(54) Title: A CARRIER RECOVERY METHOD AND APPARATUS HAVING AN ADJUSTABLE RESPONSE TIME DETERMINED BY CARRIER SIGNAL PARAMETERS
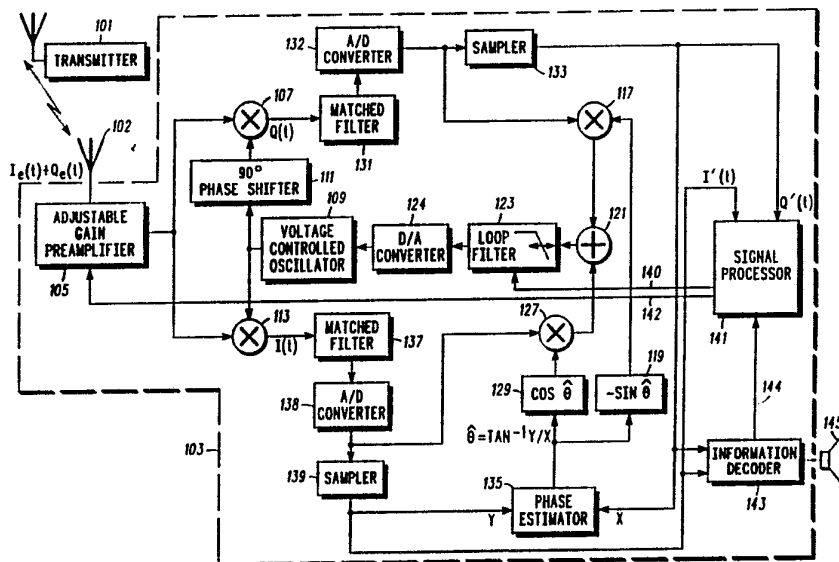
(57) Abstract

A communications receiver (103) comprising a carrier recovery apparatus having an adjustable response time loop filter (123) responsive to carrier signal parameters determined by a signal processor (141) is disclosed. Signal reception under fading conditions is improved by detecting the received signal parameters in an energy level determinator (207, a rate of change of energy level determinator (209) and a look-up table value (221) corresponding to a position of TDMA time clock (219).

A CARRIER RECOVERY METHOD AND APPARATUS
HAVING AN ADJUSTABLE RESPONSE TIME
DETERMINED BY CARRIER SIGNAL PARAMETERS.

5

Field of the Invention

The present invention relates generally to
10 communication receivers, and, more particularly, to a
communication receiver with a carrier recovery method and
apparatus having an adjustable response time determined by
carrier signal parameters.   Reference is made to U.S. Patent
Application No. (CE00347R), "Input-Estimating Fast AGC
15 System with Adaptive Gain Adjustment", filed on behalf of
Stephen Vincent Cahill on the same date herewith, containing
related subject matter, and assigned to the assignee of the
present invention.

20   Background of the Invention

A radio communication system is comprised, at
minimum, of a transmitter and a receiver. The transmitter
and the receiver are interconnected by a radio-frequency
25 channel to permit transmission of an information signal
therebetween.
Typically, the information signal is impressed upon a
radio-frequency electromagnetic wave by a process referred to
as modulation to permit transmission of the information
30 signal between the transmitter and the receiver. The radio-
frequency electromagnetic wave is referred to as a carrier
wave which is of a particular frequency, and the carrier wave,
once modulated by the information signal, is referred to as a
modulated information signal. The modulated information

signal may be transmitted through free space to transmit thereby the information between the transmitter and the receiver.

Various modulation techniques have been developed to
5   modulate the information signal upon the electromagnetic wave. Amplitude modulation (AM), frequency modulation (FM), phase modulation (PM), and composite modulation (CM) are four of such modulation techniques. Frequency and phase modulation techniques are collectively known as angle
10   modulation.

In general, an amplitude modulated signal is formed by impressing (i.e., modulating) an information signal upon a carrier wave such that the information signal modifies the amplitude of the carrier wave corresponding to the value of the
15   information signal.

An angle modulated signal formed is formed by impressing (i.e., modulating) an information signal upon a carrier wave such that the information signal modifies the phase (or the time differential of phase, frequency) of the
20   carrier wave corresponding to the value of the information signal. Angle modulation does not cause the amplitude of the carrier wave to vary, and the information content of the modulated information signal is contained in the variation of the phase (or frequency) of the signal. Because the amplitude
25   of an angle modulated signal does not vary, an angle modulated signal is referred to as a constant envelope signal.

A composite modulated signal is formed by impressing (i.e., modulating) an information signal upon a carrier wave such that the information signal modifies both the amplitude
30   and the phase of the carrier wave. Conventionally, in order to form the composite modulated signal, the carrier wave (or a carrier intermediate frequency, i.e., IF, source) is first separated into sine wave and cosine wave carrier portions. Separate portions, referred to as the in-phase (or I) and the

quadrature (or Q) components, of the information signal are impressed upon the cosine wave and sine wave carrier portions of the carrier wave, respectively. The sine wave and cosine wave components are then recombined, and the

5   resultant signal, the composite modulated signal, varies in both amplitude, and, additionally, phase. Composite modulation is advantageous in that a composite modulated signal permits a greater amount of information to be transmitted within a frequency bandwidth than a signal

10   generated by any of the previously mentioned modulation techniques. See, for instance, a discussion in the text Introduction to Communication Systems, 2nd Ed, by Ferrel G. Stremmler, ISBN 0-201-07251-3, pages 590-596.

A family type of composite modulation is quadrature

15   amplitude modulation (QAM). In this modulation method, as conventionally applied to a binary information source, the binary data stream is separated into bit pairs. The individual bits of the bit pairs are converted from unipolar to bipolar format, passed through a pair of electric wave filters, and

20   applied to the multiplier pair whose other inputs are the sine and cosine components of the carrier or carrier IF signal. A particular type of QAM is $\pi/4$-shift DQPSK (for differential quadrature phase shift keying), in which the input data stream is encoded so that the composite modulated carrier

25   shifts in increments of $\pm\pi/4$ or $\pm3\pi/4$ according to the input bit pairs. This modulation method, conventionally implemented, is discussed in Digital Communications, by John G. Proakis, 1st Ed., ISBN 0-07-050927-1, pages 171-178.

