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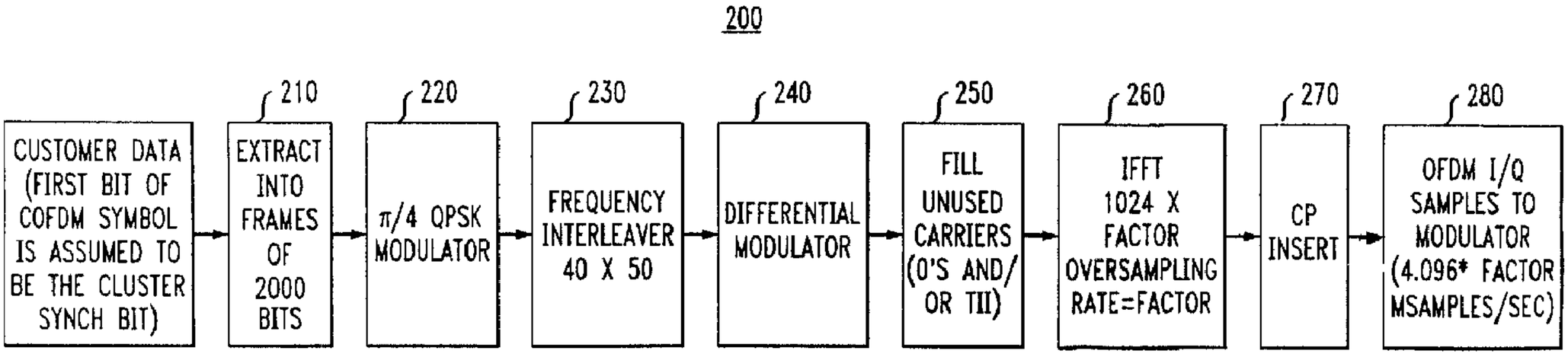
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(54) Titre : METHODE ET APPAREIL PERMETTANT L'EXECUTION D'UNE MODULATION DIFFERENTIELLE SURFREQUENCE DANS UN SYSTEME DE COMMUNICATION PAR MULTIPLEXAGE PAR REPARTITION EN FREQUENCE ORTHOGONAL (MRFO)

(54) Title: METHOD AND APPARATUS FOR PERFORMING DIFFERENTIAL MODULATION OVER FREQUENCY IN AN ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM) COMMUNICATION SYSTEM



(57) Abrégé/Abstract:
A terrestrial repeater is disclosed for use in a satellite transmission system that may also include a plurality of satellites. The terrestrial repeaters are implemented as OFDM transmitters to minimize the channel impairments caused by multi-path propagation. The OFDM terrestrial repeaters differentially encode the transmitted signal over frequency, as opposed to time, in order to avoid channel phase distortion. The OFDM receiver allocates two unmodulated sub-carriers as pilot bins and thereby provides two sub-carriers as a reference within each OFDM symbol. At the OFDM receiver, the two unmodulated pilot bins contain no phase information and provide a reference for the differential demodulation performed by the OFDM receiver. The OFDM transmitter operates in two modes, namely, a normal mode and a transmitter identifier information (TII) mode. The TII mode contains all of the functions of the normal mode, and also transmits a repeater identification signal with the customer data, using the inactive OFDM sub-carriers (bins). In a normal mode, the OFDM transmitter optionally fills unused (inactive) sub-carriers with zeroes and in a TII mode, the OFDM transmitter uses at least some of the unused (inactive) sub-carriers to transmit the transmitter identifier information (TII). The predefined TII value is mapped onto a set of complex symbols. The TII signal facilitates the receiver test equipment in associating the received signal with the terrestrial repeater(s) that generate the TII signal.

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Abstract

A terrestrial repeater is disclosed for use in a satellite transmission system that may also include a plurality of satellites. The terrestrial repeaters are implemented as OFDM transmitters to minimize the channel impairments caused by multi-path propagation. The OFDM terrestrial repeaters differentially encode the transmitted signal over frequency, as opposed to time, in order to avoid channel phase distortion. The OFDM receiver allocates two unmodulated sub-carriers as pilot bins and thereby provides two sub-carriers as a reference within each OFDM symbol. At the OFDM receiver, the two unmodulated pilot bins contain no phase information and provide a reference for the differential demodulation performed by the OFDM receiver. The OFDM transmitter operates in two modes, namely, a normal mode and a transmitter identifier information (TII) mode. The TII mode contains all of the functions of the normal mode, and also transmits a repeater identification signal with the customer data, using the inactive OFDM sub-carriers (bins). In a normal mode, the OFDM transmitter optionally fills unused (inactive) sub-carriers with zeroes and in a TII mode, the OFDM transmitter uses at least some of the unused (inactive) sub-carriers to transmit the transmitter identifier information (TII). The predefined TII value is mapped onto a set of complex symbols. The TII signal facilitates the receiver test equipment in associating the received signal with the terrestrial repeater(s) that generate the TII signal.

METHOD AND APPARATUS FOR PERFORMING DIFFERENTIAL MODULATION OVER FREQUENCY IN AN ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM) COMMUNICATION SYSTEM

Field Of The Invention

The present invention relates generally to satellite broadcasting systems, and more particularly, to terrestrial repeaters in such satellite broadcasting systems.

Background Of The Invention

Satellite broadcasting systems for transmitting programming content have become increasingly popular in many parts of the world. Direct Broadcasting Satellite (DBS) systems transmit television programming content, for example, to a geo-stationary satellite, which broadcasts the content back to the customers. In such a wireless broadcast environment, the transmitted programming can be received by anyone with an appropriate receiver, such as an antenna or a satellite dish.

