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# United States Patent [19]

Shigemori

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[45] Reissued Date of Patent: Nov. 28, 2000

[54] **DIGITALLY-CORRECTED TEMPERATURE-COMPENSATED CRYSTAL OSCILLATOR HAVING A CORRECTION-SUSPEND CONTROL FOR COMMUNICATIONS SERVICE**

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[73] Assignee: **Seiko Epson Corporation**, Tokyo, Japan

[21] Appl. No.: **08/837,217**

[22] Filed: **Apr. 22, 1997**

**Related U.S. Patent Documents**

Reissue of:

[64] Patent No.: **5,204,975**
Issued: **Apr. 20, 1993**
Appl. No.: **07/596,172**
Filed: **Oct. 10, 1990**

U.S. Applications:

[63] Continuation of application No. 08/425,489, Apr. 20, 1995, abandoned.

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Oct. 12, 1989 [JP] Japan .................................... 1-265682
Jan. 24, 1990 [JP] Japan .................................... 2-14116

[51] **Int. Cl.**[7] ........................................ **H04B 1/10**

[52] **U.S. Cl.** .......................... **455/231**; 455/256; 455/257; 455/310

[58] **Field of Search** .................................... 455/254, 256, 455/260, 231, 242, 182, 263, 196.1, 63, 67.3, 296, 310, 343, 257; 331/65–66, 175, 176, 177 R, 179

[56] **References Cited**

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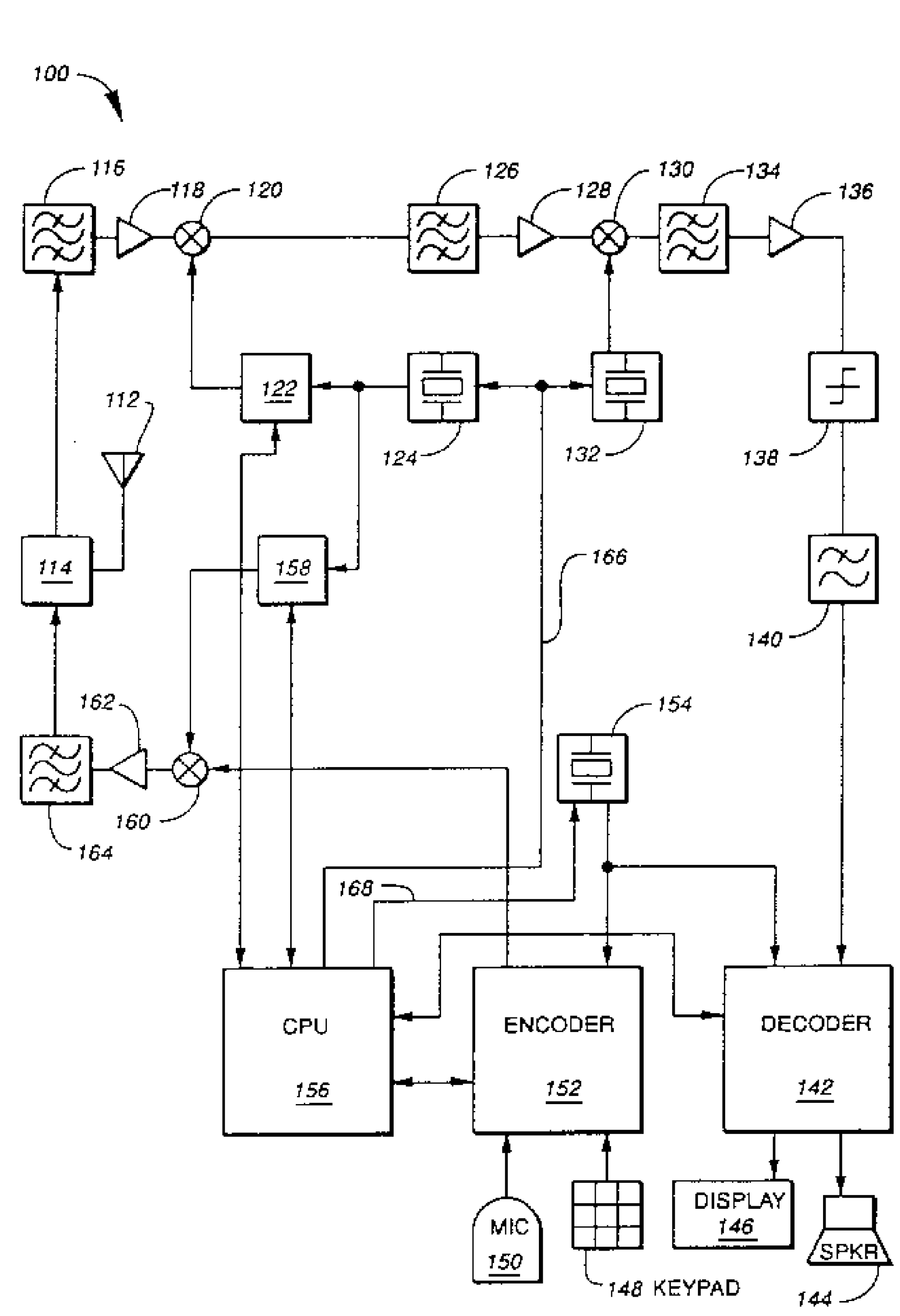
*Primary Examiner*—Nguyen Vo

[57] **ABSTRACT**

A radio transceiver having digitally-corrected temperature-compensated crystal oscillators (DTCXOs) including digital frequency temperature compensation circuits that are temporarily suspended from being updated, such that temperature compensation updates that can generate noise during periods of reception and transmission that could interfere with the audio channel and/or signal synchronization will be postponed. Temperature is converted to a digital signal that is then used to address a PROM. The PROM outputs a correction word appropriate for the temperature reading and inputs this to a latch. A timing control loads the latch after data has settled. The latched correction word is connected to a bank of switches and capacitors that trim the frequency of the crystal oscillator. During radio transmission and/or reception, the latch will be suspended from loading any new correction words. The last valid correction word, however, will remain.

**24 Claims, 10 Drawing Sheets**



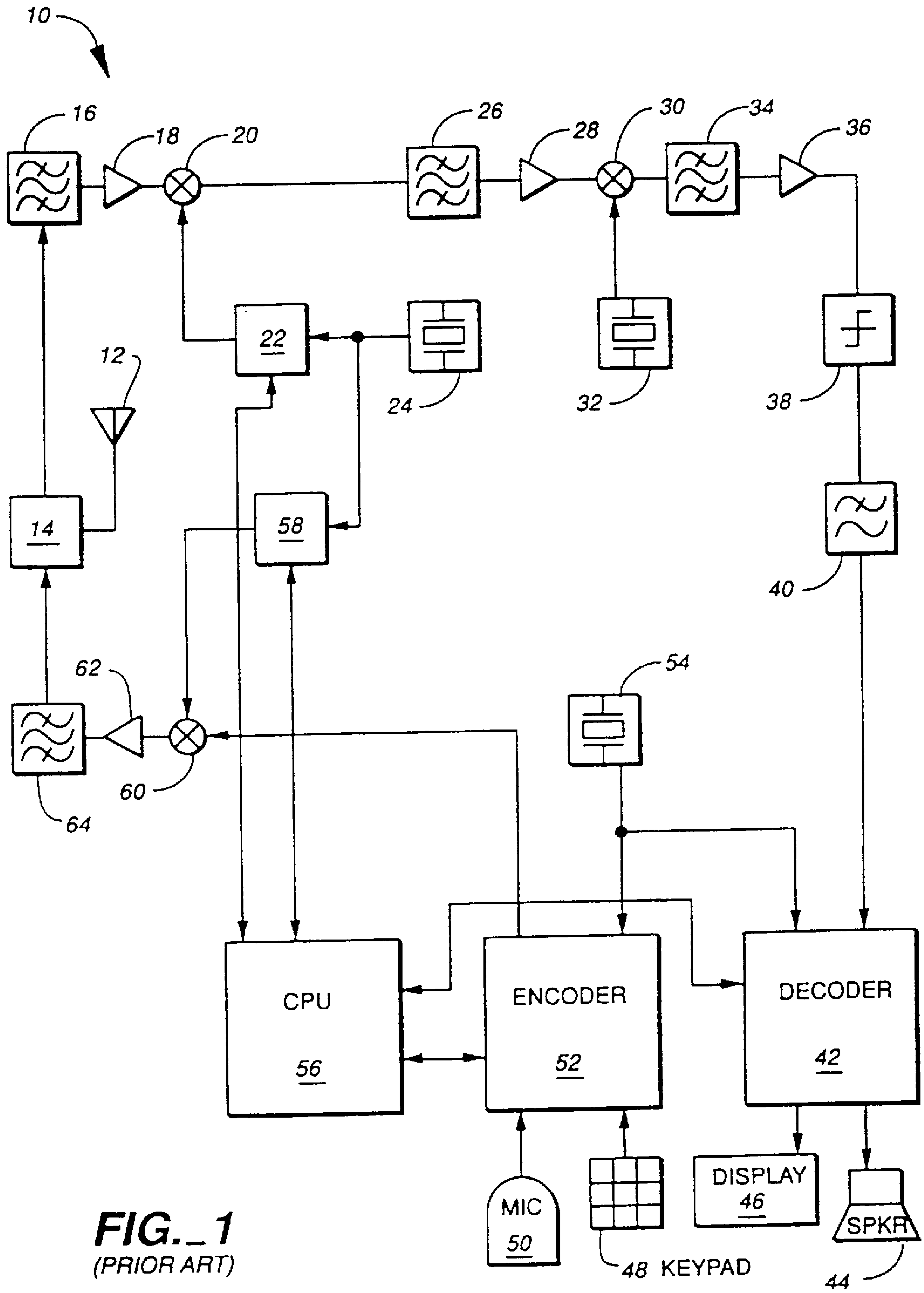



FIG._1
(PRIOR ART)

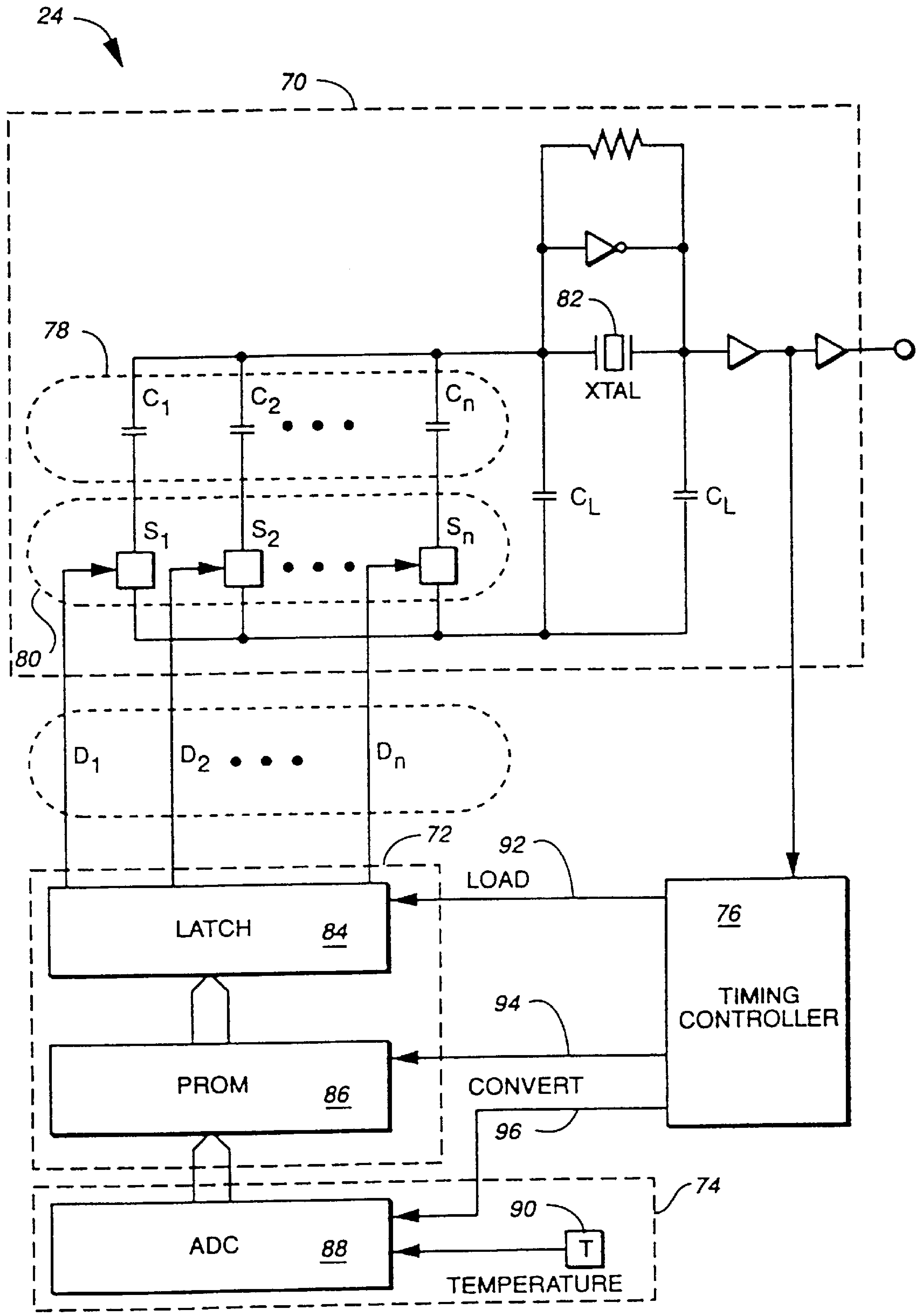
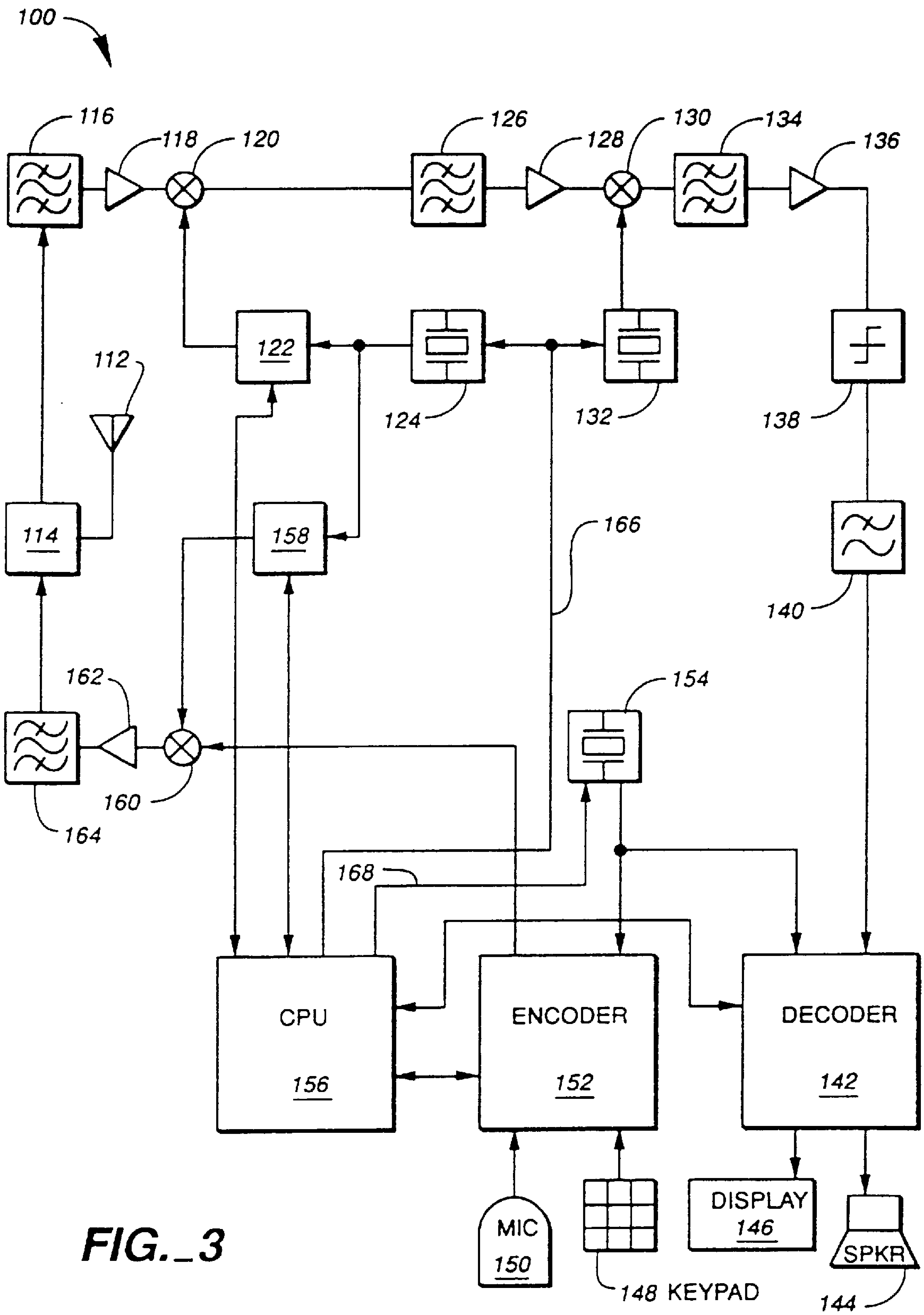