A receiver which receives a modulated information

30   signal, such as a one formed by one of the above described modulation techniques, includes circuitry to detect, or otherwise to recreate, the information signal modulated upon the carrier wave. This process is referred to as demodulation. As many different modulated information signals may be

simultaneously transmitted by a plurality of transmitters at a plurality of different frequencies, a receiver contains tuning circuitry to demodulate only those signals received by the receiver which are of certain desired frequencies. The broad

5   range of frequencies at which modulated information signals may be transmitted is referred to as the electromagnetic frequency spectrum. Regulation of radio-frequency communications in certain frequency bands of the electromagnetic frequency spectrum minimizes interference

10   between simultaneously transmitted signals.

For example, portions of a 100 MHz band of the electromagnetic frequency spectrum (extending between 800 MHz and 900 MHz) are allocated for radiotelephone communication, such as, for example, communication

15   effectuated by radiotelephones utilized in a cellular, communication system. Existing radiotelephones contain circuitry both to generate and to receive radio-frequency modulated information signals.

A cellular communications system is created by

20   positioning numerous base stations at specific locations throughout a geographical area. Each of the base stations is constructed to receive and to transmit modulated information signals simultaneously to and from radiotelephones to permit two-way communication there between. Each of the base

25   stations is provided with means to communicate with one or more switching offices which permit connection to the conventional telephone network.

The base stations are positioned at locations such that a radiotelephone at any location throughout the geographical

30   area is within the reception range of at least one of the base station receivers. The geographical area is divided into portions, and one base station is positioned in each portion. Each portion of the geographical area defined thereby is referred to as a "cell".

Although numerous modulated information signals may be simultaneously transmitted at different transmission frequencies, each modulated information signal, when transmitted, occupies a finite portion of the frequency band.

5   Substantial overlapping of simultaneously transmitted modulated information signals at the same frequency in the same geographic area is impermissible as interference between overlapping signals at the same frequency could prevent detection of either of the transmitted modulated

10   information signals by a receiver. Frequency re-use is permitted if sufficient geographic separation exists between base sites using the same frequency, because of the attenuation of signals with distance.

To prevent such overlapping, the frequency band

15   allocated for radiotelephone communication in the U.S. is divided into channels, each of which is of a 30 KHz bandwidth. A first portion, extending between 824 MHz and 849 MHz of the frequency band, is allocated for the transmission of modulated information signals from a radiotelephone to a base station. A

20   second portion, extending between 869 MHz and 894 MHz of the frequency band is allocated for the transmission of modulation information signals from a base station to a radiotelephone.

Increased usage of cellular communication systems

25   has resulted, in many instances, however, in the full utilization of every available transmission channel of the frequency band allocated for cellular radiotelephone communication. Other frequency bands of the electromagnetic frequency spectrum are oftentimes similarly

30   fully utilized.

Various attempts have been made to utilize more efficiently the frequency band allocated for radiotelephone communications to increase thereby the information transmission capacity of a cellular radiotelephone

communication system. Attempts have been similarly made to use more efficiently other frequency bands of the electromagnetic frequency spectrum.

Conventionally, the modulation technique utilized by radiotelephone communication systems to form the modulated information signal thereby is angle modulation. As mentioned previously, an angle modulated signal impresses an information signal upon a carrier wave to modify the frequency (FM) or phase (PM) of the carrier wave according to the value of the information signal. However, conventional angle modulation techniques use spectral resources inefficiently.

In addition to the aforementioned inefficiency of constant-envelope modulation, the voice signal to be transmitted, which contains substantial redundant information, is modulated onto the carrier without substantial removal of the redundancy. The total bandwidth required for transmission of information for a given modulation method, is directly proportional to the amount of information to be transmitted.

Thus, spectrum can be utilized more efficiently by using composite modulation. In addition, techniques have been developed to remove much of the redundancy present in the voice signal. The output of such a process is a discretely encoded data stream whose information content is low enough that it can be transmitted in bursts using the same spectrum portion required for continuous transmission of the original voice signal. This permits transmission of more than one signal at the same frequency, using the sequential time-sharing of a single channel by several radiotelephones. This technique is referred to as time-division multiple access (or TDMA).

Thus, in order to use TDMA, an information signal (such as a voice signal) which is to be transmitted is first

encoded according to a redundancy-reduction scheme. Once encoded, the information signal, in encoded form, is modulated upon a carrier wave and is transmitted in sequential intermittent time segments. Other information

5   signals may similarly be encoded, modulated, and transmitted in intermittent bursts at the same frequency by other transmitters. Thus, a greater number information signals may be transmitted within a particular frequency bandwidth. When the information signals are generated by users of

10   radiotelephones forming a portion of a cellular communications system, a greater number of radiotelephones may be operated within a particular frequency bandwidth when such a TDMA technique is utilized.

A receiver constructed to receive a TDMA signal, such

15   as a TDMA composite modulated signal, reconstructs the original information signal by decoding the TDMA signal transmitted to the receiver in one of the sequential time segments.

A receiver constructed to receive TDMA composite-

20   modulated signals may also require circuitry to perform channel equalization in the receiver. Equalizer circuitry is required to correct for delay problems associated with reflections of signals transmitted to the receiver which arrive at the receiver at different times. Because the signal received

25   by a receiver is actually a vector sum of all signals received at a particular frequency, the signal received by a receiver may actually be comprised of the same signal received at different times as the signal may be reflected off objects prior to reception thereof by the receiver. The signal actually received

30   by the receiver is, therefore, the sum of all signals which are transmitted to the receiver along many different paths. The path lengths may vary, and hence the signal actually received by the receiver may vary, responsive to repositioning of the receiver. Equalizer circuitry is oftentimes formed by a

processor having an appropriate software process embodied
therein. In order to permit optimal operation of the equalizer
circuitry, the receiver should be constructed to be linear (i.e.,
the demodulated signals should represent accurately the
5   original I and Q portions modulated onto the carrier).

