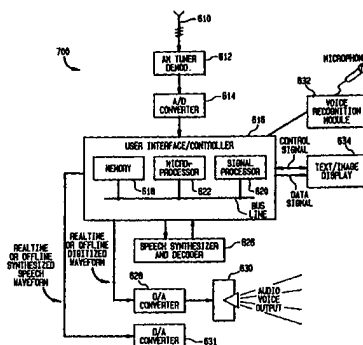




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(54) Title: SYSTEM AND METHOD OF DATA TRANSMISSION IN THE AM FREQUENCY SPECTRUM



(57) Abstract

A system and method for transmitting digital information concurrent with a co-existing monophonic amplitude modulated (AM) signal are disclosed. The system allows any AM transmission, in particular commercial AM Radio Broadcasts, to incorporate an orthogonally modulated data signal without significant interference to the on-going AM Broadcast. This data is then demodulated at the system's receiver (700). The system's receiver (700) permits user options as to delaying output of the data and choice of audio (630) or visual (624) outputs. The system also allows encryption of the data prior to transmission to thereby permit only authorized users to access it at the receiver end.

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SYSTEM AND METHOD OF DATA TRANSMISSION IN THE AM FREQUENCY SPECTRUM

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CROSS-REFERENCES TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 60/046,380, filed May 13, 1997. This Application is also a Continuation-in-Part of co-pending application No. PCT/US98/04948, filed March 13, 1998, the contents of which are incorporated herein by reference.

FIELD OF THE INVENTION

This invention relates to a system and method for transmitting digital information concurrent with a co-existing monophonic amplitude modulated (AM) signal and permitting the user at the receiver to choose various options as to delaying output of the data and as to the output format.

DESCRIPTION OF RELATED ART

A variety of methods have been proposed for concurrent transmission of two or more information bearing signals along with an amplitude modulated carrier. Most of these methods achieve relatively slow data rates as measured in terms of bits-per-second. The current standard commercial AM Stereo broadcast is one such method for analog information delivery which uses quadrature modulation of the RF Carrier to achieve the equivalent phase modulation. A U.S. Pat. 4,688,255 to Leonard R. Kahn is an example of a proposed method to deliver auxiliary data along with a stereo AM broadcast by additively incorporating an additional information bearing carrier signal. This auxiliary carrier is modulated by any step familiar to those knowledgeable in the state-of-the-art.

All of these previous methods have been restricted to low data rates due to channel bandwidth and interference considerations. In particular, the Kahn method is similarly restricted to comparatively low data rates due to these same concerns and the placement of the auxiliary carrier at the AM Broadcast carrier frequency spacing. This limits the auxiliary data rate for two reasons. The first is the need to keep the signal level of the auxiliary signal plus modulation well below (at least 25 dB) the unmodulated AM Carrier by Federal Communications Commission (FCC) regulation CFR 47, Ch. 1 Sect. 73.44. Secondly, to minimize mutual interference to the AM program broadcast and remain compatible with AM Stereo broadcasts,

auxiliary modulation bandwidth must be controlled to remain within the region of the "mixed highs" of the AM broadcast. This leads to practical limitation of the modulation bandwidth of the auxiliary information to less than 2 KHz. Thus, in Kahn, even though the auxiliary carrier is placed at the adjacent station null and is
5 in phase quadrature to the main carrier, modulation sidebands created by information modulation of any appreciable rate will fall within the modulation sidebands of the co-existing AM broadcast. These sidebands will also extend well into the spectrum of any adjacent AM channel. Thus, interference control again limits the achievable data rate.

10 Further, many of the prior art methods utilize angle modulation which causes an additional problem with the received signal. Angle modulation frequently interferes with the main broadcast reception by inadvertent activation of receiver stereo decoding when no C-QUAM stereo modulation is present. In these cases, the auxiliary data signal is incorrectly decoded as audio and directly interferes with
15 the main transmission audio.

Finally, propagation effects such as transmitter antenna and power amplifier non-linearity, multipath, and mis-tuned receivers can introduce inadvertent mutual interference. The latter is controlled by electronic tuning which is the most prevalent today. Multipath is a relatively insignificant effect under most operating
20 conditions. Transmitter non-linearities have generally been adequately addressed at all AM Broadcast stations currently employing AM Stereo (C-QUAM) transmissions.

In all cases of casting data with concurrent AM transmission, data modulation must address the issues of (1) mutual-interference with the AM
25 Broadcast amplitude modulation interfering with the data signal reception (self-induced or "virtual" fading), (2) transmission channel effects due to motion between transmitter and receiver (Doppler, fading) and (3) incidental stereo demodulation activation by the data signal.

The first of these issues, mutual-interference, is addressed in the prior art of
30 Kahn, by (a) the placement of the additive sidebands at the channel spacing (10 kHz in the US), and (b) by limiting the bandwidth of the data modulation away from the audio signal. The latter tacitly limits the data rate by trading off bandwidth of the modulating waveform for interference control.

Audio interference with the data signal is also a mutual-interference
35 problem. Extreme negative modulation of the carrier envelope by the primary (e.g.,

voice) transmission reduces the available carrier energy to the receiver. This appears as a virtual fade of the received signal without propagation effects being present. In Kahn, the data modulation rate is varied in direct proportion to the audio signal level. Thus in periods of weak carrier small or no data are present so
5 interference is controlled. This approach also reduces the effective data rate of the method.

The second issue, transmission channel effects, is addressed in the prior art by three aspects of the data modulation: embedded timing and synchronization, message packetizing and symbol design, and modulation mechanism. In mobile
10 reception of a data carrying signal, flat fading causes carrier energy to be severely attenuated. In this circumstance, recovery of phase modulated information can be interrupted to the extent that re-acquisition of the carrier would be necessitated. This is a frequent occurrence in prior art AM Transmission.

The last issue, that of inadvertent AM Stereo demodulation, can cause
15 severe interference with the main AM broadcast on those AM Radio Receivers equipped for stereo reception according to the C-QUAM standard. This phenomenon has been reported in the "Report of the National AM Stereophonic Radio Committee", Electronic Industries Assoc., Dec. 1977. One solution to this problem, as shown in the publication "Introduction to the Motorola C-QUAM AM
20 Stereo System", Motorola, Inc., 1992, is the use of a 25 Hz pilot tonal signal which is phase modulated onto the AM Carrier and which acts as the stereo indicator to a receiver. Prior art attempts to insert data below the 100 Hz audio cutoff have caused this inadvertent stereo demodulation and its associated audible interference. In the current invention, the spectrum of the baseband data signal is
25 controlled to specifically null the lower spectral region at and around 25 Hz, eliminating all intentional modulation energy in this lower spectrum.

As pointed out in the discussion of Kahn above, most prior art uses angle modulation to carry auxiliary data. However, the prior art in Kahn is substantially a linearly superposed additional amplitude modulated carrier, albeit one in phase
30 quadrature with the AM Carrier. Being an additive additional signal, it carries most of the disadvantages of amplitude modulation and the current state-of-the-art known as In-band, On-channel (IBOC) modulation. In particular, data rates are restricted by the need to limit amplitude and bandwidth with respect to the primary modulation in order to control self-interference.

SUMMARY OF THE INVENTION

The current invention overcomes many of the above noted problems of the prior art and thereby achieves higher data rates by using strictly non-linear modulation of the AM Carrier coupled with high efficiency subcarrier modulation made possible by accurate synchronization and timing recovery. The current invention further includes a receiver for picking up and manipulating signals in this modulated AM frequency and for providing the user various options as to outputting the data. These options comprise storing the received data for later output and outputting the data in audio voice format as well as text/image display format.

Briefly described, the present invention enables concurrent data and main program transmission with a minimum of interference at substantially higher data rates than in the prior art. This higher efficiency is the result of maximizing the available baseband bandwidth and controlling the phase modulation index in order to minimize mutual interference. The invention relates to many aspects of the transmission and reception of encoded digital information. At the transmission site, a Data Inserter is used which encodes, packetizes, channel encodes and subcarrier modulates the data signal into a quadrature phase modulated baseband format. A RF Exciter (or modified AM Stereo Exciter) then uses quadrature modulation to effect the constant envelope phase modulation of the AM Broadcast carrier with the baseband signal including embedded synchronization and identification mechanisms. The information signal, in one embodiment, is Error Correction coded, m-ary DPSK modulated onto an orthogonal set of 128 subcarrier signals using Gray Coding. The symboling rate is 9500/128 symbols per second per subcarrier.

The current invention organizes all data into self-contained transmission packets of finite extent. This allows continuous re-acquisition and re-synchronization of the received signal fostering rapid recovery when severe fading or loss of signal occur. Packet synchronization and symbol timing recovery can be accomplished as described in US Patent 5,220,584 wherein phase transitions of a reference signal are detected and synchronized to. In the preferred embodiment, these issues are addressed by incorporating a uniquely formulated spread spectrum sequence into each transmission packet. This design relies on the sequence having an autocorrelation function with high peak-to-sidelobe ratio. Thus, matched filtering to this common wide bandwidth sequence allows large processing gain so that highly reliable packet detection and resynchronization is assured.

It is well-known that propagation characteristics of the AM, or Medium Frequency, radio channel varies widely across the United States. Therefore, quality is not uniform in all places or at all times. In response to this variation, the invention allows the flexibility to "gear-shift" the baseband digital modulation density to match the outgoing data rate to the available channel. When propagation conditions deteriorate, modulation type can be changed to lower the data rate and thereby improve the reception quality as measured in terms of the received bit error rate (BER). The current invention encodes the modulation type as part of the transmitted packet immediately following the synchronization signal. Both of these signals are designed as spread spectrum waveforms which allow highly sensitive recovery and detection at the receiver through the use of properly designed matched filter receivers. Such filters can be designed and implemented in many alternative ways by those skilled in the art.

The current invention, like nearly all other methods previously proposed, uses angle modulation of the AM Carrier frequency to convey the information bearing signal. However, in concert with CFR 47, Ch.1 Sect. 73.127 of the FCC, AM Stereo Modulation is not employed at the time of auxiliary data transmission. In this case, the carrier phase is available for auxiliary data modulation. The current invention phase modulates the AM Carrier and controls both the spectrum of the resulting sidebands and the modulation index so as to minimize interference with the concurrent AM Broadcast. Since phase modulation of the AM Carrier is orthogonal to any amplitude modulation, envelope detection receivers are largely unaffected by the presence of the auxiliary data. In the preferred embodiment, the information bearing signal phase modulates the AM Carrier by employing quadrature amplitude modulation to effect the trigonometric double angle identity. This embodiment allows the data signal to utilize existing AM Stereo Exciters after minor modification, to provide carrier modulation.

