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(72) McCONNELL, Peter Robert Henderson, CA
(72) SCRAGG, Robert Allan, CA
(71) SONIC SYSTEMS CORPORATION, CA

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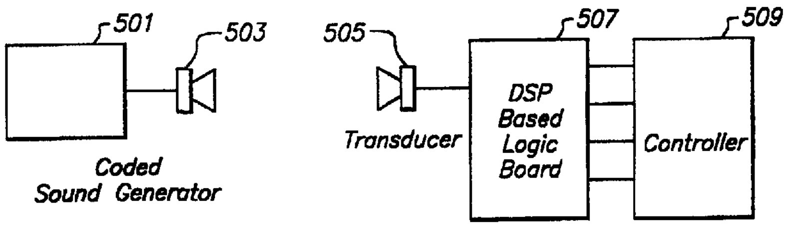
(54) **RESEAUX DE COMMUNICATIONS NUMERIQUES SONORES ET ULTRASONORES**

(54) **DIGITAL SONIC AND ULTRASONIC COMMUNICATIONS NETWORKS**



(57) On décrit un réseau de communications numériques dans lequel on utilise des techniques de communications numériques sonores et ultrasonores, c'est-à-dire des communications s'effectuant au moyen d'une énergie acoustique au lieu d'une énergie à fréquence radioélectrique. Le spectre acoustique, par opposition au spectre de fréquence radioélectrique, est dépourvu d'écho parasite et non régulé, permettant un développement commercial sans entrave de matériel destiné à des applications de système de transit intelligent (ITS), de même qu'une grande diversité d'autres applications, notamment des applications dans lesquelles on utilise des télécommunications à fréquence radioélectrique. A titre d'exemples d'applications, on peut citer le système de cabine téléphonique à paiement électronique, les système à entrée commandée, les systèmes de croisement de frontières, etc. On utilise des techniques de codage et de traitement qui permettent l'émission et la réception fiables de communications acoustiques, et notamment la communication de données numériques, même dans des environnement acoustiques bruyants.

(57) A digital communications network is provided using digital sonic and ultrasonic communications, i.e., communications using acoustic energy instead of RF energy. The "acoustic spectrum", as opposed to the RF spectrum, is uncluttered and unregulated, allowing for unfettered commercial development of equipment for ITS applications as well as a wide variety of other applications, including applications that currently employ RF communications. Exemplary applications include electronic toll boothing, controlled entry systems, border crossing systems, etc. Coding and processing techniques are employed that allow acoustic communications, including the communication of digital data, to be reliably transmitted and received even in noisy acoustic environments.

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(71) Applicant *(for all designated States except US)*: SONIC SYSTEMS [CA/CA]; 200-2386 East Mall, University of British Columbia, Vancouver, British Columbia V6T 1Z3 (CA).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: McCONNELL, Peter, Robert, Henderson [CA/CA]; 5970 Empress Avenue, Burnaby, British Columbia V5E 2S2 (CA). SCRAGG, Robert, Allan [CA/CA]; 5516 Cypress, Vancouver, British Columbia V6M 3R6 (CA).

(74) Agent: DEETH WILLIAMS WALL; National Bank Builing, Suite 400, 150 York Street, Toronto, Ontario M5H 3S5 (CA).

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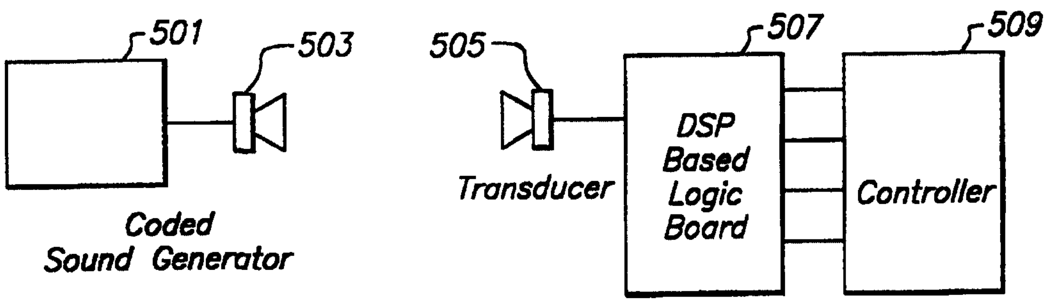


(57) Abstract

A digital communications network is provided using digital sonic and ultrasonic communications, i.e., communications using acoustic energy instead of RF energy. The "acoustic spectrum", as opposed to the RF spectrum, is uncluttered and unregulated, allowing for unfettered commercial development of equipment for ITS applications as well as a wide variety of other applications, including applications that currently employ RF communications. Exemplary applications include electronic toll boothing, controlled entry systems, border crossing systems, etc. Coding and processing techniques are employed that allow acoustic communications, including the communication of digital data, to be reliably transmitted and received even in noisy acoustic environments.

DIGITAL SONIC AND ULTRASONIC COMMUNICATIONS NETWORKS

1. Field of the Invention

The present invention relates to digital communications networks, and to communications using acoustic energy.

2. State of the Art

An industrial economy depends heavily on transportation infrastructure. The United States enjoys one of the most advanced highway systems in the world. Nevertheless, this system, designed principally in the 1950s, is beginning to show signs of age. Furthermore, because of current budgetary pressures, very few new highways are being planned or built. Instead, attention has been focussed on maximizing the utilization of existing highways through the application of computer and communications technologies. This effort is referred to generally as the Intelligent Transit System (ITS).

The tacit underlying assumption concerning the application of communications technology to transit has been that Radio-Frequency (RF) communications will be used. The widespread use of RF communications in transit applications, however, suffers in concept from a number of disadvantages. The ITS initiative appears to have gained critical momentum just at a time when the scarcity of RF bandwidth is being felt most acutely. The RF spectrum is, quite literally, "cluttered" with a wide variety of users all competing for scarce bandwidth. Federal regulatory approval is therefore required for most RF communications. Furthermore, a great deal of traffic is interstate and even international (particularly in Europe). The result is a patchwork of rules, regulations and practices, from jurisdiction to jurisdiction, concerning RF communications.

What is needed, then is additional bandwidth that may be applied within the context of the ITS and other similar transit applications. Preferably, such bandwidth should be "clutter-free" and unregulated so as to allow for the consistent commercial use of such bandwidth from jurisdiction to jurisdiction. The present invention addresses this need.

SUMMARY OF THE INVENTION

In accordance with the present invention, generally speaking, a digital communications network is provided using digital sonic and ultrasonic communications-i.e., communications using acoustic energy instead of RF energy. The "acoustic spectrum," as opposed to the RF spectrum, is uncluttered and unregulated, allowing for unfettered commercial development of equipment for ITS applications as well as a wide variety of other applications, including applications that currently employ RF communications. Exemplary applications include electronic toll boothing, controlled entry systems, border crossing systems, etc. Coding and processing techniques are employed that allow acoustic communications, including the communication of digital data, to be reliably transmitted and received even in noisy acoustic environments.

More particularly, in accordance with one embodiment of the invention, a digital acoustic communications apparatus includes one or more digital acoustic communications devices comprising a data processor; memory coupled to the data processor and storing digital data; and means for transmitting and/or receiving digital data acoustically; wherein the acoustic digital communications apparatus, during operation, transmits and/or receives digital data acoustically. In accordance with further aspects of the this embodiment of invention, the memory stores at least one of an identifying code word and a command, and the means for transmitting and/or receiving transmits and/or receives at least one of said identifying code word and said command acoustically. The means for transmitting and/or receiving may be an acoustic digital communications transmitter operating in the human audible range or may be an acoustic digital communications transmitter operating in the ultrasonic range. Alternatively, the means for transmitting and/or receiving may be an acoustic digital communications receiver comprising an analog-to-digital converter, wherein the data processor comprises a digital signal processor coupled to the analog-to-digital converter for filtering a digital representation of a received acoustic signal and for recovering digital data symbols encoded therein. The acoustic digital communications receiver may operate in the human audible range or may further comprising a downconverter, whereby the acoustic digital communications receiver operates in the ultrasonic range. Still further, the means for transmitting and/or receiving may be a digital acoustic transceiver comprising an input sound transducer, an analog-to-digital converter coupled to the input sound transducer, an output sound transducer, and a digital-to-analog converter coupled to the output sound transducer; in which case the data processor may be a digital signal processor coupled to the analog-to-digital converter for filtering a digital representation of a received acoustic signal and for recovering digital data symbols encoded therein, and coupled to the memory and to the digital-to-analog converter for transmitting the identifying code word or the command stored in memory acoustically. The acoustic digital communications transceiver may operate in the human audible range or in the ultrasonic range. A system in accordance with another aspect of the present invention comprises a plurality of digital acoustic communications devices including a plurality of acoustic digital transmitters and at least one acoustic digital receiver for, when one of said acoustic digital transmitters is within range and transmitting digital information, receiving said digital information. The system preferably further comprises a computer and at least one wide area network communications link established between the acoustic digital receiver and the computer. More preferably, the system comprises multiple acoustic digital receivers and multiple wide area network communications links, one such link being established between each of a plurality of said acoustic digital receivers and said computer.

In accordance with another aspect of the present invention, a method of digital communications comprising the steps of generating a carrier signal; modulating the carrier signal in accordance with digital information to produce a modulated signal; and applying the modulated signal to an acoustic transducer to produce a coded acoustic signal. The coded acoustic signal is propagated across a distance many times a wavelength of the coded acoustic signal.

Further steps include receiving the coded acoustic signal and transducing the coded acoustic signal to produce a modulated signal; and demodulating the modulated signal to produce the digital information.