The number of, phase of, and intensity of, signals
actually received by a receiver in a multipath environment
may vary over time as a result of repositioning of the receiver,
or of the objects from which a transmitted signal is reflected.
10   As a result, the phase and signal level of a received signal
varies over time. This variance is referred to as "fading" of the
signal. The resultant signal strength and rate of change of
signal strength at the receiver is predominantly determined by
how rapidly the receiver is moving through its environment,
15   and the frequency of the channel being used. For instance, in
the cellular frequency band, and when a cellular
radiotelephone is positioned in a vehicle travelling at sixty
miles per hour, the signal strength of the received signal can
vary by approximately twenty decibels during a five
20   millisecond period.

When two received signals of the same phase are 180°
out of phase, they effectively cancel each other out. The
received signal's intensity approaches a null and the rate of
change of the received signal intensity over time is rapid.
25   Since the received signal strength intensity is low, the
modulated information can be corrupted by noise present in
the channel. A signal corrupted by noise can alter the state of
the demodulated information thereby causing the receiver to
receive wrong information.
30   When a phase modulated signal is received, gain
control circuitry should be of a design to permit rapid and
continuous tracking of variations in received signal levels due
to fading. In addition, a radiotelephone which generates a
TDMA phase modulated signal to transmit an information

signal in a cellular communication system meeting the requirements of the U.S. Digital Cellular Standard also measures intermittently the signal strengths of transmitters located in one or more cells. This process of testing signal

5   strengths is referred to as mobile-assisted hand-off (or MAHO). The MAHO test also requires gain control circuitry which permits rapid and continuous tracking of a signal.

Optimal receiver performance is realized for composite modulation if the receiver incorporates a means for

10   generating an estimate of the carrier phase of the received signal. Receivers which generate such an estimate are known as coherent receivers. The process of generating the phase estimate is known as carrier recovery. Several methods of carrier recovery are known.

15   One such method applicable to carrier recovery for receiving a signal under fading conditions in a TDMA system with π/4-shift DQPSK modulation is a decision feedback phase lock loop (DFPLL). A DFPLL determines what the phase-error of the received signal is relative to an ideal received signal.

20   The phase-error signal is coupled through a loop filter to remove noise. The phase-error, with a reduced noise level, is coupled to a voltage controlled oscillator (VCO). The phase of the VCO is adjusted based on the phase-error input. The corrected phase out of the VCO is multiplied with the received

25   signal's quadrature components to correct the phase of the received signal.

Another method applicable to carrier recovery for the aforementioned system is to raise the received signal components to the 4th power, which removes a substantial

30   portion of the modulation, low-pass filter the resultant, and apply the low-pass filter output to a phase-correction input of the reference phase source. This can be generalized to an M-th power carrier recovery apparatus for M-ary signaling.

Another method for carrier recovery is called the generalized-Costas loop. This method requires multiplying the received signal by M-phase shifted reference signals. Where M equals 8 for π/4 DQPSK signaling. The reference

5   phase signal is separated into eight components phase shifted by 0, π/8, π/4, 3π/8, π/2, 5π/8, 3π/4 and 7π/8 radians. These components multiply the received signal; the products generated are low-pass filtered, the filter outputs are then multiplied to generate a phase-correction signal which is

10   applied to a phase correction input of the reference phase source.

These methods, conventionally implemented, are discussed in Digital Communications, by John G. Proakis, 1st Ed., ISBN 0-07-050927-1, pages 193 - 199.

15   For all of these systems, the response time of the carrier recovery process is determined by the filtering (or averaging) applied in the generation of the phase correction signal. In previous art, such methods were suitable for and commonly applied to systems where substantial multipath effects did not

20   exist, such as satellite communications links, or fixed terrestrial point-to-point links. Because of the aforementioned fading effects, it is undesirable to perform carrier recovery using methods which do not adapt to variations of the received signal due to fading effects. The signal, during a fade event, is

25   corrupted to some degree by noise energy. Thus, it corrupts the phase estimation of the received signal.

It is also true that, because of the new application of the TDMA method of transmission of information in bursts, it is undesirable not to use the timing of these bursts to time the

30   adjustment of at least the carrier recovery elements of the receiver.

It would be desirable to have a carrier recovery apparatus or method with an adjustable response time to provide the most accurate estimate of the current phase of the

received carrier signal. Therefore, there is a need for a carrier recovery method and apparatus having an adjustable response time determined by received carrier signal parameters.

5

<div align="center">Summary of the Invention</div>

A carrier recovery apparatus for receiving a carrier signal which has a carrier signal phase and carrier signal parameters has a phase-error estimate signal generated by a comparator which compares the carrier signal phase to a reference signal phase generated by a reference signal source.

At least one of the carrier signal parameters is determined from the carrier, and the phase-error estimate signal is adjustably coupled to the reference signal source in response to the determined carrier signal parameter.

<div align="center">Brief Description of the Drawings</div>

Figure 1 is a block diagram of a transmitter and receiver which may employ the present invention.

Figure 2 is a block diagram of a signal processor which may employ the present invention.

Figure 3 is a block diagram of an energy estimator which may employ the present invention.

Figure 4 is a channel state diagram for a TDMA event sequence which may employ the present invention.

Detailed Description of a Preferred Embodiment

A system which may employ the present invention is
shown in the block diagram of Figure 1. The figure shows a
5   transmitter 101 and a receiver 103. The receiver 103
comprises a carrier recovery apparatus for π/4-shift DQPSK
modulation. Receiver 103 elements comprise a signal
processor 141, an information decoder 143 and an adjustable
gain preamplifier 105. All other elements in the receiver
10   collectively comprise a decision feedback phase lock loop. The
decision feedback phase lock loop (DFPLL) generates a phase-
error term at the output of summer block 121 which corrects
the phase of the local estimate of received phase generated by
voltage controlled oscillator 109. The signal processor 141
15   uses quadrature component signals, I'(t) and Q'(t), and
synchronous signal 144 to generate a control signal 142 for
adjustable gain preamplifier 105 and synchronous TDMA
timing reference signal 140 for the frequency response of loop
filter 123. The control signal 142 for adjustable gain
20   preamplifier 105 is adjusted based on the energy level of the
received signal 102. The control signal 140 for the frequency
response of loop filter 123 is based on parameters of the
received signal. These parameters comprise: the energy
level, the rate of change of the energy level and the clocked
25   TDMA event sequence of the received signal 102. The control
signal 140 for loop filter 123 adjusts the response time for the
DFPLL. An adjustable response time may improve the quality
of the received information signal 102.

