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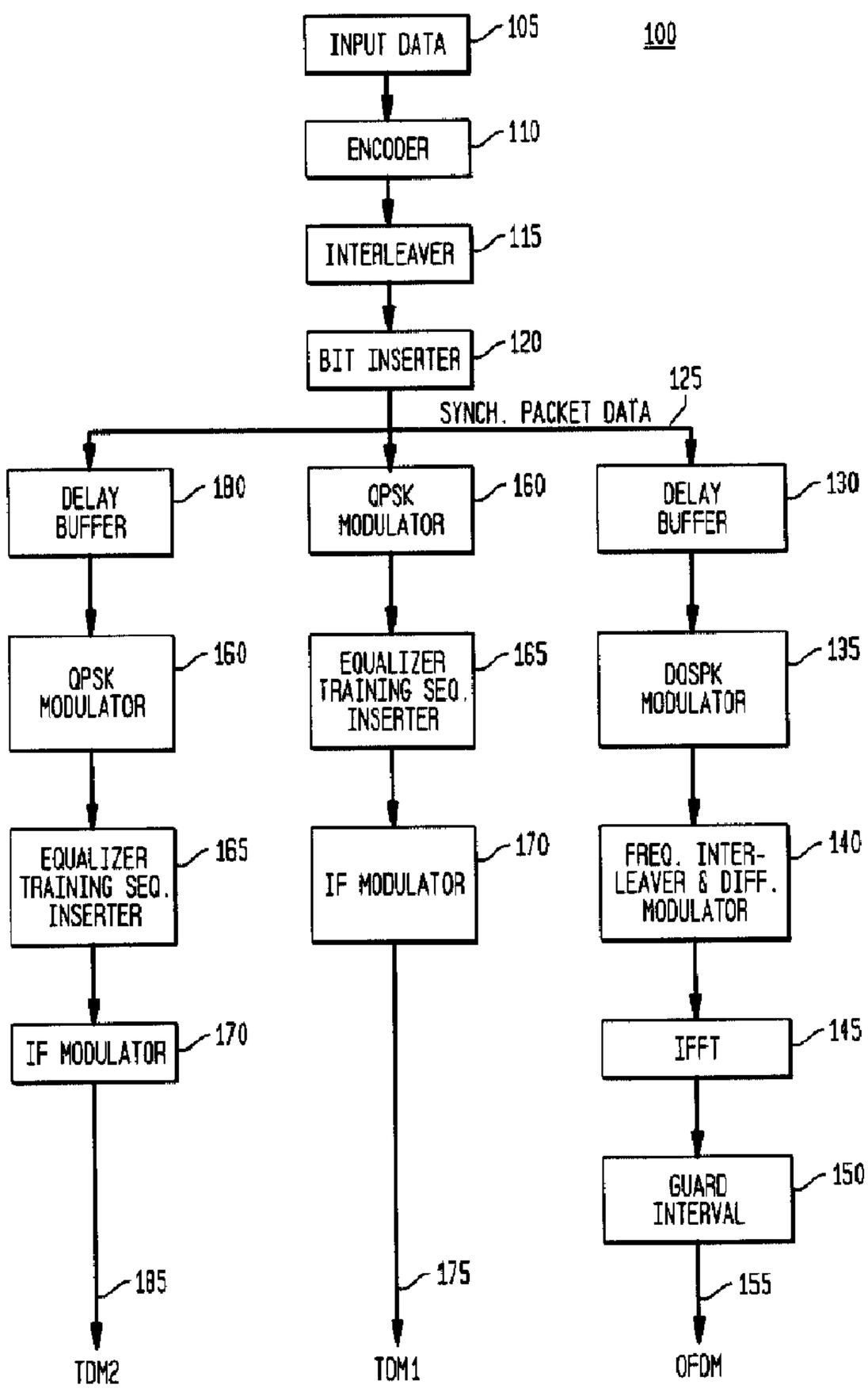
(54) **METHODE DE COMBINAISON DE SIGNAUX POUR DES SYSTEMES DE TRANSMISSION SANS FIL AYANT DES PROCEDES DE MODULATIONS MULTIPLES**

(54) **SIGNAL COMBINING SCHEME FOR WIRELESS TRANSMISSION SYSTEMS HAVING MULTIPLE MODULATION SCHEMES**



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(57) In a wireless transmission system that transmits the same information in parallel using two or more different types of modulation schemes, such as a satellite-based digital audio transmission system transmitting two TDM signals and a single OFDM signal, a receiver processes the differently modulated signals to generate separate demodulated signals that are then combined to form a single combined signal for further processing (e.g., decoding). In one embodiment, the receiver applies a maximal ratio combining (MRC) technique to generate a single optimal ratio combined signal from the differently modulated signals. By combining the differently modulated signals using an MRC technique, the adverse affects of noise related to inter- symbol interference in the individual signals can be reduced and the complexity of hardware in the receiver can be reduced.

Riazi 2-10-2

SIGNAL COMBINING SCHEME FOR WIRELESS TRANSMISSION SYSTEMS HAVING MULTIPLE MODULATION SCHEMES

Abstract

In a wireless transmission system that transmits the same information in parallel using two or more different types of modulation schemes, such as a satellite-based digital audio transmission system transmitting two TDM signals and a single OFDM signal, a receiver processes the differently modulated signals to generate separate demodulated signals that are then combined to form a single combined signal for further processing (e.g., decoding). In one embodiment, the receiver applies a maximal ratio combining (MRC) technique to generate a single optimal ratio combined signal from the differently modulated signals. By combining the differently modulated signals using an MRC technique, the adverse affects of noise related to inter-symbol interference in the individual signals can be reduced and the complexity of hardware in the receiver can be reduced.