In addition, a number of satellite broadcasting systems have been proposed or suggested for broadcasting audio programming content from geo-stationary satellites to customers in a large coverage area, such as the continental United States. Proposed systems for providing digital audio broadcasting (DAB), for example, are expected to provide near CD-quality audio, data services and more robust coverage than existing analog FM transmissions. Satellite broadcasting systems for television and radio content provide potentially national coverage areas, and thus improve over conventional terrestrial television stations and AM/FM radio stations that provide only regional coverage.

Satellite broadcasting systems transmits digital music and other audio information from an uplink station to one or more mobile receivers. Satellite broadcasting systems typically include a plurality of satellites and terrestrial repeaters operating in a broadcast mode. The satellites are typically geo-stationary, and are located over a desired geographical coverage area. The terrestrial repeaters typically operate in dense urban

areas, where the direct line of sight (LOS) between the satellites and the mobile receiver can be blocked due to the angle of elevation and shadowing by tall buildings.

It has been observed that the communication channels in such satellite broadcasting systems, and in digital audio broadcasting (DAB) systems generally, are often less dispersive in frequency than in time. Nonetheless, digital audio broadcasting (DAB) systems typically differentially encode the transmitted signal over time. The European digital audio broadcasting (DAB) standard, for example, set forth in "Radio Broadcasting Systems: Digital Audio Broadcasting (DAB) to Mobile, Portable and Fixed Receivers," European Telecommunications Standard: ETS 300 401 (May 1997), performs differential modulation over time. A need therefore exists for a terrestrial repeater that performs differential modulation over frequency. A further need exists for a terrestrial repeater that utilizes an orthogonal frequency division multiplexing (OFDM) scheme to implement differential encoding over frequency.

Summary Of The Invention

Generally, a terrestrial repeater is disclosed for use in a satellite transmission system that broadcasts programming content, such as audio and video information. The satellite transmission system may also include a plurality of satellites.

Certain exemplary embodiments can provide a method of processing a baseband signal in an orthogonal frequency division multiplexing (OFDM) system having a plurality of sub-carriers, comprising the steps of: differentially encoding said signal in the frequency domain using consecutive sub-carriers to produce differentially encoded symbols; storing said differentially encoded symbols and two or more pilot tones in an IFFT buffer such that an analog signal produced upon carrier-modulation is centered at a desired carrier frequency; and transforming an output of said IFFT buffer to create said OFDM signal.

Certain exemplary embodiments can provide an orthogonal frequency division multiplexing (OFDM) transmitter for processing a baseband signal having a plurality of sub-carriers, comprising: a differential encoder for modulating said OFDM signal in the frequency domain using consecutive sub-carriers to produce differentially encoded symbols; an IFFT buffer for storing said differentially encoded symbols and two or more pilot tones such that an analog signal produced upon carrier-modulation is centered at a desired carrier frequency; and a transformer for transforming an output of said IFFT buffer to create said OFDM signal.

Certain exemplary embodiments can provide a method of receiving a signal in an orthogonal frequency division multiplexing (OFDM) system having a plurality of sub-carriers, comprising the steps of: transforming said received signal to recover an OFDM signal in the frequency domain having a plurality of sub-carriers, wherein said transformed signal contains differentially encoded symbols and two or more pilot tones in a configuration to enable said transformed signal to be centered at a desired carrier frequency; and differentially demodulating said OFDM signal in the frequency domain wherein said differential demodulation is performed using consecutive sub-carriers.

Certain exemplary embodiments can provide an orthogonal frequency division multiplexing (OFDM) receiver for receiving an OFDM signal having a plurality of sub-carriers, comprising: a transformer for recovering said OFDM signal having a plurality of sub-carriers, wherein said recovered signal contains differentially encoded symbols and two or more pilot tones in a configuration to enable said transformed signal to be centered at a desired carrier frequency; and a differential demodulator for demodulating said OFDM signal in the frequency domain wherein said differential decoding is performed using consecutive sub-carriers.

According to one aspect of the invention, the terrestrial repeaters are implemented as OFDM transmitters to minimize the channel impairments caused by multi-path propagation. According to another aspect of the invention, the OFDM terrestrial repeaters differentially encode the transmitted signal over frequency, as opposed to time. Thus, the differential encoding is performed with respect to consecutive bins (sub-carriers) in the OFDM system in order to avoid channel phase distortion.

The OFDM receiver allocates a number of unmodulated sub-carriers as pilot bins and thereby provides such unmodulated sub-carriers as a reference within each OFDM symbol. At the OFDM receiver, the unmodulated pilot bins contain no phase information. Thus, the unmodulated pilot bins provide a reference for the differential demodulation performed by the OFDM receiver.

According to yet another aspect of the present invention, the OFDM transmitter operates in two modes, namely, a normal mode and a transmitter identifier information (TII) mode. The TII mode contains all of the functions of the normal mode, and also transmits a repeater identification signal with the customer data, using the inactive OFDM sub-carriers (bins). Thus, the OFDM transmitter can continuously or periodically transmit an identifying signal that can be used, for example, during a testing phase.

In a normal mode, the OFDM transmitter optionally fills unused (inactive) sub-carriers with zeroes and in a TII mode, the OFDM transmitter uses at least some of the unused (inactive) sub-carriers to transmit the transmitter identifier information (TII). In a TII mode, additional sub-carriers will be turned on/off in accordance with a predefined TII value. If the TII sub-carriers continuously transmit the non-varying TII value, it may be performed at reduced power. The predefined TII value is mapped onto a set of complex symbols. The TII signal facilitates the receiver test equipment in associating the received signal with the terrestrial repeater(s) that generate the TII signal.