The response time in a conventional DFPLL is not
30   adjustable during fading conditions. An adjustable response
time is desirable during fading conditions. When the received
signal is entering a fade, the energy level of the signal is gets
weaker thereby approaching the noise floor. Under this
condition, it is desirable to slow down the loop response time by

narrowing the loop bandwidth filter. The narrow loop
bandwidth filter increases the signal to noise ratio for the
received signal. The slower loop response time enables the
last good received signal's phase-error estimate to remain as
5   long as possible before the next signal is received. Likewise,
when the received signal is exiting a fade the energy level of
the signal gets stronger thereby rising higher above the noise
floor. Under this condition, it is desirable to speed up the loop
response time by widening the loop bandwidth filter. The
10   faster loop response time enables the next good received
signal's phase-error estimate to be acquired as rapidly as
possible.

The response time in the DFPLL phase-error correction
system is not dependent on the timing of the clocked TDMA
15   event sequence. There are times during the TDMA event
sequence when it is desirable to have a fast loop response time
such as when we first lock on to a received signal. There are
other times during the TDMA event sequence when it is
desirable to have a slow loop response time such as when we
20   are receiving a signal which is entering a fade.

A TDMA transmitter 101 transmits a digital
information signal which is modulated on the $I(t)$ and $Q(t)$
quadrature component signals described previously. This
information signal is broadcast to a receiver 103 which
25   receives and demodulates the information signal. As
previously noted, the information signal may be subject to
random phase delays and multipath fading which degrade the
quality of the information signal.

The phase error in the received information signal 102
30   is denoted by $I_e(t)$ and $Q_e(t)$. In receiver 103, the information
signal 102 is coupled to adjustable gain preamplifier 105 which
reduces input signal energy level variations as discussed in
U.S. Patent Application No. (CE00347R) "Input-Estimating
Fast AGC System With Adaptive Gain Adjustment". The

output signal of adjustable gain preamplifier 105 is subsequently separated into quadrature signal components I(t) and Q(t). Quadrature signal component, Q(t), is generated by applying the amplified signal to a conventional mixer 107

5   where a local oscillator signal generated by VCO 109 is shifted by a fixed 90° phase shifter 111 to create the Q(t) signal. The I(t) signal is created from mixer 113 and the output local oscillator signal from VCO 109. Quadrature signal components, I(t) and Q(t), are now phase coherent with the

10   transmitted signal.

        Quadrature signal component, Q(t), is filtered through matched filter 131 and subsequently coupled to analog to digital converter 132. Digitized signal, Q(t), is split into two paths. One path is mixed in mixer 117 with an estimated

15   phase signal processed by sine determinator 119. The other path is sampled by conventional sampler 133 before being applied to a first port of phase estimator 135, a first port of signal processor 141 and a first port of information decoder 143.

20   Likewise, quadrature signal component, I(t), is filtered through matched filter 137 and subsequently coupled to analog to digital converter 138. Digitized signal, I(t), is split into two paths. One path is mixed in mixer 127 with an estimated phase signal processed by cosine determinator 129. The other

25   path is sampled by conventional sampler 139 before being applied to a second port of phase estimator 135, a second port of signal processor 141 and a second port of information decoder 143.

        The resultant mixed signals from mixers 117 and 127

30   are coupled to a conventional summer 121. The output phase-error signal of summer 121 is coupled to a digital to analog converter 124 through loop filter 123. The analog phase-error signal is applied to VCO 109. VCO 109 generates a local

oscillator signal to be applied to mixer 113 and serially applied to 90° phase shifter 111 first then to mixer 107.

Terms are described for the quadrature signal Q(t) side of the DFPLL. The phase-error estimate signal of summer 121

5   is generated by a comparator which compares the received carrier signal phase (first input to mixer 107) to a reference signal phase (second input to mixer 107) generated by a reference signal source. The comparator comprises: mixer 107, matched filter 131, A/D converter 132, sampler 133, mixer

10   117, summer 121, sine and cosine determinator 119 and 129, mixer 127 and phase estimator 135. The reference signal source comprises: voltage controlled oscillator 109, D/A converter 124 and 90° phase shifter 111. Analogous terms may also be described for the quadrature signal I(t) side of the

15   DFPLL.

Signal processor 141 receives inputs I'(t), Q'(t) and information decoder output 144. Signal processor 141 generates two outputs. The first output is a control signal 142 for adjustable gain preamplifier 105. The second output 140 is

20   a control signal for the frequency response of loop filter 123.

Information decoder 143 receives inputs I'(t) and Q'(t) and generates outputs to the signal processor 141 and speaker 145. The information decoder represents elements of a receiver not shown in FIG. 1. The first output 144 to signal

25   processor 141 provides information about the position of a received signal 102 in the TDMA event sequence. The second output 102 is an analog output which may be coupled to a conventional speaker 145.

Referring now to FIG. 2, a block diagram of signal

30   processor 141 is shown. Digitally sampled signals, I'(t) and Q'(t), are coupled to energy estimator 205. A cellular radiotelephone transceiver in compliance with IS-54 must determine an estimate of the energy level of the received signal and process it in accordance with Section 2.4.5.4.1.2.1.

Further details on the function of the energy estimator 205 will be discussed with FIG. 3.

The output of the energy estimator 205 is coupled to adjustable gain preamplifier 105 using control signal 142,

5   energy level detector 207, and rate of change of the energy level detector 209. The output 142 from energy estimator 205 to the adjustable gain preamplifier 105 is a feedback path which reduces received input signal variations.

A software process in the signal processor determines

10   the energy level of the received information signal. The energy level determinator 207 can be described by the following equation:

$$E(x) = 1/(10^{Vctl})$$

15

where Vctl is the feedback signal 142 also used to adjust the input gain to reduce input signal variations.

The output of the energy level determinator is coupled to a limiter 211. Limiter 211 creates a threshold level for high

20   levels of received information signals. Limiter 211 only allows measured energy levels up to a maximum predetermined value. The output of 211 is coupled to product combiner 213.

