A transmitter (100), with an inphase input (102) for receiving an inphase baseband input signal, and a quadrature input (112) for receiving a quadrature baseband input signal, comprises a modulator (130), coupled to the inphase and quadrature inputs, for modulating the inphase and quadrature baseband signals, to provide a modulated radio-frequency signal, and a linear amplifier (135), coupled to the modulator, for amplifying the modulated radio-frequency signal to produce an output signal. An oscillation detector is coupled to receive the output signal, for detecting oscillation, and for producing an error signal as a result of the oscillation. The transmitter also comprises circuitry (transmission gates 124, 126, 127, and 128) for reducing the open loop gain of the feedback loop, disposed between the inphase and quadrature inputs and the modulator. The circuitry for reducing the open loop gain reduces the open loop gain of the transmitter to less than one, in response to the error signal.
## FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

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STABILIZING CIRCUIT
FOR FEEDBACK RF AMPLIFIER

Technical Field

This invention relates generally to spectrally efficient digital modulation systems and more particularly to stabilizing circuits for feedback radio-frequency (RF) amplifiers.

Background

A linear RF amplifier is an amplifier that increases the power of a modulated carrier signal while preserving both the amplitude and phase modulation components of the signal. Frequency-modulation (FM) signals have constant amplitude and thus do not require linear amplification. On the other hand, digital transmission systems may require both amplitude modulation (AM) and phase modulation (PM) of the transmitted signals. Linear amplifiers are necessary to transmit those signals.

Linear RF amplifiers typically have inherent defects, including amplitude distortion and AM-to-PM conversion, which may cause undesired interference called splatter, to adjacent channel signals. Negative feedback, as well as careful amplifier design, is required to minimize the level of splatter generated.

Linear RF amplifiers commonly use feedback to minimize the splatter. For stability (i.e., freedom from oscillation) a feedback loop must have a gain/phase versus frequency characteristic such that the open loop gain (i.e., the gain of the entire feedback loop with the loop broken at one point) is less than one at all frequencies where the phase shift is more than 180 degrees different from that at midband. Previous RF feedback loops have used a very high Q (i.e., the merit factor of
the loop) resonant circuit at the radio-frequency to achieve this condition. This approach has several disadvantages, including large size, large RF gain needed, and the limited amount of open loop gain possible.

Stability of the feedback loop is a major concern. The baseband portions of the loop can be made to have well controlled phase characteristics, but the RF portion may have large, unpredictable phase shifts due to resonant circuits, varactor effects of supply voltage variations, AM-to-PM conversion, thermal effects and aging effects. These effects substantially reduce the phase margin for stability of the loop, and may even cause oscillation of the amplifier.

**Summary of the Invention**

Briefly, a linear amplifier includes a feedback loop for providing a feedback signal. The linear amplifier also includes feedforward and feedback phase correction means.

**Brief Description of the Drawings**

Figure 1 shows a transmitter, with feedforward and feedback circuits, in accordance with the present invention.

Figure 2 shows the modulator, amplifier and feedback detector of Figure 1 in greater detail.

Figure 3 shows a soft start circuit that may be used within the circuit of Figure 1.

Figure 4 shows a possible means for detecting oscillation.

Figure 5 shows an alternative configuration for implementing the voltage controlled phase shifter.

**Detailed Description of the Preferred Embodiment**

Referring to Figure 1, a transmitter 100, with a conventional linear amplifier 135 and feedforward and feedback circuits, is shown. A baseband feedback loop is shown, but the innovations of the present invention are not limited thereto, but may also be applicable to feedback of radio frequency and other signals. The baseband feedback loop accepts an inphase baseband input signal (I_{in}) and a quadrature baseband input signal (Q_{in}). The
signal is applied to the positive input 102 of a conventional operational amplifier 106. The amplifier 106 amplifies the difference between the input signal \( I_{in} \) and the signal at its negative input 104 and acts as an input buffer for \( I_{in} \). The output of the amplifier 106 is coupled to \( I' \), through a resistor 108, and to a terminal of a transmission gate 126 (operating as a normally-closed switch), through a resistor 110. The other terminal of the transmission gate 126 is coupled to the inphase input 132 of a conventional amplitude modulator 130. A resistor 103 is disposed between the negative input 104 of the amplifier 106 and the inphase output of a feedback detector 172 (having inphase and quadrature outputs). Similarly, a resistor 113 is disposed between the negative input 114 of the amplifier 116 and the quadrature output of the feedback detector 172.