Uses of the communications method are many and varied. One such use comprising the steps of providing an acoustic digital communications transmitter to be carried with a moving object; providing an acoustic digital communications receiver in proximity to a controlled area; transmitting from the acoustic digital communications transmitter at least one of an identifying code word that identifies the acoustic digital communications transmitter and a command; receiving at the acoustic digital communications receiver the identifying code word or command; and in response to at least one of the identifying code word or command, allowing physical access of the moving object to the controlled area. Another such use comprises the steps of providing an acoustic digital communications transmitter to be carried with a moving object; providing an acoustic digital communications receiver within an area to be monitored; transmitting from the acoustic digital communications transmitter an identifying code word that identifies the acoustic digital communications transmitter; receiving at the acoustic digital communications receiver the identifying code word; and when the code word is not received within a predetermined interval of time, producing an alarm indication. Still a further use comprises the steps of providing a first acoustic digital communications transceiver to be carried on an object; providing a second acoustic digital communications transceiver at a fixed location; transmitting from one of the first and second acoustic digital communications transceivers a query message; receiving the query message at another of the first and second acoustic digital communications transceivers and transmitting a response message; determining a one-way propagation time between the first and second acoustic digital communications transceivers; and determining a distance between the first and second acoustic digital communications transceivers. The location of the object may be intended to remain fixed for a time, in which case the foregoing steps are repeated multiple times; a determination is made whether the location of the object has changed; and if the location of the object has changed, an alarm indication is produced. Alternatively, the first acoustic digital communications transceiver may be a mobile acoustic digital communications transceiver carried on a moving object, and the second acoustic digital communications transceiver may be a base acoustic digital communications transceiver, in which case the foregoing steps are repeated multiple times; and a rate of change of location of the object is determined. The foregoing steps may be repeated at multiple base acoustic digital transceivers and results communicated from the multiple base acoustic digital transceivers to a common site. In this manner one or both of a location and a heading of the object may be determined.

BRIEF DESCRIPTION OF THE DRAWING

The present invention may be further understood from the following description in conjunction with the appended drawing. In the drawing:

Figure 1 is a timing diagram of a Coded Audio Signal transmitted at fixed intervals;

Figure 2 is a block diagram of a Coded Audio Sound Generator;

Figure 3 is a plot of a correlation output for a codeword UW1 in no noise;

Figure 4 is a plot of a correlation output for codeword UW1 in noise, with the noise level set at twice the signal level;

Figure 5 is a block diagram of a Coded Detector Module System;

Figure 6 is an equivalent functional block diagram of a portion of the Coded Detector Module of Figure 5 realized by the DSP;

Figure 7 is a timing diagram of a Coded Audio Signal transmitted at fixed intervals;

Figure 8 is a diagram of an Audio Command Packet;

Figure 9 is an equivalent functional block diagram of a portion of the Coded Detector Module realized by the DSP;

Figure 10 is a block diagram of an ultrasonic Transit Control Module;

Figure 11 is a block diagram of a Coded Audio Transceiver Module;

Figure 12 is a diagram illustrating a communications sequence allowing a distance ranging operation to be performed using acoustic energy;

Figure 13 is a timing diagram illustrating the timing of query and response messages for purposes of performing a distance ranging calculation;

Figure 14 is a block diagram of an acoustic digital communications network, in particular a network for geolocation; and

Figure 15 is a diagram of a portion of a dedicated short-range communications system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Building blocks of the present digital sonic and ultrasonic communications networks include sonic transmitters (sound generators), sonic receivers (detectors) and sonic transceivers (sound generators and detectors). Different embodiments of these building blocks may possess varying degrees of sophistication. Whereas the sound generators are relatively simple in their construction, the sound detectors rely on Digital Signal Processing techniques to achieve accurate detection over moderate distances (on the order of one mile).

Three principal embodiments of a coded audio detector are described. The first embodiment provides the ability to uniquely detect a particular coded sound generator. The second embodiment adds to this unique detection capability the further ability of a vehicle operator to have the detector take specific actions. In a third embodiment, an ultrasonic downconverter module is provided, allowing the coded sound detector to operate in the ultrasonic range.

The invention will be described primarily in terms of transit applications. It should be understood, however, that the communications techniques described, besides being applicable to vehicular communications, are equally application to personal communications, the tagging of goods, etc.

In the first embodiment, a Coded Audio Detector Module is DSP-based. A vehicle is equipped with a special Coded Sound Generator which issues "codewords" at fixed intervals, or on command of the driver. Between the transmission of these special codewords, the Coded Sound Generator need not emit any sound. The DSP-based Coded Audio Detector Module receives the foregoing codewords, decodes the codeword to determine if it is one of a pre-determined set of codewords recognized as being valid, and then issues a signal to a controller if the codeword assigned to that vehicle is valid.

The Coded Audio Detector Module, or CADM, is used as part of a two-part system. The first part is an audio-based transmitter system on each vehicle that is to control or interact with the system. Referring to Figure 1, when the vehicle operator enables the Coded Sound Generator, the transmitter sends a codeword at specific time intervals, say 5 seconds, using binary FSK modulation of the audio carrier for example.

Each vehicle is provided with a Coded Sound Generator. The Coded Sound Generator may be a simple audio generator the output of which is input to the microphone input of an amplifier. This Coded Sound Generator generates the appropriate codeword.

Referring more particularly to Figure 2, a programmed microprocessor 201 is coupled to a Digital to Analog Converter (DAC) 203. An output of the DAC 203 is coupled to an amplifier 209, which is coupled to a speaker 211. A mode selection switch 213 and a manual signal switch 215 are also provided and are coupled to the microprocessor 201.

The microprocessor 201 reads the mode selection switch 213 to determine if the operator wants the Coded Sound Generator to be activated continuously at intervals or only upon user command. The microprocessor 201 generates synthetic digital waveforms representing the desired codeword. These signals are converted to an analog voltage by the DAC 203 and then input to the amplifier 209. The manual signal switch 215 allows the operator to generate codeword signals at will rather than at timed intervals.

The CADM will only issue a control signal when a coded signal which meets specific conditions is detected. This feature allows for greater security and reliability of operation.

In the first embodiment, the codewords used in the Coded Audio Detector Module are binary patterns of a specific length. The patterns are chosen such that they have desirable autocorrelation function characteristicsspecifically low auto-correlation sidelobes. Furthermore, in choosing a family of codewords, attention should also be paid to the cross-correlation properties of the codewords. In particular, in addition to there being a low degree of correlation between the codewords, their cross-correlation functions should have low sidelobes. For example, the following seven codewords represent a family of codewords which satisfy the foregoing requirements:

UW1 = 110111010100000
UW2 = 101110110100000
UW3 = 101111001100000
UW4 = 110101101100000
UW5 = 101111010010000
UW6 = 111100101010000
UW7 = 101011101000100

The audio codeword may be transmitted using simple Frequency Shift Keying (FSK) modulation at some carrier frequency, where f_c is the center frequency, $f_c + \delta f$ is the frequency for the transmission of a binary 1, and $f_c - \delta f$ is the frequency for the transmission of a binary 0. The codeword consists of a stream of binary digits sent using one of these two tones.

The CADM receives the codeword using a microphone system and then demodulates the audio codeword. Demodulation is performed using an FSK demodulator. The CADM first synchronizes to the incoming bit stream by performing a symbol timing recovery operation on the codeword. Once synchronized, the FSK CADM searches for the codeword. The search may be done by binary correlation with threshold detection, using the stored reference codewords (UW1 to UW7) as a reference. If the codeword is received with more bits matching the stored reference pattern than the threshold value, it will be processed and the desired commands will be interpreted and issued to the controller. If the packet was received with an uncorrectable number of errors, the command will be rejected and no signals will be sent to the controller.

To test the performance of the detector in searching for the codeword, the 15-bit codeword UW1 was used an example. The codeword was sent as a

15-bit sequence using the binary FSK modulation scheme discussed earlier, and was preceded and followed by silence. The signal was processed using a binary correlation algorithm, and the correlation output was plotted as a function of time as shown in Figure 3. In this case, the maximum in the correlation is seen to occur at about sample 101, which marks the location of the codeword in time. The maximum of the correlation value is 60, since the 15-bit codeword was sampled at 4 samples per bit. If a threshold value of, say, 56 was taken as a detection threshold, then only correlation outputs in excess of 56 would cause the microphone system to indicate the presence of the codeword.

The real performance advantage of binary correlation with threshold detection using the foregoing codewords is obtained under noisy conditions. Consider the same 15-bit codeword in a noisy environment where the noise level is twice the level of the codeword sound received from the vehicle. Referring to Figure 4, it may be seen that the correlation peak is still quite prominent and distinct from any correlation peaks generated by the noise itself. In this example, the correlation peak near bit 100 is still very prominent and the peaks resulting from the correlation of the stored reference with the noise are still very small.

It is possible to use longer length codewords to achieve even better performance in a noisy environment. Longer codewords also reduce the probability of false detection, i.e., the probability of the chance situation where received noise just happens to look like the stored reference signal and falsely causes the detection threshold of the binary correlator to be exceeded. The following table shows the probability of false detection and the probability of missed detection (the probability that the codeword was in fact transmitted, but that noise corrupted a sufficiently large number of bits that the binary correlator missed the codeword), for codeword lengths of 15, 20 and 32 bits, where the correlator threshold is set to tolerate two bit errors (a 1% bit error rate channel). It is readily seen that for the 32-bit codeword case tolerating two errors, there will be very few cases of false detection. Assuming that events happen at the bit interval and that the bit rate is 20 bps, then there would be on average one false detection approximately every 4.7 days. This probability can be reduced even more by using the loudness of the received codeword to trigger a signal pre-emption event (i.e., the correlation output must exceed the threshold, and the sound level must exceed a sound level threshold, indicating that the vehicle is in proximity to the microphone).

Table 1. Binary Correlation with Threshold Detection For Various Codeword Lengths.

Codeword Length (bits)	Bit Errors Tolerated	P_{false}	P_{missed}
15	1	4.88×10^{-4}	9.63×10^{-4}
20	1	2.00×10^{-5}	1.69×10^{-3}
20	2	2.01×10^{-4}	1.00×10^{-2}
32	2	1.23×10^{-7}	3.99×10^{-3}
32	3	1.28×10^{-6}	2.87×10^{-4}

In a preferred embodiment, the functionality of the CADM as described is implemented using substantially the same hardware platform as the DSP-based siren detector of WO 95/24028 (McConnell et al), published September 8, 1995, incorporated herein by reference. Only the DSP software is changed. The detection algorithm may be based on the limiter/discriminator approach of McConnell et al., but includes in addition a low-rate demodulator to perform symbol timing recovery and codeword detection.

Referring more particularly to Figure 5, a Coded Sound Generator 501 is coupled to a loudspeaker 503. At the receiver, the coded signal produced by the Coded Sound Generator and 501 is picked up by a transducer 505 and input to a DSP-based logic board 507.

The DSP-based logic board 507 processes the coded signal and outputs pre-empt signals to a controller 509 based on that processing.The DSP-based logic board 507 realizes a Coded Audio Detector Module that uses the same limiter discriminator operations as described in McConnell et al. to perform FSK demodulation of the FSK signal. The software is modified to incorporate the following additional functions:

Symbol Timing Recovery - this may be based on a simple early/late-gate symbol synchronizer.