FIG._2 (PRIOR ART)


100
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166
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162
154
160
164
168
CPU
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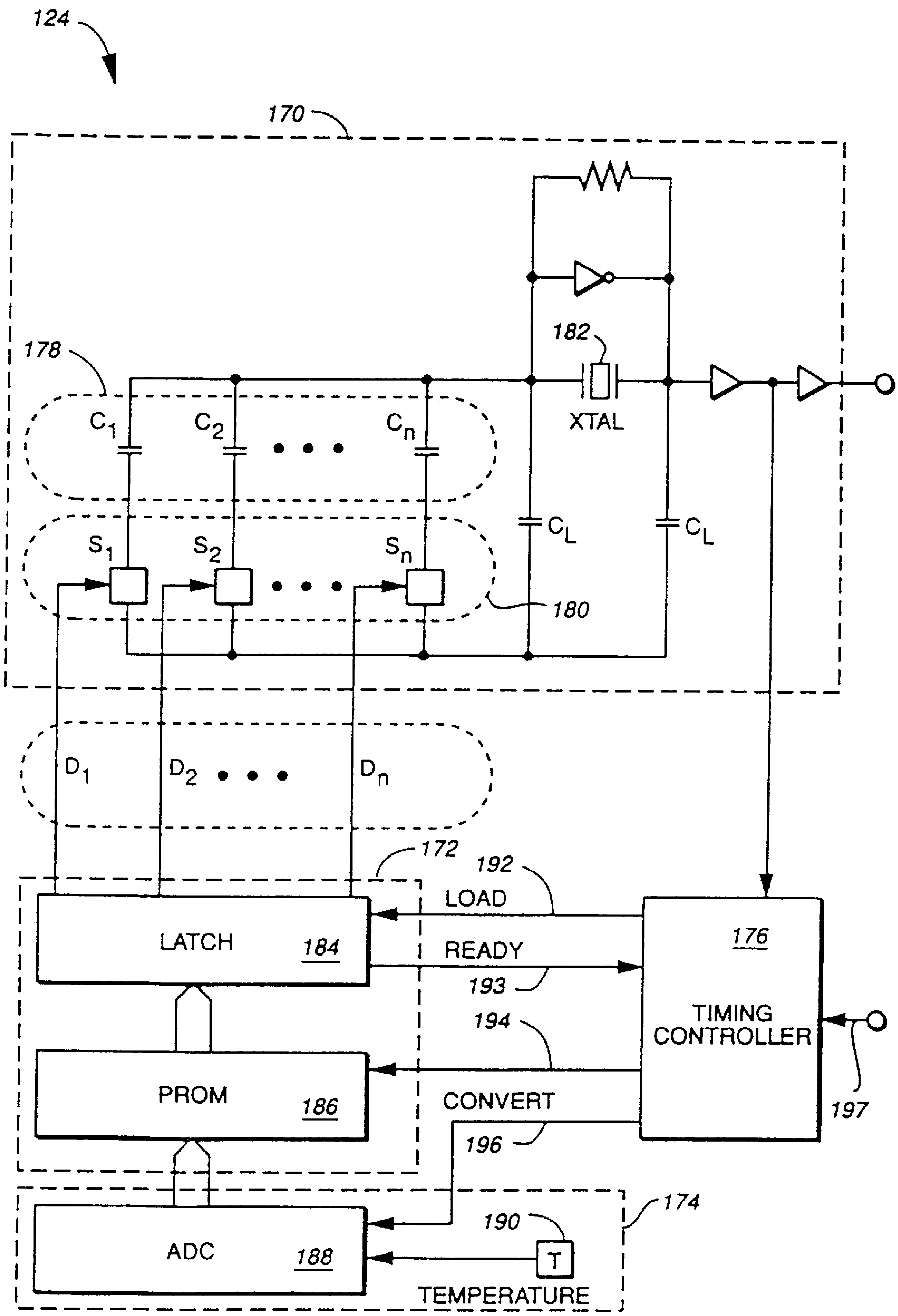
ENCODER
152
DECODER
142
DISPLAY
146
SPKR
144
MIC
150
148 KEYPAD

FIG._3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170
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180
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$D_2$
$D_n$
172
192
LOAD
LATCH
184
READY
193
176
TIMING
CONTROLLER
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PROM
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CONVERT
196
197
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ADC
188
T
TEMPERATURE