SIGNAL COMBINING SCHEME FOR WIRELESS TRANSMISSION SYSTEMS HAVING MULTIPLE MODULATION SCHEMES

Field Of The Invention

The present invention relates to wireless transmission systems.

Description Of The Related Art

Transmitted signals of a digital transmission system are usually configured to a single modulation scheme. The modulation scheme is often determined as a result of the region in which the signal is to be transmitted. For instance, time division multiplexed (TDM) signals are typically suited for rural areas whereas orthogonal frequency multiplexed (OFDM) signals are typically suited for urban areas.

TDM signals are suited for rural areas, where there is typically a clear line-of-sight (LOS) between a satellite transmitter and a ground-based receiver. Often a time-delayed signal may also be transmitted to compensate for short-term signal outages that may occur when there is an obstruction in the LOS signal path (e.g., when a mobile receiver passes under an overpass). In such cases, after the direct LOS connection has been reestablished, any data in the "on-time" LOS signal that was lost during the temporary obstruction will be available from the time-delayed TDM signal.

In urban areas, buildings and other structures form potentially long-lasting LOS obstructions. They also tend to act as a source of reflections leading to multipath signal distortions. Consequently, TDM-based service is often unacceptable in such urban areas. Since OFDM signals are well-suited for regions, such as urban areas, having LOS obstructions and multipath signals, OFDM signals are typically used.

Since each type of signal is ideally suited for different operating conditions, it is typical to use each signal only in the region suited for each signal. Additionally, it is typical to encounter increased noise at transition regions where, for example, a mobile receiver may be changing between TDM service and OFDM service. Noise at such transition regions often causes signal degradation, handoff failures, and signal losses, which detrimentally affect the quality of the service.

Summary Of The Invention

The present invention is directed to a technique for improving the quality of service for wireless transmission systems that employ two or more different modulation schemes to transmit the same information in parallel, such as satellite-based digital audio transmission systems that transmit digital audio data using both TDM and OFDM modulation schemes.

In the satellite-based digital audio transmission system, two TDM signals and one OFDM signal are used. A transmitter transmits two TDM signals that carry the same information, where one signal is delayed in time (e.g., by a few seconds) in relation to the other. The two TDM signals are used to compensate for short-term signal outages that may occur when there is an obstruction in the LOS signal path (e.g., when a mobile receiver passes under an overpass). The transmitter also transmits an OFDM signal which is typically used as a terrestrial gap filler signal for regions where TDM signals do not provide acceptable service. In particular, OFDM signals carrying the same information as the TDM signals are transmitted in parallel with the TDM signals, and terrestrial OFDM repeaters are deployed to fill the regional gaps in the TDM service.

According to one embodiment of the present invention, for TDM/OFDM digital audio transmission systems, a TDM/OFDM transmitter transmits two TDM signals and a single OFDM signal that are then received at a receiver. The two TDM signals (i.e., the on-time TDM signal and the time-delayed TDM signals) and the single OFDM signal received at a mobile receiver are combined using suitable signal combining techniques to generate a single combined signal for subsequent signal processing (e.g., signal decoding). By combining the differently modulated signals, the adverse affects of noise in the individual signals can be reduced. As a result, the occurrence of signal losses and handoff failures may also be reduced.

In general, the principles of the present invention can be applied to improve the quality of service for any signal transmission system that uses two or more different modulation schemes to transmit the same information in parallel. Satellite-based digital audio transmission systems based on TDM and OFDM modulation schemes are just one particular application of the present invention.

In one particular implementation of the present invention for a TDM/OFDM digital audio transmission system, the two TDM signals (i.e., the on-time TDM signal and the time-delayed TDM signals) and the single OFDM signal are received at a receiver, where they are demodulated and combined using a maximal ratio combining (MRC) technique to generate a combined signal for

further processing (e.g., decoding). The combining of the two differently-modulated signals reduces the adverse effects of noise, thereby improving quality of service.

In one embodiment, the present invention is a method for processing wireless signals, comprising the steps of (a) receiving two or more wireless signals containing a common set of information and conforming to two or more different modulation schemes; (b) demodulating each of the received wireless signals using a corresponding different demodulation scheme; and (c) combining the two or more demodulated signals using a signal combining technique to generate a combined signal.

In another embodiment, the present invention is an apparatus for processing wireless signals, comprising (a) an antenna, configured to receive an analog signal corresponding to two or more wireless signals containing a common set of information and conforming to two or more different modulation schemes; (b) a converter, electrically connected to the antenna and configured to convert the analog signal to a baseband signal; (c) a separator, electrically connected to the converter and configured to separate the baseband signal into two or more sub-signals corresponding to the two or more wireless signals; (d) for each sub-signal, a demodulator electrically connected to the separator and configured to apply demodulation processing corresponding to the modulation scheme for the corresponding sub-signal; (e) a synchronizer, electrically connected to each demodulator and configured to synchronize each demodulated sub-signal; and (f) a signal combiner, electrically connected to the synchronizer and configured to combine the two or more demodulated sub-signals using a signal combining technique to generate a combined digital signal.

Brief Description Of The Drawings

Other aspects, features, and advantages of the present invention will become more fully apparent from the following detailed description, the appended claims, and the accompanying drawings in which:

Figure 1 shows a block diagram of a transmitter for a satellite-based transmission system utilizing both TDM and OFDM signals, according to the present invention.