In another aspect of the invention, a receiver and data demodulator are disclosed which make maximum advantage of the angle modulated nature of the data signal. The receiver performs phase-locked loop (PLL) tracking of the carrier/IF to persist through carrier fades, self-synchronize to the transmitted subcarrier and recover symbol timing in order to synchronously demodulate the auxiliary data.

In yet another aspect of the invention, the receiver is equipped with the means for permitting the user to choose from a variety of output modes, to include

delaying outputting of data and of outputting the data in audio or visual formats. Further, the system permits the user to select these options in a variety of ways, to include selection by means of a keypad, touch screen, or speech input.

These and other features of the invention will be more fully understood by
5 reference to the following drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a schematic diagram of the auxiliary data insertion and modulation process according to the preferred embodiment of the invention.

FIG. 1B is a schematic diagram of a conventional C-QUAM Stereo Exciter.

10 FIG. 2 is a graphical presentation of the data encoding and modulation structures used for digital modulation.

FIG. 3A is a schematic diagram of the invention's use of multiple orthogonal subcarrier modulation method.

15 FIG. 3B depicts the preferred embodiment's efficient method of digitally generated orthogonal subcarrier modulation.

FIG. 4 is a graphic diagram of the invention's phase modulated signal spectrum as produced in the preferred embodiment.

FIG. 5 depicts the preferred embodiment's transmission packet structure incorporating timing recovery and phase reference information.

20 FIG. 6 is a schematic of the preferred embodiment of the quadrature modulator arrangement to constant envelope phase modulate a carrier signal

FIG. 7 is a schematic diagram of the radio receiver design according to the preferred embodiment of the invention.

25 FIG. 8 is a diagram of the process of digital demodulation in the invention's preferred embodiment.

FIG. 9 is a depiction of the complex demodulator used in the preferred embodiment of the invention.

30 FIG. 10 is a schematic representation of the method of frequency division demultiplex used in the preferred embodiment of the receiver-demodulator aspect of the invention.

FIG. 11 is a graphic illustration of byte level de-interleaver in the preferred embodiment.

FIG. 12A is a schematic diagram of the receiver system having audio voice output of the received data.

FIG. 12B is a schematic diagram of the receiver system in the preferred invention having alternative voice or visual output of the received data.

DETAILED DESCRIPTION OF THE INVENTION

5 During the course of this description like numbers will be used to identify like elements according to the different figures which illustrate the invention.

1. Transmitter

1.1 Digital Subcarrier Generation and Modulation

The preferred embodiment of data signal subcarrier modulation and carrier
10 phase modulation is illustrated in FIG. 1A. Baseband modulation is accomplished by first applying an **10** Error Correction Encoding of the incoming information source. This error correction encoding is optional and may be omitted in alternative embodiments. The preferred method is an efficient block code such as a Reed-Solomon code for which methods are well known to those skilled in the art.
15 Redundantly encoded data is next **12** Byte Interleaved using a block interleave based on the packet structure. Each transmission packet, depending on the selected modulation type **16**, consists of a fixed number of encoded data blocks.

FIG 2 illustrates the data structures as the data is organized and processed for packet transmission. In the preferred embodiment, M encoded data blocks **72**,
20 used to form a transmission packet, is shown in Fig. 2 along with the associated data bytes. Byte interleaving **74** re-organizes the encoded data in preparation for digital modulation **14**. Modulation results in a set **78** of K Data Frames, each containing N channel coded symbols. In the preferred embodiment, the channel coding is differentially encoded m-ary PSK, so a phase reference frame **79** is
25 included at the head of the data. Packet framing **20** concatenates the unique Synchronization sequence **18**, the Modulation type identification sequence **16** and the assembled data frames to form a transmission packet. Data frames are generated at a sample rate equivalent to four times the symbol rate. In one embodiment, as illustrated in the example in FIG. 2, each data frame is generated
30 from 128 16-PSK symbols.

The invention uses multiple orthogonal subcarriers for the baseband digital modulation. FIG. 3A depicts the Digital Modulation **14** in more detail. Referring to FIG. 3A, interleaved bytes are mapped **80** to the appropriate symbol (Trellis Coded, PSK, etc.) and these symbols are loaded into a serial-to-parallel buffer **82** to form
35 the basis of a data frame. Each parallel symbol is integrated **84** with the

corresponding symbol in the immediately previous frame. Each symbol of a frame
86 modulates one of N orthogonal tonals which are subsequently summed 88 to
form the baseband data frame time waveform. Thus the digital modulation is a form
of frequency division multiplex. Baseband frame samples are interpolated 94 to the
5 required output rate and then a guard band is appended. This guard band circularly
extends each data frame by a time span sufficient to support uncorrupted decoding.
In normal practice the guard band is equal to the expected multipath differential
delay. In the current invention, multipath effects are not manifest in a linear manner.
The guard band is still used in the invention however to counteract the symbol
10 smearing effects of timing jitter in the receiver/demodulator.

The preferred embodiment of the digital modulator is seen in FIG. 3B. An
inverse fast-Fourier Transform (IFFT) 108 performs the subcarrier modulation and
summation of the differentially encoded symbols of buffer 106. 104 represents a
unit delay in feedback of the integrated symbol buffer. Therefore, T is the reciprocal
15 of the orthogonal subcarrier spacing, or the time span of the N input symbols. The
maximum signaling rate is therefore (N/T) symbols-per-second. Assuming m-bit
symbols, the maximum transmission rate allowed is $m(N/T)$ bits-per-second. The
need for the guard band limits the actual rate to $(T/(T+g))$ times the maximum
possible rate, where 'g' is the length in seconds of the guard band inserted.

20 The preferred embodiment is the most efficient modulation method for
several reasons. First, the IFFT is well known to those skilled in the art to be
computationally optimal for the process employed. Second, it provides an equally
efficient and effect method of performing sample rate interpolation. By performing
an IFFT of length $L > N$, setting the unassigned input points to zero identically, the
25 resulting time series will represent the $\sin(Nx)/\sin(x)$ interpolated series having the
interpolation ratio (L/N). Having L a highly composite value (e.g., power of 2, 3 or 4
or product of primes) results in maximum efficiency. FIG. 4 depicts the spectrum of
the composite phase modulated AM Carrier. The IFFT facilitates the selective
nulling of the frequency region immediately surrounding the carrier frequency.
30 Assuming $L > 2N$, the N subcarrier tones may be selected to be any subset of the
first half of the L tonal positions of the IFFT input. In the preferred embodiment, 128
orthogonal tonals are used and $L=512$. The input symbols for a data frame are
aligned in the input buffer at frequency "bins" 3 through 130. The first 100 Hertz to
either side of the AM Carrier are therefore nulled in the sidebands generated by the

phase modulation. FIG. 5 shows the final transmission packet structure in the invention's preferred embodiment.

1.2 RF Carrier Modulation

As depicted in FIG 1A, successive transmission packets are concatenated
5 and filtered to the required bandwidth (<10,000 Hz in the preferred embodiment) using a complex-valued, half-band, low pass finite-impulse response (FIR) filter 22. To those skilled in the art such filters are well known to have linear phase response and permit efficient implementations. Continuously filtered transmission packet data samples (at 38,043.478 Hz sampling rate in the preferred embodiment) are
10 quadrature phase modulated by taking the 28 SIN and 24 COS of each sample and then converting the two orthogonal sequences to analog form using a dual, synchronous analog-to-digital converter 26. The imparted timing jitter in the conversion process must be carefully controlled to a small fraction of the symboling rate in order to limit imparted phase noise to the waveform synchronism.

15 Baseband in-phase (I) and quadrature (Q) analog waveforms from the 52 Data Inserter are applied to the "L" and "R" inputs to a modified C-QUAM compatible Stereo Exciter, such as Broadcast Electronics Model AX-10 AM Stereo Exciter. Required modification to the standard C-QUAM Exciter, FIG. 1B, entails configuring the L+R 58 and L-R 60 quadrature modulation circuits to remove the
20 10% L-to-R and R-to-L audio mixing 56 common to stereo and converting the (L+R +dc) input to the Data Inserter "I" output, and the (L-R) input to the Data Inserter "Q" output. The 25 Hz stereo pilot is also removed from the (L-R) modulator input path. For example, FIG. 6 is a schematic of the quadrature modulation circuit that results from this modification to the AX-10 Exciter. This modification assumes differential
25 inputs from the Data Inserter 52 in the preferred embodiment, wherein, I and I-not are input to amplifiers 320 and 322 respectively. Q and Q-not are input to associated amplifiers 324 and 326, respectively. 320 and 322 incorporate 11K potentiometers for gain balancing between the in-phase and quadrature channels to control modulation phase error in the IF Carrier. Clocking source 328 clocks at a
30 50% duty cycle at the chosen IF frequency (nominally 250khz in the preferred embodiment). 328 outputs four orthogonally phased clocks to chopping modulator switch 330 where the differential I and Q signals are quadrature modulated by the IF signal. Summation junction 334 adds the now in phase differential waveforms to produce the quadrature IF signals:

$$I \{ \cos(\omega_c t) + a_1 \cos(3\omega_c t) + a_2 \cos(5\omega_c t) + \dots \}$$

$$Q \{ \sin(\omega_c t) + a_1 \sin(3\omega_c t) + a_2 \sin(5\omega_c t) + \dots \}$$

Filter **332** serves to remove the unwanted odd order harmonics and sums the quadrature components to produce the desired phase modulated IF Carrier. The output of this modulator circuit is now passed to a limiter-amplifier **40** and to additional filtering **42**, as required. The signal is now passed to AM Modulator **44** and the RF Up-converter **46** to place the fully modulated signal at the desired AM Broadcast frequency.

2. Receiver-Demodulator

2.1 Radio

FIG. 7 provides a simplified schematic of the invention's phase modulation radio receiver. The receiver is designed to operate in the AM Broadcast band in the preferred embodiment and as such builds upon the available C-QUAM integrated circuit technology. In the preferred embodiment, Motorola part numbers MC13030, MC145157-2 from the C-QUAM Radio chip set are utilized. FIG. 7 is one approach of those equivalent others that could be arranged by those skilled in the art. Referring to FIG. 7, the radio is electronically tuned to the desired broadcast frequency by a PLL circuit used to adjust the voltage controlled oscillator **408** to the required mixing frequency, $F_{RF} + 10.7\text{Mhz}$, used in mixer **404**. Phase Detector/Comparator **412** provides an output signal proportional to the phase difference of the reference tuning setting and the gain adjusted VCO **408** output signal. Loop filter **410** is set to allow relatively quick response frequency adjustment. Mixer **404** output is amplified into the Bandpass Filter **416** and Limiter **418** combination to produce the constant envelope phase modulation.