A more complete understanding of the present invention, as well as further features and advantages of the present invention, will be obtained by reference to the following detailed description and drawings.

Brief Description Of The Drawings

FIG. 1 illustrates a satellite transmission system where the present invention can operate;

FIG. 2 illustrates the OFDM transmitter of FIG. 1 in accordance with the present invention;

FIG. 3 is a table containing a sample record from an entry matrix utilized by the frequency interleaver of FIG. 2; and

FIG. 4 illustrates the OFDM receiver of FIG. 1.

Detailed Description

FIG. 1 illustrates a satellite transmission system 100 in accordance with the present invention. The satellite transmission system 100 transmits digital music and other audio information from an up-link station (not shown) to one or more mobile receivers, such as the mobile receiver 150. As shown in FIG. 1, the illustrative satellite transmission system 100 includes two satellites 110, 120 operating in a broadcast mode. The satellites 110, 120 are designed to be geo-stationary, and are located over a desired geographical coverage area, such as over the eastern and western United States, at appropriate angles of elevation, as dictated by the requirements of a geo-stationary system. In one embodiment, the satellites 110, 120 are implemented as conventional time division multiplexed (TDM) transmitters.

In addition, the satellite transmission system 100 includes a plurality of terrestrial repeaters, such as the terrestrial repeater 140, discussed below, that will operate in dense urban areas, where the direct line of sight (LOS) between the satellites 110, 120 and the mobile receiver 150, can be blocked due to the angle of elevation and shadowing by tall buildings. According to a feature of the present invention, the terrestrial repeaters 140 are implemented as OFDM transmitters to minimize the channel impairments caused by multi-path propagation. In addition, the OFDM terrestrial repeaters 140 can differentially encode the transmitted signal over frequency, as opposed to time. Thus, the differential encoding is performed with respect to consecutive bins (sub-carriers) in the OFDM system bins in order to avoid channel phase distortion.

The OFDM terrestrial repeater 140 generally differentially encodes the transmitted signal over frequency when the channel exhibits phase coherence (the channel phase from one differentially modulated symbol to the next does not change much). In the illustrative DQPSK implementation, the consecutive channel phases should vary by less than 45/2 degrees. In a channel environment where the channel phase variations are more over frequency than over time, the terrestrial repeater 140 may implement a conventional mechanism that differentially encodes over time.

According to another feature of the present invention, the OFDM transmitter 200 can operate in two modes, namely, a normal mode and a TII mode. As discussed further below, the TII mode contains all of the functions of the normal mode, and in addition transmits a repeater identification signal with the customer data, using the inactive OFDM sub-carriers (bins).

The satellites 110, 120 receive the broadcast signal from a studio, over a robust radio frequency (RF) link, and the satellites 110, 120 will broadcast the signal after down-converting the signal to the carrier frequency. The terrestrial repeaters 140 retrieve the information directly from an up-link studio (not shown), using well-known technical means, such as wireline or microwave links, or from a dedicated satellite (not shown). In the illustrative implementation, the terrestrial repeaters 140 receive the information directly from the studio.

OFDM SIGNAL

In the illustrative embodiment, each OFDM symbol of duration Ts will be composed of 978 active bins (sub-carriers) equally spaced, at a carrier spacing of 4 kHz (Δf). The duration of the symbol, Ts, is 266.11 mu-sec, where Ts equals Tu plus Tg. The useful OFDM symbol duration, Tu, illustratively equals 250 mu-sec, and the guard interval duration or cyclic prefix duration, Tg, illustratively equals 16.11 mu-sec. The inter-carrier spacing, Δf , of 4KHz is equal to the inverse of the useful symbol duration (1/Tu). The main signal is defined as follows:

$$s(t) = \mathrm{Re}\left\{ \sum_{l=-\infty}^{\infty} \left(\sum_{k=-489}^{489} z(l,k) \times g(t - lTs, l, k) + \sum_{k=-511}^{-490} m(533+k) g(t - lTs, l, k) + \sum_{k=490}^{511} m(k-490) g(t - lTs, l, k) \right) \right\}$$

where,

z(l,k) equals the differentially coded complex symbol for to the kth sub-carrier in the lth OFDM symbol for k $\neq$ 0 and 0 for k = 0;

m(k) equals the complex TII information (transmitted only in the TII mode, 0 in normal mode);

g(t, *l*, k) = exp(j*2*π*k*(t-Tg)/Tu)*rect(t/Ts) for all *l;*

rect(x) = 1 for 0<=x<1 or 0 otherwise. In addition, where the *Factor* equals two (2), T is defined as (1/(2048*4000)) (approximately 122.07 ns); Tg is defined as approximately 16.11 mu-sec (= 132T); Tu is defined as 250 mu-sec = 2048T and Ts is defined as approximately 266.11 mu-sec (= 2180T).

OFDM TRANSMITTER

FIG. 2 illustrates the OFDM baseband transmitter 200 in accordance with the present invention. The studio encoder (not shown) supplies the transmitter 200 with the bits to be transmitted. These bits have been source and channel encoded, interleaved and presented to the OFDM transmitter 200.

As shown in FIG. 2, the OFDM transmitter 200 includes a block 210 that collects the input data stream into frames of 1952 bits. In one implementation, the customer data is arranged into blocks of 2000 bits such that the first bit of the frame serves as a synchronization bit. Therefore, the OFDM transmitter 200 will have to extract the framing of the OFDM frame with the proper assignment of the first bit to the cluster synchronization bit. The selection of the cluster synchronization bit value (1 or 0) is not a function of the OFDM signal generator. These 1952 bits will correspond to the 1952 bits belonging to one OFDM symbol. In the illustrative embodiment, the time duration of one 1952-bit-frame is 266.11 mu-sec (microseconds), of which 250 mu-sec will be assigned to the useful OFDM symbol, and 16.11 mu-sec to the guard interval or cyclic prefix (CP).