Figure 2 shows a block diagram of a receiver according to one embodiment of the present invention.

Figure 3 shows details of the synchronizing block generating inputs to the combining block of Figure 2.

Detailed Description

The present invention may be implemented in a one-way digital audio transmission system (e.g., digital radio) that uses two or more differently-modulated signals, such as TDM and OFDM signals to transmit the same information in parallel using adjacent frequency bands. More particularly, in a preferred embodiment of the present invention, two TDM signals (an on-time signal and a time-delayed signal) and a single OFDM signal, are combined using a maximal ratio combining technique to generate a single combined signal for subsequent signal processing (e.g., signal decoding). Accordingly, the adverse affects of noise related e.g., to inter-symbol interference in the individual signals is reduced as is the occurrence of signal losses and handoff failures. For the present invention, there is a reduced need for receiver complexity and receiver hardware since a single de-interleaver and a single channel decoder may be used for all three of the received signals.

Figure 1 shows a block diagram of a TDM/OFDM transmitter **100** of the present invention. The transmitter **100** is a common source for two TDM signals -- TDM1 **175** and TDM2 **185** -- and one OFDM signal **155**. The first TDM signal **175** is an on-time signal, and the second TDM signal **185** is a time-delayed signal. The input data is formatted and transmitted by the transmitter **100** such that the different signals may be received at a receiver (not shown in Figure 1) with acceptable differential delays.

The input data **105**, which is typically binary data, is encoded by a channel encoder **110** to add redundancy to the data sequence. An interleaver **115** interleaves the resulting encoded symbols for output as interleaved symbols in packet data frames. A bit inserter **120** inserts synch bits into the packet data frames to generate synchronized packet data **125**. Frame synchronization is generally known in the art, and other synchronization methods may be additionally or alternatively used in the present invention. Copies of the synchronized packet data **125** are then processed in parallel to generate the three output signals for parallel transmission: OFDM signal **155**, TDM1 signal **175**, and TDM2 signal **185**.

In particular, the TDM1 signal **175** is generated by modulating one copy of the synchronized packet data **125** at a quadrature-phase shift-key (QPSK) modulator **160**, inserting equalizer training symbols at regular intervals (e.g., every 1 msec) at an equalizer training sequence

inserter **165**, and further modulating using an IF modulator **170** to position the signal in the desired band.

The TDM2 signal **185** is generated using an analogous sequence of QPSK modulator **160**, equalizer **165**, and IF modulator **170**, but before doing so, the corresponding copy of the synchronized packet data **125** is delayed at delay buffer **180** for a specified time (e.g., about 4 seconds). This delay is added to the second TDM signal to provide continuity of data to a mobile receiver which is temporarily blocked by an obstacle.

For the OFDM signal **155**, the corresponding copy of the synchronized packet data **125** is also delayed at a delay buffer **130** for a specified time that is preferably identical to the delay used in generating the TDM2 signal **185**. By using the same delay for both the OFDM signal **155** and the TDM2 signal **185**, a receiver of all three transmitted signals will only have to buffer the first on-time TDM1 signal **175**. The delayed signal is then modulated at differential QPSK (DQPSK) modulator **135** to produce a DQPSK constellation. The data is then modulated by a differential modulator over frequency **140** and encoded by an inverse fast Fourier transform (IFFT) **145** which outputs a complex function having imaginary and real parts. A guard interval (GI) is introduced at a guard interval block **150** to mitigate channel multipath effects. The duration of the guard interval is preferably greater than the maximum expected delay spread of the channel.

Figure 2 shows a block diagram of a receiver **200**, according to one embodiment of the present invention. In general, the received signal is first converted to baseband and is then separated into its corresponding bands. Alternatively, the received signal is separated into its corresponding bands before converting the signal to baseband. Equalizing symbols and guard intervals are removed as necessary, and the signals are demodulated in accordance with their particular modulation scheme. Time delays are added to synchronize the demodulated signals as needed. The time-aligned outputs are then combined using a maximal ratio combining technique to generate a single signal output for subsequent decode processing.

In particular, the signal **203** received at an antenna **206** is converted to baseband data by a converter **209**. A separator **212** then separates the converted baseband output into three bands **215**, **230**, and **236**, corresponding to the TDM1, TDM2, and OFDM signals, respectively.

Each of TDM1 **215** and TDM2 **230** is equalized as a complex function by an equalizer **218** which also removes the equalizer training symbols by a stripping function implemented within the

equalizer **218**. The complex output from each equalizer **218** is then demodulated by a QPSK demodulator **221**. Since the TDM2 signal is delayed with respect to the TDM1 signal, after demodulator **221**, the TDM1 data is delayed at a delay buffer **224** by an amount equivalent to the delay of the TDM2 signal (e.g., 4 seconds) to synchronize the two TDM signals. The two resulting TDM signals **227** and **230** are input into a signal synchronizing block **257**.

For the OFDM signal, following separation at the separator **212**, the guard interval on the OFDM signal **236** is removed by a guard interval stripper **239**. Once removed, the differentially modulated data of the OFDM signal **236** undergoes a fast Fourier transform (FFT) operation **242** to recover the differentially modulated data. The output of the FFT operation is then differentially demodulated by a differential demodulator **245**. The output from the demodulator **245** is then de-interleaved by a frequency de-interleaver **248** to separate sub-carriers from the resulting de-interleaved signal. The output de-interleaved signal is then DQPSK-demodulated by a DQPSK demodulator **251**, resulting in a mapping of real and imaginary soft bits in the OFDM signal output **254**, which is also input into the signal synchronizing block **257**.