Reference Oscillator **432** provides the phase referencing signal for the second stage down conversion and for the Demodulator Analog-to-digital conversion clock. The limiter **418** output is mixed with the PLL **436** controlled secondary IF signal. This signal is used to phase lock the second IF output to the reference frequency phase. PLL **436** is also used to track minor variations in the carrier frequency, hence the reference to carrier-follower design. IF Filter **422** is designed to allow a bandpass of not more than 28,000 Hz centered at the nominal IF frequency, 76,086.95 Hz or one-fourth the conversion clock phase reference frequency. Since the nominal spectral bandwidth of the significant part of the phase modulated IF signal is approximately 2.2 times the baud rate of the digital

modulation (i.e., about 21,250 Hz), this IF is a reasonable compromise between noise rejection, adjacent channel rejection and carrier tracking.

The reference frequency out of divide down circuit **414** is at a ratio of 23:1 from the input reference oscillator frequency. PLL loop filter **428** is designed to provide a loop bandwidth of 100 Hz or less. This should be compared to the phase modulated IF spectrum, as depicted in FIG. 4, and insures that the tracking loop does not respond to data modulation of the carrier. Loop design is set to free-wheel from the last state whenever the input to phase comparator **430** drops below the locking threshold. This insures that under conditions of RF drop-out due to fading or large negative amplitude modulation from the audio signal, the receiver will recover lock on the RF Carrier (i.e., IF) without excessively long re-acquisition time.

2.2 Digital Demodulator

2.2.1 IF Phase Demodulation

FIG. 8 is a depiction of the process of recovering the base band data modulation from the phase of the IF signal. The figure depicts one method (i.e., a digital method) of performing phase demodulation of the IF signal: analog-to-digital **440** conversion followed by a complex demodulation **442** and arctangent **444** computation. Several other methods are available to phase demodulate the IF signal as could be devised by those skilled in the art. The preferred embodiment is as depicted for the purposes of efficient use of the requisite implementation Digital Signal Processing hardware. The Complex Demodulator **442** of the preferred embodiment is as depicted in FIG. 9. IF waveform is sampled synchronously to the carrier phase by virtue of PLL **436** as shown in FIG. 7. The sampling rate (F_s) of the preferred embodiment is four times the IF frequency, $F_s = 304,347.82$ Hz. The first step in the complex demodulation process is the complex bandshift to baseband of the IF signal. Because of the chosen relationship between the IF frequency and F_s , the two mixers **480** are created by a table of 4 sin/cos look-up values and then two multiplies per incoming sample. The resulting two data channels are low pass filtered (nominally) to the signaling baud rate, approximately 9500 Hz in the preferred embodiment. The sampling rate of these channels is also decimated to maximize efficiency of the invention. Those skilled in the art will note that sampling rate decimation is often most efficiently accomplished through staged filtering and rate reductions. The preferred embodiment use two such stages and the use of half-band FIR digital filters **482** and **486** leads to the most efficient

method of filtering and simultaneous down-sampling to target rate of four times the baud rate: 38043.47 Hz in the preferred embodiment. Decimation is performed as an integral part of the FIR filtering computation and occurs in a decimation by 4 followed by decimation by 2 in the second FIR filter.

5 Final phase demodulation occurs by computing the angle associated with the phasor represented by the in-phase and quadrature phase complex demodulator output. The arctangent computation **444**, implemented by a quadrant based successive approximation/table look-up procedure. The arctangent look-up table is designed to limit the maximum angular error to less than one degree of
10 phase.

2.2.2 Packet Detection and Frame Synchronization

A critical aspect of data recovery is to accurately determine when a transmission packet has arrived and to synchronize to the data framing structure, as indicated in FIG. 2. The invention facilitates packet detection and data
15 synchronization by incorporating a known polyphase sequence in every transmission packet. This sequence is optimally detected in the receiver-demodulator by applying matched filter **448** to the phase demodulator output data. The matched filter (MF) output is sent to threshold detector **450** which compares the local maximum MF output power to the surrounding RMS power over the
20 processing block. The comparison **446** implements the maximum likelihood test for sequence presence at fixed probability of false detection. The preferred embodiment utilizes a sequence with a bandwidth-time product of 128 (21 dB processing gain).

When packet presence detection **446** has occurred, data frame
25 synchronization is achieved by sample selection of the central N samples in each anticipated data frame offset from the packet detection MF peak time index. The guard band inserted at the modulator now comes into play in that any timing alignment jitter due to noise or weak signal is offset by the timing guard band on each data frame. Cumulative timing error across a transmission packet, due to
30 synchronization timing error, clock drift, differential sampling skews or Doppler is also addressed by the use of guard bands. The length of each guard band must be selected to at least twice the total expected timing drift over a packet duration divided by the number of data frames per packet. As an example, a design for commercial AM Broadcast channels and 50 ppm (parts per million) clock-oscillators
35 would allow for approximately 9 msec/second of timing jitter at the receiver. This

approach also allows a trade-off of transmission packet duration against timing recovery overhead.

2.2.3 Frequency Demux and Soft-symbol Recovery

The following disclosure refers back to subcarrier modulation description and, in particular, the timing references of FIG. 5. Subcarrier signal recovery (FIG 10) is accomplished through application of a fast Fourier transform to perform frequency demux. Beginning at the (phase) reference frame, $(T_h + T_m + g/2)$ seconds after the leading edge of packet sync, L samples are loaded into FFT input buffer **500**. An L-point FFT **504** is performed once every $T_r = (T + g)$ seconds and the phasors associated with frequency bins assigned to the subcarriers, number three through 130 in the preferred embodiment, are selected from the FFT output and loaded into the differential decoder **502** history buffer. The current output phasors are also passed to the decoder where they are complex conjugated and multiplied with the immediately previous FFT output phasors at the corresponding frequency bins to effect differential decoding **506**. The first FFT output phasors following packet synchronization represent the reference frame. The first output from the differential decoder following packet synchronization will be the complex conjugated reference frame for use in channel assessment.

2.2.4 Symbol Decode/Frame Recovery

As depicted in FIG. 8, Symbol decode **464** is effected in each embodiment according to the digital modulation format employed at the modulator. The decoding operation in all cases maps the differentially decoded phasors representing soft-symbols to a corresponding bit pattern representing the transmitted encoded binary data. Methods of accomplishing this are varied and well-known to those skilled in the art.

Frame recovery **466** assembles the decoded bits from each of the N symbols per data frame every T_r seconds. Because the modulation type is encoded in each packet header, symbol decode **464** and frame recovery **466** will produce a variable amount of binary data according the bandwidth efficiency used at the transmitter. The table below codifies the relationship between modulation density, in bits-per-symbol (bpsy), and the number of Reed-Solomon blocks per transmission packet assuming a fixed packet length of 27 data frames, as in the preferred embodiment:

TABLE 1

bpsy	bit/frame	bytes/pkt	blks/pkt
2	256	864	12
3	384	1296	18
4	512	1728	24
5	640	2160	30
m	128m	432m	6m

Frame recovery aggregates decoded symbols into bytes. Bytes are
 5 organized into blocks of 72 and arranged in the de-interleave buffer in accordance
 with TABLE 1.

2.2.5 Error Correction

De-interleaver **468** in the preferred embodiment is designed to work with an
 interleave pattern which disperses code symbols in both time and frequency as
 10 illustrated in FIG 11. Those skilled in the art will be able to devise suitable
 alternative interleave functions provided interleaving spans at least one
 transmission packet. The selected algorithm is defined as follows:

If memory byte address order of the frame recovery output buffer is defined
 as:

$$15 \quad a(k) = k ; \quad k=0, 1, 2, \dots 72M$$

where M is the appropriate value from Table 1. Viewing the interleaver input as an
 Mx72 byte matrix **508**, consecutive encoder symbols (i.e., bytes) are mapped
 according to **510**. This mapping is defined as follows:

20 Define the parameters:

$m >$ minimum effective code length (odd and relatively prime to 72
 and M)

N = block length of encoder (In the preferred embodiment, $N=72$)

M = encoder blocks per packet

25 $k = 0, 1, \dots, MN-1$

$p = k m \bmod(MN)$

$row(p)$ = row index of interleave result for input byte address 'p'

$col(p)$ = column index of interleave result for input byte address 'p'

then row and col are given by

30 $col(p) = k \bmod(N)$

$row(p) = p \bmod(mN)$

The de-interleaver re-assembles the original byte order by placing consecutive frame recovery output bytes at memory locations separated by the distance 'm'. That is, if $n = 0, 1, \dots, MN-1$ represent the consecutive output order of bytes from frame recovery, then the corresponding de-interleaved destination address is given by

$$p = n m \bmod (MN).$$

Error correction **470** performs Reed-Solomon error detection and correction processing is applied to the de-interleaved transmission packet buffer **514**. Reed-Solomon (RS) decoding is well-known and has several efficient alternative available implementations, as known by those skilled in the art. In the preferred embodiment coding blocks are organized around 50 byte data blocks. Accordingly, the preferred embodiment performs RS Decoding of the RS(72,50) coded blocks using the well known Berlekamp-Massey and Forney Algorithms. The preferred embodiment of the invention uses a table driven methodology based on 8-bit symbols in the Golais field associated with the primitive polynomial:

$$p(z) = z^8 + z^7 + z^2 + z + 1$$

and the code generating polynomial:

$$g(z) = z^{22} + g_{21}z^{21} + \dots + g_1z + g_0$$

created in the usual manner, as understood by those skilled in the art.

The output from RS Decoding results in 50 byte blocks in the preferred embodiment. Therefore, 300m bytes per transmission packet are delivered to the intended application by the invention. This equates to a payload rate of 6126.16m bits-per-second or a conservative minimum of 6126 bps. In particular, Table 2 provides the generator for the preferred embodiment.