The output of energy estimator 205 is also coupled into a rate of change of energy level determinator 209. The rate of

25   change of energy level determinator describes how the energy level of the received information signal changes with time. In the preferred embodiment, the rate of change of energy level can be described by the following equation:

30                 $$dE(x)/dt = d(1/10^{Vctl})/dt + K$$

The output of the rate of change of energy level determinator 209 is coupled to limiter 215. Limiter 215 creates a low threshold for the measure of the rate of change of energy level.

'The low threshold is set to a predetermined value to prevent the calculation of rate of change of the energy level from approaching zero. The output of limiter 215 is coupled to product combiner 213.

5   The input 144 from information decoder 143 coupled to TDMA time clock 219 provides information about the position of the received signal in the TDMA event sequence. The output of the TDMA time clock 219 is coupled to look-up table 221. Look-up table 221 contains a number of predetermined values 10   based on the receiver design and location within the TDMA event sequence. The output of look-up table 221 is coupled to product combiner 213.

       The product combiner 213 has as its inputs the energy level determinator 207 processed through a high threshold 15   limiter 211, the rate of change of energy level determinator 209 processed through a low threshold limiter 215 and a predetermined value from look-up table 221 based on the clocked TDMA event sequence 221. The product combiner 213 is a software process which multiplies its three inputs to 20   produce an output. The output of the product combiner is described by the following equation.

$$(1/10^{Vctl}) \times (d(1/10^{Vctl})/dt + K) \times (\text{Value from lookup table})$$

25   The output of product combiner 213 is coupled to a digital to analog converter 223. The digital to analog converter 223 converts the digital signal from the signal processor 141 into an analog signal to adjust the frequency response time of the loop filter 225.

30   In the preferred embodiment, the response time of the carrier recovery apparatus is adjusted with a variable

bandwidth filter. Adjusting the response time may also be accomplished by varying the gain of the phase-error signal coupled to a fixed bandwidth filter or by averaging the phase-error signal over an adjustable time period.

5   In the preferred embodiment, signal processor 141 is implemented as a digital signal processor (DSP) employing a DSP 56001 available from Motorola, Inc. and executing a series of preprogrammed steps to determine the energy level of the received information signal, the rate of change of the energy

10   level of the received information signal, and the position within the TDMA event sequence. The DSP combines these parameters to achieve an output which controls the decision feedback phase lock loop frequency response time for loop filter 225. The DSP also produces an output to control the adjustable

15   gain preamplifier 105.

          Now referring to FIG. 3, there is shown a block diagram of the contents of the energy estimator 205.
          Received quadrature component signals, I'(t) and Q'(t), are coupled to averager 301 which calculates an average signal

20   energy from the addition of sample pairs of the squared amplitude of I'(t) and Q'(t). The averaged output is coupled to feedback gain adjust circuit 303 which adjusts the value to which $I'^2(t)$ and $Q'^2(t)$ are normalized. The logarithm (base 10) is conventionally taken (in 305) to produce the signal having

25   logarithmic characteristics to match the exponential control function characteristics of the adjustable gain preamplifier 105. The output of $\log_{10}(x)$ calculator 305 is coupled to voltage control sensitivity estimator 307 and mixer 309. The output of mixer 309, which represents a control signal corrected for rate

30   of change of gain versus control voltage of the adjustable gain preamplifier 105, is coupled to delay and compare function 311. The output of delay and compare function 311 is coupled to control voltage sensitivity estimator 307 to correct for errors in the estimate of the rate of change of energy level of the

adjustable gain preamplifier 105, and is also output to the other functions of the receiver.

5   This output of the energy estimator 205 is provided as an automatic gain control (AGC) signal to adjustable gain preamplifier 105. The voltage control sensitivity estimator 307 and the energy estimator 205 are further described in U.S. Patent Application No. (CE00347R) "Automatic Gain Control Apparatus and Method", filed on the same date herewith in behalf of Cahill.

10   Now referring to figure 4, there is shown a timed sequence of events for mobile transmit and receive channels in a TDMA system. The mobile channel state 401 for a TDMA event sequence is generally divided into three time slots. The three time slots comprise transmitting (T) time slot 403,

15   receiving (R) time slot 405, and idle (I) time slot 407. Each time slot is approximately 6.66 milliseconds long thereby generating a clocked sequence of events of 20 milliseconds for all three time slots. The transmitting 403, receiving 405, and idle 407 time slots are sequentially repeated in a TDMA event

20   sequence. As previously described, the advantage of a TDMA is to multiplex the number of users operating on the same frequency channel.

The idle time slot 407 defines a time in the TDMA event sequence in which a particular mobile unit is neither

25   transmitting nor receiving. During this idle time slot 407, the mobile unit intermittently measures the energy levels of transmitters located in one or more cells. This process of testing signal energy level is referred to as mobile-assisted hand-off or MAHO.

30   The mobile receive 409 describes the receive time slots for three different mobile receivers described as R_x 411, R_y 413 and R_z 415. Each mobile receiver can only receive information during its allocated time slot.

The mobile transmit channel 417 is likewise divided into three time slots. The three time slots comprise T_x 419, T_y 421, and T_z 423. Each mobile unit may only transmit during its own allocated time slot. The transmit 417 and receive 419

5 channel pattern of the three adjacent time slots is sequentially repeated over time.

Note that the end of a transmit time slot for one particular mobile channel does not line up with the beginning of the corresponding receive mobile time slot. In particular,

10 mobile transmit time slot T_x 419 is offset from mobile receive time slot R_x 411. This offset is primarily needed to account for real world system considerations such as propagation delay and the physical distance between transmitting and receiving units.

15 The values in the look-up table 221 and the position within a TDMA event sequence help determine response time. A position in a TDMA event sequence defines a specific location in a time slot of a mobile channel. When the TDMA time clock 219 encounters a predetermined position in the

20 received signal 102 a value from the look-up table 221 is coupled into the product combiner 213. Specific positions with respect to time occur during the TDMA time frame when a fast loop response time is needed and other times a slow or intermediate loop response time is needed. A fast loop

25 response time is desirable immediately prior to the receive time slot 405 in order to rapidly acquire the phase-error and lock on to the received signal. During the receive time slot 405 the loop response time is determined by the energy level of the received signal and the rate of change of the energy level of the

30 received signal. During the idle time slot 407, the control signal to adjust the loop response time is minimized or eliminated.