The quadrature signal \( Q_{in} \) is applied to the positive input 112 of an operational amplifier 116. The amplifier 116 operates in substantially the same manner as the amplifier 106. Moreover, the output of the amplifier 116 is coupled to its negative input 114, through a resistor 118, and it is also coupled to a transmission gate 127 (also operating as a normally-closed switch) through a resistor 120. The other terminal of the transmission gate 127 is coupled to the quadrature input 134 of the modulator 130.

A transmission gate 124 (operating as a normally-open switch) is disposed between an adjustable power supply 122 and the inphase input 132 of the modulator 130. Another transmission gate 128 (operating as a normally-open switch) is disposed between ground potential and the quadrature input 132 of the modulator 130.

The modulator 130 mixes the signals \( I_{in} \) and \( Q_{in} \) up to radio-frequency, and the linear amplifier 135 amplifies the resulting modulated low power RF signal 133 to provide an output signal 143 for transmission by an antenna 138. A sample of the RF output 143 is mixed back down to baseband frequency by the feedback detector 172, to produce detected inphase and quadrature baseband signals, \( I' \) and \( Q' \), respectively. An attenuator 136 is disposed between the output of the linear amplifier 135 and the input of the feedback detector 172, so that
the power level of the feedback is lower than that of the output signal. The I' and Q' baseband signals are applied to the negative inputs (104 and 114) of the amplifiers 106 and 116, respectively, to be combined, out of phase, with the input signals (I_in) and (Q_in); thus forming a negative feedback loop around the linear amplifier 135.

Assuming that a carrier component is always present in the transmission, it can be used as a phase reference signal for the amplifier 135. Thus, the Q' output of the feedback detector 172 may operate as a phase detector. This is because the carrier signal, at baseband, is a DC voltage on the inphase (I') channel only. Any DC voltage at the Q' output of the detector 172 is proportional to sin(\phi), where \phi is the phase error in the RF amplifier 135. The resulting error voltage is applied to the negative input of the amplifier 140, through the resistor 164. The amplifier 140 combines the feedback (error) and feedforward signals and applies the combined signal 139 to a phase shifter 218 (as will become more apparent in the discussion of Figure 2). The combined signal 139 causes the phase shifter 218 to shift the phase of the modulated signal 133 to compensate for any shift in the phase of the output signal 143.

The modulator 130 includes a conventional envelope detector (216, shown in Figure 2) providing an output signal 137 to the positive input of a conventional operational amplifier 154. The operational amplifier 154 has its output coupled to its negative input, through a resistor 160, and its negative input also coupled to ground, through a resistor 162. The amplifier 154, and the resistors 160 and 162 operate as a buffer from the envelope detector signal 137.

Conventional operational amplifiers 166 and 140 are loop filters and amplifiers to drive a voltage controlled phase shifter (218, shown in Figure 2). These elements together with the Q' detector form the equivalent of a phase locked loop which corrects any slowly varying phase effects (e.g., supply voltage, resonant circuits, and thermal effects) in the RF amplifier 135 (i.e., a feedback phase corrector). The amplifier 166, with its positive input grounded and its output coupled to the node 167, also
operates as a low-pass filter and amplifier. The output of the amplifier 166 is coupled to its negative input, through a resistor 168 in parallel with a capacitor 170, and to the quadrature output of the feedback detector 172, through a resistor 174.