Table 2
Generator Polynomial Coefficients
Used In
Preferred Embodiment

	coef #	Zech's log	Binary Code
5	g_{21}	36	-- 0 1 0 1 0 1 1 1
10	g_{20}	21	-- 0 1 0 1 1 1 1 1
	g_{19}	167	-- 1 1 1 0 0 1 1 0
	g_{18}	22	-- 1 0 1 1 1 1 1 0
	g_{17}	228	-- 1 0 1 1 1 0 0 0
	g_{16}	147	-- 1 1 0 1 0 1 0 1
15	g_{15}	50	-- 0 0 1 1 0 1 1 0
	g_{14}	13	-- 0 0 1 1 1 1 0 1
	g_{13}	194	-- 0 1 0 0 1 0 0 1
	g_{12}	74	-- 1 0 1 1 1 0 1 1
	g_{11}	73	-- 1 0 0 1 1 1 1 0
20	g_{10}	97	-- 0 1 1 0 0 0 0 1
	g_9	240	-- 0 0 1 1 0 0 1 1
	g_8	82	-- 1 0 1 1 0 1 1 1
	g_7	142	-- 0 0 1 0 0 0 1 0
	g_6	7	-- 1 0 0 0 0 0 0 0
25	g_5	111	-- 1 1 1 0 0 0 0 0
	g_4	183	-- 1 1 1 1 1 1 1 1
	g_3	96	-- 1 1 1 1 0 0 1 1
	g_2	228	-- 1 0 1 1 1 0 0 0
	g_1	11	-- 1 0 1 0 1 1 0 1
30	g_0	253	-- 1 0 1 0 0 0 1 0

3. Receiver System

Once the data has been received and demodulated, the present invention permits the user to control the manner of outputting the received data.

Fig. 12A describes one embodiment of this control function of the invention. An antenna **610** receives an analog AM broadcast signal from a transmitter (not shown). The signal is relayed to a tuner/demodulator **612** where it is decoded and passed through an analog-to-digital converter **614** prior to being sent to a user interface/controller (UIC) **616**. The user interface/controller **616** is essentially a microcomputer having resident random access memory **618** and a signal processing unit **620**. The UIC **616** is directly linked to keypad entry device **624**, a speech synthesizer/decoder **626** and a digital-to-analog converter **628**. A control signal is passed between UIC **616** and keypad entry device **624**. This control signal

allows the user to select from all available options. For instance, the user can opt to receive information in real-time or may store data in memory for later "off-line" retrieval. The user listens to the data via an audio output **630**.

Once the signal is received and processed by UIC **616** into compressed
5 text/speech it is passed to the speech synthesizer/decoder **626** where it is processed and returned to UIC **616** as a speech waveform. An example of a well-known device capable of performing such functions is DecTalk by Digital Equipment Corporation. This waveform may be immediately played for the user in real-time or stored for later retrieval in memory **618**.

10 The audio voice output **630** may be any vocoder technique that is well known in the art but the preferred embodiment would be a technique that allows "talk" radio quality audio to be produced. The synthesizer/vocoder would provide the user with an audible presentation of system options. The audible presentation could comprise a menu driven interface requiring the user to select a title
15 corresponding to a particular selection. The audible presentation could incorporate known compact diskette (CD) control features as a user response mechanism or speech recognition.

In the preferred embodiment **700**, depicted in Fig. 12B an antenna **610** receives an analog AM broadcast signal from a transmitter (not shown). The signal
20 is relayed to a tuner/demodulator **612** where it is decoded and passed through an analog-to-digital converter **614** prior to being sent to a user interface/controller (UIC) **616**. The user interface/controller **616** is essentially a microcomputer **622** having resident random access memory **618** and a signal processing unit **620**. The UIC **616** is directly linked to a text/image display **634**, a speech recognition module
25 **632**, a speech synthesizer **626** and a digital-to-analog converter **628**. A control signal is passed between UIC **616** and text/image display **634**. This control signal allows the user to select from all available options. For instance, the user can opt to receive information in real-time or may store data in memory for later "off-line" retrieval. Further, the user can opt to view the data as textual/image or may listen to
30 the data via an audio output **630**. If the data is textual originally, it can be sent as text and voice synthesized at the receiver by speech synthesizer/decoder **626** in order to provide an audio output

The text image display **634** may be any display that is well known in the art but the preferred embodiment would be a liquid crystal display (LCD). The display
35 would provide the user with a visual of the available system options. The visual

display could comprise a menu driven interface requiring the user to select a number corresponding to a particular selection. The display could also incorporate touch screen technology in which the user need only touch the area of the screen corresponding to the desired selection in order to trigger a control signal.

5 The audio output or speaker **630** may also include an adjustable volume control (not shown) in order to allow the user to raise or lower the volume of a broadcast dependent on the current environment.

10 The receiver system is designed specifically for picking up and manipulating signals in the AM frequency spectrum. Specifically, those signals inserted into typical AM monophonic broadcast baseband as subcarriers. Insertion of the data into the subcarrier has been described earlier in this paper. The receiver can be made portable, i.e. pager size or may be an augmented form of a typical AM/FM stereo receiver of the size and type found in automobiles or may even be an augmented form of a typical home stereo AM/FM tuner/receiver. In the case of the latter two embodiments, the audio output **630** (speakers) would be separate from the receiver unit itself. The receiver unit may be connected in typical fashion to the speaker(s) **630** by way of wire or may be implemented in a wireless fashion.

15 In a subscriber system, the subcarrier broadcast signals may be encrypted at the transmission end of the system in order to ensure that only those subscribing to a particular service would be able to convert received signals into a usable format, be it text/image or audio. For instance, one local broadcaster may use the subcarrier of a local AM radio station to insert 24 hour sports scores and updates for users who subscribe and pay a fee for such a service. In this case the broadcaster would encrypt the data to prevent unauthorized users access to the information. Similarly, other content providers could do the same. The receiver would then be outfitted with a decryption device to allow authorized users to access data for which they are paying.

20 As noted above, the present invention overcomes many shortcomings of the prior art to thereby more efficiently transmit digital data concurrent with AM monophonic broadcasts. As an example, in the preferred embodiment, interference with the audio is addressed by isolating all data modulation to a subcarrier based signal which in turn phase modulates the carrier. The subcarrier is permitted to fill the audio band to the fullest extent possible with a limit at the low frequency end at 100 Hz to avoid inadvertent activation of the stereo decoder in AM Stereo receivers.

Thus a minimum of 9 K Hz of bandwidth is available for data modulation, nearly four times that possible in Kahn or any other previous approach.

Further, the present invention permits the individual receiving the transmitted data to elect several options for outputting the data to include delaying
5 the output and choosing an image or speech output format.

While the invention has been described with reference to the preferred embodiment thereof, it will be appreciated by those of ordinary skill in the art that various modifications can be made to the structure and function of the individual parts of the system without departing from the spirit and scope of the invention as a
10 whole.

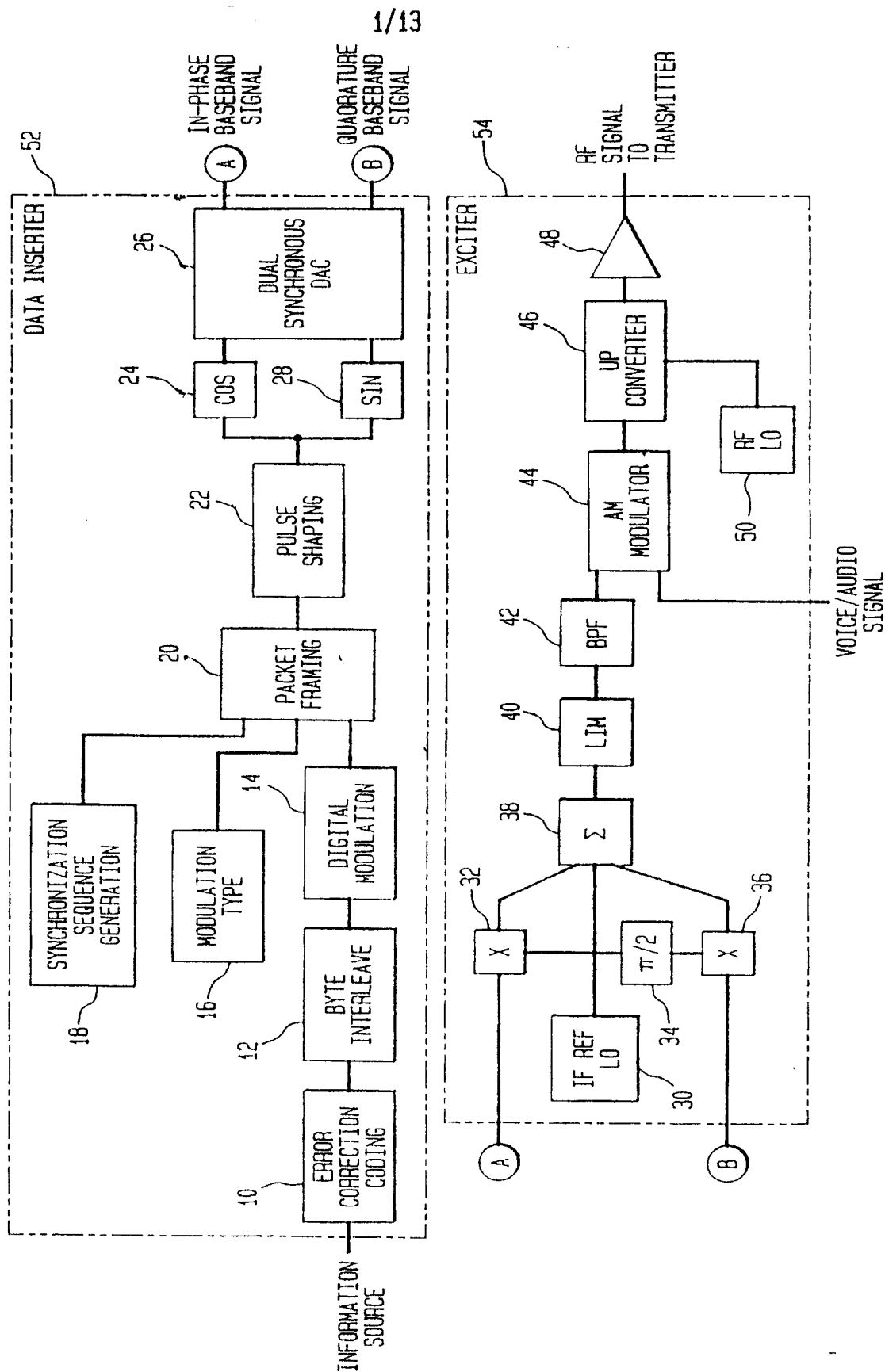
WHAT IS CLAIMED IS:

1. A data transmission system comprising:
an AM subcarrier data insertion device for inserting data into the subcarrier
5 of a monophonic AM broadcast;
a transmitter for transmitting the subcarrier data as an AM radio signal;
a tuner/demodulator for receiving and demodulating the transmitted AM
radio subcarrier signal; and,
a user interface/controller for processing the signal and communicating with
10 a user wherein said communication may comprise deciding whether to receive data
in real-time or store data for later retrieval.
2. The system of claim 1 further comprising:
a speech synthesizer/decoder for converting compressed, digitized voice
15 data to speech waveform data and for converting text data to audio data; and
a speaker for outputting speech waveform data and audio data.
3. The system of claim 2 further comprising a text/image display for displaying
user options and accepting user entries as well as displaying text and/or image
20 data.
4. The system of claim 1 further comprising:
an encryption device for encrypting the inserted data; and,
a decryption device for decrypting any encrypted signal;
25
5. The system of claim 1 wherein the user interface/controller comprises a
processor and memory.
6. The system of claim 4 wherein the memory comprises both volatile and non-
30 volatile memory.
7. The system of claim 1 further comprising a volume adjusting means for
adjusting the volume of the speaker output.
- 35 8. The system of claim 1 wherein the receiver is a portable device such as a

voice pager or cellular phone.