Thus, the quality of the received information signal in a TDMA system can be improved in the presence of fading by

adjusting the loop response time of the decision feedback phase lock loop. The loop response time is adjusted based on the energy level of the received signal, the rate of change of energy level of the received signal and the timed sequence of events in

5   a TDMA system.

What is claimed is:

Claims

1. A carrier recovery apparatus for receiving a carrier
signal having a carrier signal phase and a carrier signal
5   parameter, the carrier recovery apparatus including a
reference signal source responsive to a control signal and a
comparator for generating a phase-error estimate signal by
comparing the carrier signal phase to a reference signal
phase generated by the reference signal source, the carrier
10   recovery apparatus comprising:
        means for determining a value related to the carrier
signal parameter; and
        means for adjusting the phase-error estimate signal in
accordance with said determined value to generate the control
15   signal.

2.   A carrier recovery apparatus in accordance with claim 1 wherein said means for determining said value related to the carrier signal parameter further comprises means for determining an energy level related to the carrier

5   signal parameter.

3.   A carrier recovery apparatus in accordance with claim 1 wherein the carrier signal parameter is a position with respect to time in at least one of three sequential time

10   slots in a TDMA event sequence, said means for determining a value related to said position further comprises:
       means for generating a clock signal synchronized with the TDMA event sequence; and
       means for selecting a value related to said position with

15   respect to time in the TDMA event sequence located by said synchronous clock signal.

4.   A carrier recovery apparatus in accordance with claim 1 wherein said means for adjusting the phase-error

20   estimate signal further comprises a variable bandwidth filter responsive to said determined value.

5.   A carrier recovery apparatus in accordance with claim 1 wherein said means for adjusting the phase-error

25   estimate signal further comprises a variable gain stage, responsive to said determined value, coupled to a fixed bandwidth filter.

6.   A carrier recovery method for receiving a carrier
signal having a carrier signal phase and a carrier signal
parameter, the carrier recovery method including a reference
signal source responsive to a control signal and a comparator
5   for generating a phase-error estimate signal by comparing the
carrier signal phase to a reference signal phase generated by
the reference signal source, the carrier recovery method
comprising the steps of:
        determining a value related to the carrier signal
10   parameter; and
        adjusting the phase-error estimate signal in accordance
with said determined value to generate the control signal.

7.   A carrier recovery method in accordance with
claim 6 wherein the carrier signal parameter is a position
with respect to time in at least one of three sequential time
slots in a TDMA event sequence, the step of determining a
5   value related to said position further comprises:
generating a clock signal synchronized with the TDMA
event sequence; and
selecting a value related to said position with respect to
time in the TDMA event sequence located by said synchronous
10   clock signal.

8. A radio receiver having the capability of detecting a lack of coherence between a transmitted carrier signal phase and a received carrier signal phase, a received carrier signal having the received carrier signal phase and a received carrier signal parameter, the radio receiver including a reference signal source responsive to a control signal and a comparator for generating a phase-error estimate signal by comparing the carrier signal phase to a reference signal phase generated by the reference signal source, the radio receiver comprising:

means for determining a value related to the received carrier signal parameter; and

means for adjusting the phase-error estimate signal in accordance with said determined value to generate the control signal.

9.   A radio receiver in accordance with claim 8
wherein the received carrier signal parameter is a position
with respect to time in at least one of three sequential time
slots in a TDMA event sequence, means for determining a
5   value related to said position further comprises:
        means for generating a clock signal synchronized with
the TDMA event sequence; and
        means for selecting a value related to said position with
respect to time in the TDMA event sequence located by said
10   synchronous clock signal.

10.   A digital radio receiver in a TDMA system having
a decision feedback phase lock loop with the capability of
detecting a lack of coherence between a transmitted phase of a
carrier signal and a received phase of the carrier signal, a

5   received carrier signal having parameters and having
quadrature signal components displaced from a
predetermined phase coordinate system, the digital radio
receiver including a reference signal source responsive to a
control signal and a comparator for generating a phase-error

10   estimate signal by comparing the received carrier signal
phase to a reference signal phase generated by the reference
signal source, and the reference signal phase also referenced
to the predetermined coordinate system, the digital radio
receiver comprising:

15   means for determining an energy level value related to
the received carrier signal parameter;
            means for determining a value for a rate of change of
energy level related to the received carrier signal parameter;
            means for generating a clock signal synchronized with

20   a TDMA event sequence;
            means for determining a value related to a position with
respect to time in said TDMA event sequence located by said
synchronous clock signal;
            means for producing an output control signal by

25   combining the product of said limited energy level value, said
limited value for said rate of change of energy level and said
determined value related to said position with respect to time
in said TDMA event sequence located by said synchronous
clock signal; and