Following framing, the incoming bits are then mapped into a π/4 shifted QPSK constellation by a π/4 QPSK modulator 220. In other words, the input bit-stream is mapped into a stream of complex QPSK constellation points, such that the output lies on

the complex unit circle, and the points are shifted by $\pi/4$ from the axes. The exact operations are:

Input: Bit stream {p0, p1, ... p1951}

where p(i) = 0 or 1

Output: complex symbols {q0, q1, ... q975 }

where q(i) = Complex float: lying on the unit circle at $\pi/4$, $3\pi/4$, $5\pi/4$, $7\pi/4$

q(n) = (1/sqrt(2))* [(1-2*p(2n)) + j*(1-2*p(2n+1))] for n = 0, 1, ... 975.

The QPSK-mapped stream is then frequency interleaved by an interleaver 230. The OFDM signal contains information in both the time and frequency domains. The OFDM transmitter 200 generates a signal that has 976 sub-carriers plus 2 unmodulated pilots and a nulled sub-carrier, each with 4 kHz separation between sub-carriers. The channel that distorts the signal varies in both time and frequency. The time variations, due to the motion of the receiver 400 relative to the transmitter 200, are taken advantage of by the time interleaver (not shown) of the encoder block. The frequency variations, due to the delay spread of the channel, is taken advantage of by the frequency interleaver 230. The channel would present correlated fading to nearby sub-carriers, and will decorrelate from itself at a frequency separation equal to approximately the inverse of the delay spread of the channel. The following describes the OFDM frequency interleaver in detail:

Input : {q0, q1, q2, ... q975} where q(i) = complex QPSK symbols

Output: {y0, y1, ... y975} where y(i) = complex QPSK symbols

Let q(i) be represented as I(i) + jQ(i);

arrange the complex stream {q0, q1, ... q975} as:

B: I0 I1 I2 ... I975 Q0 Q1 ...Q975, as a 1952 sample wide buffer.

This stream will be interleaved using a 61 by 32 block interleaver, such that the buffer, B, is written to a matrix row by row and the output, T, is read out from the matrix column by column. The entry matrix 300 when fully occupied is shown in FIG. 3.

Therefore, the output, T, equals {t0, t1, ... t1951}, which can be expressed as follows:

{I0, I32, I64, .. I960,Q16, ..., Q912, Q944, I1, I33, I65, ..., I961,Q17 ... Q913, Q945, ... I31, I63, ...Q15,Q47, ... Q943 ,Q975},

where the leftmost entry of the stream is the oldest sample out of the interleaver 230.

The stream T is then de-multiplexed such that:

$$y(0) = t0 + j* t1$$

$$y(1) = t2 + j*t3$$

....

$$y(975) = t1950 + j*t1951$$

The stream of complex samples {y0, y1, ... y975} denotes the output of the frequency interleaver 230.

As previously indicated, the OFDM terrestrial repeater 140 differentially encodes the transmitted signal over frequency, as opposed to time. Thus, a differential modulator 240 differential encodes the interleaved data with respect to consecutive bins (sub-carriers) in the OFDM system. At the receiver 400, the 489th sub-carrier will contain no phase information. Also by the structure of the IFFT buffering, discussed below, the 1st sub-carrier will also be devoid of any phase information. Therefore, the differential modulator 240 initiates the encoder memory with phase $\pi/4$ every 489th received complex sample. It is noted that the unmodulated pilot bins provide a reference for the differential demodulation. Thus, the OFDM transmitter 200 provides, for example, two

sub-carriers as a reference within each OFDM symbol. The following details the operations of the differential modulator 240:

Input = {y0, y1, ... y975} where y(i) = complex

Output = {z0, z1, ... z1955} where z(i) = complex

The differential modulator 240 operates as follows. Initially, the input is arranged such that:

t_0 = (1/sqrt2, 1/sqrt2)

t_1 = y0

t_2 = y1

....

t_{488} = y487

t_{489} = (1/sqrt2, 1/sqrt2)

t_{490} = y488

t_{491} = y489

...

t_{977} = y975

The values 1/sqrt(2) and 1/sqrt(2) are to be pilot tones at the beginning k=-489 and the middle (k=1) of the spectrum. Thereafter, the output values, z(i), of the differential modulator 240 are generated using complex multiplication as follows:

z(0) = t(0)

z(1) = t(1)*z(0)

z(2) = t(2)*z(1)

...

z(488) = t(488)*z(487)

$$z(489) = t(489)$$

$$z(490) = t(490)*z(489)$$

....

$$z(977) = t(977)*z(976)$$

As shown in FIG. 2, block 250 fills unused (inactive) carriers with zeroes (in a normal mode) or with transmitter identifier information (TII) (in a TII mode). In a TII mode, additional sub-carriers will be turned on/off. The on/off is governed by a repeater identification number b_0, b_1, ... b_{43}, which is a 44 bit number, and is mapped onto complex symbols m_0 m_1 ... m_{43}. The TII signal facilitates the receiver test equipment in associating the received signal with the terrestrial repeater(s) that generate the TII signal. The illustrative TII is capable of identifying at most 2^{44} repeaters. Due to considerations of limiting interference to TDM bands associated with the satellites 110, 120, a subset of these numbers may be properly selected.