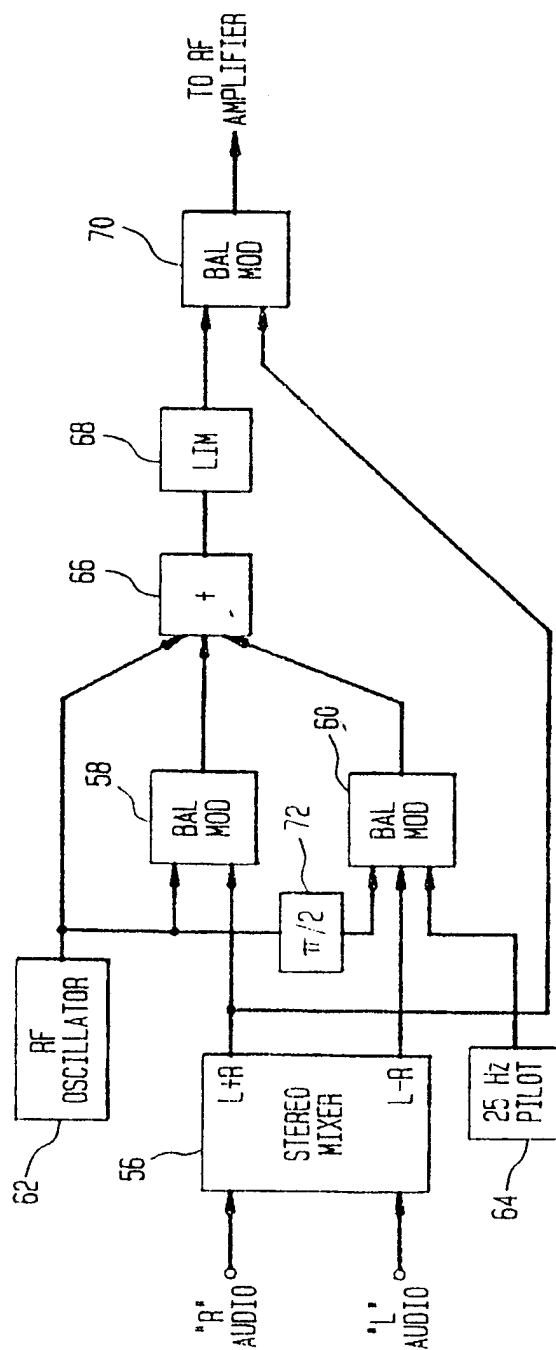
- 5
9. The system of claim 1 wherein the receiver is the size of an automobile radio.
10. The system of claim 1 wherein the receiver system is the size of a home stereo receiver.
- 10 11. The system of claim 1 wherein the user interface comprises a keypad entry device menu system.
12. The system of claim 1 wherein the user interface comprises an audio entry device.
- 15 13. The system of claim 11 further comprising a microphone and a voice recognition module.
14. The system of claim 1 wherein the user interface comprises touch screen technology.
- 20 15. The system of claim 1 wherein the display is an LCD.

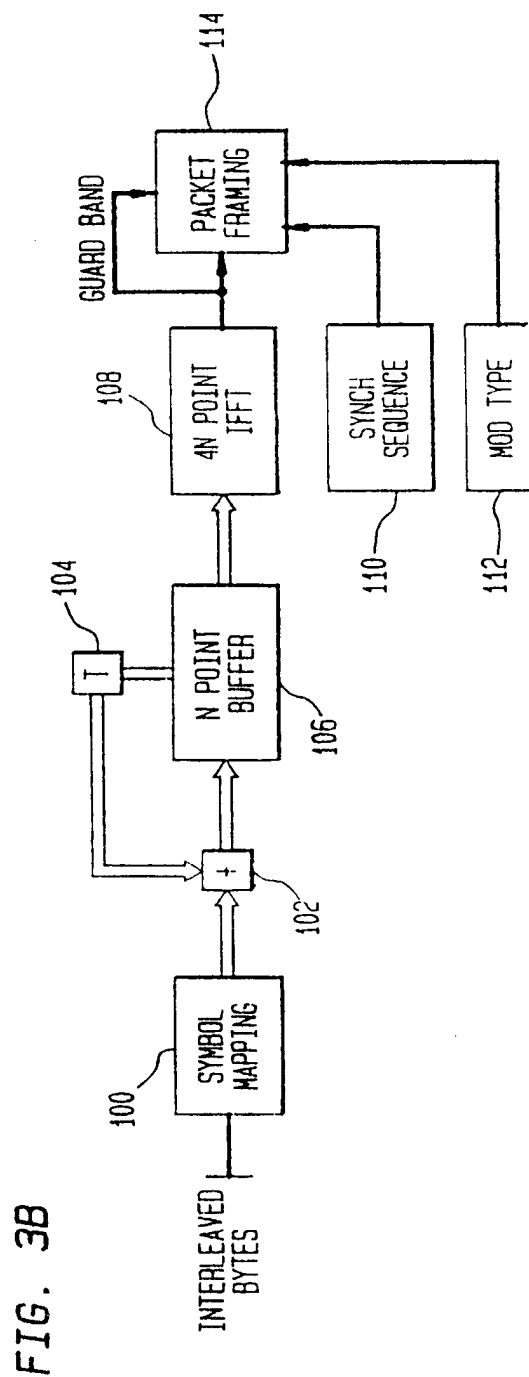
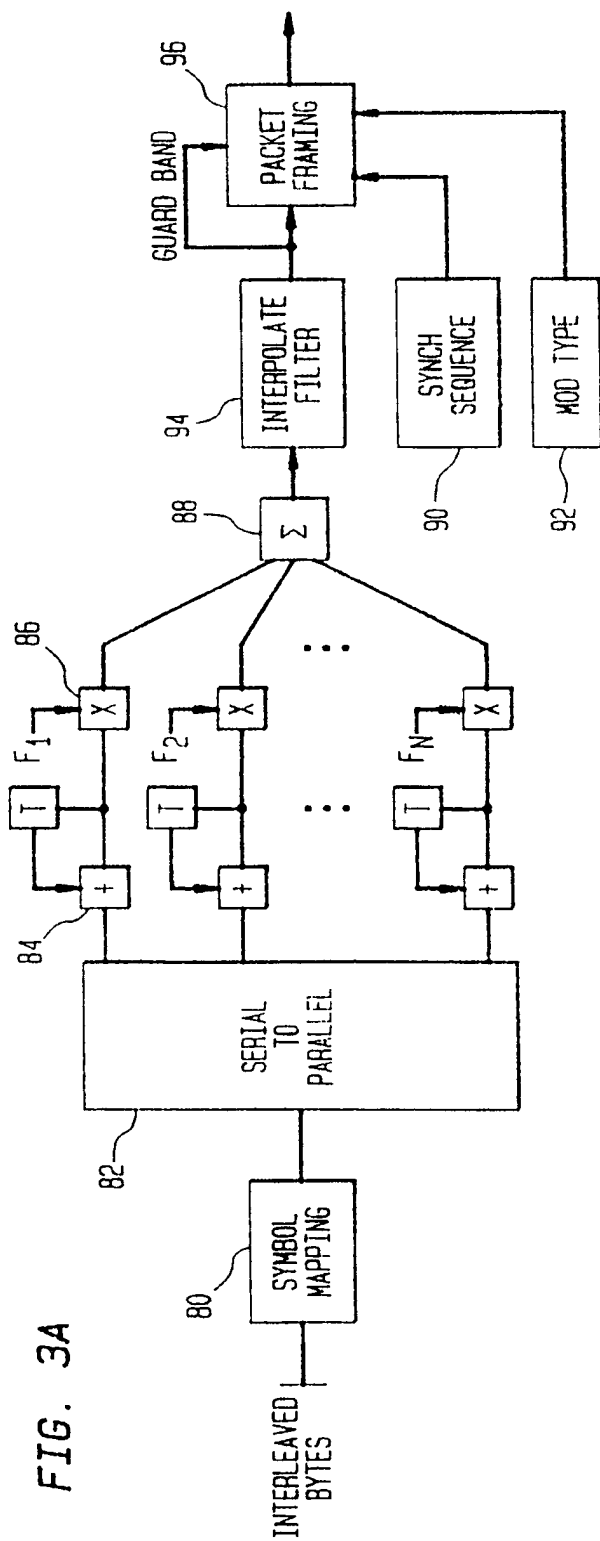
FIG. 1A



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FIG. 1B
(PRIOR ART)