Codeword Search - this may be based on a binary correlation with threshold detection technique, using the pre-stored reference codewords as templates for the binary correlation.

In addition to these functions, the software is modified to include a command parser to determine which codeword was received and to then take appropriate action based on the command and data in the command packet.

An equivalent functional block diagram of the CADM is shown in Figure 6. An output signal from a microphone 601 is filtered in a band-pass filter 603. The filtered signal is then input to a combination of a discriminator 605, a decimator 607 and a median filter 609. An output of the median filter 609 is coupled to a symbol synchronization block 611, followed by a codeword search block 613. An output of the codeword search block is input to a block 615 to control whether a signal is issued to the controller. Also input to the block 615 is the output of the decimator 607, indicative of the received signal level.

As compared to the DSP-based detector of McConnell et al., the discriminator, decimator, and median filter operations are the same, to ensure the highest sensitivity possible for the CADM based on the excellent signal detection capability inherent in that technique. Signal detection is followed by the operations of blocks 611, 613 and 615, required to decode the codeword and then execute the command associated with that codeword.

The CADM may be provided with a multiplicity of channels. Different channels are allocated to different approaches to an installation. In the vast majority of cases, a four channel detector system will suffice. Cases with more than four approaches may be dealt with by assigning additional channels.

In accordance with a second embodiment, the DSP-based Coded Audio Detector Module offers increased functionality, above and beyond that of the first embodiment. As in the first embodiment, the CADM is based on the DSP siren detector module of McConnell et al., with the following exceptions. First, the vehicle which is to activate the control function is equipped with a special Coded Sound Generator which issues coded "frames" at fixed intervals or on command of the driver. Between the transmission of these special coded frames, the Coded Sound Generator need not emit any sounds. Second, the DSP-based siren detector is modified to receive the coded frames, decode the frame content, and then issue a control signal if the unique address assigned to that vehicle matches one of a list of addresses that the detector recognizes as being valid.

As before, the Coded Audio Detector Module, or CADM, is part of a two part system. The first part is an audio based transmitter system on each vehicle that is to control or interact with the system. Referring to Figure 7, when the vehicle operator enables the Coded Sound Generator, the transmitter at specific time intervals, say 5 seconds, sends a packet frame, using binary FSK modulation of the audio carrier for example.

Each vehicle is provided with a Coded Sound Generator. The Coded Sound Generator may be a simple audio generator the output of which is input to the microphone input of an amplifier system. This Coded Sound Generator generates the appropriate packet frame.

The physical hardware used to realized the Coded Sound Generator may be the same as previously described in relation to Figure 2. Referring again to Figure 2, the microprocessor reads the mode selection switch to determine if the operator wants the sound generated at intervals or only upon user actuation of a switch, for example. The microprocessor generates synthetic digital waveforms representing the packet frame (as opposed to a singular codeword as in the previous embodiment). These signals are converted to an analog voltage by the Digital to Analog Convertor (DAC) and then input to the amplifier. A manual signal switch is also available to allow the operator to generate packet frame signals at will rather than at timed intervals.

The CADM will only issue a control signal when a packet frame which meets specific conditions is detected. This feature allows for a greater security and reliability of operation.

The audio command packet is structured in a fashion similar to a standard X.25 packet frame, described for example in Kuo, *Protocols and Techniques For Data Communications Networks*, Prentice Hall, 1981, incorporated herein by reference. Referring more particularly to Figure 8, the audio command packet is transmitted using a simple Frequency Shift Keying (FSK) modulation at some carrier frequency, where f_c is the center frequency, $f_c+\delta f$ is the frequency for the transmission of a binary 1, and $f_c-\delta f$ is the frequency for the transmission of a binary 0. The packet consists of a stream of binary digits sent using one of these two tones. The purpose of the various segments of the packet are as follows:

Preamble - to allow the CADM to synchronize to the symbol centers of the binary data signal. The preamble is typically an alternating binary sequence, such as 1010101010.

Frame Synch - to provide word alignment to the control, data, and parity portions of the command packet. The frame synch is typically a short binary sequence such as a Barker code, Lindner Sequence, Maury-Styles Sequence, etc. One suitable frame synch word consists of the binary sequence 0010 0000 0111 0101.

Header - this field of the frame contains binary address information that is unique to each vehicle in the fleet, as well as a packet type identifier, and control flags. The actual binary sequence depends on the values given to the elements of the header field. In an exemplary embodiment, the field is 20 bits in length.

Data - this field may consist of anywhere from 0 bits to say 256 bits of information. In order to process the commands expeditiously, this field will typically be kept small in practice and may only consist of 8 bits of data.

Parity - parity information to be used for error correction and detection in the packet. If a CRC-16 is used, then 16 parity bits are required.

Postamble - a known sequence of data used to allow clearing of buffers in the receiver. The postamble would typically be a short sequence of alternating binary 1's and 0's, such as 101010.

As an added security measure, the header, data, and parity bits may be exclusive OR'ed with a known but secret pseudorandom Number (PRN) sequence to provide scrambling and a limited degree of security. Other more elaborate encryption schemes may also be applied, if desired.

The CADM module receives the packet using a microphone system and demodulates the audio packet command. Demodulation is performed using an FSK demodulator. The CADM first synchronizes to the incoming bit stream by performing a symbol timing recovery operation on the packet, with the preamble being used to assist this synchronization. Once synchronized, the FSK CADM searches for the frame synch word to achieve frame synchronization, after which it applies the PRN descrambling sequence, then extracts the command, data, and parity fields from the packet. It then uses the parity bits to perform error correction and/or detection on the control and data fields of the packet. If the packet is received without errors or with a correctable number of errors, it will be processed and the desired commands will be interpreted and issued to the controller. Examples of such commands are commands to open a gate, etc. If the packet was received with an uncorrectable number of errors, the command will be rejected and no signals will be sent to the controller.

As in the previous embodiment, the functionality of the CADM as described is implemented using substantially the same hardware platform as the DSP-based siren detector of McConnell et al. (See Figure 5.) Only the DSP software is changed. The detection algorithm may be based on the limiter/discriminator approach of McConnell et al., but includes in addition a low-rate demodulator to perform symbol timing recovery and synch word detection. The header and data fields are processed by the CPU for activation of transit control signals, for example.

The CADM uses the same limiter discriminator operations as described in McConnell et al. to perform FSK demodulation of the FSK signal. The software is modified to incorporate the following additional functions:

Symbol Timing Recovery - this may be based on a simple early/late-gate symbol synchronizer.

Frame Synchronization - this may be based on a binary correlation with threshold detection technique.

Descrambling - this may be an Exclusive OR of the header, data, and parity fields with the known PRN sequence.

Frame Extraction - as per conventional practice.

Error Correction/Detection Coding - this may be based on any of a number of well established error correction coding schemes, such as Hamming codes, Golay codes, BCH, etc.

In addition to these functions, the software is modified to include a command parser to extract, interpret, and to then take appropriate action based on the command and data in the command packet.

An equivalent functional block diagram of the CADM is shown in Figure 9. An output signal from a microphone 901 is filtered in a band-pass filter 903. The filtered signal is then input to a combination of a discriminator 905, a decimator 907 and a median filter 909. An output of the median filter 909 is coupled to a symbol synchronization block 911.

Thus far, the block diagram of the enhanced CADM is identical to that of Figure 6. The symbol synchronization block 911, however, is followed by a frame synch block 913 and an optional descrambler 915. An output of the descrambler 915 is input to an error correction block 917. The error-corrected packet frame is then input to a command parser 919. The command is input to a block 920, where the validity of the command is checked. If the command is valid, a block 921 is notified, which controls whether a signal is issued to the controller. Also input to the block 921 is the output of the decimator 907, indicative of the received signal level.

Again, as compared to the DSP-based siren detector of McConnell et al., the discriminator, decimator, and median filter operations are the same, to ensure the highest sensitivity possible for the CADM based on the excellent signal detection capability inherent in that technique. Signal detection is followed by the operations required (blocks 911 through 921) to decode the packet frame, and then execute the command and associated data for that packet.

The foregoing description has assumed operation in the audible frequency range. However, both the CADM of the first embodiment and the CADM of the second embodiment may be based on ultrasonic sound energy operating above the threshold of human hearing (i.e. > 20 kHz). The module when used to perform detection of ultrasonic control signals in transit applications is referred to herein as a Transmit Control Module, or TCM. In a preferred embodiment, the TCM detects a digital packet which is binary FSK coded onto an ultrasonic audio carrier at approximately 44 kHz, although multilevel FSK (i.e. 4-level FSK) could also be used. The packet structure may be the same as that the CADM of the second embodiment of the invention, described previously in relation to Figure 8.

The reason for using ultrasonic audio frequencies is to reduce the nuisance value of the transit control signals issued by the transit vehicle. These frequencies are beyond the upper limit of the human hearing range, typically in excess of 20kHz. Although for purposes of the present description a frequency in the vicinity of 44 kHz is assumed, other ultrasonic frequency ranges could be used.

Referring to Figure 10, the TCM, like the CADM previously described, is implemented using a DSP/CPU logic board 1001. The DSP/CPU logic board issues control signals to a controller 1003. In the case of the TCM, however, the DSP/CPU logic board is preceded by a conventional audio down-conversion board 1005 which converts the 44 kHz ultrasonic carrier to a nominal carrier frequency of 1 kHz. The ultrasonic carrier may be modulated by ±500 Hz to represent binary 1 or 0.

The down-converter simply converts the carrier frequency, in this case 44 kHz, down to an intermediate frequency which is suitable for processing by the TCM (300 Hz to 2500 Hz). In this case, the intermediate frequency is chosen to be 1 kHz. A low pass filter (LPF) 1009 follows a mixer 1007 to ensure that the only the difference frequency is processed by the TCM.

As in the CADM previously described, preferably the sound level of the ultrasonic sound is also used in determining if the received command is valid. This feature ensures that only vehicles in close proximity to the TCM can actually issue a command at a specific installation.

A Coded Audio Transceiver Module (CATM) results by appropriately combining elements of the Coded Sound Generator of Figure 2 and the Coded Audio Detector Module of Figure 5. Referring more particularly to Figure 11, a DSP-based logic board 1103 is coupled to an input sound transducer 1101 through an A/D converter 1105. The DSP-based logic board is also coupled to a Coded Sound Generator consisting of a D/A converter 1107 and an output sound transducer 1109. If the CATM is to operate in the ultrasonic region, a down-converter 1102 and an up-converter 1108 may also be provided. In many instances, the CATM will be coupled to a controller 1111.