The TII number is specified as b_0, b_1, ... b_{43}, where b(i) can be 0 or 1. The mapping of the bits b(i) to m(i) may be performed as follows:

$$m(i) = 1/\mathrm{sqrt}(2) + j*1/\mathrm{sqrt}(2); \text{ if } b(i) = 1, \text{ or}$$

$$= 0; \qquad \text{if } b(i) = 0.$$

In a normal mode, all m(i) will be zero.

The differentially encoded data is passed to an IFFT block 260 that creates the OFDM signal. In the illustrative implementation, a factor of 2 oversampling is used, requiring the IFFT 260 to have a length of 2048. Generally, an implementation may require higher oversampling by a factor, *Factor*, which will then necessitate a 1024*Factor IFFT. To ensure that the highest frequency sub-carriers are reproduced without aliasing the IFFT 260 must be made twice as large as the number of active sub-carriers. It is noted that the value of *Factor* must at-least be 2.

The buffering of the 1024X*Factor* long buffer is designed to accommodate 978 sub-carriers (1022 in TII Mode), such that the 0^{th} location of the buffer will contain the nulled sub-carrier (required for acquisition purposes) and then the next 489 samples will occupy the next consecutive locations. The last 489 locations of the buffer is filled with the latter half of the incoming 978 samples. The rest of the buffer is filled with zero's at block 250. To visualize, this IFFT arrangement will produce the positive frequency components (relative to the carrier at 2.9 GHz) with the first 489 samples coming in, the negative frequency components with the latter 489 samples that come in, and the central carrier (the carrier at 2.9 GHz) being nulled. In the TII Mode additional sub-carriers are turned on/off.

The details of the block 250 are as follow:

Input = {z0, z1, ... z977} where z(i) = complex

Output = {f0, f1, f2, ... f(*Factor**1024-1)} where f(i) = complex

(an oversampling rate of *Factor* is assumed).

Arrange z(n) {n=0, ...977} such that:

The central null is established as follows:

f(0) = (0,0);

The sub-carriers are established as follows:

<u>first half</u>	<u>latter half</u>
f(1) = z(0);	f(1024X*Factor*-489) = z(489)
...	
f(488) = z(487);	f(1024X*Factor*-2) = z(976)
f(489) = z(488).	f(1024X*Factor*-1) = z(977)

The TII signal is established as follows:

first half	latter half
f(490) = m(0);	f(1024X*Factor*-511) = m(22)
f(491) = m(1);	f(1024X*Factor*-491) = m(42)
....	
f(511) = m(21).	f(1024X*Factor*-490) = m(43).

Inactive carriers are set to zero, as follows:

f(512) = (0,0);

...

f(1024X*Factor*-512) = (0,0).

The operation of the IFFT block 260 can be expressed as follows:

Input = {f0, f1, ...f(1024X*Factor* – 1)}, where f(i) = complex

Output = {a0, a1, a2, ... a(1024X*Factor* –1)},

where a(i) is complex and belongs to the complex plane and does not lie on a grid. The IFFT block 260 generates a Complex to Complex Inverse FFT and generates an output in I/Q format. For a more detailed discussion of the IFFT block 260, see, for example, W. H. Press et al., Numerical Recipes in C - The Art of Scientific Computing, Cambridge University Press, Cambridge (1991).

A cyclic prefix is added to the signal at block 270 to mitigate the effects of the channel and inter-repeater delay spreads. The operation of the CP block 270 can be expressed as follows:

Input = {a0, a1, a2, ... a(*Factor*X1024 –1)} where a(i) = complex

Output = {A0, A1, A2, ... A((1024+GI)X*Factor* -1)} where A(i) = complex

It is noted that GI is set to 66 samples, and oversampling of *Factor* is assumed for OFDM signal generation. *Factor* must at-least be 2. This creates a cyclic prefix of

16.11 mu-sec, slightly larger than design. The number of samples in the cyclic prefix is GIX*Factor*. The CP block 270 simply takes the last GIX*Factor* samples of the incoming 1024X*Factor* samples, and repeats these samples at the beginning of the (1024+GI)X*Factor* buffer. The latter part of the buffer is then filled with the incoming 1024X*Factor* samples.

As previously indicated, the transmitter 200 runs at two times oversampling, in the illustrative embodiment, which produces a I/Q sample stream at the transmitter output 280 at a rate of 4.096**Factor* Msamples/sec in both the I and Q rails.

For a detailed discussion of a conventional orthogonal frequency division multiplexing (OFDM) system, including digital-to-analog converter 275, see, for example, W. Y. Zou and Y. Wu, "COFDM - An Overview", IEEE Trans. Broadcasting, Vol. 41, No. 1, 1-8 (March 1995) or J.A.C. Bingham, "Multicarrier Modulation for Data Transmission: An Idea Whose Time Has Come", IEEE Comm., 5-14 (May 1990).

OFDM RECEIVER

FIG. 4 shows an exemplary OFDM receiver 400 in accordance with the present invention. The OFDM receiver 400 contains elements 470, 460, 450, 440 and 430 that perform the inverse function of the corresponding element in the OFDM transmitter 200, in a manner well-known to those skilled in the art. The elements 470, 460, 450, 440 and 430 in the OFDM receiver 400 are operative once the timing and frequency offset have been acquired, in a manner well-known to those skilled in the art.

According to one feature of the present invention, the OFDM receiver 400 also operates in two modes, namely, a normal mode and a transmitter identifier information (TII) mode. As shown in FIG. 4, block 450 multiplexes the sub-carriers to separate the TII/unused bins from the active, data-carrying bins. The TII/unused bins are processed by a TII demodulator 435 to process the TII information or to discard the unused sub-carriers. The active, data-carrying bins are processed by the differential demodulator 440 (over frequency), frequency de-interleaver 430, QPSK demodulator 420 and a bit sink 410.