Each of the demodulated signals **227**, **233**, and **254** is a complex digital signal having an imaginary part and a real part, wherein each may therefore be represented as a complex vector function in a complex plane having imaginary and real axes. In the synchronizing block **257**, each of the demodulated signals **227**, **233** and **254** is time-aligned, has synch bits removed, and is weighted by its signal-to-noise ratio (SNR) such that the three signals are output from the synchronizing block **257** as TDM1 signal **260**, TDM2 signal **263**, and OFDM signal **266** as input to the combining block **269**. Combining block **269** combines the three time-aligned, SNR-weighted signals **260**, **263**, and **266** to generate a combined output signal **272**. In a preferred embodiment, the combining block **269** employs a maximal ratio combining technique to generate an optimal ratio combined signal **272**, which is then input into a channel decoder **275** whose output is stored in a data sink **278**. In an MRC technique, signals are combined according to r_1*sqrt(SNR_1) + r_2*sqrt(SNR_2) + r_3*sqrt(SNR_3), in which each r represents data information in the corresponding signal and each SNR is the signal-to-noise ratio estimate for the corresponding signal obtained as described further below.

Figure 3 shows details of the synchronizing block **257** of Figure 2. Each of the demodulated signals **227**, **233**, and **254** is time synchronized by a data synchronizer **300**, and has synch bits removed by a bit stripper **310**. The output signal from each stripper **310** is then weighted by its signal-to-noise ratio (SNR). For example the time-aligned, demodulated OFDM signal **380** is multiplied at a multiplier **330** by its respective SNR factor to SNR-weight the signal.

SNR estimation is known in the art. It is known to estimate SNR values for TDM signals such as **227** and **233**. For example, it is known to obtain an SNR estimate for a TDM signal by obtaining the a priori knowledge of the synch symbols of the signal and estimating the noise from the hard decisions of the signal following demodulation. Each TDM signal is then SNR-weighted in relation to its respective SNR estimate as determined by the equalizer block **218**.

Similarly, SNR estimation for OFDM signals is known in the art and is often estimated by known algorithms. As an example, an SNR estimate may be determined in relation to the complex output of a demodulator and its sub-carrier gain. Other methods of SNR estimation are known and are incorporated herein. It is desired to weight the OFDM demodulated soft bits in relation to the power and the SNR estimates for each signal, thereby utilizing the signal's complex nature and rotation to the first quadrant, then a majority of the signal lies on the real axis and the noise is predominately concentrated in the imaginary axis. The demodulated and time-aligned OFDM signal **380** is weighted in relation to the square root of the product of the SNR estimate **340** and the

power ratio **350**. The power ratio **350** is the ratio of the OFDM signal power to the average power of the two TDM signals. As such, a product factor is determined at the multiplier **360** as a result of the SNR estimate **340** multiplied by the power ratio **350**. The value of the square root **370** of the product factor is then determined. The time-aligned, demodulated OFDM signal **380** is then SNR-weighted by multiplying the result of **370** with the signal **380**, resulting in signal **266**.

In the preferred embodiment of the present invention, all three of the signals are operating at the same coded data throughput rate. The duration of the training sequence, the training-sequence-to-data-sequence length ratio, and the guard interval may be predetermined for each signal to ensure that the three received signals, following digital demodulation, produce the same encoded data stream with independent noise and channel distortion at a constant rate.

While the exemplary embodiments of the present invention have been described with respect to processing of OFDM and TDM signals, including possible implementation as in an audio transmission system, the present invention is not so limited. As would be apparent to one skilled in the art, various other signals and modulation schemes, including QAM and higher order PSK, may also be used. Additionally, signal combining techniques other than MRC may also be implemented such as switched combining, which selects the best signal and prevents the poorer signal from entering the combiner.

The present invention may be implemented as circuit-based processes, including possible implementation on a single integrated circuit. As would be apparent to one skilled in the art, various functions of circuit elements may also be implemented in the digital domain as processing steps in a software program. Such software may be employed in, for example, a digital signal processor, micro-controller, or general-purpose computer.

While the exemplary embodiments of the present invention have been described with respect to processes of circuits, including possible implementation as a single integrated circuit, the present invention is not so limited. As would be apparent to one skilled in the art, various functions of circuit elements may also be implemented in the digital domain as processing steps in a software program. Such software may be employed in, for example, a digital signal processor, micro-controller, or general purpose computer.

The present invention can be embodied in the form of methods and apparatuses for practicing those methods. The present invention can also be embodied in the form of program code embodied in tangible media, such as floppy diskettes, CD-ROMs, hard drives, or any other

machine-readable storage medium, wherein, when the program code is loaded into and executed by a machine, such as a computer, the machine becomes an apparatus for practicing the invention. The present invention can also be embodied in the form of program code, for example, whether stored in a storage medium, loaded into and/or executed by a machine, or transmitted over some transmission medium or carrier, such as over electrical wiring or cabling, through fiber optics, or via electromagnetic radiation, wherein, when the program code is loaded into and executed by a machine, such as a computer, the machine becomes an apparatus for practicing the invention. When implemented on a general-purpose processor, the program code segments combine with the processor to provide a unique device that operates analogously to specific logic circuits.