FIG._4

FIG.5A

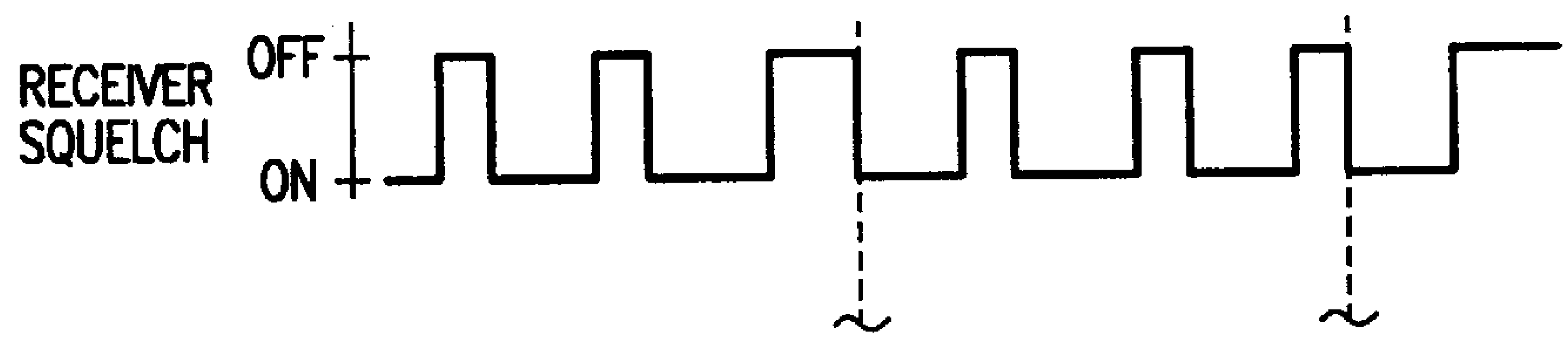



FIG.5B

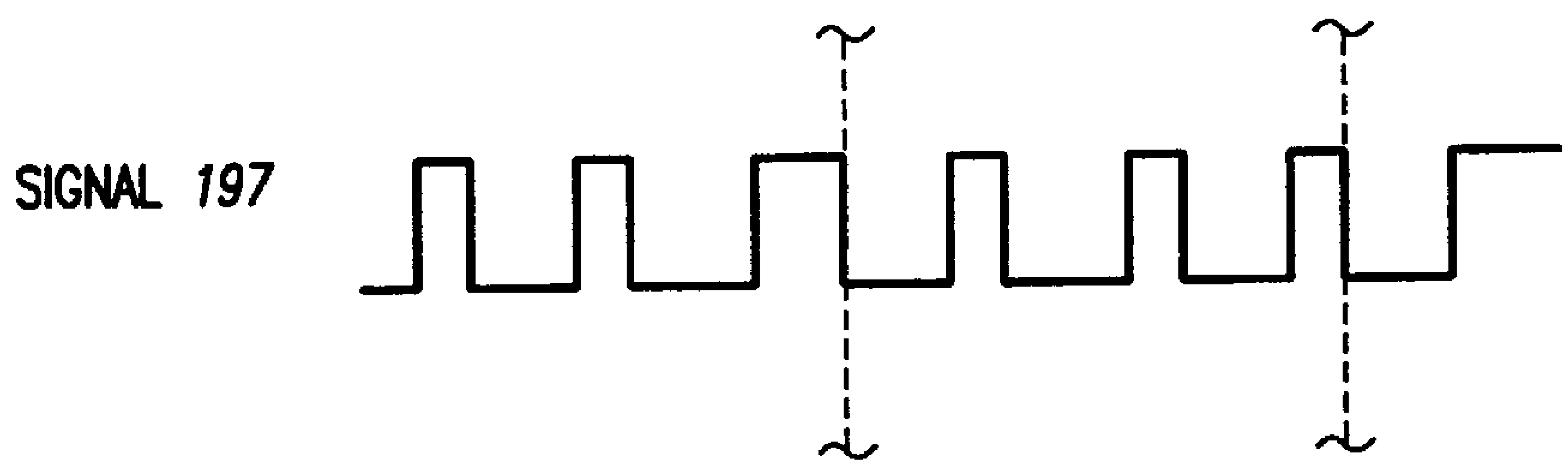



FIG.5C

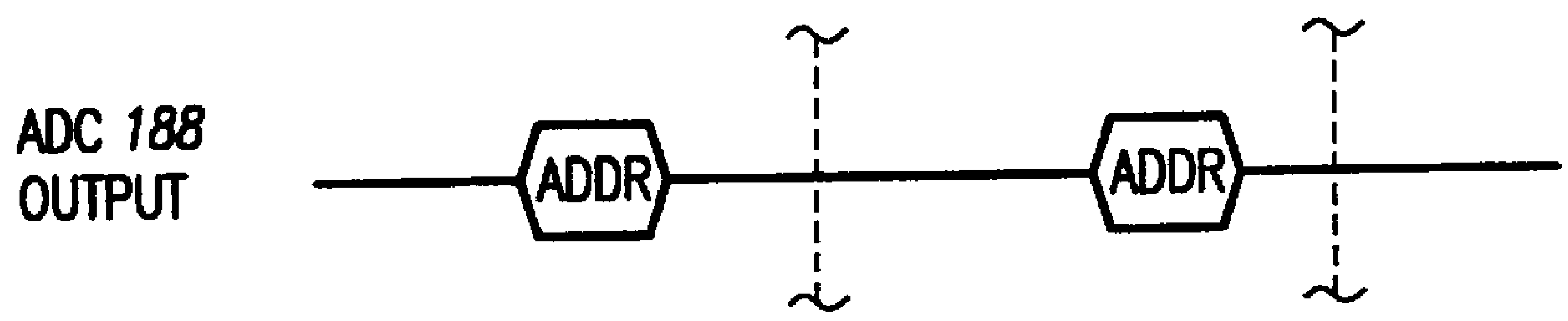



FIG.5D

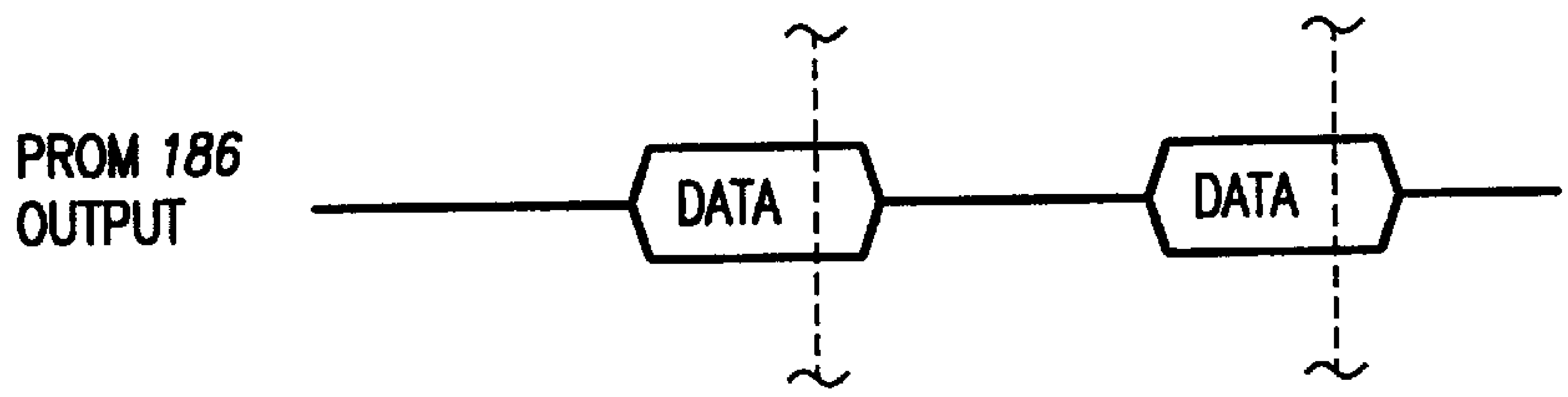



FIG.5E

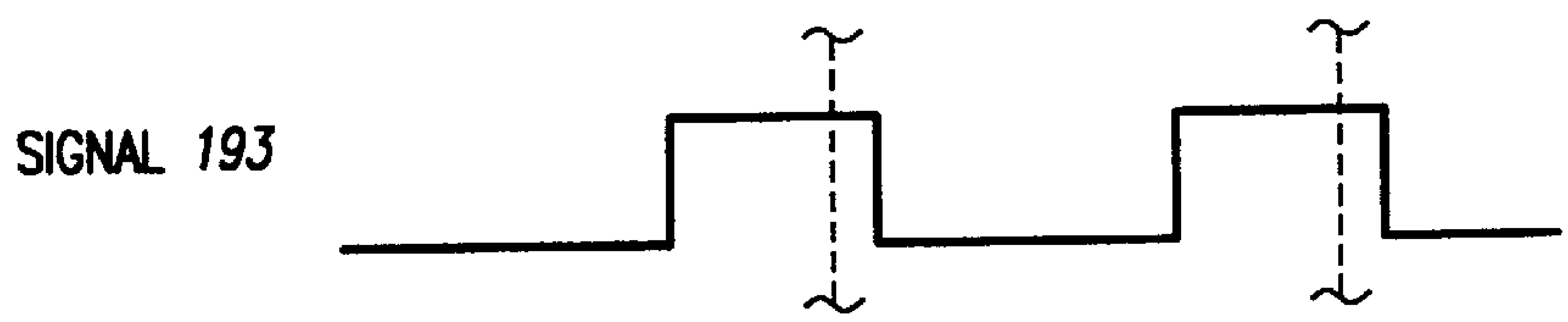



FIG.5F

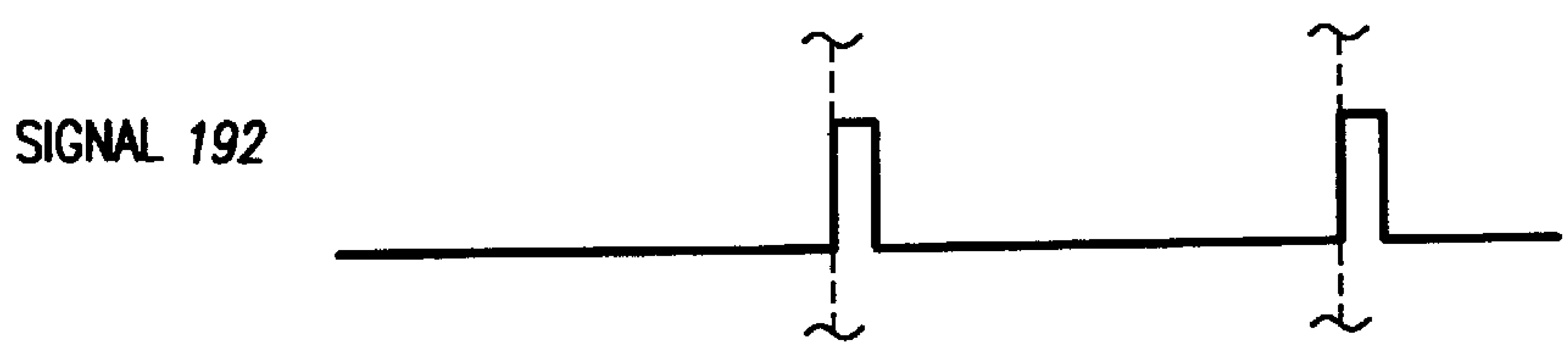



FIG.5G

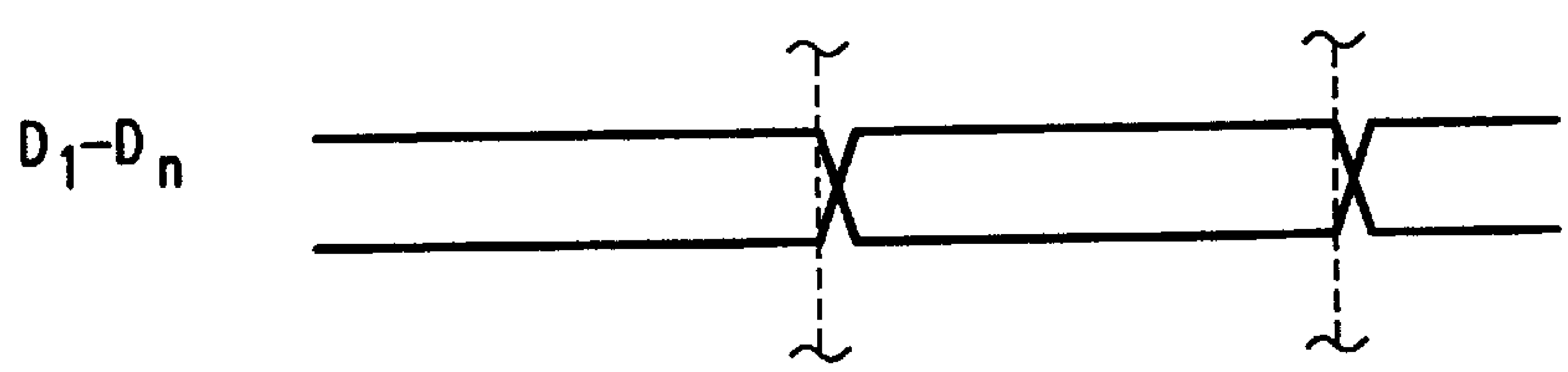



FIG.5H

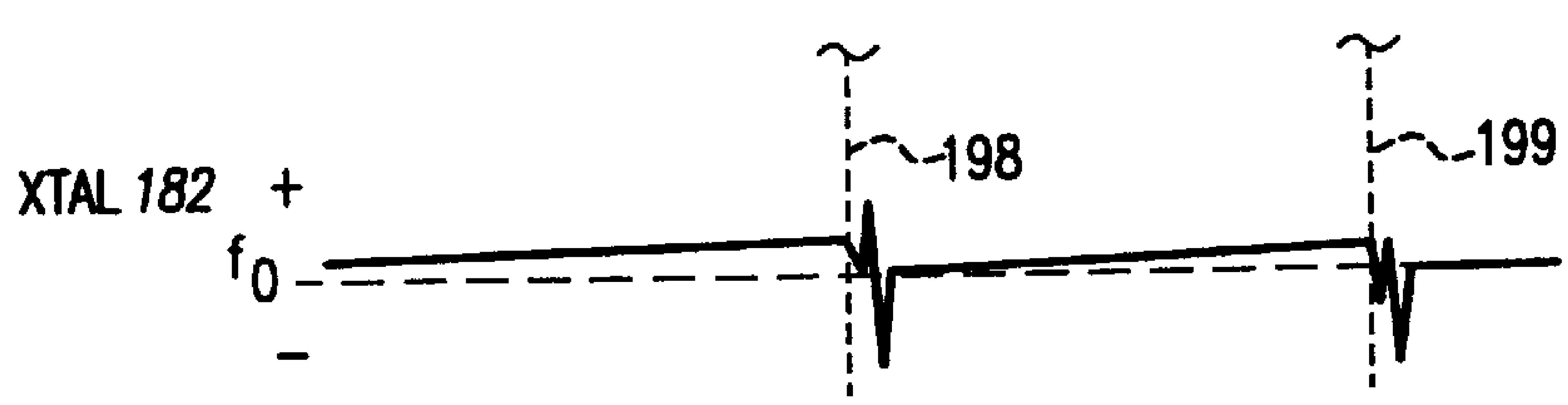


FIG.6A PRIOR ART

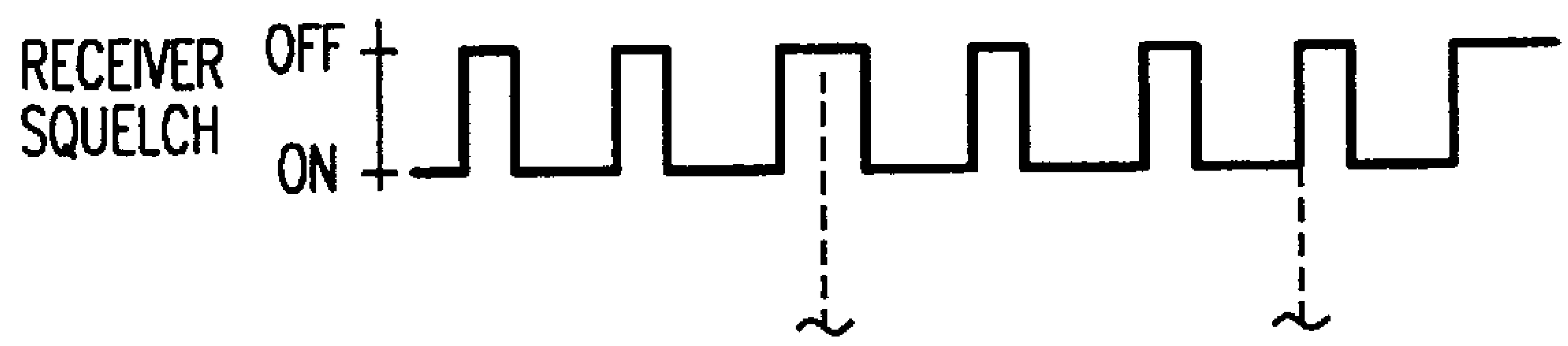



FIG.6B PRIOR ART

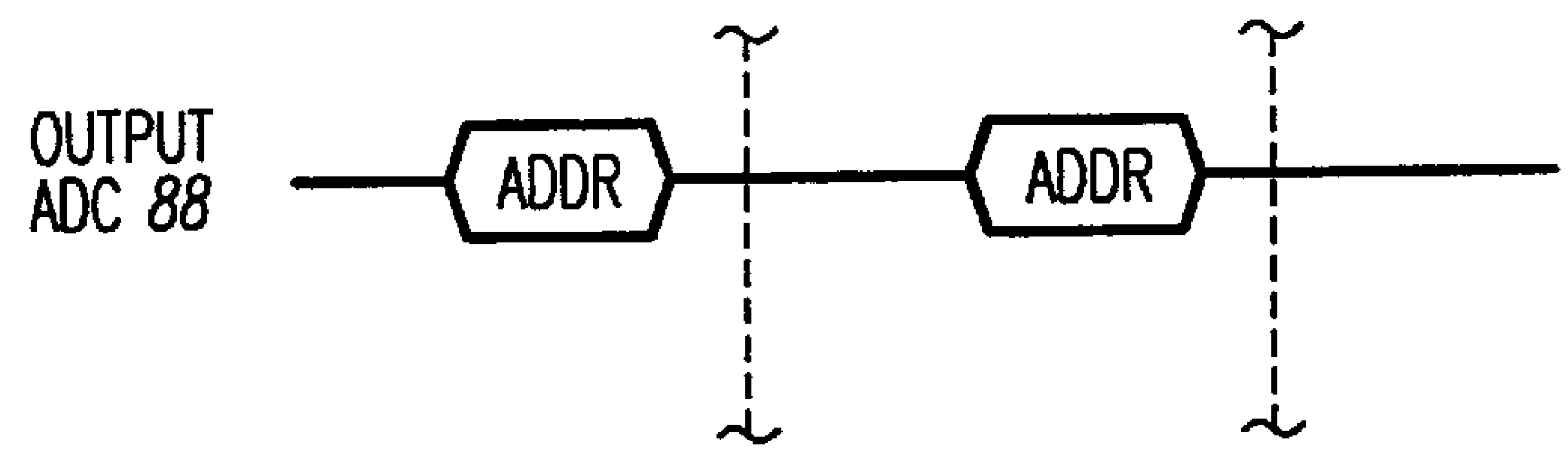



FIG.6C PRIOR ART

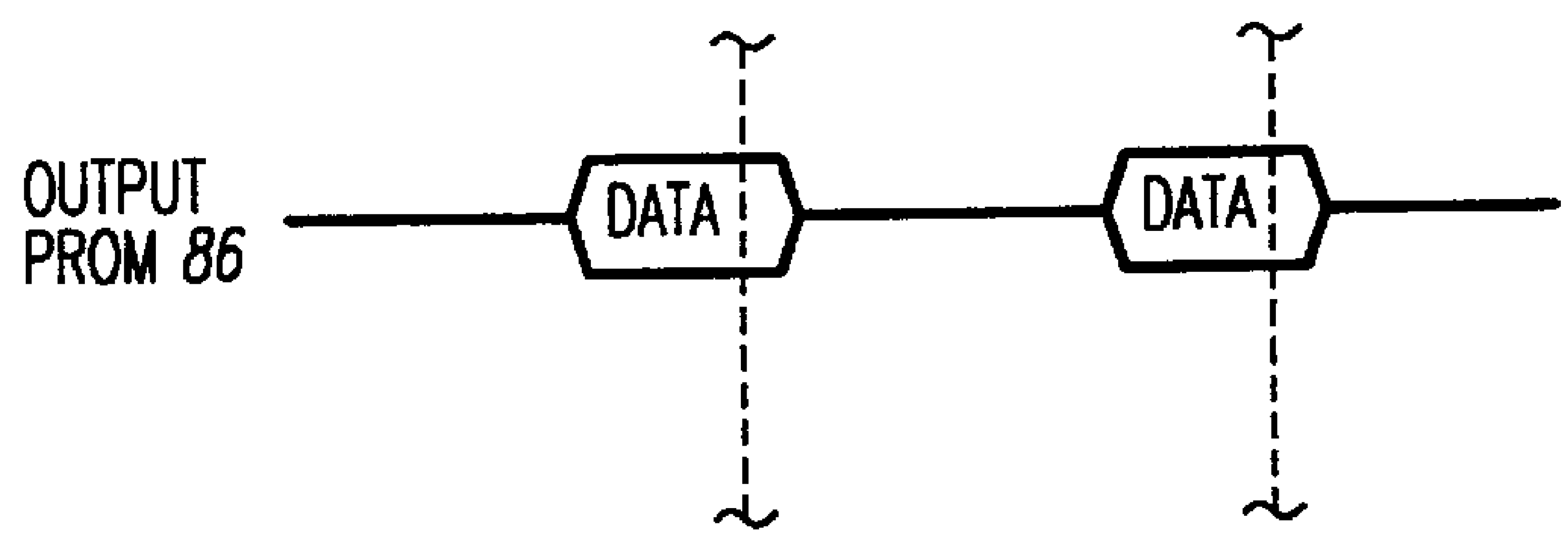



FIG.6D PRIOR ART

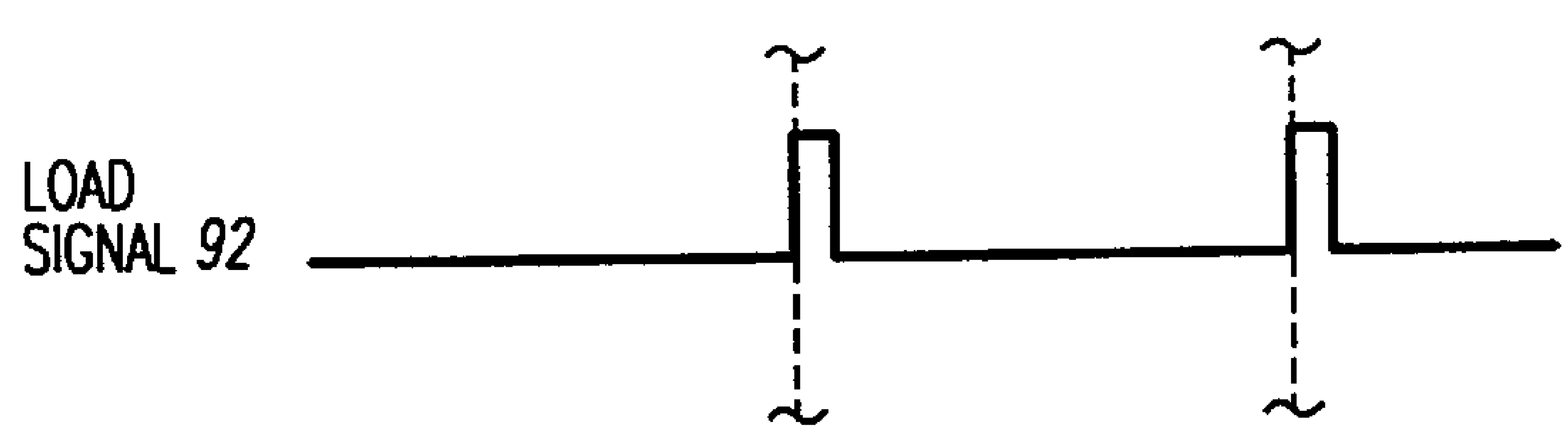



FIG.6E PRIOR ART

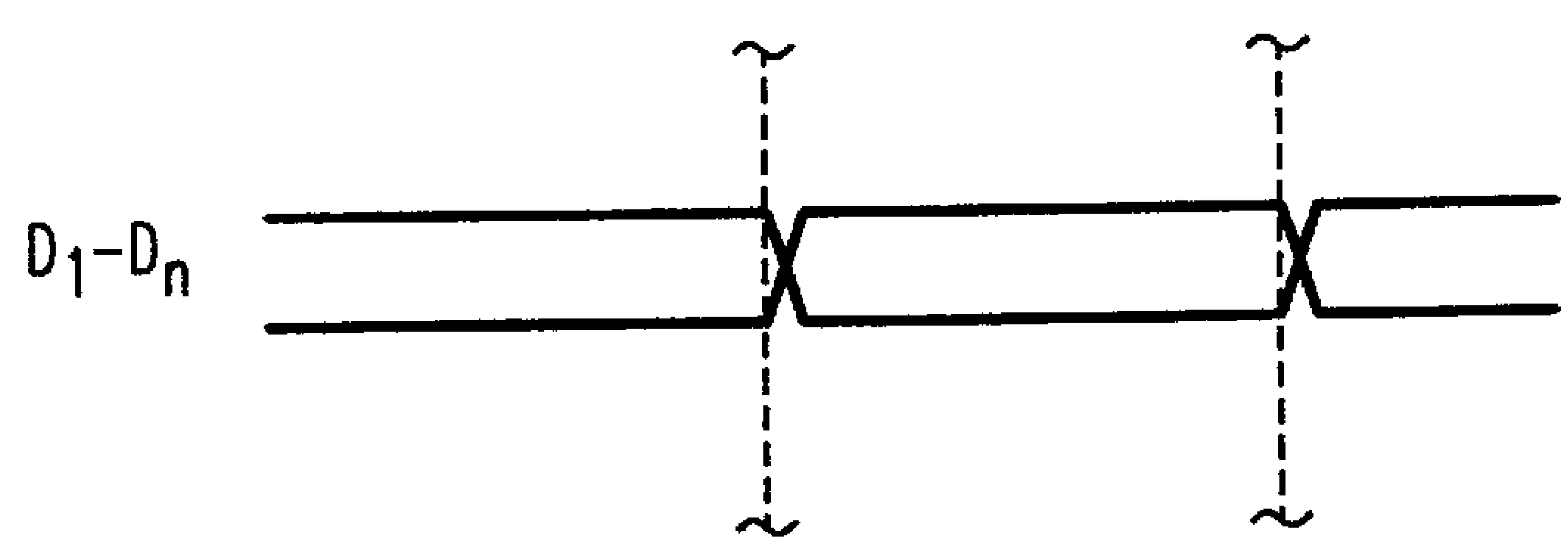



FIG.6F PRIOR ART

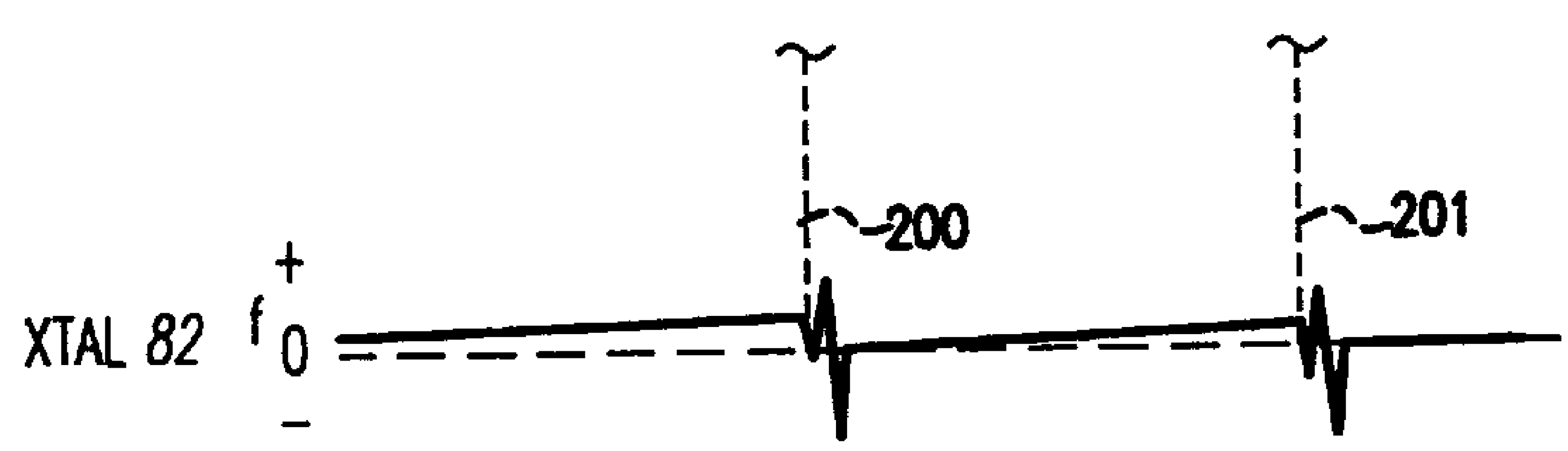


FIG.7A

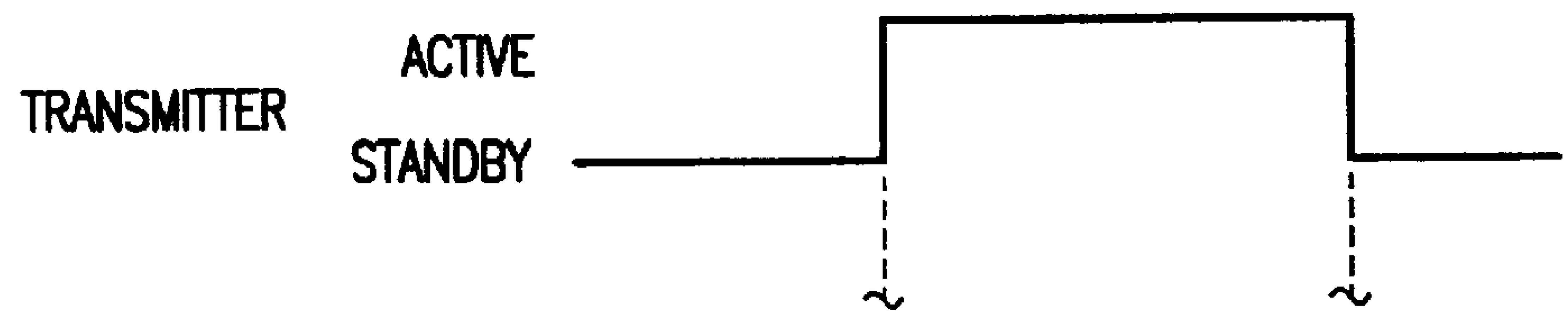



FIG.7B

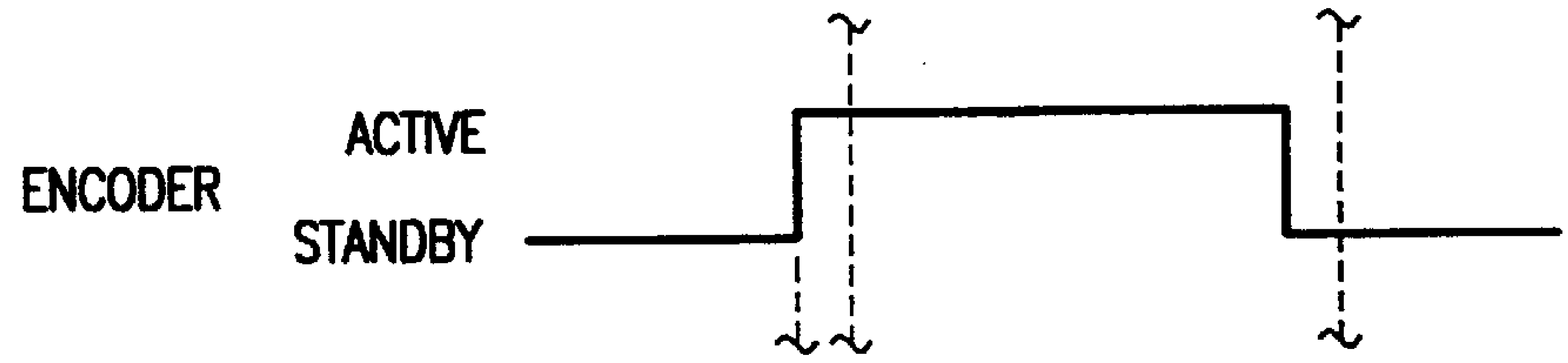



FIG.7C

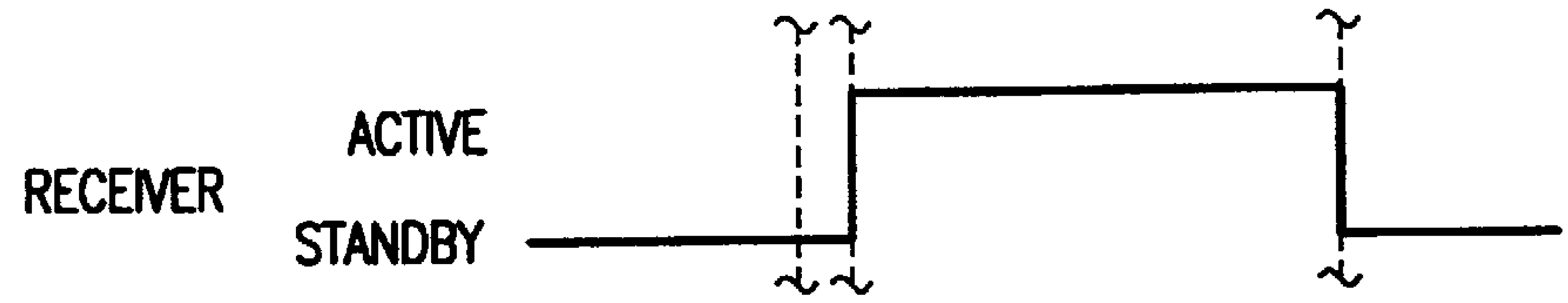



FIG.7D

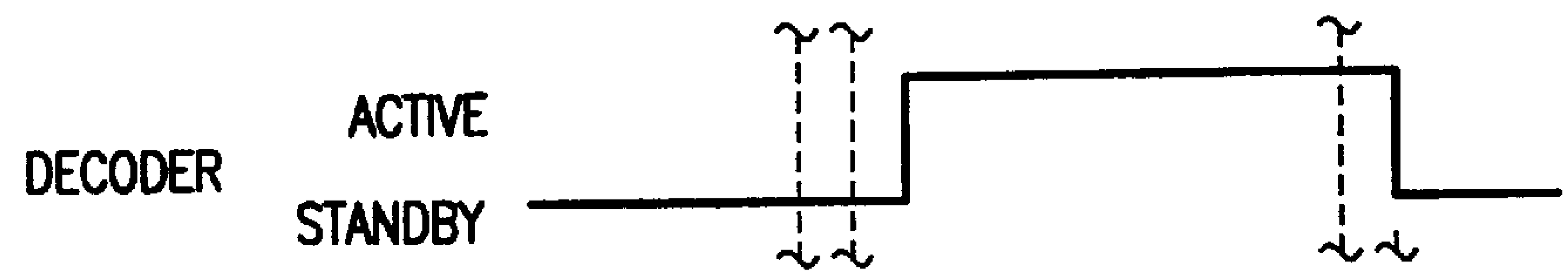



FIG.7E

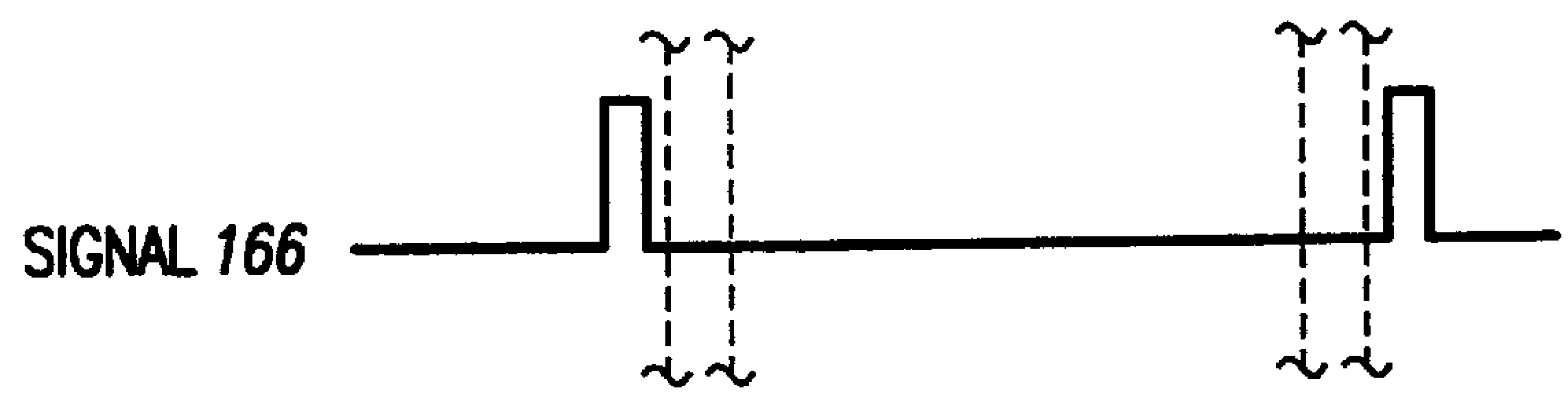



FIG.7F

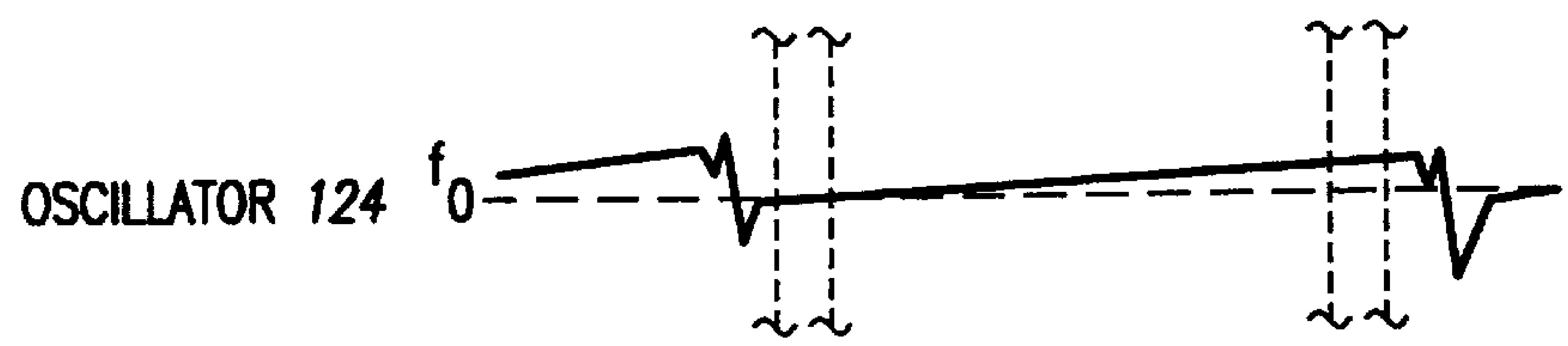



FIG.7G

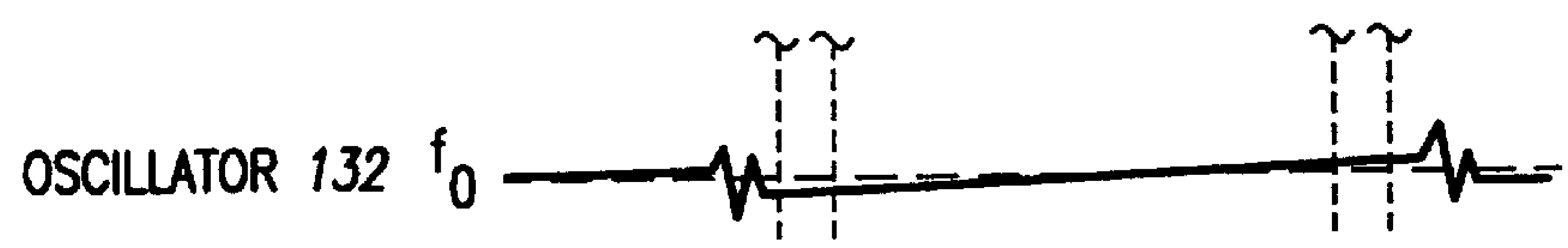



FIG.7H


FIG.7I

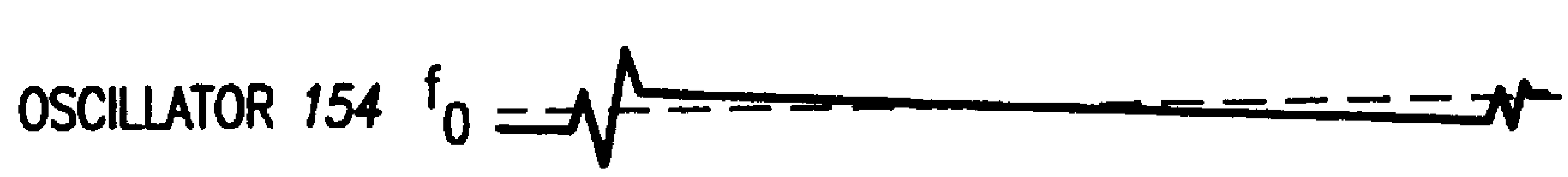


FIG.8A
FIG.8B
FIG.8C
FIG.8D
FIG.8E
FIG.8F
FIG.8G
FIG.8H

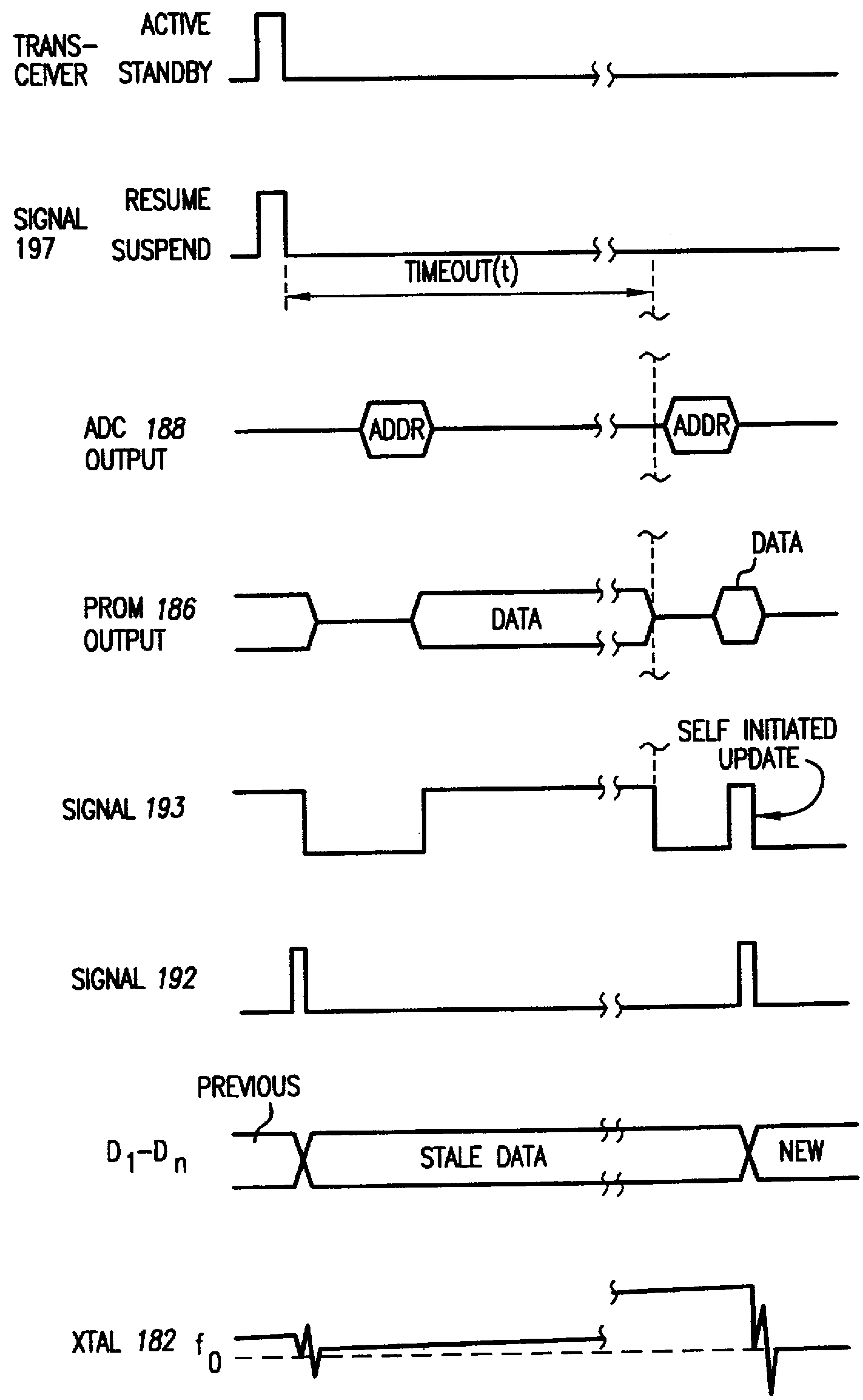


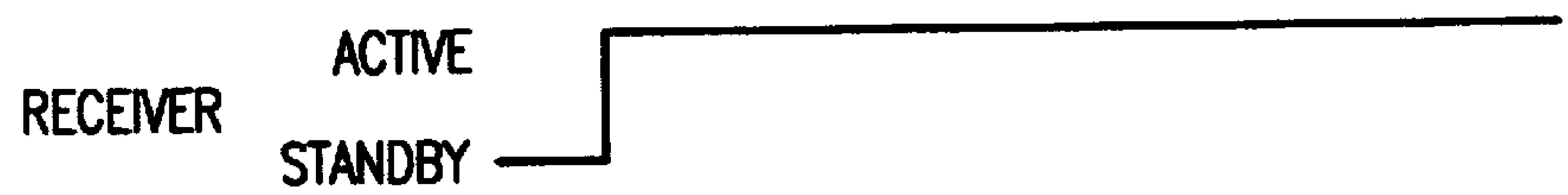
FIG.9A


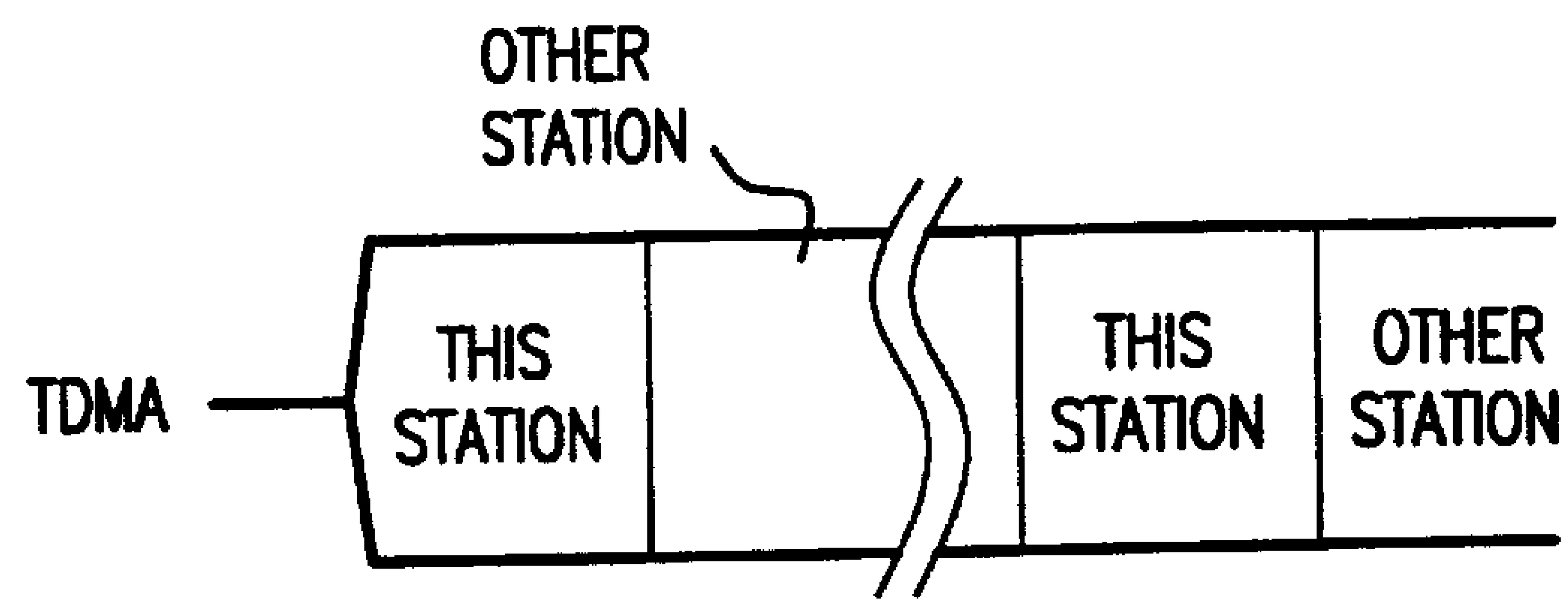

FIG.9B


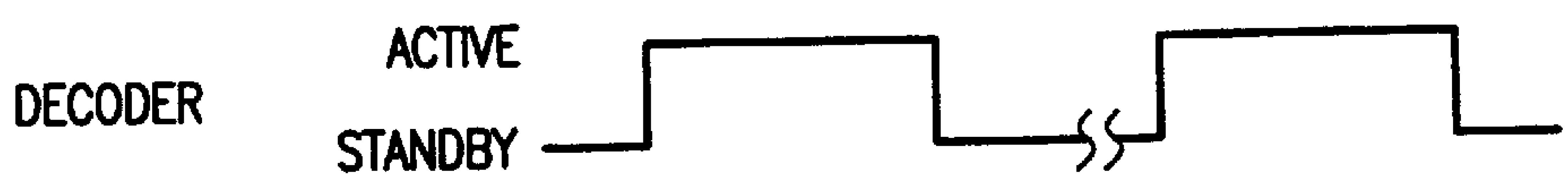

FIG.9C



FIG.9D



FIG.9E


FIG.10A

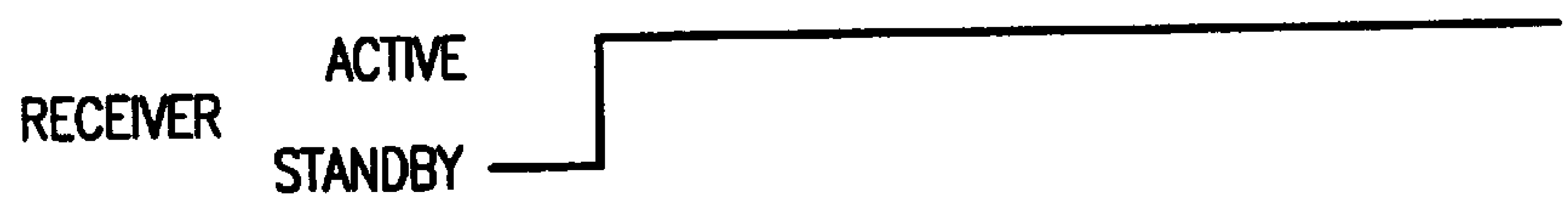



FIG.10B

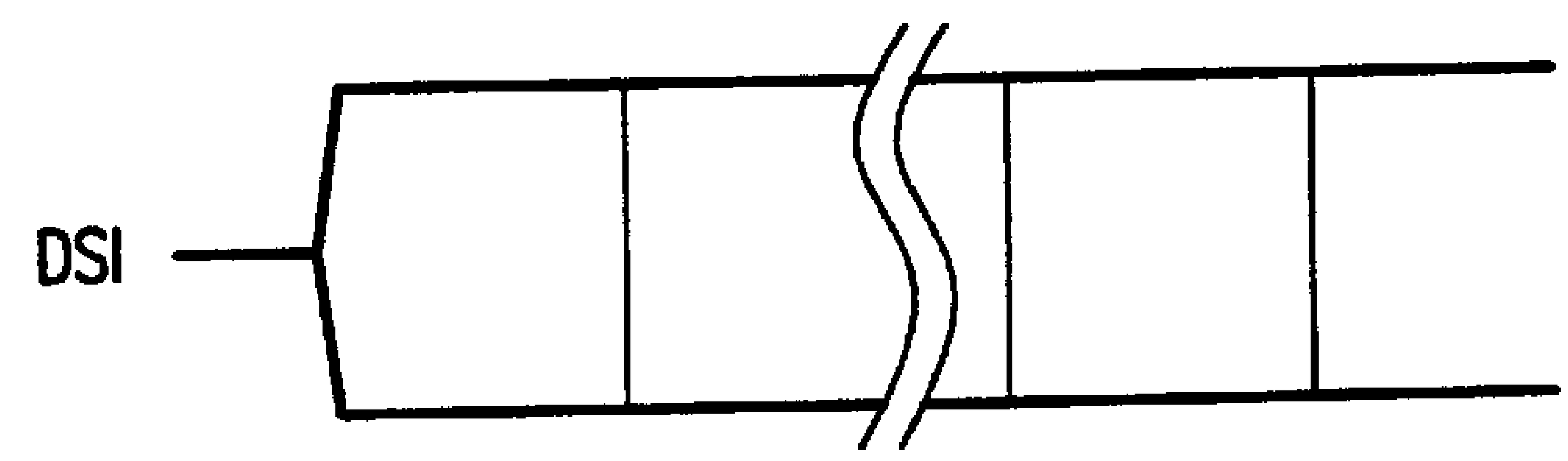



FIG.10C

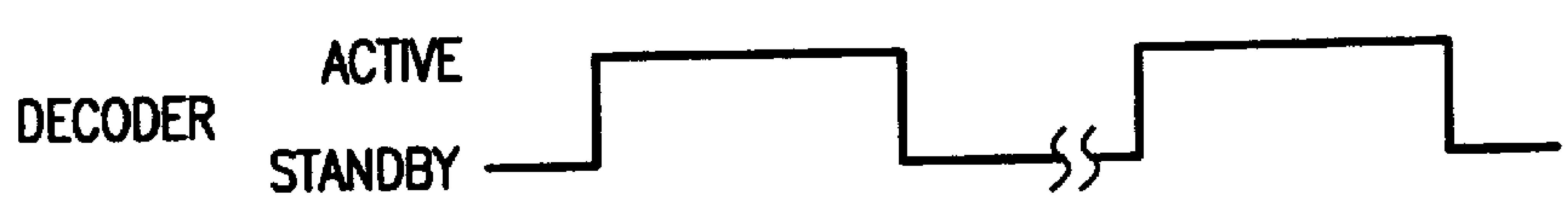



FIG.10D

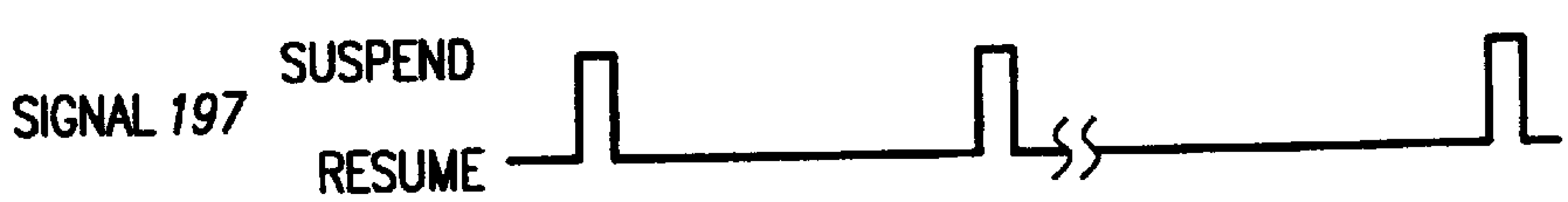
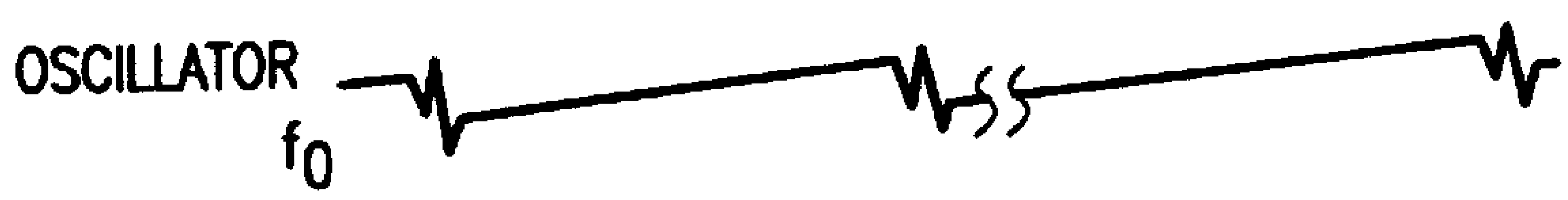



FIG.10E



# DIGITALLY-CORRECTED TEMPERATURE-COMPENSATED CRYSTAL OSCILLATOR HAVING A CORRECTION-SUSPEND CONTROL FOR COMMUNICATIONS SERVICE

**Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.**

*This is a Continuation of application Ser. No. 08/425,489 filed Apr. 20, 1995 now abandoned, which in turn is a reissue of application Ser. No. 07/596,172, filed Oct. 10, 1990, U.S. Pat. No. 5,204,975.*