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FIG. 4

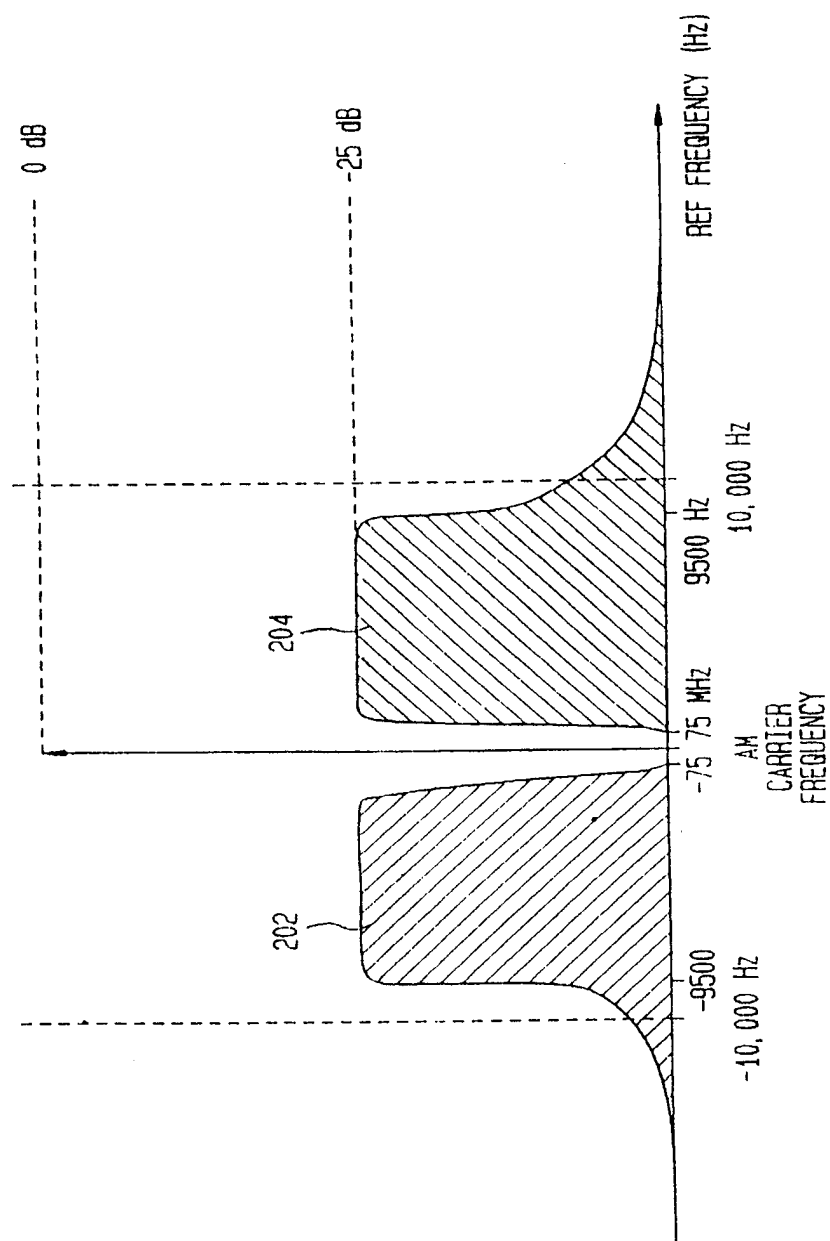
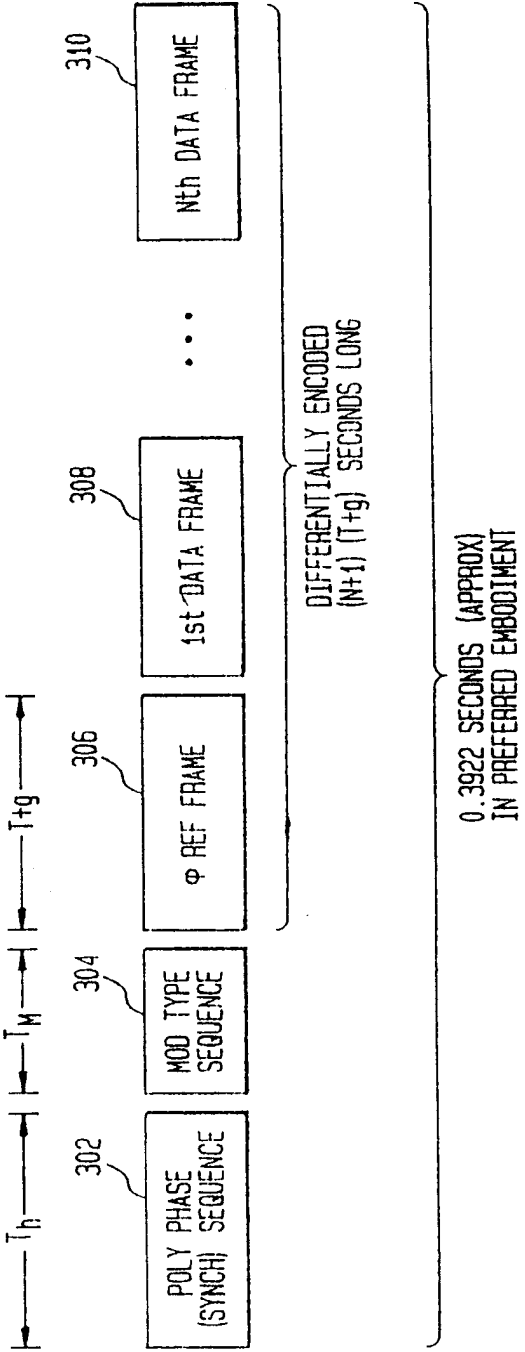
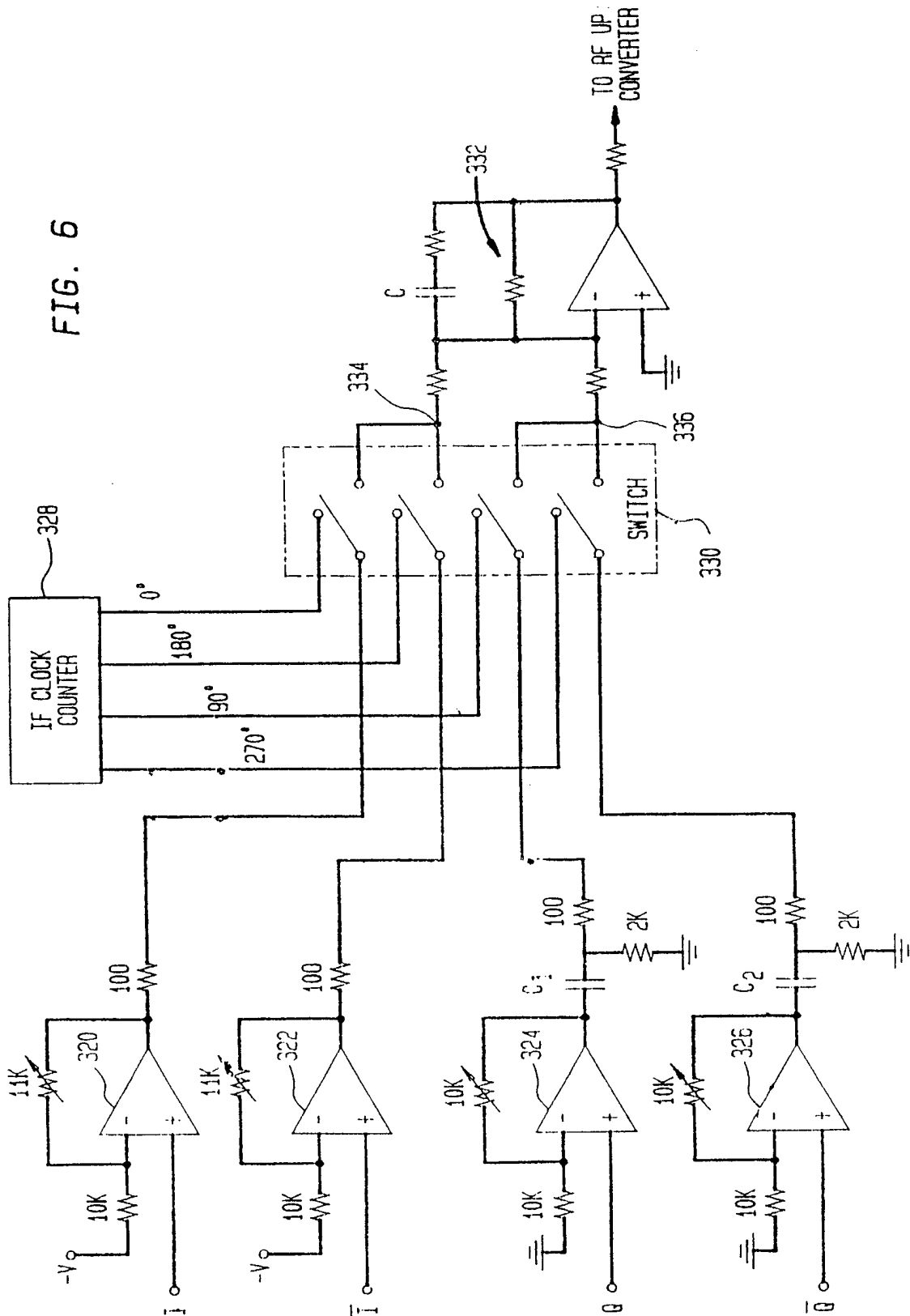


FIG. 5



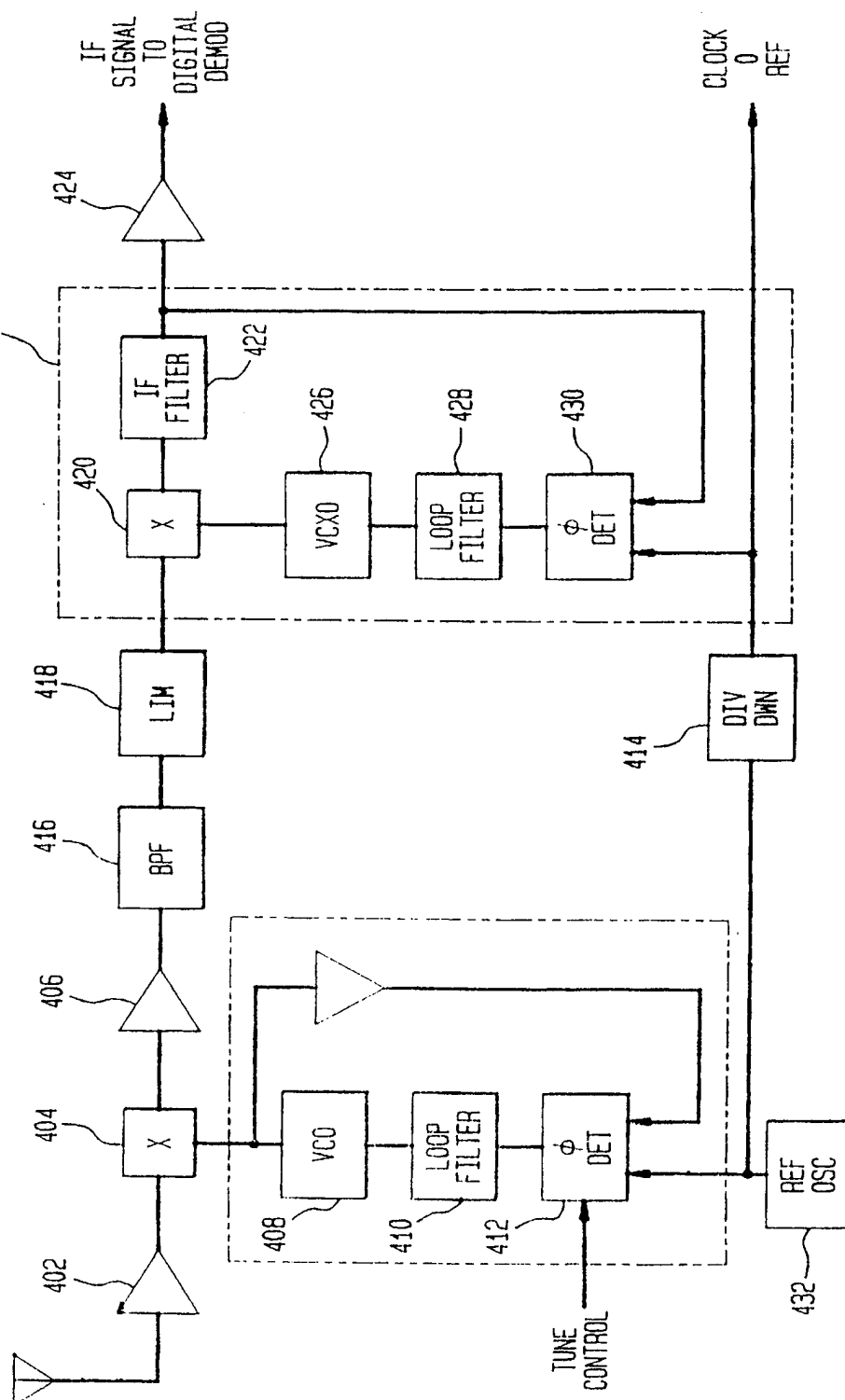
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FIG. 6