It is to be understood that the embodiments and variations shown and described herein are merely illustrative of the principles of this invention and that various modifications may be implemented by those skilled in the art.

CLAIMS:

1. A method of processing a baseband signal in an orthogonal frequency division multiplexing (OFDM) system having a plurality of sub-carriers, comprising the steps of:

differentially encoding said signal in the frequency domain using consecutive sub-carriers to produce differentially encoded symbols;

storing said differentially encoded symbols and two or more pilot tones in an IFFT buffer such that an analog signal produced upon carrier-modulation is centered at a desired carrier frequency; and

transforming an output of said IFFT buffer to create said OFDM signal.

2. The method of claim 1, wherein said transforming step implements an Inverse Fast Fourier Transform.

3. The method of claim 1, wherein said transforming step implements an orthogonal transformation.

4. The method of claim 1, wherein said transforming step generates said OFDM signal with said plurality of sub-carriers for carrying data.

5. The method of claim 4, wherein at least one unmodulated sub-carrier generated by said transforming step is allocated as a pilot bin to provide a reference within each OFDM symbol.

6. The method of claim 4, wherein said differential encoding is performed with respect to consecutive sub-carriers in said OFDM system.

7. An orthogonal frequency division multiplexing (OFDM) transmitter for processing a baseband signal having a plurality of sub-carriers, comprising:

a differential encoder for modulating said OFDM signal in the frequency domain using consecutive sub-carriers to produce differentially encoded symbols;

an IFFT buffer for storing said differentially encoded symbols and two or more pilot tones such that an analog signal produced upon carrier-modulation is centered at a desired carrier frequency; and

a transformer for transforming an output of said IFFT buffer to create said OFDM signal.

8. The transmitter of claim 7, wherein said transformer implements an Inverse Fast Fourier Transform.

9. The transmitter of claim 7, wherein said transformer implements an orthogonal transformation.

10. (Previously Presented) The transmitter of claim 7, wherein said transformer generates said OFDM signal with said plurality of sub-carriers for carrying data.

11. The transmitter of claim 10, wherein at least one unmodulated sub-carrier generated by said transformer is allocated as a pilot bin to provide a reference within each OFDM symbol.

12. The transmitter of claim 10, wherein said differential encoding is performed with respect to consecutive sub-carriers in said OFDM system.

13. A method of receiving a signal in an orthogonal frequency division multiplexing (OFDM) system having a plurality of sub-carriers, comprising the steps of:

transforming said received signal to recover an OFDM signal in the frequency domain having a plurality of sub-carriers, wherein said transformed signal contains differentially encoded symbols and two or more pilot tones in a configuration to enable said transformed signal to be centered at a desired carrier frequency; and

differentially demodulating said OFDM signal in the frequency domain wherein said differential demodulation is performed using consecutive sub-carriers.

14. The method of claim 13, wherein said transforming step implements a Fast Fourier Transform.

15. The method of claim 13, wherein said transforming step implements an orthogonal transformation.

16. The method of claim 13, wherein at least one unmodulated sub-carrier recovered by said transforming step is allocated as a pilot bin to provide a reference within each OFDM symbol.

17. The method of claim 13, wherein said differential decoding is performed with respect to consecutive sub-carriers in said OFDM system.

18. An orthogonal frequency division multiplexing (OFDM) receiver for receiving an OFDM signal having a plurality of sub-carriers, comprising:

a transformer for recovering said OFDM signal having a plurality of sub-carriers, wherein said recovered signal contains differentially encoded symbols and two or more pilot tones in a configuration to enable said transformed signal to be centered at a desired carrier frequency; and

a differential demodulator for demodulating said OFDM signal in the frequency domain wherein said differential decoding is performed using consecutive sub-carriers.