## BACKGROUND OF THE INVENTION

The present invention relates generally to digitally-corrected temperature-compensated piezoelectric crystal oscillators (DTCXOs) having frequency outputs that are stable despite changes in the ambient temperature, and specifically to DTCXOs used in mobile communications service, such as in cellular phones and telephone call pagers.

Crystal oscillators tend to be the most stable of oscillators and so are frequently used in radio transmitters and receivers. The crystal oscillator derives its stability from the piezoelectric phenomenon exhibited by certain crystals. Cutting a piezoelectric crystal to a certain shape and size will determine its resonant frequency. The resonant frequency can be fine tuned by loading the crystal with a capacitance. Temperature changes will induce corresponding resonant frequency shifts in crystal oscillators. Since U.S. government regulations concerning radio transmitter carrier stability and accuracy are very demanding, thermal instability of crystal reference oscillators must be controlled. An early method of stabilizing crystal oscillators was to place the crystal in an "oven" that maintained a constant temperature. Because the temperature in the crystal oven did not vary, neither did the resonant frequency. Other methods have used varactor diodes to control frequency shifts by adjusting an analog voltage on the varactor according to ambient temperature. Crystals that have had their temperature-versus-resonant frequencies characterized can be corrected if the temperature is known. The technique also requires the load capacitance-to-resonant frequency shift to have been characterized. The prior are includes analog-to-digital conversion methods and the switching of a bank of load capacitors across a crystal.

FIG. **1** is typical example of a prior art cellular telephone transceiver, referred to by the general reference numeral **10**, comprising an antenna **12**, a transmit/receive (T/R) transfer switch **14**, a bandpass filter **16**, an RF amplifier **18**, a first mixer **20**, a receiver PLL synthesizer **22**, a reference oscillator circuit **24**, a first intermediate frequency (IF) bandpass filter **26**, a first IF amplifier **28**, a second mixer **30**, a second local oscillator **32**, a second IF bandpass **34**, a second IF amplifier **36**, a detector **38**, a low-pass filter **40**, a data/voice decoder **42** having a speaker **44** and an alphanumeric display **46**, an alphanumeric keypad **48**, a microphone **50**, a frequency modulation (FM)/pulse modulation (PM) encoder **52**, an encoder/decoder oscillator **54**, a central processing unit (CPU) **56**, a transmitter PLL synthesizer **58**, a transmitter mixer **60**, a transmitter amplifier **62**, and a transmitter bandpass **64**. An RF receiver is thus formed of elements **12–46**, and a matching RF transmitter by elements **48–64**, and also sharing **12–14**. Receiver PLL synthesizer **22** provides a first local oscillator frequency for the first mixer **20** to beat with the incoming RF frequency to produce a first IF. Receiver PLL synthesizer **22** can be digitally programmed to output various frequencies, and therefore the frequencies received by transceiver **10** can be selectively tuned in. Reference oscillator **24** comprises a first DTCXO and supplies a master reference clock to PLL synthesizers **22** and **58**. Because reference oscillator **24** provides the master reference for both transmit and receive, Federal Communications Commission (FCC) rules and good performance demand that the frequency be accurate and have minimal temperature drift. Second local oscillator **32** comprises a second DTCXO, and is similar to oscillator **24** (only the frequencies are different). Alternatively, a divider from reference oscillator **24** is used to provide the second local oscillator frequency (which will normally be a fixed frequency). Demodulator is provided by an FM discriminator, detector **38**. The low-pass filter **40** allows only audio frequencies through to decoder **42**. Decoder **42** will squelch speaker **44** until a proper calling code identification is received and recognized. Display **46** will keep a user informed of the status of transceiver **10**. Voice input is picked up by microphone **50**. Outgoing calling codes and operating modes are entered on keypad **48**. If appropriate, encoder **52** will output to transmitter mixer **60** to beat with and modulate a transmit carrier frequency coming from PLL synthesizer **58**. Just the desired products of transmitter mixer **60** are passed by transmitter bandpass **64**. Transceiver **10** is capable of full duplex operation, so transmission will be