps wherein successive predetermined amounts
decrease by half and is thereafter in accordance with a
linear search process wherein each said predetermined
amount is substantially the same.
INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER
According to International Patent Classification (IPC) or to both National Classification and IPC
INT. CL. 8 H04B 1/16
U.S. CL. 455/182

II. FIELDS SEARCHED

<table>
<thead>
<tr>
<th>Classification System</th>
<th>Classification Symbols</th>
</tr>
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<tbody>
<tr>
<td>U.S.</td>
<td>455/182-186</td>
</tr>
<tr>
<td></td>
<td>358/191.1</td>
</tr>
</tbody>
</table>

Documentation searched other than Minimum Documentation to the extent that such Documents are included in the fields searched.

III. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of Document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to Claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>US, A, 4,525,866, (Templin), 25 June 1985, see column 4, line 52, to column 5, line 25.</td>
<td>1</td>
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<tr>
<td>Y</td>
<td></td>
<td>2,3,4</td>
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| X        | US, A, 4,220,922, (Ikeguchi), 02 September 1980, see column 5, line 68, to column 6, lines 44-62, and column 14, lines 50-60. | 1                     |
| Y        |                                                                                   | 2,3,4                 |

| X        | US, A, 4,298,988, (Dages), 03 November 1981, see column 5, lines 23-35, and column 6, lines 16-24. | 1                     |
| Y        |                                                                                   | 2,3,4                 |

| X        | US, A, 4,476,584, (Dages), 09 October 1984, see whole document. | 1                     |
| Y        |                                                                                   | 2,3,4                 |


| Y        | US, A, 4,247,952, (Shibuya), 27 January 1981, see column 3, lines 57-63, and column 6, lines 17-30. | 12-17                 |

(continued)

IV. CERTIFICATION

Date of the Actual Completion of the International Search: 11 August 1986
Date of Mailing of this International Search Report: 29 August 1986

International Searching Authority: ISA/US

Signature of Authorized Officer: Elissa Seidenglanz
FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET


V OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE 10

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. Claim numbers ...... , because they relate to subject matter 12 not required to be searched by this Authority, namely:

2. Claim numbers 5-11 , because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out 12, specifically:

claim 5 which is multiple dependent depends on multiple dependent
claim 3 (Rule 6.4(a)).

Claims 6-11 depend on claim 5.

VI OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING 11

This International Searching Authority found multiple inventions in this international application as follows:

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4. As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.
☐ No protest accompanied the payment of additional search fees.