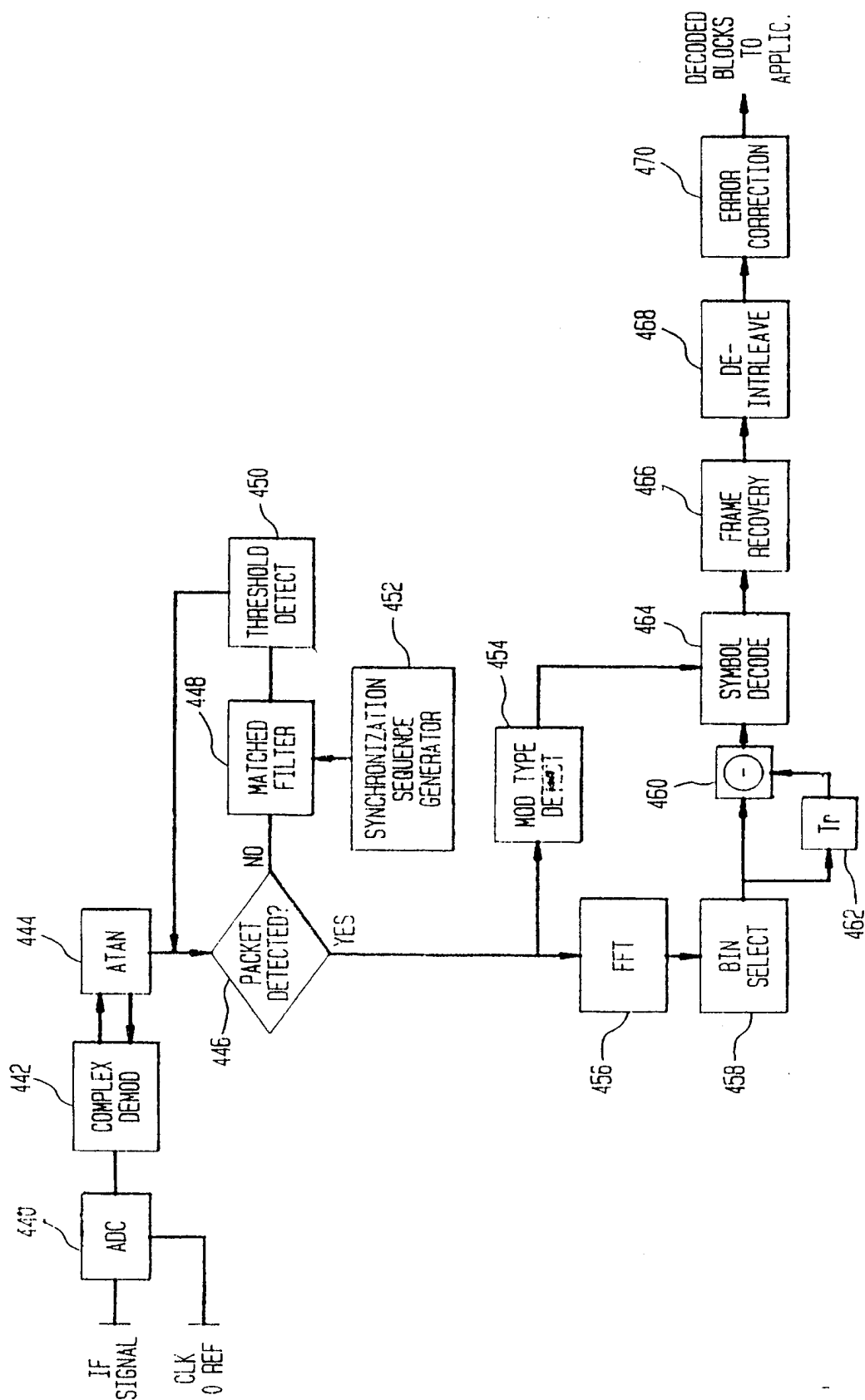
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FIG. 7



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FIG. 8



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FIG. 9

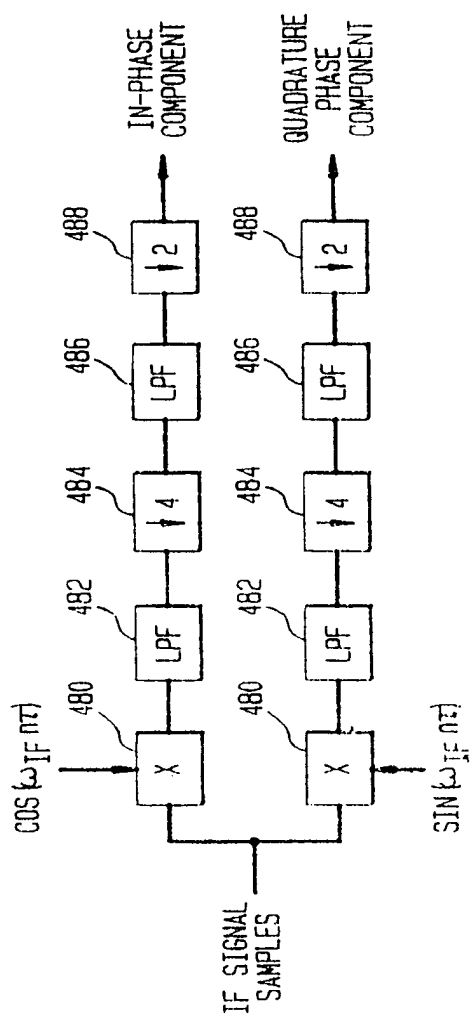
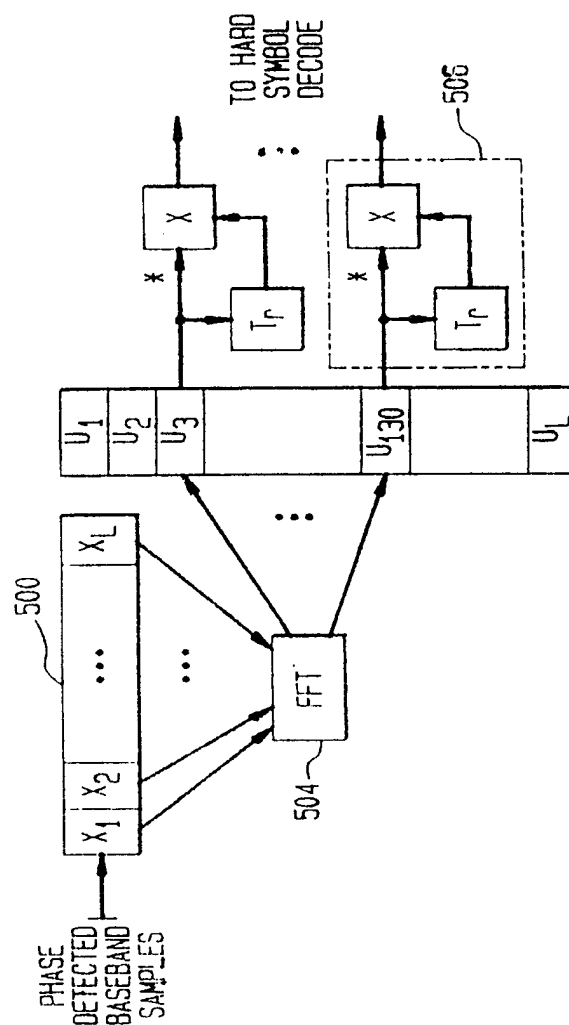
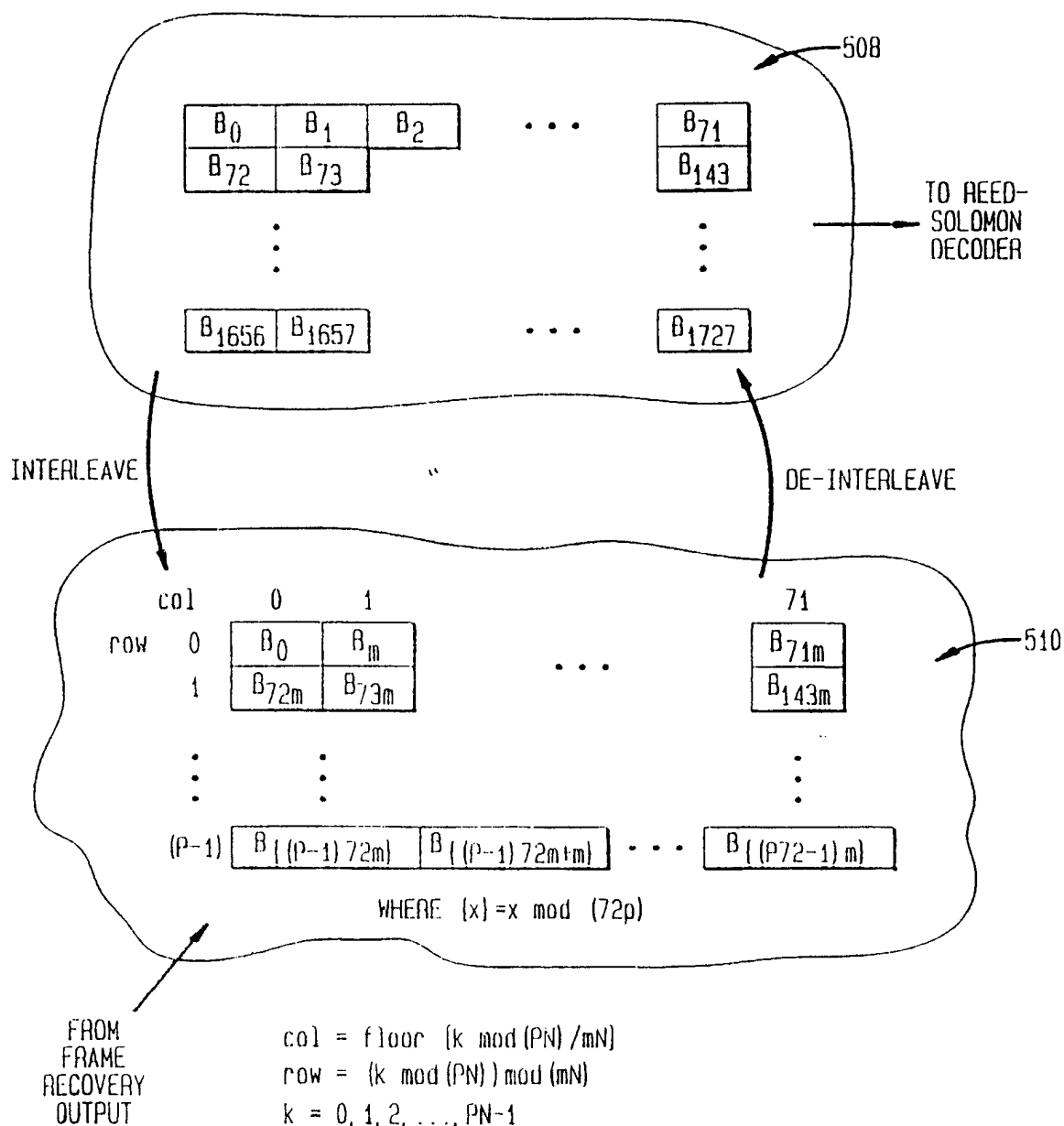