simultaneous with reception, albeit at different frequencies. Encoder/decoder oscillator **54** supplies a common signal to encoder **52** and decoder **42**, and is based on a third DTCXO similar to the first two. CPU **56** controls decoder **42**, encoder **52** and the transmit and receive frequencies by virtue of its connects to PLL synthesizers **22** and **58**.

Although FIG. **2** diagrams oscillator **24**, it is also representative of the construction of oscillators **32** and **54**. Oscillator **24** is comprised of a crystal oscillator unit **70**, a switch bank controller **72**, a temperature unit **74**, and a timing controller **76**. Unit **70** has a capacitor trimming bank **78**, a capacitor switching bank **80**, and a piezoelectric crystal (XTAL) **82**. Switch bank controller **72** has two parts, a parallel digital latch **84** and a programmable read only memory (PROM) **86**. Data in PROM **86** matches the characteristic temperature profile of XTAL **82** and also takes into account the effect of $C_1$–$C_n$ on the frequency output ($f_o$) of XTAL **82**. The temperature unit **74** has a temperature sensor **90** and a analog-to-digital converter (ADC) **88**. At any particular temperature, a code will be output by ADC **88** to PROM **86** that will apply just the right combination of $C_1$–$C_n$ to bring $f_o$ back to nominal. (At least according to ideal XTAL **82** performance parameters.) Controller **76** has three output signals: **92**, **94**, and **96**. Periodically, controller **76** will cause ADC **88** to begin a new conversion. (Also see FIG. **6** discussion below.) The output of ADC **88** and PROM control signal **94** will cause a particular digital correction word to be output from PROM **86**. That word will be output to latch **84** and loaded by signal **92**. Latch **84** controls switch bank **80**, which in turn can switch in and out various capacitors in capacitor bank **78** in order to trim the resonant frequency of XTAL **82** and keep it stable despite ambient temperature variations. Oscillator **24** is therefore a digitally-corrected temperature-compensated crystal oscillator (DTCXO). Control of the oscillating frequency of the DTCXO is continuous, regardless of whether the radio is active or not.