It will be further understood that various changes in the details, materials, and arrangements of the parts which have been described and illustrated in order to explain the nature of this invention may be made by those skilled in the art without departing from the scope of the invention as expressed in the following claims.

Claims

1. A method for processing wireless signals, comprising the steps of:

(a) receiving two or more wireless signals comprising a common set of information and conforming to at least two different modulation schemes;

(b) demodulating each of the received wireless signals; and

(c) combining the two or more demodulated signals using a signal combining technique to generate a combined signal.

2. The method of claim 1, wherein the signal combining technique is a maximal ratio combining (MRC) technique.

3. The method of claim 1, further comprising the step of decoding the combined signal.

4. The method of claim 1, wherein step (c) further comprises the step of synchronizing the demodulated signals before combining the signals.

5. The method of claim 1, wherein step (c) further comprising the step of weighting each demodulated signal based on its signal-to-noise ratio (SNR) before combining the signals

6. The method of claim 1, wherein the wireless signals comprise a first time division multiplexed (TDM) signal, a second TDM signal, and an orthogonal frequency division multiplexed (OFDM) signal, wherein the second TDM signal and the OFDM signal are approximately delayed in time by a known delay value with respect to the first TDM signal.

7. The method of claim 6, wherein:

step (a) comprises the steps of:

(1) receiving the wireless signals as a single analog signal corresponding to a parallel transmission of the first and second TDM signals and the OFDM signal; and

(2) converting and separating the analog signal into the first and second TDM signals and the OFDM signal;

step (b) further comprises the step of delaying the first TDM signal by the known delay value after demodulating the first TDM signal; and

step (c) further comprises the step of synchronizing and weighting each demodulated signal based on its SNR before combining the signals using an MRC technique.

8. An apparatus for processing wireless signals, comprising:

(a) means for receiving two or more wireless signals containing a common set of information and conforming to two or more different modulation schemes;

(b) means for demodulating each of the received wireless signals; and

(c) means for combining the two or more demodulated signals using a signal combining technique to generate a combined signal.

9. A receiver, comprising:

(a) a receiving means for receiving a signal corresponding to two or more wireless signals comprising a common set of information and conforming to two or more different modulation schemes signal;

(b) a converter, connected to a receiving means and configured to convert a signal to a baseband signal;

(c) a separator, connected to the converter and configured to separate the baseband signal into two or more sub-signals corresponding to the two or more wireless signals;

(d) for each sub-signal, a demodulator connected to the separator and configured to apply demodulation processing corresponding to the modulation scheme for the corresponding sub-signal;

(e) a synchronizer, connected to each demodulator and configured to synchronize each demodulated sub-signal; and

(f) a signal combiner, connected to the synchronizer and configured to combine the two or more demodulated sub-signals using a signal combining technique to generate a combined digital signal.

10. The receiver of claim 9, wherein the receiving means is an antenna.

11. The receiver of claim 9, wherein the signal combining technique is an MRC technique.

12. The receiver of claim 9, further comprising a decoder, connected to the signal combiner and configured to decode the combined signal.

13. The receiver of claim 9, wherein the synchronizer weights each demodulated signal based on its SNR before the signal combiner combines the signals.

14. The receiver of claim 9, wherein the wireless signals comprise a first TDM signal, a second TDM signal, and an OFDM signal, wherein the second TDM signal and the OFDM signal are approximately delayed in time by a known delay value with respect to the first TDM signal.

15. The receiver of claim 14, wherein:

for the first TDM signal, a delay buffer is connected to the corresponding demodulator to delay the first TDM signal by the known delay value after demodulating the first TDM signal;

the synchronizer is further configured to weight each demodulated signal based on its SNR; and

the signal combiner is configured to combine the signals using an MRC technique.

16. A transmitter, comprising:

(a) an encoder to add redundancy to a data sequence;

(b) an interleaver connected to the encoder to output encoded symbols as interleaved symbols in data frames;

(c) an inserter connected to the interleaver to insert synch bits into data frames to generate synchronized data, of which copies of the synchronized data undergo further processing;

(d) a first modulator for modulating a first copy of the synchronized data to generate a signal having a first modulation scheme; and

(e) a second modulator for modulating a second copy of the synchronized data to generate a signal having a second modulation scheme;

17. The transmitter of claim 16, wherein:

the first modulator is a DQSPK modulator and the first modulation scheme is OFDM.