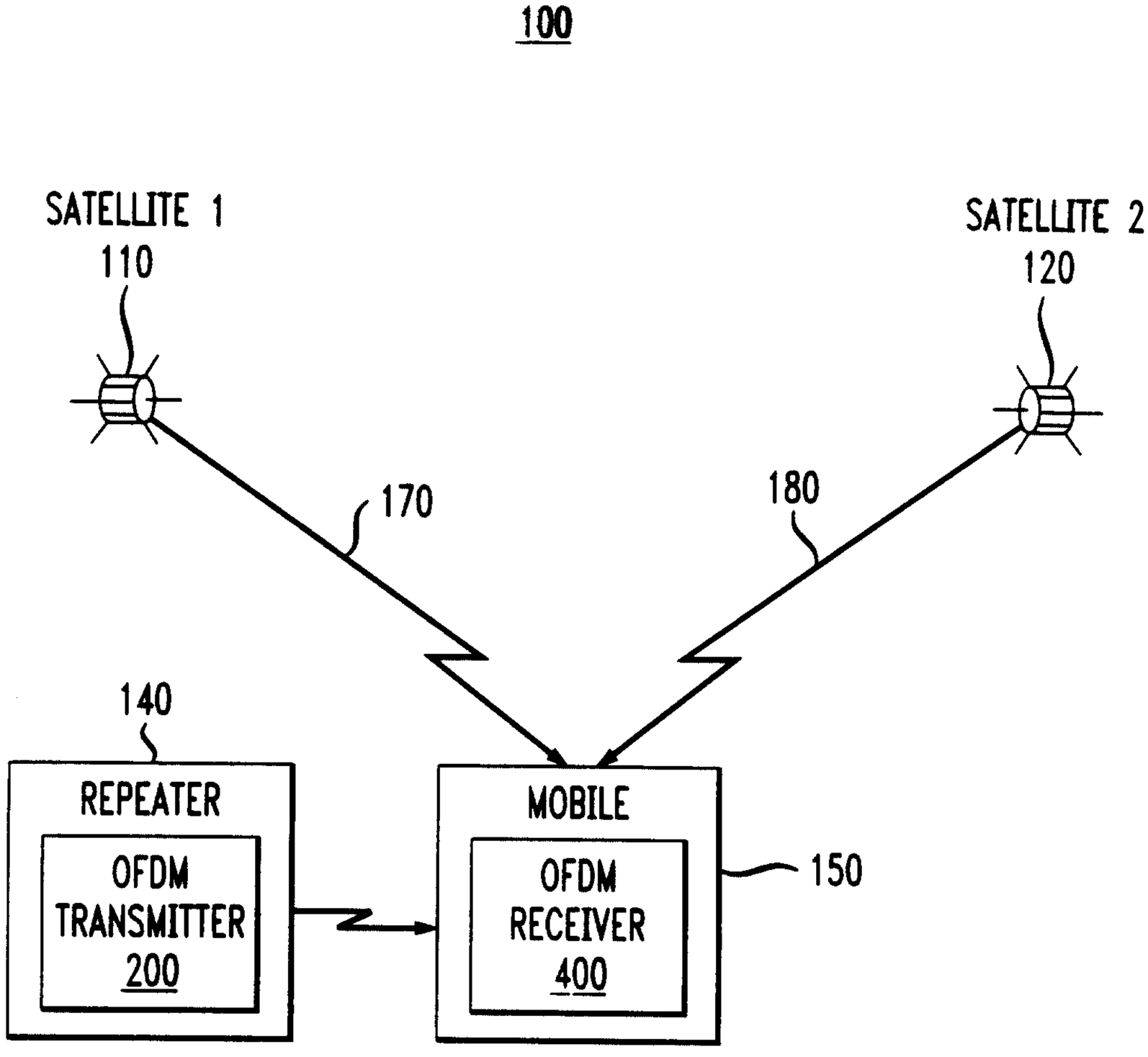
19. The receiver of claim 18, wherein said transformer implements a Fast Fourier Transform.

20. The receiver of claim 18, wherein said transformer implements an orthogonal transformation.

21. The receiver of claim 18, wherein at least one unmodulated sub-carrier recovered by said transformer is allocated as a pilot bin to provide a reference within each OFDM symbol.

22. The receiver of claim 18, wherein said differential demodulator demodulates said OFDM signal with respect to consecutive sub-carriers in said OFDM system.

FIG. 1


100
SATELLITE 1
110
SATELLITE 2
120
170
180
140
REPEATER
OFDM
TRANSMITTER
200
MOBILE
OFDM
RECEIVER
400
150

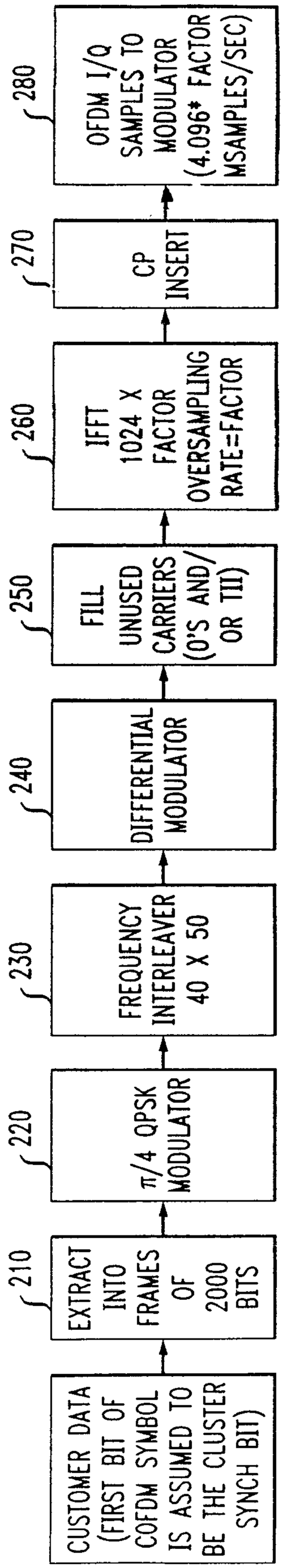

CUSTOMER DATA (FIRST BIT OF COFDM SYMBOL IS ASSUMED TO BE THE CLUSTER SYNCH BIT)
210
EXTRACT INTO FRAMES OF 2000 BITS
220
π/4 QPSK MODULATOR
230
FREQUENCY INTERLEAVER 40 X 50
240
DIFFERENTIAL MODULATOR
250
FILL UNUSED CARRIERS (0'S AND/ OR TII)
260
IFFT 1024 X FACTOR OVERSAMPLING RATE=FACTOR
270
CP INSERT
280
OFDM I/Q SAMPLES TO MODULATOR (4.096* FACTOR MSAMPLES/SEC)

FIG. 2
200

FIG. 3

300

FREQUENCY INTERLEAVER ENTRY MATRIX							
	COL 0	COL 1	COL 2	. . .	COL 29	COL 30	COL 31
ROW 0	I0	I1	I2	. . .	I29	I30	I31
ROW 1	I32	I33	I34	. . .	I61	I62	I63
ROW 2	I64	I65	I66	. . .	I93	I94	I95
⋮	⋮	⋮	⋮	. . .	⋮	⋮	⋮
ROW 31	I960	I961	I962	. . .	Q13	Q14	Q15
ROW 32	Q16	Q17	Q18	. . .	Q45	Q46	Q47
⋮	⋮	⋮	⋮	. . .	⋮	⋮	⋮
ROW 59	Q912	Q913	Q914	. . .	Q941	Q942	Q943
ROW 60	Q944	Q945	Q946	. . .	Q973	Q974	Q975