Prior art DTCXO circuits generate spurious frequency fluctuation noise (FM) and phase fluctuations noise (PM) whenever the DTCXO circuits vary the temperature correction (for example, by switching on and off capacitors ($C_1$–$C_n$ in capacitor bank **78**). As was mentioned above, capacitors $C_1$–$C_n$ are binary-weighted and are combined to produce various correction totals. As an example, capacitors $C_1$–$C_n$ could be weighted as: 1, 2, 4, 8, and 16 picofarads. A range of 0–31 picofarads could then be accommodated in one picofarad steps. The smallest step, one picofarad, results in a certain granularity that will cause oscillator **24** (for example) to display discrete frequency steps when the temperature compensation is hunting. These frequency and phase steps, or fluctuations will consequently be reflected by similar modulating the transmitter and receiver frequencies (which add audible noise to the transmitted and received signals). These spurious modulations can interfere not only with the voice, but data traffic too, and at both ends of the radio communication. If oscillator **54** also shows such fluctuations, the encoder and decoder processes timed by it can experience a loss in signal synchronization, which will necessitate a switch being made to an alternative, "cleaner" channel (when it really wasn't necessary).

Reducing the amount of stepping in a DTCXO frequency control can reduce the impact of any frequency and phase fluctuations generated by the temperature compensation. But the resolution of the temperature measurements and the resolution of the frequency adjustments both would have to be increased, and that would greatly increase the width of the digital control word $D_1$–$D_n$. To support these increases, a higher quality temperature sensor would also be required. Very fine frequency control, such as this, requires very complex circuits and increases the cost of manufacture.

## SUMMARY OF THE INVENTION

According to this invention, a radio transceiver having digitally-corrected temperature-compensated crystal oscillators (DTCXOs) comprising digital frequency temperature compensation circuits that are temporarily suspended from being updated, such that temperature compensation updates that can generate noise during periods of reception and transmission that could interfere with the audio channel and/or signal synchronization will be postponed. Temperature is converted to a digital signal that is then used to address a PROM. The PROM outputs a correction word appropriate for the temperature reading and inputs this to a latch. A timing control loads the latch after data has settled. The latched correction word is connected to a bank of switches and capacitors that trim the frequency of the crystal oscillator. During radio transmission and/or reception, the latch will be suspended from loading any new correction words. The last valid correction word, however, will remain.

An advantage of the present invention is that the adverse effects of even large amounts of FM and PM noise that would otherwise occur during transceiver activity are avoided. The accuracy of oscillator frequencies is updated during any times when the transceiver is inactive and carries that accuracy over to active periods.

A further advantage of the present invention is that temperature compensation during active periods of transmission/reception can be suspended in order to control spurious FM and PM modulations that would otherwise appear in the transmitted and received signals.

A further advantage of the present invention is that it has reduced power consumption.

A further advantage of the present invention is that it yields substantially the same benefits as the more complex and expensive configurations of the prior art.



A further advantage of the present invention is that it leads to an improvement in the sensitivity of reception and to the improvement of the stability of the carrier frequency of the transmitter carrier.

A further advantage of the present invention is that integrated circuits may be used to implement it, thus having the consequential advantage of high circuit reliability.

A further advantage of the present invention is that frequency regulation accuracy is maintained at a high level.

These and other objects and advantages of the present invention will no doubt become obvious to those of ordinary skill in the art after having read the following detailed description of the preferred embodiments which are illustrated in the various drawing figures.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a prior art cellular telephone transceiver;

FIG. **2** is a schematic diagram of the prior art digitally-corrected temperature-compensated crystal oscillator shown in FIG. **1**;

FIG. **3** is a block diagram of a cellular telephone transceiver embodiment of the present invention. FIG. **3** is similar to FIG. **1** in most details, except that control signal lines appear between the CPU and DTCXOs;

FIG. **4** is a schematic diagram of the digitally-corrected temperature-compensated crystal oscillator shown in FIG. **3**, FIG. **4** is similar to FIG. **2** in most details, except that an extra control signal line appears between the latch and timing controller. The timing controller also has an extra SUSPEND input control;

FIG. **5** is a diagram showing the timing relationship between the circuits of FIG. **4**;

FIG. **6** is a diagram showing the timing relationship between the circuits of FIG. **2**. These are presented in contrast to FIG. **5**;

FIG. **7** is a timing diagram showing how transmitter, encoder, receiver, and decoder activity are logically OR'ed together to cause signals **166** and **168** to suspend temperature compensation. The output frequencies of oscillators **124**, **132**, and **154** are shown drifting without temperature compensation updates during the OR'ed activity;

FIG. **8** is a timing diagram showing that a temperature compensation update cycle will be self-initiated and automatically inserted if signal **197** suspends temperature compensation too long;

FIG. **9** is a timing diagram showing how the present invention will detect opportunities to update temperature compensation when a transceiver is in the TDMA mode of operation; and

FIG. **10** is a timing diagram showing how the present invention will detect opportunities to update temperature compensation when a transceiver is in the DSI mode of operation.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **3** is a cellular telephone transceiver embodiment of the present invention, referred to by the general reference numeral **100**, comprising an antenna **112**, a transmit/receive (T/R) transfer switch **114**, a bandpass filter **116**, an RF amplifier **118**, a first mixer **120**, a receiver PLL synthesizer **122**, a reference oscillator circuit **124**, a first intermediate frequency (IF) bandpass filter **126**, a first IF amplifier **128**, a second mixer **130**, a second local oscillator **132**, a second IF bandpass **134**, a second IF amplifier **136**, a detector **138**, a low-pass filter **140**, a data/voice decoder **142** having a speaker **144** and an alphanumeric display **146**, an alphanumeric keypad **148**, a microphone **150**, a frequency modulation (FM)/pulse modulation (PM) encoder **152**, an encoder/decoder oscillator **154**, a central processing unit (CPU) **156**, a transmitter PLL synthesizer **158**, a transmitter mixer **160**, a transmitter amplifier **162**, and a transmitter bandpass **164**. CPU **156** is preferably a microprocessor. An RF receiver is thus formed of elements **112–146**, and a matching RF transmitted by elements **148–164**, and also sharing **112–114**. Receiver PLL synthesizer **122** provides a first local oscillator frequency for the first mixer **120** to beat with the incoming RF frequency to produce a first IF. Receiver PLL synthesizer **122** can be digitally programmed to output various frequencies, and therefore the frequencies received by transceiver **100** can be selectively tuned in. Reference oscillator **124** comprises a first DTCXO and supplies a master reference clock to PLL synthesizers **122** and **158**. Because reference oscillator **124** provides the master reference for both transmit and receive, Federal Communications Commission (FCC) rules and good performance demand that the frequency be accurate and have minimal temperature shift. Second local oscillator **132** comprises a second DTCXO, and is similar to oscillator **124** (only the frequencies are different). Alternatively, a divider from reference oscillator **124** is used to provide the second local oscillator frequency (which will normally be a fixed frequency). Demodulator is provided by an FM discriminator, detector **138**. The low-pass filter **140** allows only audio frequencies through to decoder **142**. Decoder **142** will squelch speaker **144** until a proper calling code identification is received and recognized. Display **146** will keep a user informed of the status of transceiver **100**. Voice input is picked up by microphone **150**. Outgoing calling codes and operating modes are entered on keypad **148**. If appropriate, encoder **152** will output to transmitter mixer **160** to beat with and modulate a transmit carrier frequency coming from PLL synthesizer **158**. Just the desired products of transmitter mixer **160** are passed by transmitter bandpass **164**. Transceiver **100** is capable of full duplex operation, so transmission will be simultaneous with reception, albeit at different frequencies. Encoder/decoder oscillator **154** supplies a common signal to encoder **152** and decoder **142**, and is based on a third DTCXO similar to the first two. CPU **156** controls decoder **142**, encoder **152** and the transmit and receive frequencies by virtue of its connects to PLL synthesizers **122** and **158**.

The major difference between transceiver **100** and the prior art is CPU **156** can disable the temperature compensation of oscillators **124** and **132** through the connection of a signal line **166** and oscillator **154** through the connection of a signal line **168**.

Although FIG. **4** diagrams oscillator **124**, it is also representative of the construction of oscillators **132** and **154**. Oscillator **124** is comprised of a crystal oscillator unit **170**, a switch bank controller **172**, a temperature unit **174**, and a timing controller **176**. Unit **170** has a capacitor trimming bank **178**, a capacitor switching bank **180**, and a piezoelectric crystal (XTAL) **182**. Switch bank controller **172** has two parts, a parallel digital latch **184** and a programmable read only memory (PROM) **186**. The temperature unit **174** has a temperature sensor **190** and a analog-to-digital converter (ADC) **188**. Controller **176** has a load signal **192**, a ready input signal **193**, a PROM control signal **194**, a convert-start output signal **196**, and a disable input signal **197**. Periodically, controller **176** will sample the output frequency of unit **170** and cause ADC **188** to begin a new conversion. The other outputs of controller **176** are phased to provide smooth digital flow from ADC **188**, to PROM **186**, to Latch **184**, and on to switching bank **180**. The output of ADC **188** and PROM control signal **194** will cause a particular digital correction word to be output from PROM **186**. That word will be output to latch **184** and loaded by signal **192**. Latch **184** controls switch bank **180**, which in turn can switch in and out various capacitors in capacitor bank **178** in order to trim the resonant frequency of XTAL **182** and to keep it stable despite ambient temperature variations. Oscillator **124** is therefore a digitally-corrected temperature-compensated crystal oscillator (DTCXO) that can have the digital correction slowed or disabled completely.

A characteristic of the present invention is that when latch **184** receives digital frequency correction word from PROM **186**, READY signal **193** will be output to timing controller **176**. If signal **197** is low, a LOAD signal **192** will cause latch **184** to update. But if signal **197** is high, timing controller **176** will be disabled from issuing LOAD signal **192**. Signal **197** therefore functions as a DTCXO temperature compensation update SUSPEND/RESUME.

An alternative embodiment of the present invention includes the use of DTCXOs, such as above, in the local oscillators and signal processing clock circuits of a telephone call pager. In order to reduce the power consumption, the pager will be in standby and periodically turn on its receiver, anywhere from every several milliseconds to every several seconds. During active reception (squelch off). The local oscillator and signal processing circuit clock must be accurate and stable, and noise generated by the temperature compensation must be avoided. For this reason, during reception, any updating of the oscillating frequency control will be suspended. Oscillating frequency control updates will resume after the received signal ceases.

FIG. **5** shows that when receiver squelch is off (the radio is actively receiving a signal) the control signal **197** will track it and rise to suspend temperature compensation updating. When the receiver squelch is on, control signal **197** is lowered to signal that updates may resume. Resumption occurs at times **198** and **199**. Asynchronously with signal **197**, ADC **188** will output a digital temperature word. After an access time delay, PROM **186** will output a digital correction word and hold it. Signal **193** rises to indicate the correction word is valid (ready). When signal **197** drops low, and signal **193** is high, then signal **192** will clock high, loading the latch **184** and causing $D_1$–$D_n$ and $S_1$–$S_n$ to change state. These transitions will cause glitches to occur in XTAL **182** $f_o$, thereafter $C_1$–$C_n$ assume a temperature compensating condition that was proper at times **198** and **199**.

FIG. **6** is presented in contrast to FIG. **5**. It shows what happens in the prior art when a temperature compensation cycle, at a time **200**, occurs randomly and on top of receiver operation. XTAL **82** $f_o$ glitches and interferes with reception and transmission. Another random cycle occurs at a time **201** and again interferes with reception and transmission.

FIG. **7** demonstrates that the first of the transmitter, encoder, receiver, or decoder to become active will cause temperature compensation to be suspended and to hold its last valid correction word until the last of the transmitter, encoder, receiver, or decoder to become inactive. During the temperature compensation suspension, the output frequencies $f_o$ of oscillators **124**, **132**, and **154** are shown thermally drifting during the period of no temperature compensation updating. Oscillators **124** and **132** are controlled by signal **166**, and oscillator **154** is controlled by signal **168**. In an alternative embodiment, signal **168** suspends temperature compensation of oscillator **154** only during encoder or decoder activity. Similarly, signal **166** suspends temperature compensation of oscillators **124** and **132** only during transmitter of receiver activity.

FIG. **8** shows what happens if temperature compensation has suspended too long, for any reason. After the last drop of signal **197**, a timeout (t) will be initiated that will discard stale data and start a fresh update cycle resulting in signal **192** clocking in a new correction. Thermal drift errors are therefore zeroed periodically.

FIG. **9** is a timing diagram of the time division multiple access (TDMA) mode of operation. TDMA is a time compression communications method that multiplexes several communications devices together within a fixed amount of time. Using this method, a communications device will receive "This Station" data and suspend temperature compensation updates. However, when the data of an "Other Station" is on the channel, temperature compensation will resume. The adverse effects of frequency fluctuation and phase fluctuation can therefore be avoided.

FIG. **10** is a timing diagram of the digital speech interpolation (DSI) mode of operation. DSI is a time compression communications method in which the data of a first speaker is squeezed in during the time period in which a second speaker is not speaking. As with the preceding TDMA method, when this method is receiving required data for "This Station" temperature compensation updates are suspend. When the data of an "Other Station" is on the channel, temperature compensation will resume. Again, the adverse effects of frequency fluctuation and phase fluctuation are avoided.

Wireless communications devices are described above, however, the same advantages and benefits can be realized with hard-wired communications devices as well.

Above, CPU **156** determines when temperature compensation is to be suspended and resumed. Alternatively, such control could be a simple switch on the transmitter key or the receiver squelch and automatic gain control (AGC). Other combinations of operating modes dictating temperature compensation suspension can be defined as the conditions warrant.

Although the present invention has been described in terms of the above embodiments, it is to be understood that the disclosure is not to be interpreted as limiting. Various alterations and modifications will no doubt become apparent to those skilled in the art after having read the above disclosure. Accordingly, it is intended that the appended claims be interpreted as covering all alterations and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

[1. A temperature-compensated oscillator, comprising:

means to generate a frequency having an output;

means to adjust said frequency coupled to said frequency generator means;

temperature measurement means, coupled to said frequency adjustment means, in thermal proximity to the frequency generator means;

means to periodically update the frequency adjustment means, coupled to said frequency adjustment means, in response to the temperature measurement means;

means to suspend the periodic update of the frequency adjustment, coupled to said update means, in response to an external control signal; and

means to limit to a predetermined timeout the duration in time the suspension means can suspend said periodic update coupled to said means to suspend.]

[2. The oscillator of claim **1**, wherein:

the frequency generation means comprises a piezoelectric crystal oscillator having a bank of trimming capacitors controlled by switches such that a digital code presented to said switches will cause said crystal oscillator to vary in output frequency.]