Amplitude to phase modulation (AM to PM) conversion can be compensated for by a nonlinear feedforward correction circuit. The feedforward correction circuit comprises the amplifier 154, a nonlinear network 141 (that includes diodes 156 and 146). The nonlinear network 141 has the following structure. A resistor 152 has a terminal coupled to the output of the amplifier 154. The other terminal of the resistor 152 is coupled to the anode of a diode 156 at a node 151. A resistor 158 is disposed between the cathode of the diode 156 and ground potential and a resistor 148 is disposed between the cathode of the diode 146 and ground. A resistor 150 is coupled between the node 151 and a node 145. The anode of a diode 146 is coupled to the node 145. A resistor 144 is disposed between the node 145 and the positive input of the amplifier 140. The output of the amplifier 140 is also coupled to its negative input, through a resistor 142. The negative input of the amplifier 140 is coupled to a a node 167, through a resistor 164.

The output of the amplifier 154 represents the instantaneous AM component of the signal 133. It is applied to the phase shifter 218 through a nonlinear network 141 and the amplifier 140. The characteristics of the nonlinear network 141 are selected to approximately cancel the AM to PM conversion characteristic of the amplifier 135. The combination of feedforward and feedback phase correction allows a greater degree of phase correction than is possible with either method alone.

A diode 176 has its anode coupled to the node 167, and its cathode coupled to the positive input of a conventional operational amplifier 180. The operational amplifier 180, with its negative input coupled to an adjustable power supply 178, detects any low frequency oscillation of the feedback loop. The output of the amplifier 180 is coupled to the negative input of a conventional operational amplifier 186, through a resistor 182,
and to the control terminal of the transmission gates 124 and 128. The amplifier 180 also has its positive input coupled to ground. The output of the amplifier 186 is coupled to its negative input through a resistor 184. Thus the amplifier 186 inverts the output of the amplifier 180. The output of the amplifier 186 is applied to the control terminal of the transmission gates 126 and 127. In case oscillation is detected, the detector 180, and the inverter 186 switch the transmission gates 126 and 127 off, while switching the transmission gates 124 and 128 on. This opens the feedback loop (to stop oscillation) and applies a DC signal to the inphase input 132 and grounds 134 of the modulator 130 to reestablish correct carrier phase. After this, the transmitter 100 will stabilize.

According to another embodiment of the present invention, transmission gates can be replaced by a commercially available voltage controlled attenuator to attenuate the output signals from the amplifiers 106 and 116, respectively, at times when the amplifier 180 detects an error signal indicating that oscillation exists in the feedback loop, thus eliminating the oscillation since the gain of the loop has been reduced to below unity.

Referring to Figure 2, the modulator 130 and the feedback detector 172 of Figure 1 in are shown in greater detail. The modulator 130 comprises an inphase modulator 206 that receives the inphase input signal 132 and mixes that signal with a carrier-frequency signal 207 provided by a carrier-frequency oscillator 208 to produce a first mixed signal 209.

The quadrature input signal 134 is applied to a mixer 212 for multiplication by the signal 207, shifted (210) by 90 degrees, to produce a second mixed signal 213. The first and second mixed signals 209 and 213 are added by an adder 214, to produce a signal 215. An envelope detector 216 samples the signal 215 to provide the feedforward signal 137. A voltage-controlled phase shifter 218 shifts the phase of the modulated signal 215 in response to the combined signal 139, to compensate for phase shifts in the output signal 143 and produce the signal 133.

The feedback detector 172 comprises a multiplier 234 that multiplies the sampled signal 143 (attenuated by the attenuator 136) and the signal 207, produced by the carrier frequency
oscillator 208. The resulting product is then filtered by a low-pass filter (consisting of a series resistor 232 and a capacitor 230 coupled to ground), thus producing the detected inphase signal (I').

The feedback detector 172 further comprises a multiplier 240 that multiplies the sampled signal 143 (attenuated by the attenuator 136) and the signal 207, phase shifted by 90°). The resulting product is then filtered by a low-pass filter (consisting of a series resistor 238 and a capacitor 236 coupled to ground), thus producing the detected quadrature signal (Q').