FIG. 10



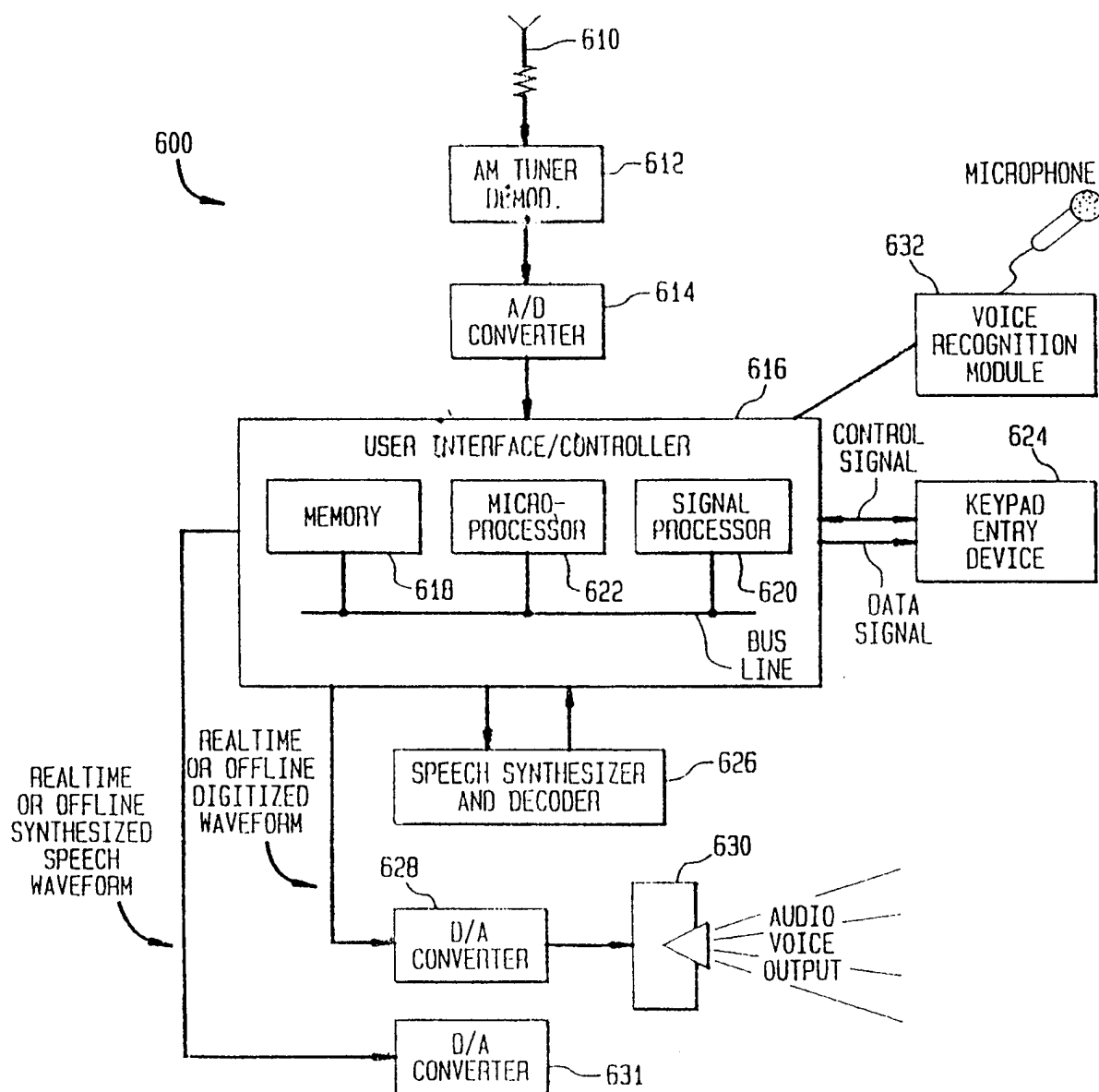
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FIG. 11



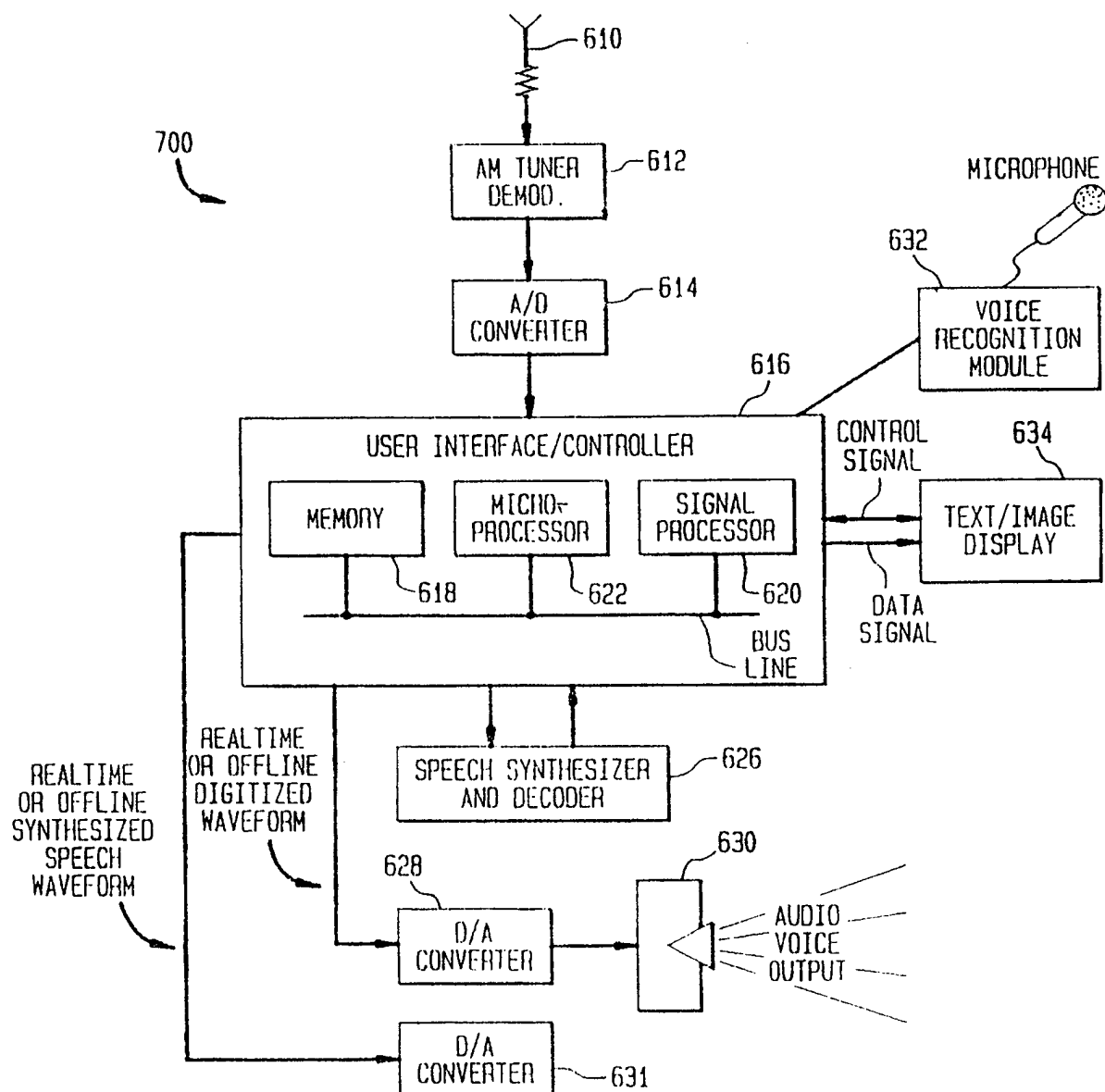
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FIG. 12A



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FIG. 12B



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/10061

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : H04L 9/00

US CL : 380/9

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 380/9, 28, 49

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 3,959,592 A (EHRAT) 25 May 1976 (25/05/76), See Figs. 3 and 17 and claim 8.	1-15
Y	US 4,841,571 A (KAGE) 20 June 1989 (20/06/89), See Figs. 1 and 3.	1-15
Y	US 4,920,567 A (MALEK) 24 April 1990 (24/04/90), See Figs. 2 and 4.	1-15
Y	US 5,003,593 A (MIHM, JR) 26 March 1991 (26/03/91), See Fig. 2B.	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	*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
A document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
E earlier document published on or after the international filing date	*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
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)	*Z* document member of the same patent family
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	

Date of the actual completion of the international search

09 JULY 1998

Date of mailing of the international search report

20 OCT 1998

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Telephone No. (703) 305-1837

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/10061

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,341,427 A (HARDY ET AL) 23 August 1994 (23/08/94), See Fig. 5.	1-15
Y	US 5,465,300 A (ALTSCHULER ET AL) 07 November 1995 (07/11/95), See Figs. 7 and 8.	1-15