[3. The oscillator of claim **1**, wherein:

the temperature detecting means comprises an ambient temperature sensor and a analog-to-digital converter connected to the frequency adjusting means.]

[4. The oscillator of claim **1**, wherein:

the frequency adjusting means comprises a programmable read only memory responsive to the temperature detecting means and a latch connected to the frequency generating means.]

[5. A digitally-corrected temperature compensated crystal oscillator (DTCXO) having an output and a control input, comprising:

means for generating a free-running frequency signal connected to the output, comprising a piezoelectric crystal oscillator having a bank of trimming capacitors controlled by switches such that a digital code presented to said switches will cause said DTCXO to vary in output frequency;

means for detecting an ambient temperature proximate to the frequency generating means, comprising an ambient temperature sensor and a analog-to-digital converter;

means for adjusting said free-running frequency signal responsive to the detection means and connected to the frequency generating means, comprising a programmable read only memory responsive to the temperature detecting means and a latch connected to the frequency generating means; and

means to suspend the adjusting means such that a last valid adjustment value is held during a period of suspension, the suspension means responsive to the control input and connected to the frequency adjusting means.]

[6. The DTCXO of claim **5**, further comprising:

means to periodically disable the suspension means upon the occurrence and reoccurrence of a predetermined timeout responsive to the suspension means and a timer.]

[7. A radio communications unit, comprising:

at least one digitally-corrected temperature-compensated crystal oscillator (DTCXO) having an output and a control input, having:

(a) means for generating a free-running frequency signal connected to the output, comprising a piezoelectric crystal oscillator having a bank of trimming capacitors controlled by switches such that a digital code presented to said switches will cause said DTCXO to vary in output frequency;

(b) means for detecting an ambient temperature proximate to the frequency generating means, comprising an ambient temperature sensor and a analog-to-digital converter;

(c) means for adjusting said free-running frequency signal responsive to the detection means and connected to the frequency generating means, comprising a programmable read only memory responsive to the temperature detecting means and a latch connected to the frequency generating means; and

(d) means to suspend the adjusting means such that a last valid adjustment value is held during a period of suspension, the suspension means responsive to the control input and connected to the frequency adjusting means.

means for receiving communications responsive to a signal from the DTCXO.]

[8. The unit of claim 7, further comprising:

means for transmitting communications responsive to a signal from the DTCXO.]

[9. The unit of claim 7, further comprising:

a microprocessor connected such that said DTCXO control input is manipulated in response to a plurality of operating modes existing in the radio communications unit.]

[10. A method for improving the quality of electronic telecommunications in a multi-mode communication means utilizing an oscillator having a temperature compensation means to update a value based upon detected temperature at said oscillator and, via adjustment means, change the frequency of oscillation of said oscillator to a predetermined frequency of oscillation based upon said updated value, comprising the steps of:

detecting which, if any, modes of electronic telecommunication are active;

suspending the updating by said temperature compensation means upon detection of an active mode to prevent said updating from generating interference that can degrade the operation of the active mode of said communications means;

providing a delay period commencing from the point in time when updating last occurred; and

updating said temperature compensation means value after the expiration of the delay period whether or not an active mode is detected.]

[11. The method of claim 10, wherein:

said modes comprise transmission, message encoding, reception, and message decoding.]

[12. A method for improving the quality of communications in a cellular telephone having modes comprising transmission, message encoding, reception, and message decoding, the telephone utilizing an oscillator having a temperature compensation means to update a value based upon detected temperature at said oscillator and, via adjustment means, change the frequency of oscillation of said oscillator to a predetermined frequency of oscillation based upon said updated value, comprising the steps of:

detecting which, if any, modes of electronic telecommunication are active;

suspending the updating by said temperature compensation means upon detection of an active mode to prevent said updating from generating interference that can degrade the operation of the active mode of said cellular telephone;

providing a delay period commencing from the point in time when updating last occurred; and

updating said temperature compensation means value after the expiration of the delay period whether or not an active mode is detected.]

[13. A computer-implemented process for improving electronic communications in a radio having a microprocessor, comprising the following steps:

detecting whether or not at least one mode of electronic communication is active, said modes comprising transmission, message encoding, reception, and message decoding;



suspending an updating of a temperature compensation correction word in an oscillator system providing reference frequencies that are supporting said electronic communications, such that interference and errors otherwise generated by said updating of said temperature compensation correction word will not be induced during the time activity of said mode is detected; and

waiting a timeout period from a point of last inactivity of said mode and then forcing the updating of said temperature compensation correction word in said oscillator system.]

[14. A method for improving receiver sensitivity and for reducing power consumption in a telephone pager utilizing an oscillator having a temperature compensation means to update a value based upon detected temperature at said oscillator and, via adjustment means, change the frequency of oscillation of said oscillator to a predetermined frequency of oscillation based upon said updated value, comprising the steps of:

detecting when the pager is in a standby mode of operation;

suspending the updating by said temperature compensation means upon detection of said standby mode to prevent said temperature compensation updating means from generating interference that can deteriorate the receiver sensitivity of the pager and from consuming power;

providing a delay period commencing from the point in time when updating last occurred; and

updating said temperature compensation means value after the expiration of the delay period whether or not an active mode is detected.]

*15. A digitally-corrected, temperature-compensated crystal oscillator circuit having an output terminal and a control input terminal inputting an external control signal indicating a state of a communication circuit, said digitally-corrected, temperature-compensated crystal oscillator circuit, comprising:*

*an oscillator circuit generating a frequency signal, the frequency signal output on the output terminal;*

*a compensation circuit connected to the oscillator, wherein a frequency of the frequency signal is based on a state of the compensation circuit;*

*a temperature sensor circuit detecting an ambient temperature and outputting a temperature signal based on the detected ambient temperature;*

*a conversion circuit connected to the temperature sensor circuit and the compensation circuit and inputting the temperature signal and outputting a ready signal and a compensation signal, the state of the compensation circuit based on the compensation signal; and*

*a control circuit connected to the conversion circuit and inputting the external control signal and outputting a control signal to the conversion circuit only when the external control signal indicates that the communication circuit is not active and the ready signal is generated by the conversion circuit, the conversion circuit updating the compensation signal based on the control signal.*

*16. The digitally-corrected, temperature-compensated crystal oscillator circuit of claim 15, wherein the temperature sensor is in thermal proximity to the oscillator circuit.*

*17. The digitally-corrected, temperature-compensated crystal oscillator circuit of claim 15, wherein the control circuit comprises a timer circuit, wherein, when the timer* circuit times out, the control circuit operates the conversion circuit to update the compensation signal independently of the sate of the external control signal.

18. The digitally-corrected, temperature-compensated crystal oscillator circuit of claim 15, wherein the conversion circuit comprises:

a memory device storing a temperature conversion table, wherein the memory device inputs the temperature signal as an address and outputs the compensation signal; and

a latch circuit for latching the compensation signal based on the control signal output by the control circuit.

19. The digitally-corrected, temperature-compensated crystal oscillator circuit of claim 15, wherein the temperature sensor circuit comprises:

a temperature sensing device outputting an analog temperature signal; and

an analog-to-digital converter inputting the analog temperature signal and outputting a digital temperature signal as the temperature signal to the conversion circuit.

20. The digitally-corrected, temperature-compensated crystal oscillator circuit of claim 15, wherein the compensation circuit comprises:

a switching circuit, comprising a plurality of switches, and inputting the compensation signal, a state of each switch based on the compensation signal; and

a capacitor trimming circuit comprising a plurality of capacitors, each capacitor connected to a corresponding one of the plurality of switches of the switching circuit, each one of the plurality of capacitors switched in and out of the capacitor trimming circuit based on the state of the corresponding switch, wherein a total effective capacitance of the capacitor trimming circuit is based on which capacitors are switched in, the total effective capacitance adjusting the frequency of the signal output by the oscillator circuit.

21. The digitally-corrected, temperature-compensated crystal oscillator circuit of claim 15, wherein the compensation circuit comprises at least one varactor, a state of each at least one varactor based on the compensation signal.

22. The digitally-corrected, temperature-compensated crystal oscillator circuit of claim 15, wherein the oscillator circuit comprises a piezoelectric crystal oscillator.

23. A communication unit, comprising:

an oscillator circuit outputting a pulse signal;

a temperature sensor circuit outputting a temperature signal indicative of a sensed temperature;

a temperature conversion circuit outputting a ready signal and a temperature compensation signal based on the temperature signal;

a temperature compensation circuit, wherein a state of the temperature compensation circuit is based on the temperature compensation signal, the state of the temperature compensation circuit adjusting a frequency of the pulse signal output by the oscillator circuit; and

a communication circuit inputting the pulse signal, wherein based on an operating state of the communication circuit and generation of the ready signal by the temperature conversion circuit, an update of the adjustment of the frequency of the pulse signal by the temperature compensation circuit is suspended.

24. The communications unit of claim 23, wherein the temperature sensor circuit is in thermal proximity to the oscillator circuit.

25. The communication unit of claim 23, further comprising a control circuit inputting an external control signal indicative of the operating state of the communication circuit and outputting a control signal, based on the state of the external control signal, to the temperature conversion circuit to cause the temperature conversion circuit to output the temperature compensation signal, the control circuit including a timer circuit, wherein, when the timer circuit times out, the control circuit outputs the control signal to the temperature conversion circuit independently of the state of the external control signal.

26. The communications unit of claim 23, wherein the temperature conversion circuit comprises:

a memory device storing a temperature conversion table, wherein the memory device inputs the temperature signal as an address and outputs the temperature compensation signal; and a latch circuit for latching the temperature compensation signal based on the control signal output by the control circuit.

27. The communications unit of claim 26, wherein the temperature compensation circuit further comprises:

a switching circuit, comprising a plurality of switches, and inputting the temperature compensation signal, a state of each switch based on the temperature compensation signal; and

a capacitor trimming circuit comprising a plurality of capacitors, each capacitor connected to a corresponding one of the plurality of switches of the switching circuit, each one of the plurality of capacitors switched in and out of the capacitor trimming circuit based on the state of the corresponding switch, wherein a total effective capacitance of the capacitor trimming circuit is based on which capacitors are switched in, the total effective capacitance adjusting the frequency of the pulse signal output by the oscillator circuit.

28. The communications unit of claim 26, wherein the temperature compensation circuit further comprises at least one varactor, a state of each at least one varactor based on the temperature compensation signal.

29. The communications unit of claim 23, wherein the temperature sensor circuit comprises:

a temperature sensing device outputting an analog temperature signal; and

an analog-to-digital converter inputting the analog temperature signal and outputting a digital temperature signal as the temperature signal to the temperature conversion circuit.

30. The communication unit of claim 23, wherein the oscillator circuit comprises a piezoelectric crystal oscillator.

31. The communications unit of claim 23, wherein the communications circuit comprises at least one of a receiving circuit and a transmitting circuit.

32. The communication unit of claim 23, wherein the temperature compensation circuit periodically adjusts the frequency of the pulse signal output by the oscillator circuit.

33. The communication unit of claim 23, wherein the communication circuit is a radio communication circuit.

34. The communication unit of claim 23, wherein the communication circuit is a wire communication circuit.

35. A communications unit, comprising:

an oscillator circuit outputting pulse signal;

a communications circuit inputting the pulse signal of the oscillator circuit, wherein the communications circuit alternates, periodically, between a receive state and a standby state, the communications circuit outputting an external control signal based on the state of the communications circuit;

*a temperature sensor circuit outputting a temperature signal indicative of a sensed temperature;*

*a temperature conversion circuit inputting the temperature signal and outputting a ready signal and a temperature compensation signal based on the temperature signal;*

*a temperature compensation circuit, wherein a state of the temperature compensation circuit is based on the temperature compensation signal, the state of the temperature compensation circuit adjusting a frequency of the pulse signal output by the oscillator circuit; and*

*a control circuit inputting the external control signal and outputting a control signal to the temperature conversion circuit to operate the temperature conversion circuit to update the state of the temperature compensation circuit only when the communications circuit is in the standby state and the ready signal is generated by the temperature conversion circuit, wherein the control circuit is prevented from outputting the control signal to the temperature conversion circuit when the external control signal indicates that the communications circuit is in the receive state.*

*36. A time division multiple access communications unit, comprising:*

*an oscillator circuit outputting a pulse signal;*

*a time division multiple access communications circuit inputting the pulse signal of the oscillator circuit, wherein the communications circuit has receive operation periods, send operation periods, and idle periods, the communications circuit outputting an external control signal;*

*a temperature sensor circuit outputting a temperature signal indicative of a sensed temperature;*

*a temperature conversion circuit outputting a ready signal and a temperature compensation signal based on the temperature signal;*

*a temperature compensation circuit, wherein a state of the temperature compensation circuit is based on the temperature compensation signal, the state of the temperature compensation circuit adjusting a frequency of the pulse signal output by the oscillator circuit; and*

*a control circuit inputting the external control signal and outputting a control signal to the temperature conversion circuit to operate the temperature conversion circuit to update the state of the temperature compensation circuit only when the communications circuit is in said idle periods and the ready signal is generated by the temperature conversion circuit, wherein the control circuit is prevented from outputting the control signal to the temperature conversion circuit when the external control signal indicates that the communications circuit is in one of a receive operation period or a send operation period.*



*37. A compensated oscillator, comprising:*

*an oscillator circuit outputting a pulse signal;*

*a compensation signal generating circuit outputting a compensation signal and a ready signal;*

*a compensation circuit, wherein a state of the compensation circuit is based on the compensation signal, the state of the compensation circuit adjusting a frequency of the pulse signal output by the oscillator circuit; and*

*a control circuit inputting an external control signal and outputting a control signal to the compensation signal generating circuit to operate the compensation signal generating circuit to output the compensation signal to update the state of the compensation circuit, wherein, the control circuit is prevented from outputting the control signal when the external control signal indicates that a communication circuit that uses said pulse signal is active and the ready signal is not generated by the compensation signal generating circuit.*

*38. A communication unit, comprising:*

*an oscillator circuit outputting a pulse signal;*

*a compensation signal generating circuit outputting a compensation signal and a ready signal;*

*a compensation circuit, wherein a state of the compensation circuit is based on the compensation signal, the state of the compensation circuit adjusting a frequency of the pulse signal output by the oscillator circuit; and*

*a communication circuit inputting the pulse signal, wherein, based on an operating state of the communication circuit and generation of the ready signal by the compensation signal generating circuit, an update of the adjustment of the frequency is suspended.*

* * * * *