Referring to Figure 3, a conventional timer 300 is shown used as a "soft start" circuit. The soft start timer 300 is disposed between the amplifier 180 and the amplifier 186. It is used to prevent oscillation when the transmitter 100 is turned on by causing the transmission gates 126 and 127 (shown in Figure 1) to attenuate the outputs of the amplifiers 106 and 116, respectively, for a short period of time when the transmitter 100 is first turned on (i.e., at startup). Alternatively, the soft start timer 300 could cause the transmitter to operate on a carrier-only mode (i.e., transmission gates 126 and 127 are open while 124 and 128 are closed) at startup, thus preventing oscillation. Normal operation would begin after a predetermined time or when the amplifier 180 indicates that a normal phase condition has been established (i.e., that there is no oscillation).

Referring to Figure 4, an alternate means for detecting oscillation is shown. This detects not only high amplitude at Q', but also abnormally low amplitude carrier level at I', which would indicate saturation of the amplifier by oscillator. Conventional threshold detectors and drivers 314 receive the detected I' and Q' signals (filtered through the low pass filters consisting of series resistors 306 and 308 and capacitors 310 and 312). An abnormally low DC component at I' indicates that the carrier is being suppressed by oscillation. An abnormally high amplitude low frequency component at Q' also indicates oscillation. In addition, current drawn by the amplifier or the RF output voltage, if greater than normal, could serve as an indication of oscillation.
Referring to Figure 5, an alternative configuration for the phase shifting means of the transmitter 100 is shown. If desired, separate oscillators could be used to drive the I and Q modulators (130) and the I and Q feedback detector (172), and the oscillator 410 driving the modulators (130) could be used as a VCO replacing the voltage controlled phase shifter 218 of Figure 2.

When the amplifier 135 is first turned on, it could start oscillating before the feedback phase corrector can establish the correct phase relationship. In addition, an external event such as a sudden change in RF load impedance could cause a rapid phase change which would start an oscillation. The present invention provides means to detect and eliminate any such oscillation. According to the present invention, there are several possible means to detect an oscillation:

1. If the frequency of oscillation is expected to be within the bandwidth allocated to the carrier, then a high amplitude signal at the Q' output of the feedback detector 172 will indicate oscillation.

2. As discussed with respect to Figure 4, a more general method is to introduce threshold detectors and drivers between the I' and Q' outputs of the detector 172, and the gain control elements. This method detects not only high amplitude at Q' but also abnormally low amplitude carrier level at I' which would indicate saturation of the amplifier by oscillation.

3. Abnormally high DC current drain and/or RF output voltage could also be used as an indication of oscillation. These methods do not depend on a carrier component being present.

When oscillation is detected, the present invention operates to use one or more of the following methods to stop the oscillation and restore normal operation.

In Figure 1, when an oscillation is detected transmission gates 126 and 127 are opened. This breaks the feedback loop and immediately stops the oscillation. At the same time, a DC component is applied to the in phase modulator input 132.
through transmission gate 124 and zero volts applied to the quadrature modulator input 134 through transmission gate 128. This inserts a carrier component with the proper phase and will allow the feedback phase corrector to establish the correct phase relationship while the loop is open. Once the phase is corrected, the loop can be automatically closed and normal operation will follow.

As an alternative to opening the loop and inserting carrier, the transmission gates can be arranged to merely insert a predetermined amount of attenuation in the forward path. This attenuation would reduce the loop gain sufficiently to stop oscillation and allow the correct phase to be reestablished. As before, normal operation would then ensue.

As an alternative to having attenuators in the forward I and Q paths, a single attenuator could be used in the forward RF path to accomplish the same purpose. This could be accomplished with a PIN diode attenuator or other means.

In summary, the present invention provides a transmitter with negative feedback in which oscillation may be prevented or eliminated by reducing the open loop gain of the transmitter (possibly to zero, by opening the loop and inserting the carrier) alone or in combination with other methods discussed herein.

What is claimed is:
Claims

1. A linear amplifier for receiving an input signal and producing an output signal, comprising:
   a feedback loop for providing a feedback signal;
   feedforward phase correction means; and
   feedback phase correction means.
2. The linear amplifier of claim 1, wherein the feedforward phase correction means comprises a nonlinear network with a characteristic selected to approximately cancel the AM to PM conversion characteristic of the amplifier.