The foregoing description has focussed primarily on hardware and software for vehicular and personal transponders using digital sonic and ultrasonic communications. The following description will focus on exemplary applications of such transponders in systems and digital sonic and ultrasonic communications networks incorporating the same.

In transit applications, it is often desired to know the distance of a vehicle from a particular location (distance ranging). It may further be desired to know the actual location of the vehicle, its speed, heading, etc. In a bus system, for example, passengers at a bus stop would be interested to know how far away the next bus assigned to a particular route is, and its estimated time of arrival at the bus stop. All of the foregoing information may be obtained through the use of a digital sonic or ultrasonic communications network.

Referring to Figure 12, distance ranging is based on the two way messaging concept used in the Transit Detector Module. It requires that an intersection-mounted unit and a vehicle-mounted unit both support a transmit and receive capability. In brief, what the system does is as follows. The intersection-mounted unit (called the base) sends out periodic Query messages which contain a message sequence number. These are short transmissions which are addressed to all vehicle-mounted units (called mobiles). Upon receiving this mobile Query message, a mobile will send a Response message back to the base which contains that vehicle's identity code and the message sequence number to which it is responding. If the mobile always transmits the Response message a fixed time after receiving the Query message, the base unit can calculate the distance of that particular mobile from the intersection. If the mobile responds to a number of sequential Query messages, the distance of the mobile over time can be established, hence enabling the vehicle velocity to be derived.

The time for the Query message to cover the distance between the base and the mobile is simply given by:

$$T = d/340$$

where d is the distance in meters, 340 is the speed of sound in meters/second, and T is the time for the Query message to cover the distance between the base and the mobile. The time for the Response message to cover the distance between the base and the mobile is simply given by same equation. If TP is used to represent the total processing time of the message by mobile and the base, then the total time TTOTAL for a Query message to be sent by the base and receive a Response message back from the mobile is:

$$T_{TOTAL} = \mathrm{T}+\mathrm{T}+\mathrm{T}_{\mathrm{P}}$$

By rearranging the above equation, the one-way propagation time T can be solved for as follows:

$$T = (T_{TOTAL}-T_{p)/2}$$

Since the nominal speed of sound in air is 340 meters/second, the one-way distance between the base and mobile simply becomes:

$$D = (T_{TOTAL}-T_p)/(2 \cdot 340)$$

The Query message acts as an ALL CALL message to any vehicle in the vicinity of the base that it wants any vehicle hearing the Query to respond with the message sequence number and the vehicle ID. The reason for the message sequence number in the Query and Response messages is to avoid a situation where a distant vehicle hears the Query and sends a response message which arrives after the base has issued a second Query message. In such a situation, the base could falsely interpret the mobile as being closer than it actually is.

In another application, the "mobile" units may be stationary, and it may be desired to know if they actually move when they are not expected to. An example of this is in monitoring cargo trailers in storage facilities. These trailers are not expected to move unless a controller or yard manager has issued a release for that particular trailer. If the base detects a trailer as moving when it shouldn't, it may raise an alarm to indicate possible theft of the trailer unit.

Figure 13 illustrates the timing of messages between the base and mobile, and how the base unit measures speed and distance using this technique. In this example, the time duration T represents the one-way time of travel for a message between the mobile and the base, and TP represents the processing time. This example shows the mobile receiving a Query message with the Sequence Number 1. Upon receiving the Query, the mobile responds T + TP seconds later with a Response message containing the Sequence Number of the Query it received plus the MOBILE ID number. The base receives this Response T seconds after transmission by the mobile.

If the base sends Query messages at frequent rate, say once every 5 seconds for example, then it can estimate the vehicle velocity by dividing the distance of the vehicle at two sequential locations by the time between the queries. This capability may be used to provide management information to determine what the vehicle velocity was at fixed distances from the base. This information is useful in determining if the mobile approaching the location where the base unit is located is: approaching faster than a recommended speed; approaching slower than a recommended speed; accelerating as it approaches the location; decelerating as it approaches the location, etc.

This technique can be applied using the two-way communications device at audible or inaudible (e.g., ultrasonic) frequencies, with the only change being that the speed of sound used in determining the distance is chosen to correspond to the speed of sound at the frequency of operation used.

As indicated, the technique can be applied to vehicles in motion or those that are stationary. However, its application is not limited to vehicles. In general, it is applicable to any object the distance and or speed of which is to be determined as a function of time. Other exemplary uses may include, without limitation:

- Location of marine objects or craft on the water-to detect the presence of vehicles and/or objects in areas where they should not be located, or help in locating specific cargo.
- Location of vehicles and/or objects on an airport loading ramp-to detect the presence of vehicles and/or objects in areas where they should not be located.
- Personal locators to locate people.

The discussion to this point has focussed on a single base unit. If the scope is broadened to include several base units, it is possible to obtain not only speed and distance information, but also actual location and heading information. Referring to Figure 14, in such a system, each base (1412a, b and c) sends Query messages which contain the ID of the base. A mobile 1413 sends a Response to every Query it hears from every base unit, the Response including not only the time t but also the ID of the base unit it heard, along with the Sequence Number and Mobile ID. Each base unit 1412 calculates the distance and speed pertaining to the MOBILE ID, and sends this information to a central computer 1416 along with the BASE ID of the base that sent the Query and the Time at which the measurement was made. The central computer 1416 receives similar information from the other base units. The central computer 1416 then has information pertaining to each MOBILE ID which would consist of: the distance to a particular based identified by the BASE ID; and the time the mobile was at that distance.

Since the central computer 1416 knows the coordinates of every base 1412 in the system, it is able to triangulate the actual coordinates of the mobile 1413 at various instants in time. By calculating the location at various points in time, the actual heading and route of the mobile 1413 may easily be calculated and used for various purposes, such as audit records, notification of speed violations, notification of movement when not authorized, tracking, etc.

More generally, the system of Figure 14 provides a two-way audio communication system in which one or more vehicles may communicate with a network of fixed or mobile units (which could be one unit) to exchange command, control, and information between the devices. The vehicles may be mobile or fixed. The communication network is based on an acoustic communication medium and not an electromagnetic one.

Each network element typically comprises an acoustic transceiver, i.e., an acoustic transmitter and receiver. It may send commands or requests to mobile/fixed vehicles, or even to other network elements. The network element may do a number of things based on these commands/requests, such as: relay this information to some application program running on a computer somewhere in the communications network, and relay a response back to the device over the network element; or convey this command/request from a mobile/fixed vehicle to another mobile/fixed vehicle from the same network element or via another network element elsewhere in the network.

Communication between the mobile end systems and the network occurs using acoustic energy, which is typically in the range of about 100 Hz to over 100kHz. It is important to note that this is an acoustic link and not an electromagnetic link as in radio.

The system uses the fact that acoustic transmission has a limited range of transmission distance, which is used to advantage by keeping all communication local to some small area. Wide area coverage is provided by using a conventional wide area communication network to link all the elements of the communication network. Hence in Figure 14, for example, lines 1414a, b and c linking the base stations 1412a, b and c to the central computer 1416 may be part of the wide-area telephone network, such as dial-up lines or leased lines.

One particularly advantageous method of connecting acoustic transponders a wide-area network is through the use of wireless CDPD (Cellular Digital Packet Data) modems, for example of a type sold by Sierra Wireless of Vancouver, British Columbia. The CDPD network is IP (Internet Protocol) -based, allowing for nearly seamless interface with the Internet as well as certain transit network that are also based on a variant of IP.

Many or all of the foregoing principles may be applied in the area of siren detection and preemption as described generally in the aforementioned PCT application. Network connectivity and the ability to detect speed are particularly advantageous in this application. Digital acoustic transmitters are mounted on emergency vehicles, e.g., within the grill or bumper area. Digital acoustic receivers are mounted on semaphore overheads at intersections. As an emergency vehicle approaches, the traffic signals may be preempted to give the emergency vehicle a green light and other vehicles and pedestrians red lights. Furthermore, taking advantage of network connectivity, an indication of the location of the emergency vehicle may be transmitted to a computer at a central traffic control center. The location of emergency vehicles may be displayed for viewing by traffic control personnel. Furthermore, the central computer may perform anticipatory control of other traffic lights in the vicinity of the emergency vehicle. As the emergency vehicles takes one of several possible anticipated routes, the vehicle therefore finds traffic already cleared. As the path of the vehicle is communicated back to the central computer, the anticipatory preemption of traffic lights along paths not taken is then reversed.

Another promising application of digital acoustic communications is toll collection and vehicle spacing. Electronic toll booths, widespread in Europe, are just beginning to achieve commercial acceptance in the United States. Also proposed are toll highways requiring vehicles spacing equipment to achieve maximum safe utilization of the highway. Using directional acoustic transponders mounted in the front and rear bumper areas of a vehicle, both electronic toll boothing and vehicle spacing may be achieved. The electronic toll booth transmits at regular intervals a query signal. When a vehicle approaches the electronic toll booth, its front-facing acoustic transponder detects the query and replies. A debit or billing transaction then ensues. As the vehicle gets underway on the highway, an "autopilot"-like program is engaged. The front-facing and rear-facing acoustic transponders engage in query/response communications with vehicles in front of and in back of the subject vehicle (assuming such vehicles are present). As a result, each vehicle has available to an on-board computer the distance to the vehicle in front and the distance to the vehicle in back. Speed control is executed to maintain the appropriate distance (not too great, not too small) from the vehicle in front.

The same type of arrangement may be used for collision avoidance, whether on a toll highway or public highway. The distance, front and back, to the next vehicle, and the rate of change of distance, is monitored. If an alarm limit is reached, an alarm may be sounded to the driver. A further alarm limit may be set to (assuming forward movement of the vehicle) cause the vehicle to brake (in the case of imminent forward contact) or accelerate (in the case of imminent rearward contact).