30   means for adjusting the phase-error estimate signal
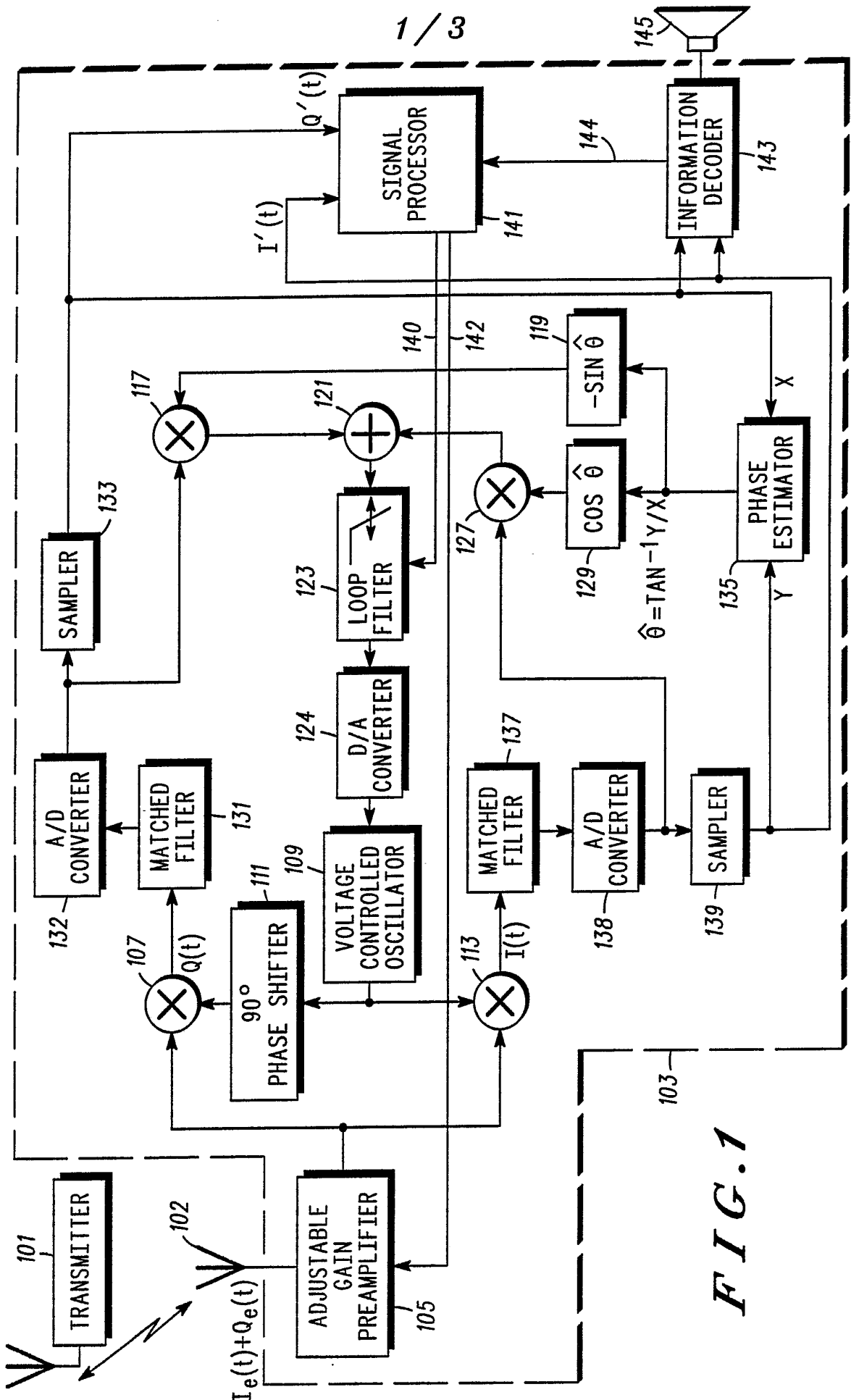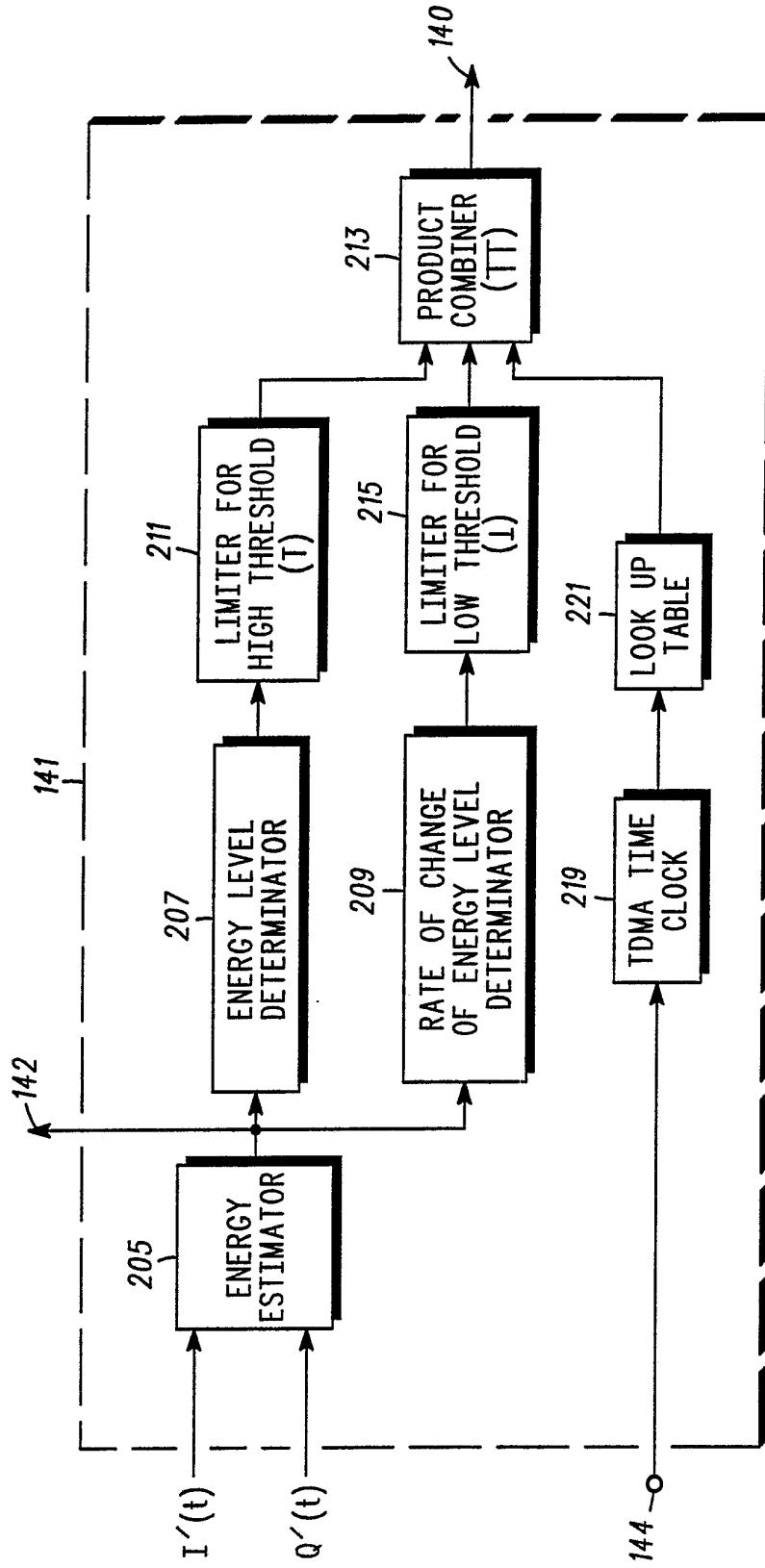with a variable bandwidth filter responsive to the control
signal.