3. The linear amplifier of claim 2, wherein the feedback phase correction means comprises phase detection means for detecting a difference between the phase of the feedback signal and the phase of the input signal.

4. The linear amplifier of claim 3 further comprising means for stopping oscillation in the linear amplifier when the phase detection means detects a difference between the phase of the feedback signal and the phase of the input signal.
5. A linear amplifier, with a feedback loop, for receiving an input signal and producing an output signal, comprising:
detection means for detecting oscillation in the linear amplifier; and
means for stopping the oscillation when the detection means detects oscillation in the linear amplifier.
6. The linear amplifier of claim 5 further comprising:
   oscillation detector means, coupled to receive the output
   signal, for detecting oscillation, and for producing an error signal
   as a result of the oscillation; and

5          means for reducing the open loop gain of the feedback
   loop to less than one, in response to the error signal.
7. A linear amplifier, with a feedback loop, for receiving an input signal and producing an output signal, comprising:
   detection means for detecting oscillation in the linear amplifier; and
   a soft start circuit to force the open loop gain of the feedback loop to be less than one for a period of time beginning at startup, to prevent oscillation from occurring before a normal phase relationship has been established in the linear amplifier.
8. A transmitter, with an inphase input for receiving an inphase baseband input signal, and a quadrature input for receiving a quadrature baseband input signal, comprising:

- a modulator, coupled to the inphase and quadrature inputs, for modulating the inphase and quadrature baseband signals to provide a modulated radio-frequency signal;
- a linear amplifier, coupled to the modulator, for amplifying the modulated radio-frequency signal to produce an output signal;
- oscillation detector means, coupled to receive the output signal, for detecting oscillation, and for producing an error signal as a result of the oscillation; and
- means for reducing the open loop gain of the feedback loop to less than one, in response to the error signal.
9. The transmitter of claim 8, further comprising:
inphase feedback combiner means, coupled to the oscillation detector means to receive the detected baseband inphase signal, and coupled to receive the inphase baseband input signal, for combining the inphase baseband feedback signal with the inphase input signal, to provide an inphase difference signal to the means for reducing the open-loop gain; and

quadrature feedback combiner means, coupled to the oscillation detector means to receive the detected baseband quadrature signal, for combining the detected baseband quadrature feedback signal with the quadrature input signal to provide a quadrature difference signal to the means for reducing the open-loop gain.

10. The transmitter of claim 9, wherein the means for reducing the open-loop gain comprises:
a first normally-closed switch disposed between the inphase feedback combiner means and the modulator, the first normally-closed switch also having a control electrode coupled to receive the error signal so that the first normally-closed switch opens when it receives the error signal and is closed when the error signal is not applied thereto;
a first normally-open switch disposed between a supply of direct-current voltage and the modulator, the first normally-open switch also having a control electrode coupled to receive the error signal so that the first normally-open switch closes when it receives the error signal and is open when the error signal is not applied thereto;
a second normally-closed switch disposed between the quadrature feedback combiner means and the modulator, the second normally-closed switch also having a control electrode coupled to receive the error signal so that the first normally-closed switch opens when it receives the error signal and is closed when the error signal is not applied thereto; and
17
a second normally-open switch disposed between a
ground voltage and the modulator, the first normally-open switch
also having a control electrode coupled to receive the error signal
so that the second normally-open switch closes when it receives
the error signal and is open when the error signal is not applied
thereto.