Digital acoustic communications may also be used to advantage to provide information services to vehicle occupants. Increasingly, vehicles are equipped with CD-ROMs for use in navigation. Typically, the user is required to ascertain and enter into a computer the vehicle's location, in addition to desired destination. The computer will then retrieve and display a map of the locale, showing a selected route to the destination. In strange surroundings, however, ascertaining one's location is not always an easy task. Referring to Figure 15, a Dedicated Short-Range Communications System (DSRCS) is shown. A large number of DSRCSs may be supported by a wide area communications network, e.g., a typical land-line type of network which supports ITS applications such as fleet management, emergency management, etc. The DSRCSs provide a wireless communications link between the land-side network and the vehicles using the services of the network. As a vehicle moves along the road system, its physical location changes with time. Many Road-Side Systems (RSSs) are placed along the road so that the vehicle-based communication element can be in contact either continuously or intermittently as it travels along the road. Likely locations for RSSs include major intersections and key points along roads and highways, similar to a cellular radio system where many cell sites are placed over a large geographic region to provide wide area coverage for cellular radio users. Unlike cellular radio, however, the illustrated network is based on digital acoustic communications. Furthermore, the RSSs are only placed along a roadway, and there may be small to large gaps in coverage along the roadway. Each RSS in the network is located at a physically unique location, with this location having a known geographic location (i.e., latitude/longitude). Each RSS broadcasts a specific packet (RSS Identifier Packet) which announces the presence of the RSS to any nearby vehicles which can hear the RSS. The RSS Identifier Packet contains a unique Cell Identifier associated with the RSS. A unique Cell Identifier is assigned by the network management system to each RSS.In the example of Figure 15, five RSSs provide coverage at key points along the road. Between cells 1 and 99, there is an area with no coverage. Cells 3, 11 and 65 provide almost continuous coverage along a main artery.

A computer system in the vehicle, upon receiving the RSS Identifier Packet, associates the unique Cell Identifier with a geographic location (latitude/longitude) for that cell using some form of mass storage such as CD-ROM. The geographic location may then be used to retrieve information of use to a driver in the vicinity of that RSS. For example, the geographic location may be used to recall stored map information for the area in the vicinity of the RSS location and display it to a driver. Or, in the case of a tourist, display points of interest to a driver. Similarly, hotel, restaurant or other information may be recalled and displayed to the driver. In the case of a utility or service vehicle, Graphical Information System (GIS) data could be recalled and displayed to a driver. This could include such information as location of gas lines, location of electrical lines, sewer information, etc. In the case of emergency vehicles, information specific to the emergency service may be recalled from the mass storage device. In the case of a fire department vehicle, for example, such information could include the location of hazardous or toxic materials, information on nearby hydrants, etc. CD-ROMs containing information of interest may be purchased by drivers or installed in vehicles by fleet operators. The low cost and high storage capacity of CD-ROM makes it very attractive for this purpose. Furthermore, the storage capacity of CD-ROM-like media (DVD, etc.) may be expected to increase, allowing for the storage and retrieval of media-rich information such as maps, photos, video, and audio in addition to text.

Other transit-related applications of the digital sonic and ultrasonic communications networks include controlling access to controlled areas. The controlled area may be a structure such as a garage, a toll-bridge or toll-road, etc. Alternatively, the controlled area may be a geographic area, as in the case of border crossings between states or countries. Acoustic transponders may also be carried on one's person. Exemplary applications of personal acoustic transponders include access control and personnel monitoring. An acoustic transponder may be used to provided access to a locked building, for example. An acoustic transponder may also be used to monitor the whereabouts of children or pets. Numerous other applications of sonic systems as described herein will be apparent to one of ordinary skill in the art.

It will be apparent to those of ordinary skill in the art that the invention can be embodied in other specific forms without departing from the spirit or essential character thereof. The foregoing description is therefore considered in all respects to be illustrative and not restrictive. The scope of the invention is indicated by the appended claims rather than the foregoing description, and all changes which come within the meaning and range of equivalents thereof are intended to be embraced therein.

What is claimed is:

1. Digital acoustic communications apparatus, including one or more digital acoustic communications devices comprising:

a data processor;

memory coupled to the data processor and storing digital data; and

means for transmitting and/or receiving digital data acoustically;

wherein the acoustic digital communications apparatus, during operation, transmits and/or receives digital data acoustically.

2. The apparatus of Claim 1, wherein said memory stores at least one of an identifying code word and a command, and wherein said means for transmitting and/or receiving transmits and/or receives at least one of said identifying code word and said command acoustically.

3. The apparatus of Claim 1 or 2, wherein said means for transmitting and/or receiving is an acoustic digital communications transmitter operating in the human audible range.

4. The apparatus of Claim 1 or 2, wherein said means for transmitting and/or receiving is an acoustic digital communications transmitter operating in the ultrasonic range.

5. The apparatus of Claim 1 or 2, wherein said means for transmitting and/or receiving is an acoustic digital communications receiver comprising an analog-to-digital converter and wherein said data processor comprises a digital signal processor coupled to the analog-to-digital converter for filtering a digital representation of a received acoustic signal and for recovering digital data symbols encoded therein.

6. The apparatus of Claim 5, wherein the acoustic digital communications receiver operates in the human audible range.

7. The apparatus of Claim 5, said digital acoustic communications receiver further comprising a downconverter;

wherein the acoustic digital communications receiver operates in the ultrasonic range.

8. The apparatus of Claim 1 or 2, wherein said means for transmitting and/or receiving is a digital acoustic transceiver comprising an input sound transducer, an analog-to-digital converter coupled to the input sound transducer, an output sound transducer, and a digital-to-analog converter coupled to the output sound transducer;

wherein said data processor is a digital signal processor coupled to the analog-to-digital converter for filtering a digital representation of a received acoustic signal and for recovering digital data symbols encoded therein, and coupled to the memory and to the digital-to-analog converter for transmitting at least one of said identifying code word and said command acoustically.

9. The apparatus of Claim 8, wherein the acoustic digital communications transceiver operates in the human audible range.

10. The apparatus of Claim 8, wherein the acoustic digital communications transceiver operates in the ultrasonic range.

11. The apparatus of Claim 1 or 2, comprising a plurality of digital acoustic communications devices including a plurality of acoustic digital transmitters and at least one acoustic digital receiver for, when one of said acoustic digital transmitters is within range and transmitting digital information, receiving said digital information.

12. The apparatus of Claim 11, further comprising:

a computer; and

at least one wide area network communications link established between said acoustic digital receiver and said computer.

13. The apparatus of Claim 12, further comprising:

multiple acoustic digital receivers; and

multiple wide area network communications links, one such link being established between each of a plurality of said acoustic digital receivers and said computer.

14. A method of digital communications comprising the steps of:

generating a carrier signal;

modulating the carrier signal in accordance with digital information to produce a modulated signal; and

applying said modulated signal to an acoustic transducer to produce a coded acoustic signal.

15. The method of Claim 14, comprising the further step of propagating the coded acoustic signal across a distance many times a wavelength of the coded acoustic signal.

16. The method of Claim 15, comprising the further steps of:

receiving the coded acoustic signal and transducing the coded acoustic signal to produce a modulated signal; and

demodulating the modulated signal to produce said digital information.

17. A method of using an acoustic digital communications system operating according to Claim 15, comprising the steps of:

providing an acoustic digital communications transmitter to be carried with a moving object;

providing an acoustic digital communications receiver in proximity to a controlled area;

transmitting from the acoustic digital communications transmitter at least one of an identifying code word that identifies the acoustic digital communications transmitter and a command;

receiving at the acoustic digital communications receiver at least one of said identifying code word and said command; and

in response to at least one of said identifying code word and said command, allowing physical access of the moving object to the controlled area.

18. The method of Claim 17, wherein the acoustic digital communications transmitter and receiver operate in the human audible range.

19. The method of Claim 17, wherein the acoustic digital communications transmitter and receiver operate in the ultrasonic range.

20. A method of using an acoustic digital communications system operating according to Claim 15, comprising the steps of:

providing an acoustic digital communications transmitter to be carried with a moving object;

providing an acoustic digital communications receiver within an area to be monitored;

transmitting from the acoustic digital communications transmitter an identifying code word that identifies the acoustic digital communications transmitter;

receiving at the acoustic digital communications receiver said identifying code word; and

when said code word is not received within a predetermined interval of time, producing an alarm indication.

21. The method of Claim 20, wherein the acoustic digital communications transmitter and receiver operate in the human audible range.

22. The method of Claim 20, wherein the acoustic digital communications transmitter and receiver operate in the ultrasonic range.

23. A method of using an acoustic digital communications system operating according to Claim 15, comprising the steps of:

providing a first acoustic digital communications transceiver to be carried on an object;

providing a second acoustic digital communications transceiver at a fixed location;

transmitting from one of the first and second acoustic digital communications transceivers a query message;

receiving said query message at another of the first and second acoustic digital communications transceivers and transmitting a response message;

determining a one-way propagation time between the first and second acoustic digital communications transceivers; and determining a distance between the first and second acoustic digital communications transceivers.

24. The method of Claim 23, wherein a location of said object is intended to remain fixed for a time, said method comprising the further steps of:

repeating the foregoing steps multiple times;

determining whether the location of the object has changed; and

if the location of the object has changed, producing an alarm indication.

25. The method of Claim 23, wherein the first acoustic digital communications transceiver is a mobile acoustic digital communications transceiver carried on a moving object, and the second acoustic digital communications transceiver is a base acoustic digital communications transceiver, said method comprising the further steps of:

repeating the foregoing steps multiple times; and

determining a rate of change of location of the object.

26. The method of Claim 25, comprising the further steps of:

repeating the foregoing steps at multiple base acoustic digital transceivers;

communicating results from the multiple base acoustic digital transceivers to a common site; and

determining at least one of a location and a heading of the object.

27. The method of Claim 26, wherein the first and second acoustic digital communications transceivers operate in the human audible range.

28. The method of Claim 26, wherein the first and second acoustic digital communications transceivers operate in the ultrasonic range.

29. The method of Claim 23, wherein the first and second acoustic digital communications transceivers are mobile acoustic digital communications transceiver carried on a moving objects, said method comprising the further steps of:

repeating the foregoing steps multiple times;

determining a rate of change of distance between the objects; and

exercising control over movement of at least one of the objects to avoid collision of the objects.

30. A method of using an acoustic digital communications system operating according to Claim 15, comprising the steps of:

providing a plurality of acoustic digital communications transmitters at fixed roadside locations;

providing an acoustic digital communications receiver to be carried on a moving object;

transmitting from one of said acoustic digital communications transmitters a unique identifier indicative of the location of the acoustic digital communications transmitter;

receiving at the acoustic digital communications receiver the unique identifier and determining the location of the acoustic digital communications receiver; and

based on the location of the acoustic digital communications receiver, retrieving and displaying stored, locale-specific information.