18. The transmitter of claim 16, wherein:

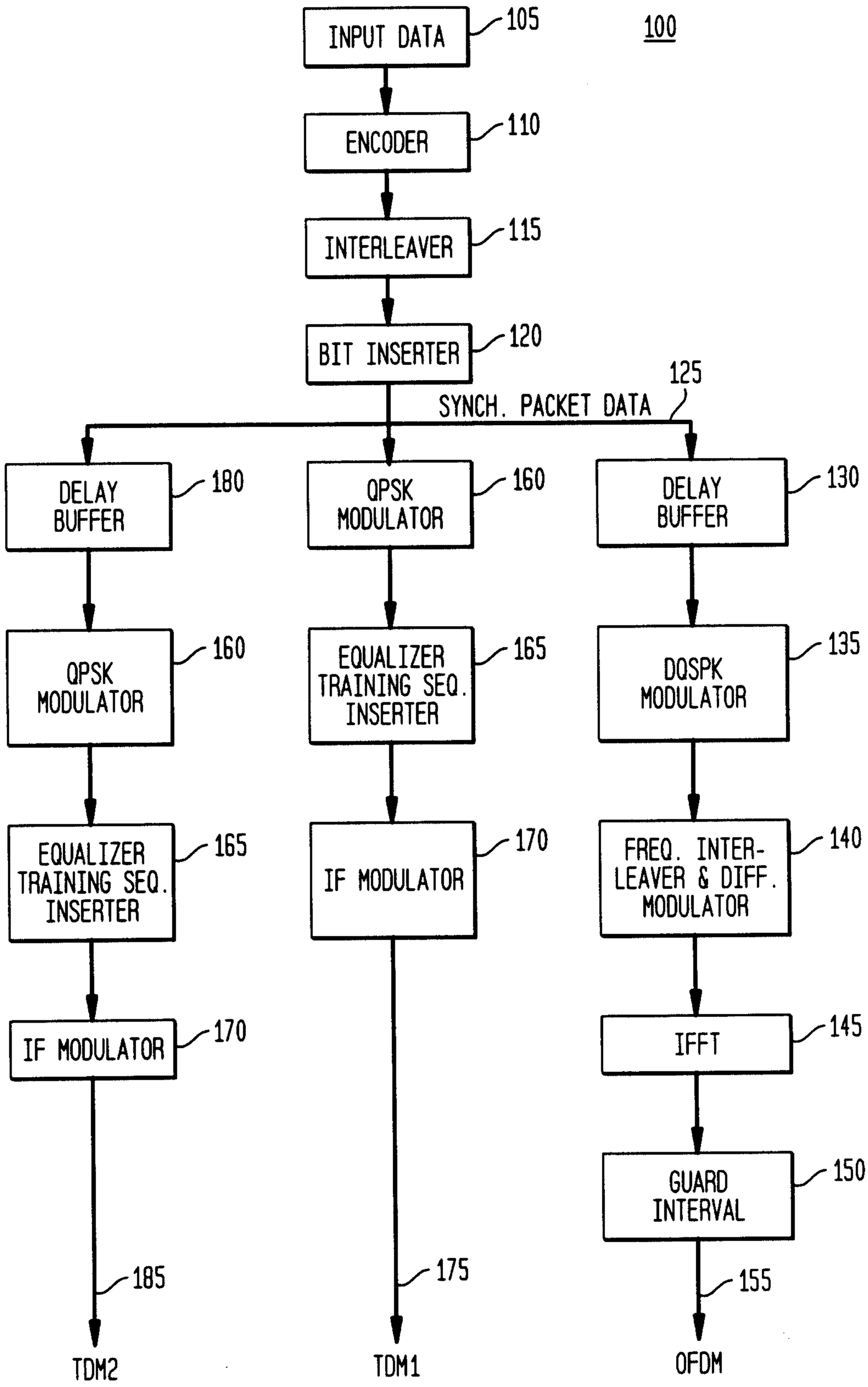
the second modulator is a QSPK modulator and the second modulation scheme is TDM.

19. The transmitter of claim 16, further comprising a third modulator for modulating a third copy of the synchronized data to a generate a time-delayed signal having a third modulation scheme.

20. The transmitter of claim 19, wherein:

the third modulator is a DQSPK modulator and the third modulation scheme is TDM, wherein the time-delayed signal is delayed by a delay buffer configured with the third modulator to a known delay value.