5

11. The transmitter of claim 10, wherein the inphase and
quadrature combiner means comprise operational amplifiers.
12. A transmitter, having input means for receiving
inphase and quadrature baseband input signals, comprising:
a modulator, coupled to the input means, for providing a
modulated radio-frequency signal;
a linear amplifier, coupled to the modulator, for amplifying
the modulated radio-frequency signal to produce an output
signal;
detection means for detecting oscillation in the transmitter
and for producing detected baseband inphase and quadrature
feedback signals and applying the feedback signals to the input
means
an inphase feedback combiner, coupled to the feedback
detector for combining the inphase feedback signal with the
inphase input signal, to provide an inphase difference signal,
a quadrature feedback combiner, coupled to the feedback
detector for combining the quadrature feedback signal with the
quadrature input signal to provide a quadrature difference signal;
an inphase attenuator, coupled to the inphase feedback
combiner, for reducing the open loop gain of the feedback loop, in
response to the quadrature feedback signal; and
a quadrature attenuator, coupled to the quadrature
feedback combiner, for reducing the open loop gain of the
feedback loop, in response to the quadrature feedback signal.
13. A transmitter, with an inphase input for receiving an inphase baseband input signal, and a quadrature input for receiving a quadrature baseband input signal, comprising:

- a modulator, coupled to the inphase and quadrature inputs, for providing a modulated signal and a feedforward signal that comprises an error signal;
- a linear amplifier, coupled to the modulator, for amplifying the modulated signal to produce an output signal;
- a phase detector, coupled to receive the output signal, for detecting phase error and for producing detected baseband inphase and quadrature feedback signals, and the error signal as a result of the phase error; and
- phase correction means, coupled to receive the error signal, for shifting the phase of the modulated signal to compensate for any shifts in the phase of the output signal.
14. The transmitter of claim 13, further comprising:
   an inphase feedback combiner, coupled to the oscillation
detector to receive the detected baseband inphase signal, and
coupled to receive the inphase baseband input signal, for
combining the inphase baseband feedback signal, out of phase,
with the inphase input signal, to provide an inphase difference
signal to the modulator; and
   a quadrature feedback combiner, coupled to the feedback
detector for combining the quadrature feedback signal, out of
phase, with the quadrature input signal to provide a quadrature
difference signal to the modulator.

15. The transmitter of claim 14, further comprising:
a soft start means, disposed between the phase correction means
and the modulator, for attenuating the inphase baseband input
signal and the quadrature baseband input signal at a selected
time for a selected period of time.

16. The transmitter of claim 15, wherein the inphase and
quadrature combiner means comprise operational amplifiers.
FIG. 3

FROM THE DIODE 176

FROM SUPPLY VOLTAGE 178

SOFT START TIMER

TO TRANSMISSION GATES 126 AND 127

TO TRANSMISSION GATES 124 AND 128
INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) 3

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC (5) : H03F 1/26
U.S. Cl. : 330/149

II. FIELDS SEARCHED

Minimum Documentation Searched 4

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Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched 6

III. DOCUMENTS CONSIDERED TO BE RELEVANT 14

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<td>US,A 3,900,823 (SOKAL ET AL) 18 August 1975 See Figure 4 and Column 19 to Column 11, Line 36.</td>
<td>1-3</td>
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<td>X</td>
<td>GB,A 1,246,209 (BRADSHAW) 15 September 1971 See Page 2, Column 1, Lines 33-54.</td>
<td>1-3</td>
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<td>X</td>
<td>US,A 4,367,443 (HULL ET AL) 04 January 1983 See Figures 1,2B &amp; 3B, and Column 5, Lines 28-41.</td>
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<tr>
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<td>US,A 4,439,741 (TURNER, JR.) 27 March 1984 See Figure 3 and Column 3, Lines 11-27.</td>
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* Special categories of cited documents: 15
  "A" document defining the general state of the art which is not considered to be of particular relevance
  "E" earlier document but published on or after the international filing date
  "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
  "O" document referring to an oral disclosure, use, exhibition or other means
  "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"A" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search 2
13 DECEMBER 1990

Date of Mailing of this International Search Report 3
04 FEB 1991

International Searching Authority 1
ISA/US

Signature of Authorized Officer 16

JAMES B. MULLINS

Form PCT/ISA/210 (second sheet) (May 1986)
FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

| X | US, A | 4,673,886 (BICKLEY ET AL) |
|   |      | 16 June 1987               |
|   |      | See Column 3, Line 56 to Column 5, Line 64. |

V. □ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE

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 not required to be searched by this Authority, namely:

2. □ Claim numbers . . . . 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, specifically:

3. □ Claim numbers . . . . because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. □ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING

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.