31. A method of pre-emptively controlling a traffic signal, comprising the steps of:

producing an acoustic coded siren signal including a recurring codeword signifying a traffic signal command;

detecting the codeword and determining the traffic signal command;

and

controlling the traffic signal in accordance with the traffic signal command.

32. The method of Claim 31, wherein the coded siren signal is audible.

33. The method of Claim 31, wherein the coded siren signal is inaudible.

34. The method of Claim 31, wherein the traffic signal command provides for one of the following: pre-emptive passage directly through an intersection, a pre-emptive left turn, and a pre-emptive right turn with no pedestrian traffic.

AMENDED SHEET

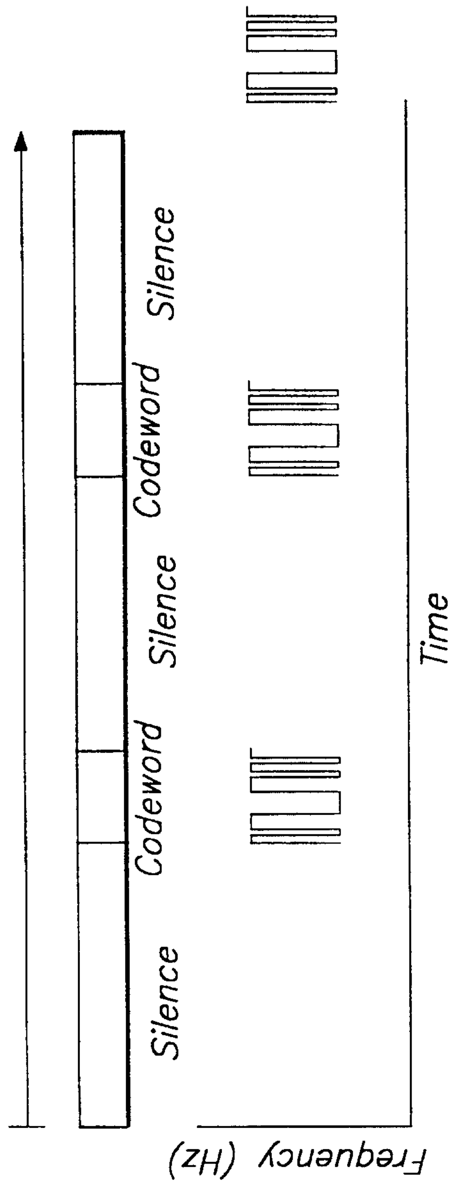

Silence
Codeword
Silence
Codeword
Silence
Time
Frequency (Hz)

FIG. 1

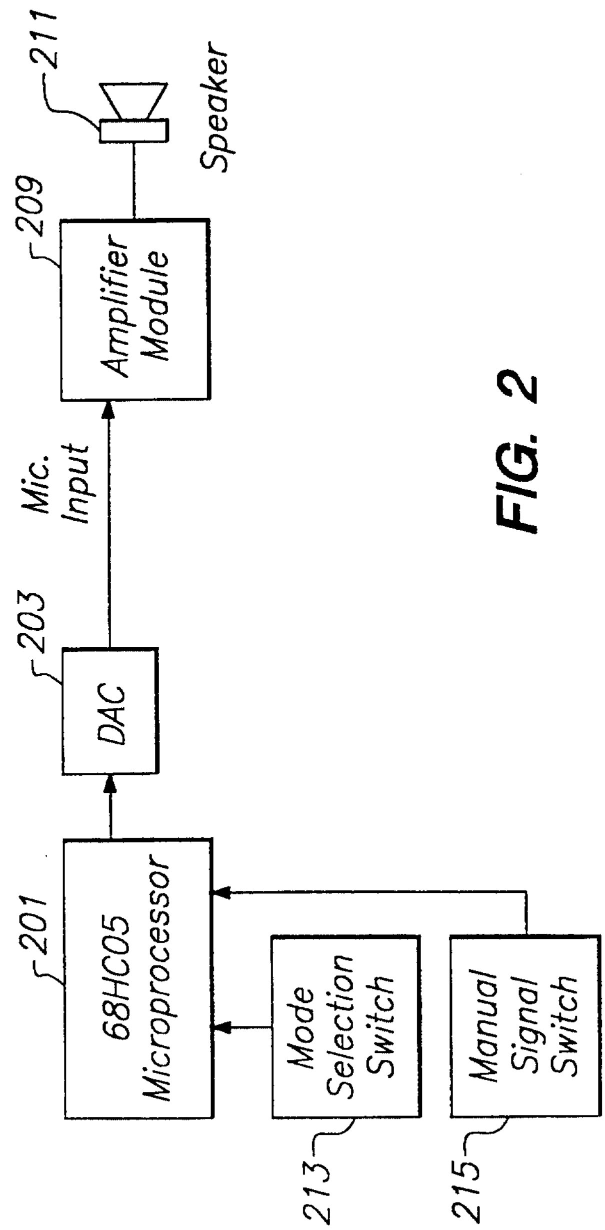

201
68HC05 Microprocessor
203
DAC
Mic. Input
209
Amplifier Module
211
Speaker
Mode Selection Switch
213
Manual Signal Switch
215