FIG. 1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INTERLEAVER
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125
SYNCH. PACKET DATA
DELAY BUFFER
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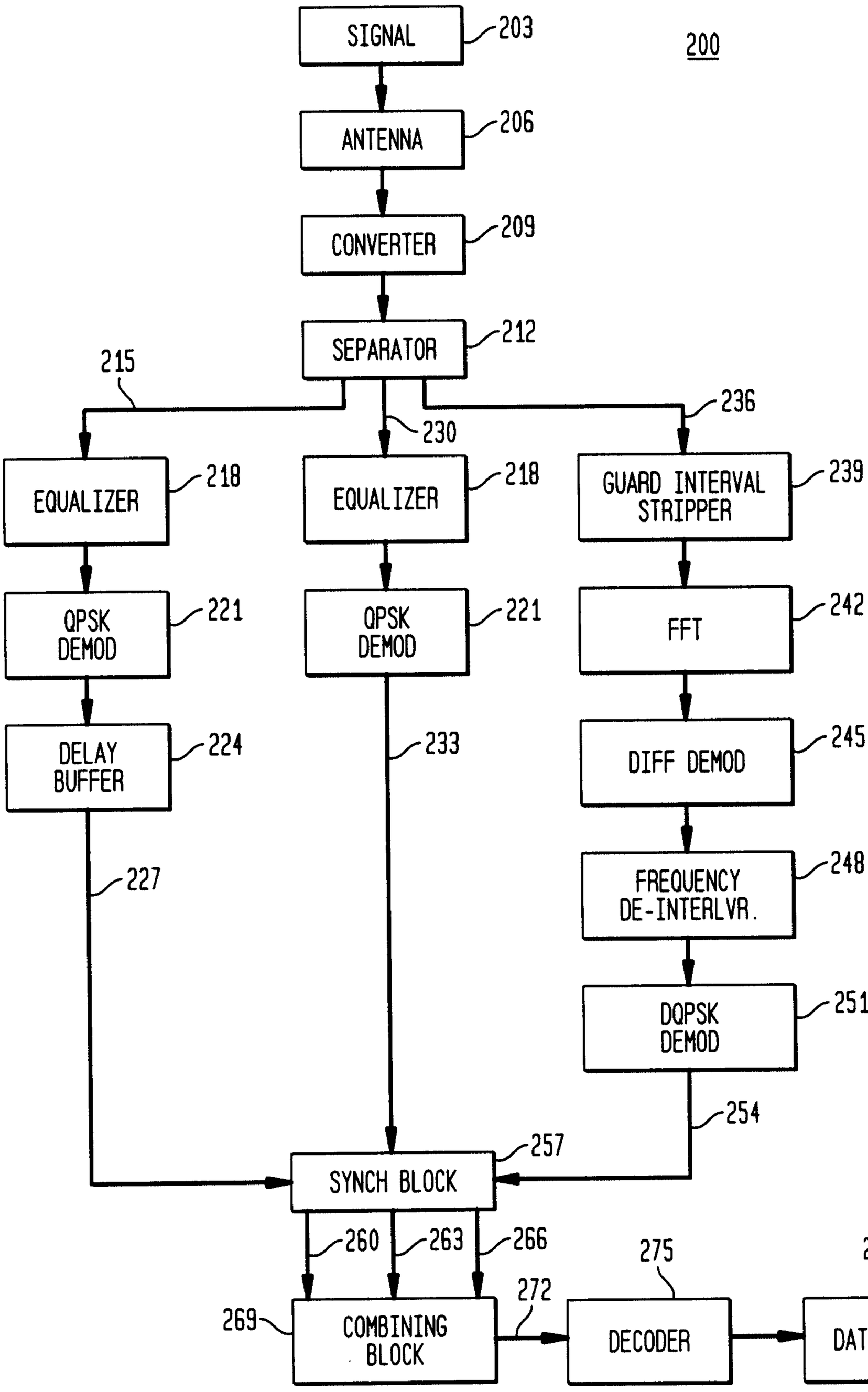
QPSK MODULATOR
160
EQUALIZER TRAINING SEQ. INSERTER
165
IF MODULATOR
170
185
TDM2
QPSK MODULATOR
160
EQUALIZER TRAINING SEQ. INSERTER
165
IF MODULATOR
170
175
TDM1
DELAY BUFFER
130
DQSPK MODULATOR
135
FREQ. INTER-LEAVER & DIFF. MODULATOR
140
IFFT
145
GUARD INTERVAL
150
155
OFDM

FIG. 2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FFT
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DELAY BUFFER
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233
DIFF DEMOD
245
227
FREQUENCY DE-INTERLVR.
248
DQPSK DEMOD
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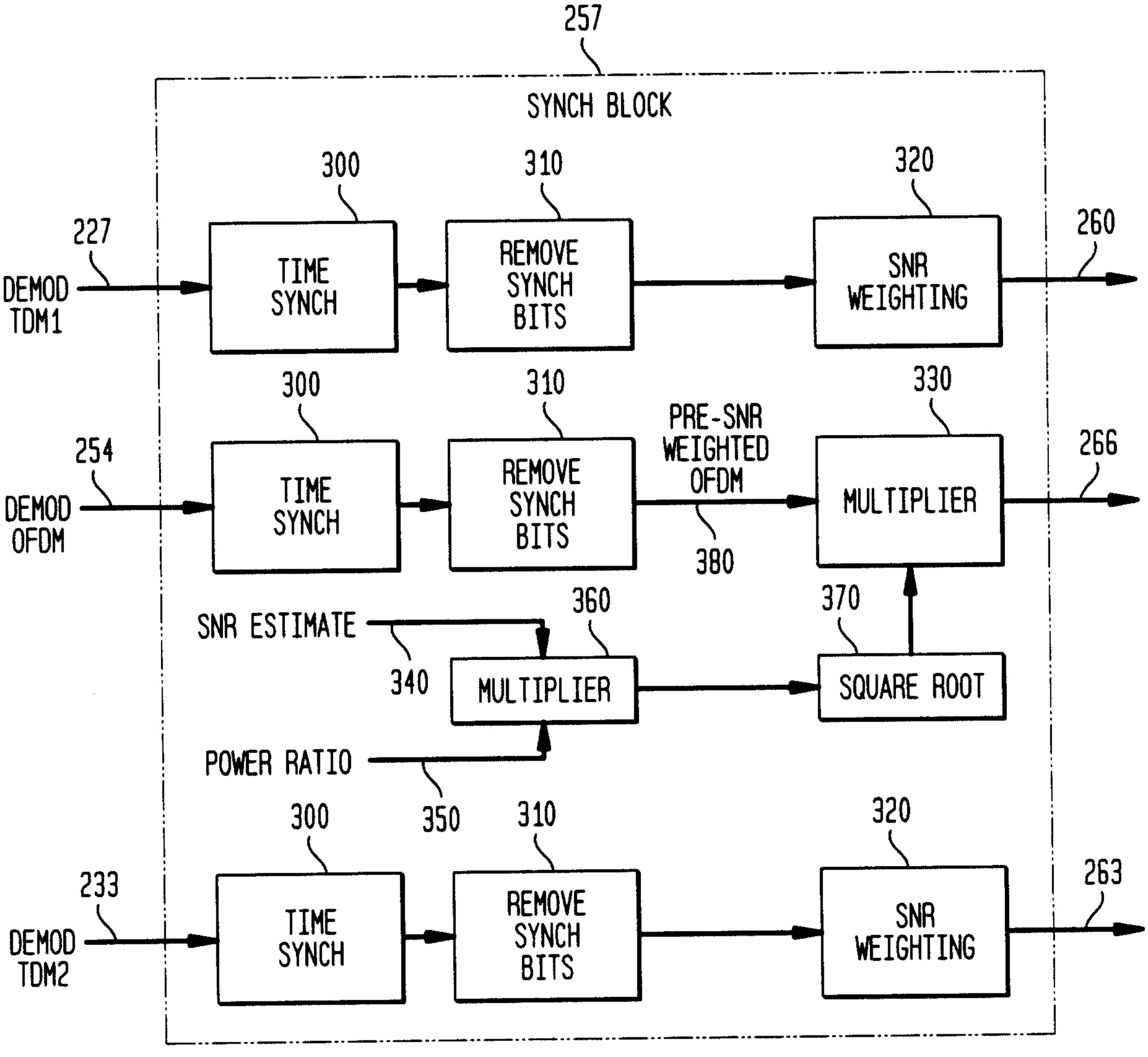
275
278
269
COMBINING BLOCK
272
DECODER
DATA SINK