1 / 3

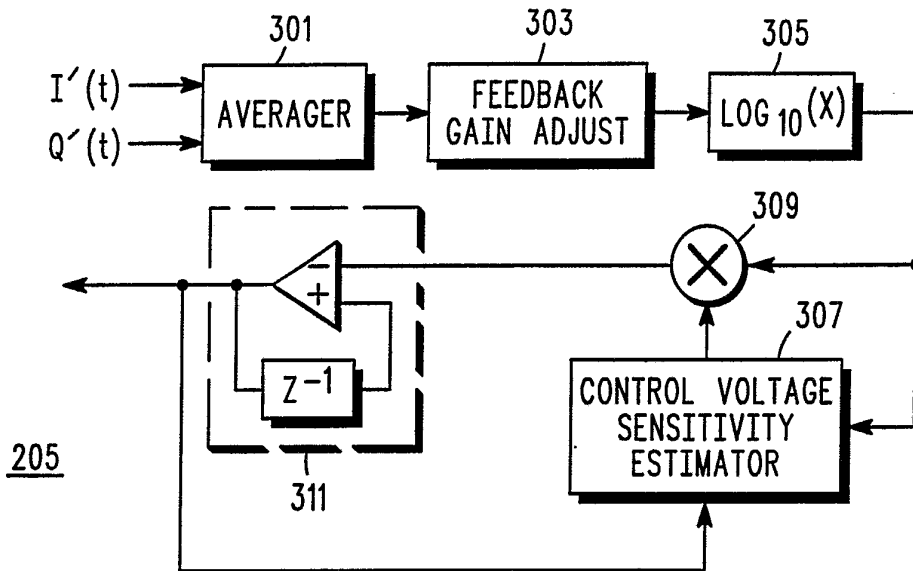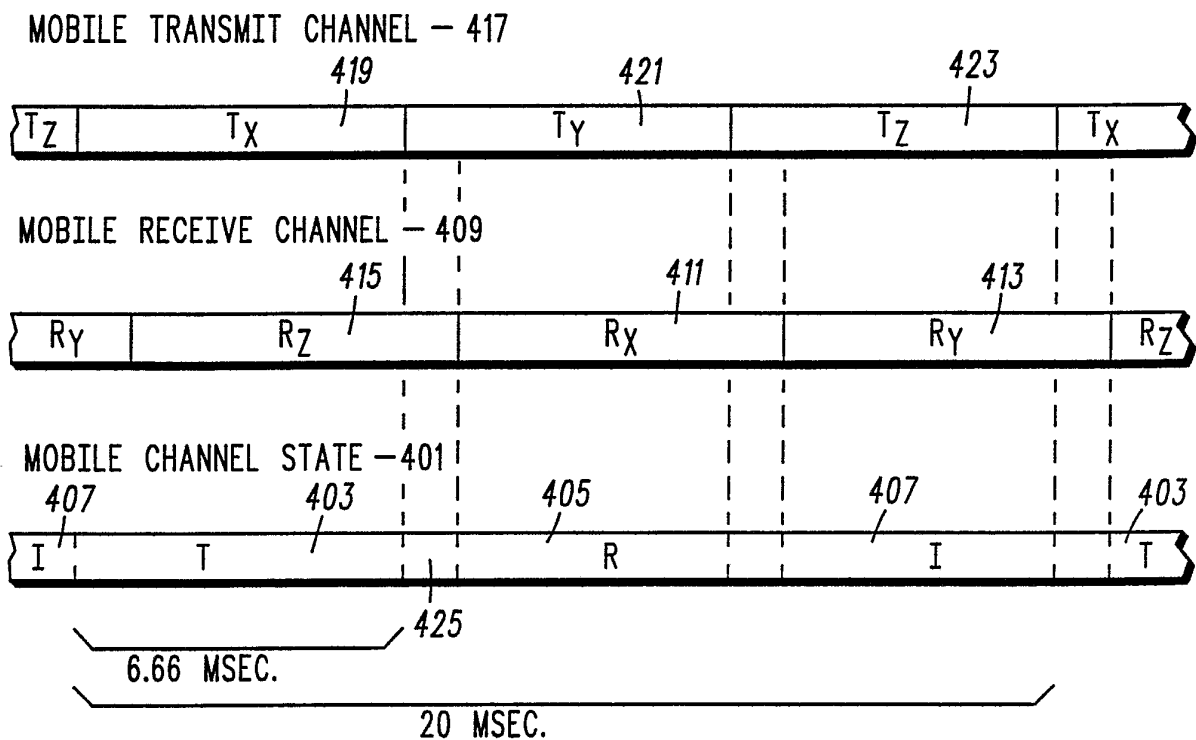*F I G . 1*

FIG.2

FIG.3

FIG.4

INTERNATIONAL SEARCH REPORT

International Application No.   PCT/US91/06924

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) 6

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

INT. CL.5 H04B 1/16
U.S. CL.   375-97

II FIELDS SEARCHED

Minimum Documentation Searched 7

Classification System	Classification Symbols
U.S.	375-77, 97; 455-257, 258, 259, 260; 331-17 329-323, 375, 326, 356, 358, 360, 361

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched 8

NONE

III. DOCUMENTS CONSIDERED TO BE RELEVANT 9

Category *	Citation of Document, 11 with indication, where appropriate, of the relevant passages 12	Relevant to Claim No. 13
X / Y	US, A, 4,485,487 (ALLAN ET AL) 27 November 1984 (See Figure 4, column 3, line 59 to column 4, line 2)	1,2,6,8 3,7,9
X	US, A, 4,336,616 (CARSON ET AL) 22 June 1982 (See Figure 1)	4
X	US, A, 4,473,801 (MAURER ET AL) 25 September 1984 (See Figure 4)	5
Y	US, A, 4,466,108 (RHODES) 14 August 1984 (See abstract)	3,7, 9

* Special categories of cited documents: 10

"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.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
10 December 1991	10 JAN 1992

International Searching Authority	Signature of Authorized Officer NGUYEN NGOC-HO INTERNATIONAL DIVISION
ISA/US	Benedict V. Safourek

Form PCT/ISA/210 (second sheet) (Rev.11-87)