FIG. 2

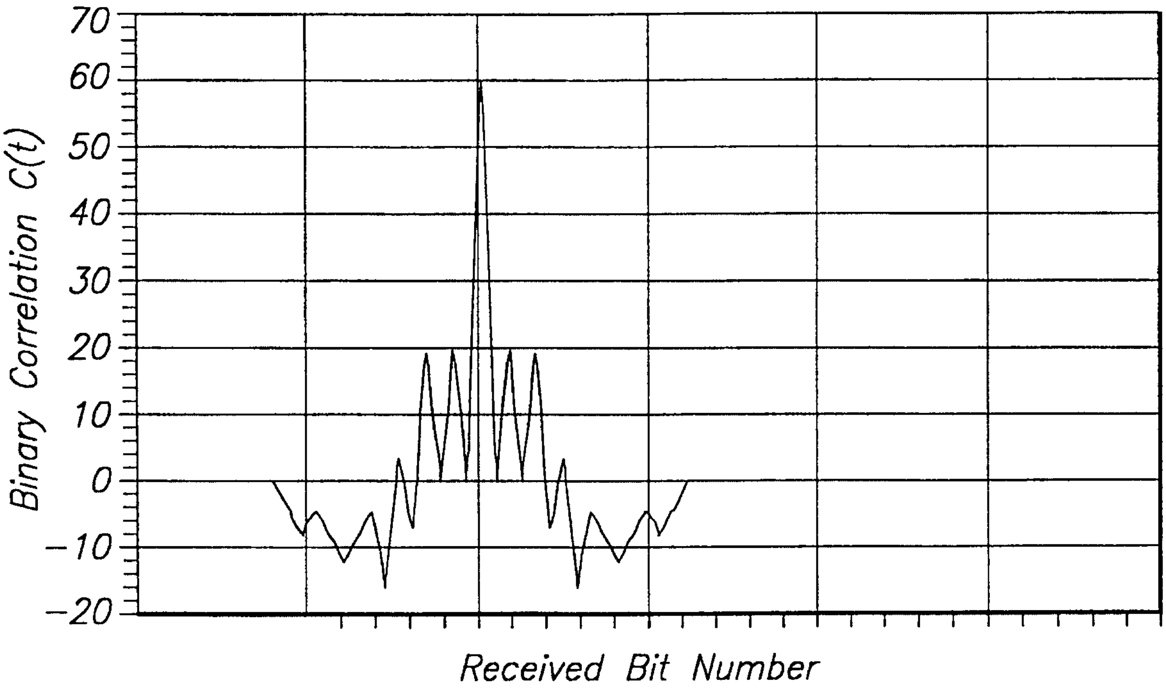


FIG. 3

Noise Level = twice signal level

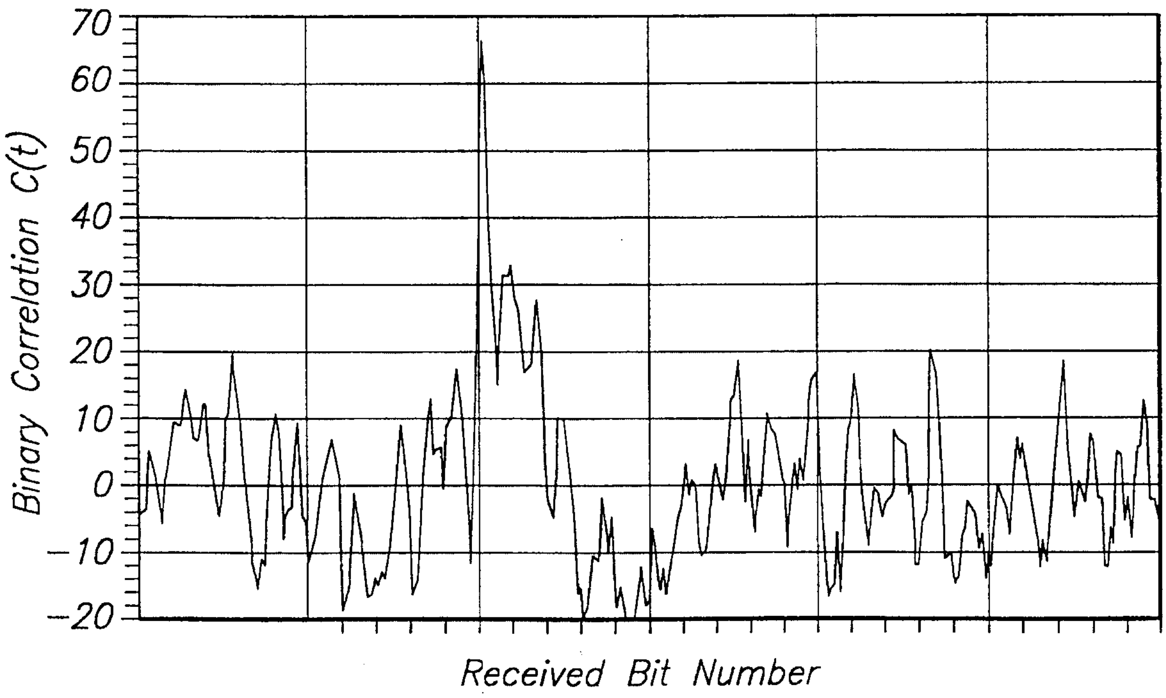


FIG. 4

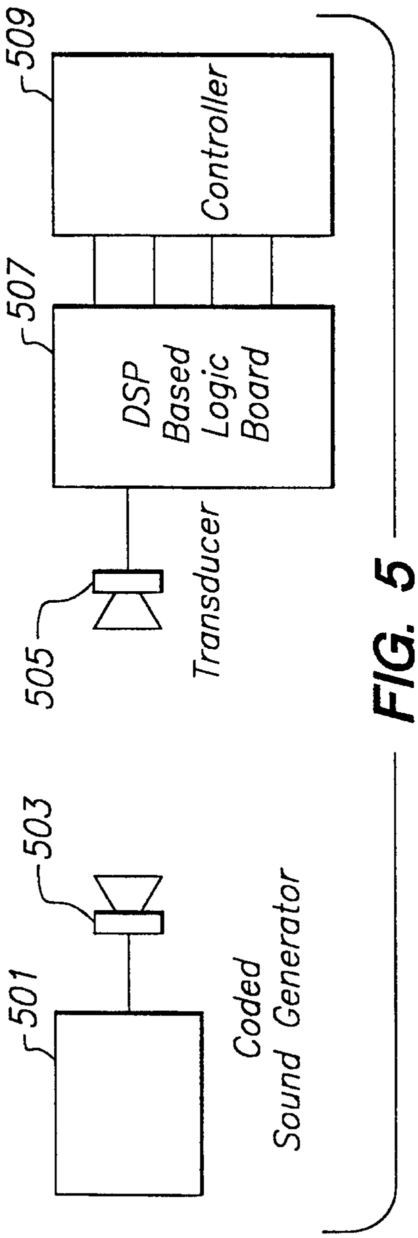

501
503
Coded Sound Generator
505
Transducer
507
DSP Based Logic Board
509
Controller

FIG. 5

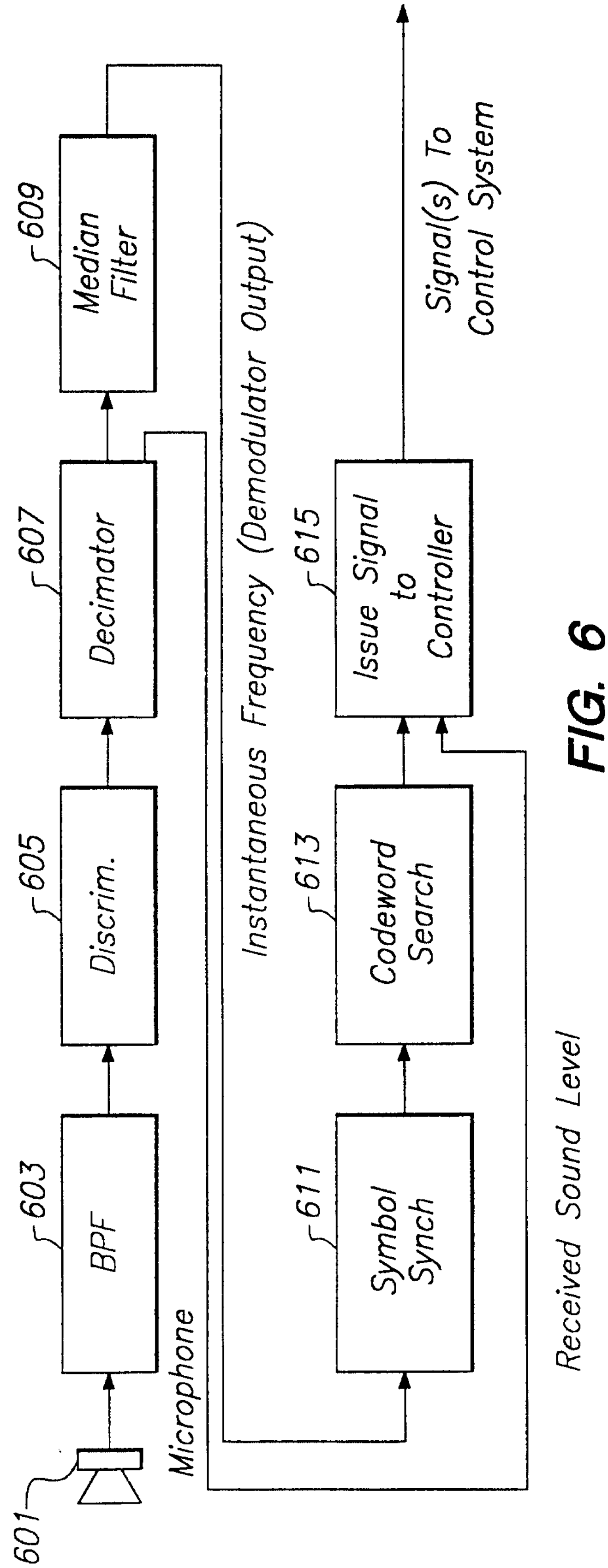

601
Microphone
603
BPF
605
Discrim.
607
Decimator
609
Median Filter
Instantaneous Frequency (Demodulator Output)
611
Symbol Synch
613
Codeword Search
615
Issue Signal to Controller
Signal(s) To Control System
Received Sound Level