FIG. 3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DEMOD OFDM
TIME SYNCH
REMOVE SYNCH BITS
PRE-SNR WEIGHTED OFDM
MULTIPLIER
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380
370
360
SNR ESTIMATE
340
MULTIPLIER
SQUARE ROOT
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320
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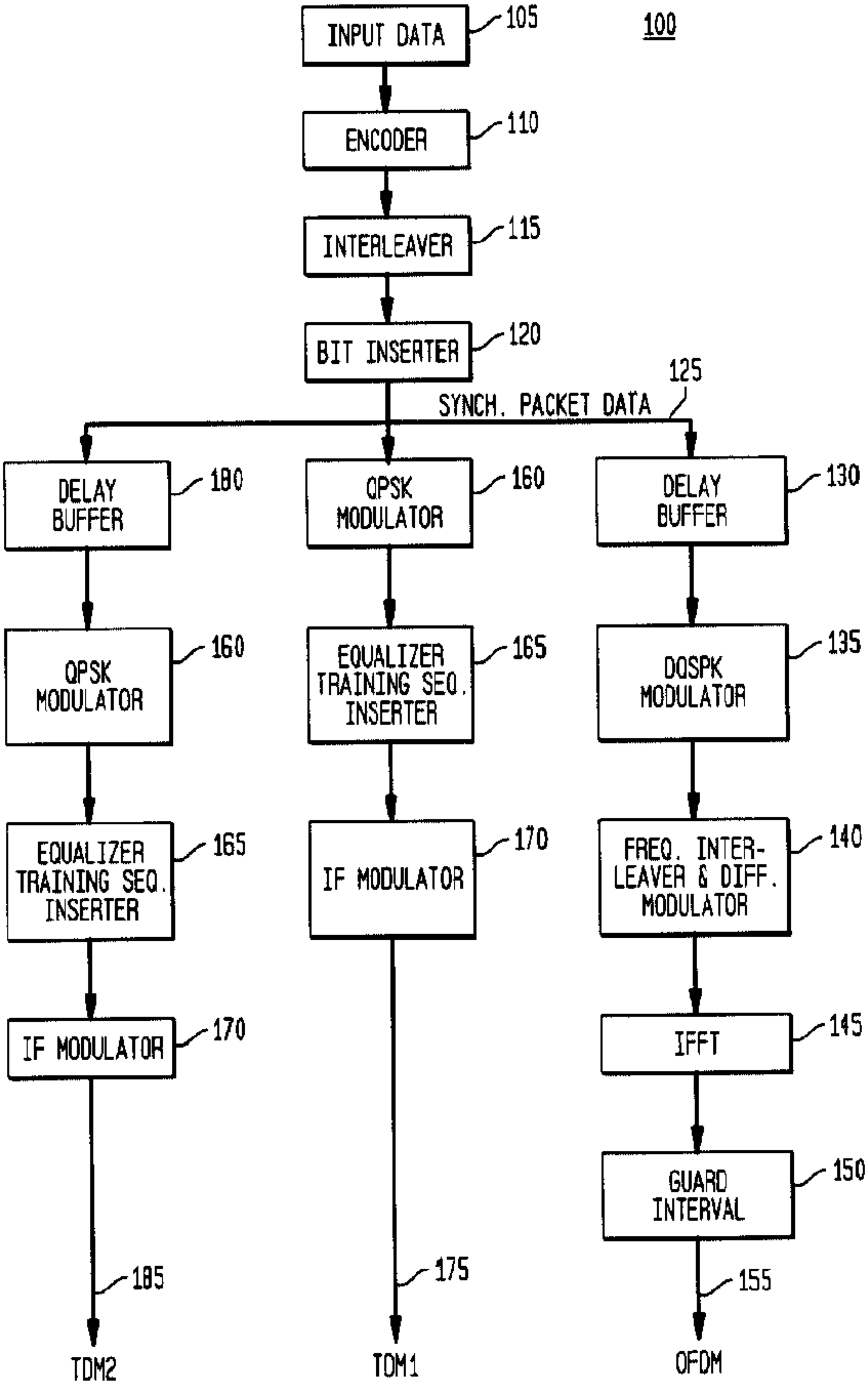
REMOVE SYNCH BITS
SNR WEIGHTING
263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IF MODULATOR
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QPSK MODULATOR
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EQUALIZER TRAINING SEQ. INSERTER
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IF MODULATOR
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TDM1
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FREQ. INTER-LEAVER & DIFF. MODULATOR
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IFFT
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OFDM