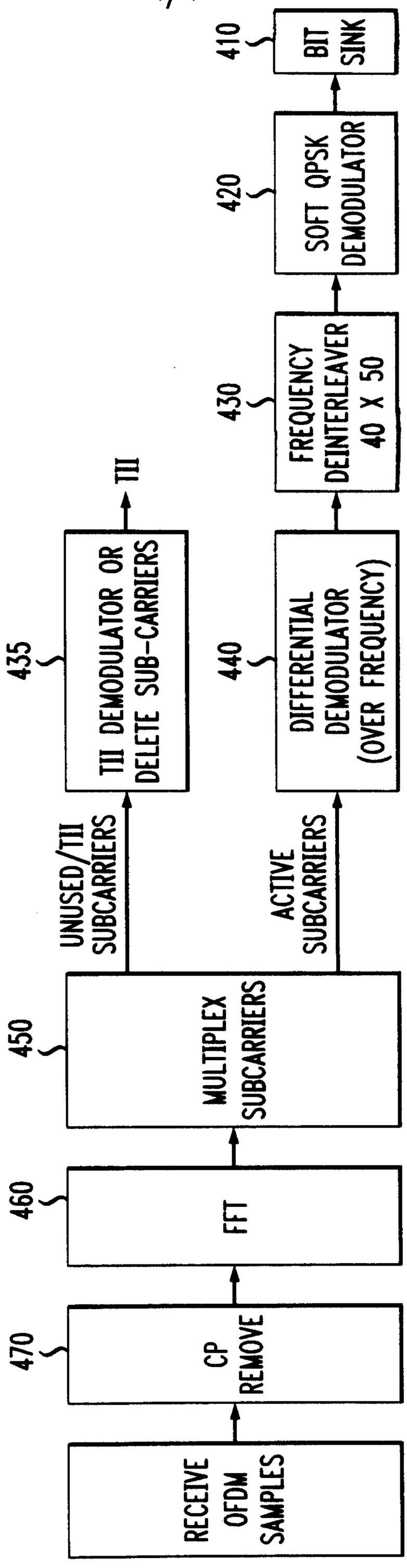
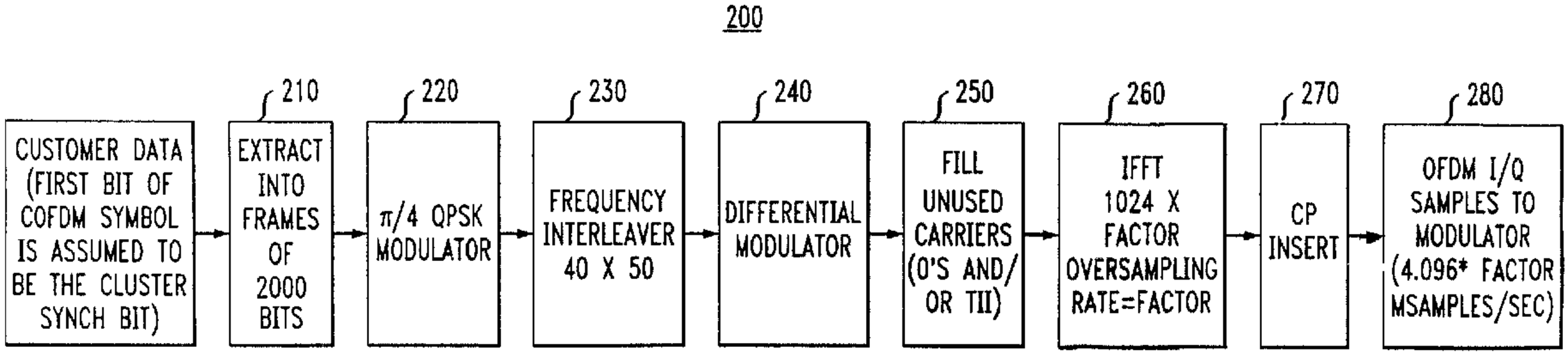

400
410
BIT SINK
420
SOFT QPSK DEMODULATOR
430
FREQUENCY DEINTERLEAVER 40 X 50
435
TII DEMODULATOR OR DELETE SUB-CARRIERS
TII
440
DIFFERENTIAL DEMODULATOR (OVER FREQUENCY)
UNUSED/TII SUBCARRIERS
ACTIVE SUBCARRIERS
450
MULTIPLEX SUBCARRIERS
460
FFT
470
CP REMOVE
RECEIVE OFDM SAMPLES

FIG. 4


200
CUSTOMER DATA (FIRST BIT OF COFDM SYMBOL IS ASSUMED TO BE THE CLUSTER SYNCH BIT)
210
EXTRACT INTO FRAMES OF 2000 BITS
220
π/4 QPSK MODULATOR
230
FREQUENCY INTERLEAVER 40 X 50
240
DIFFERENTIAL MODULATOR
250
FILL UNUSED CARRIERS (0'S AND/ OR TII)
260
IFFT 1024 X FACTOR OVERSAMPLING RATE=FACTOR
270
CP INSERT
280
OFDM I/Q SAMPLES TO MODULATOR (4.096* FACTOR MSAMPLES/SEC)