FIG. 6

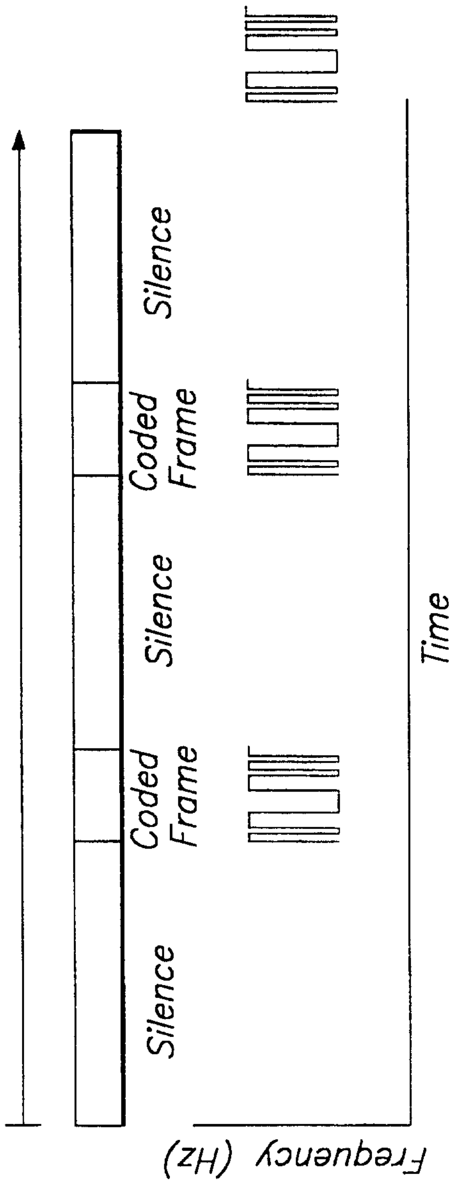

Silence
Coded Frame
Silence
Coded Frame
Silence
Frequency (Hz)
Time

FIG. 7

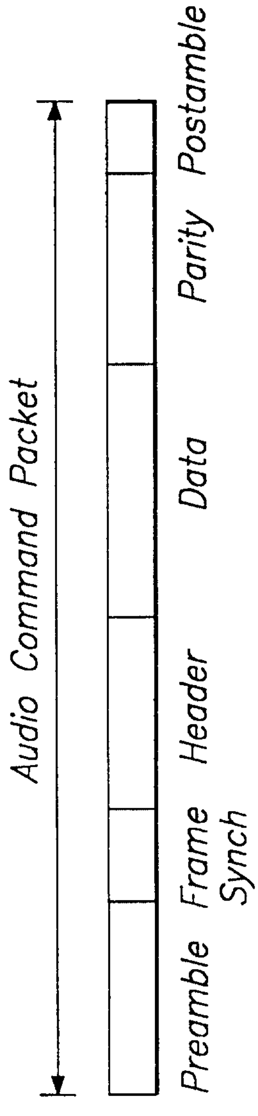

Audio Command Packet
Preamble
Frame Synch
Header
Data
Parity
Postamble

FIG. 8

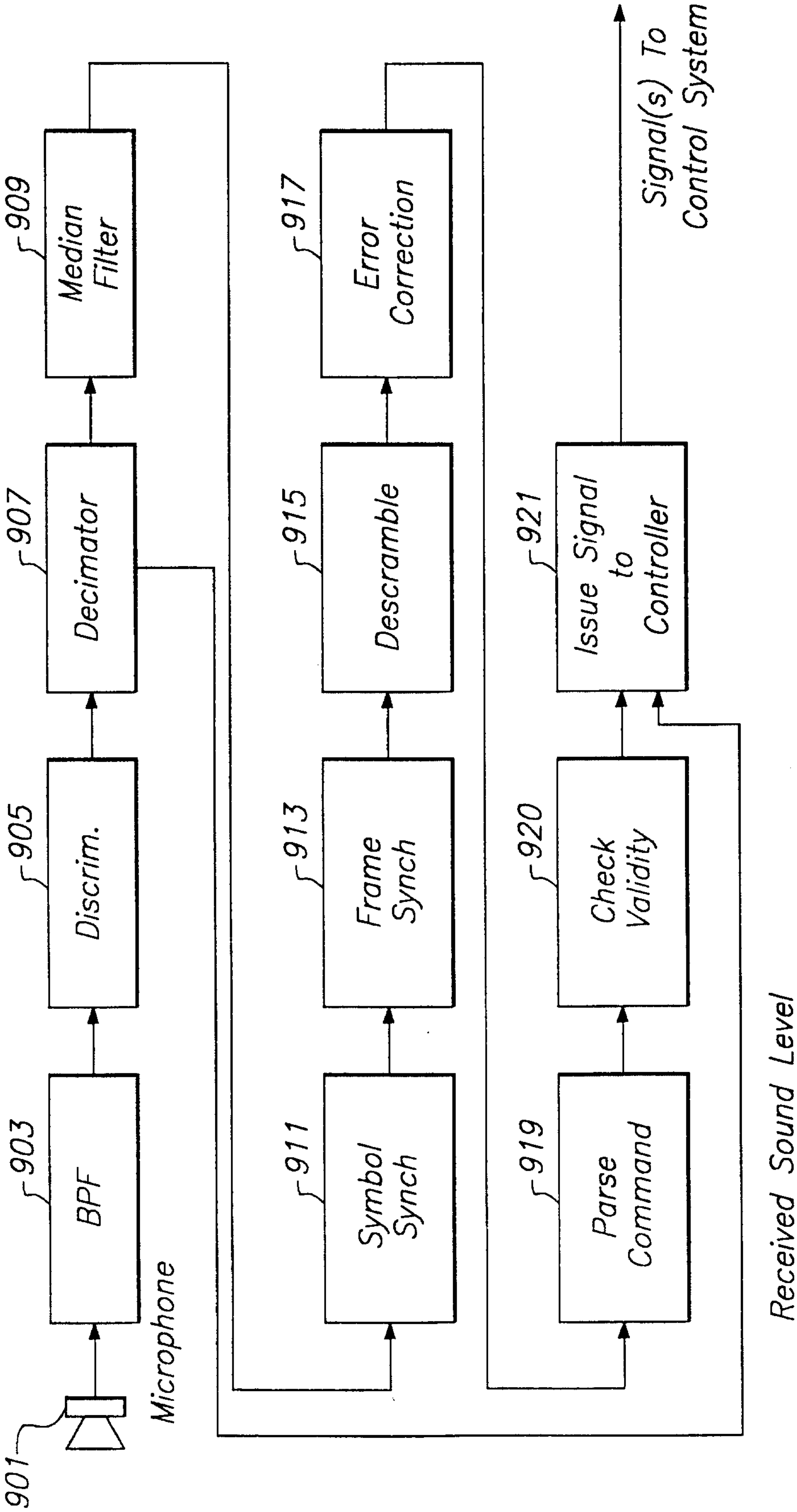

901
Microphone
903
BPF
905
Discrim.
907
Decimator
909
Median Filter
911
Symbol Synch
913
Frame Synch
915
Descramble
917
Error Correction
919
Parse Command
920
Check Validity
921
Issue Signal to Controller
Signal(s) To Control System
Received Sound Level

FIG. 9

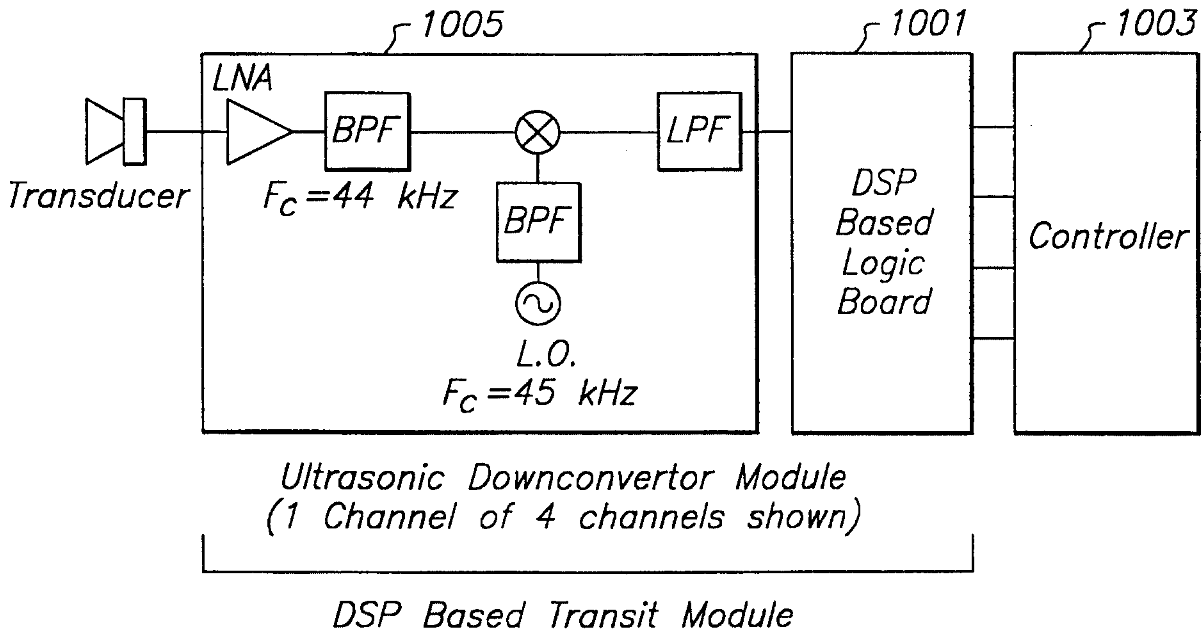

1005
1001
1003
LNA
BPF
LPF
Transducer
Fc =44 kHz
BPF
DSP
Based
Logic
Board
Controller
L.O.
Fc =45 kHz
Ultrasonic Downconvertor Module
(1 Channel of 4 channels shown)
DSP Based Transit Module

FIG. 10

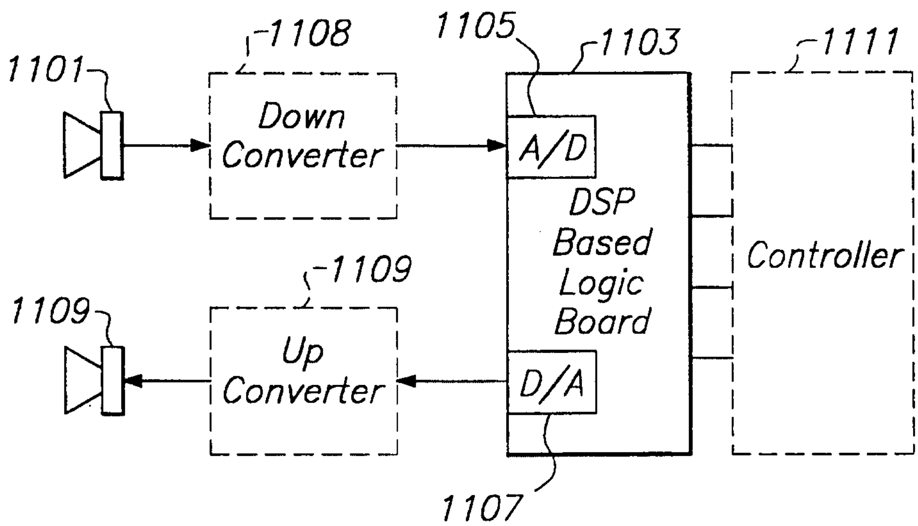

1108
1105
1103
1111
1101
Down
Converter
A/D
DSP
Based
Logic
Board
Controller
1109
1109
Up
Converter
D/A
1107

FIG. 11

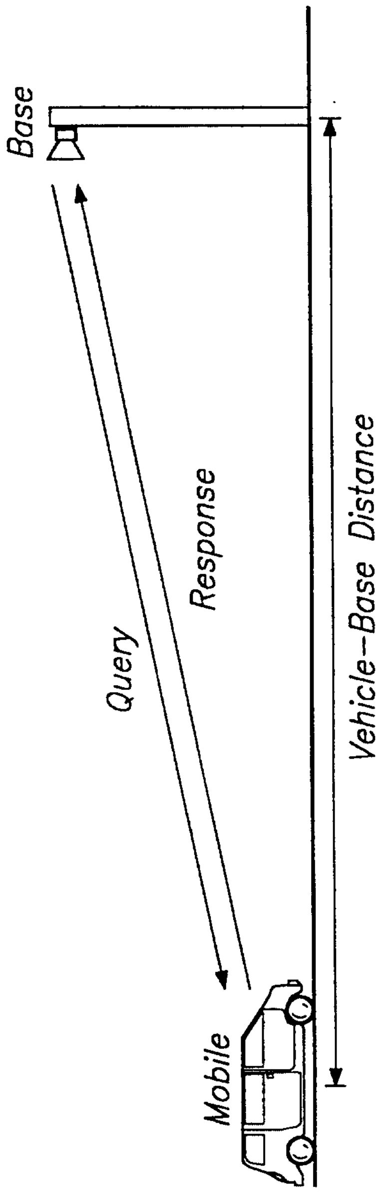

Base
Query
Response
Mobile
Vehicle–Base Distance

FIG. 12

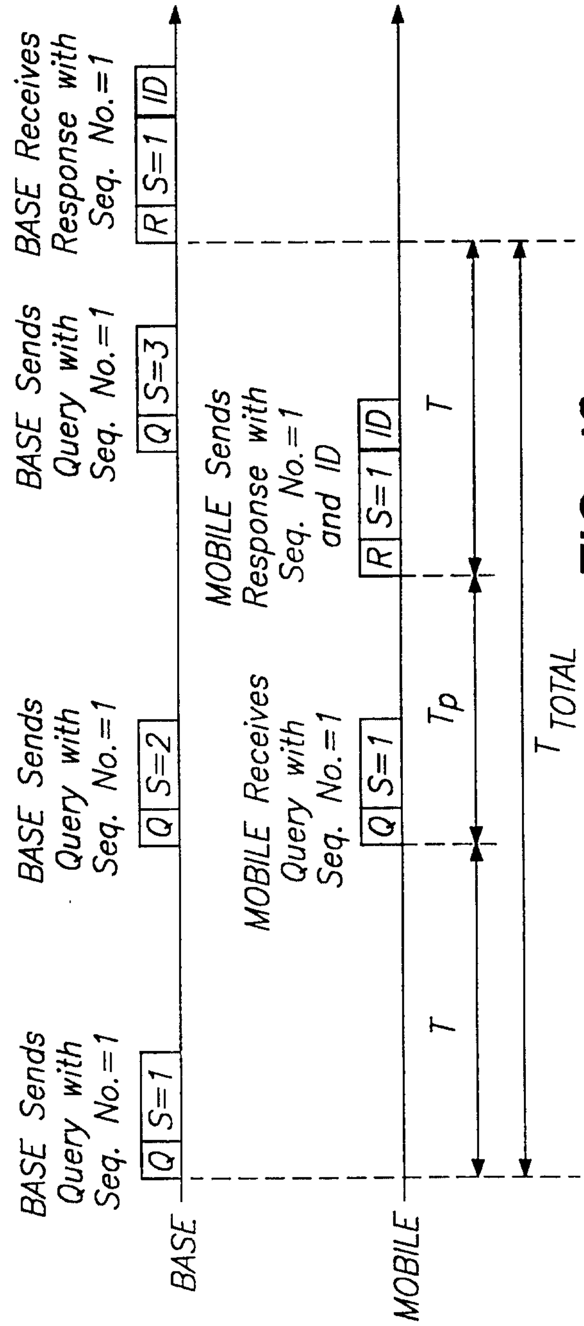

BASE Sends Query with Seq. No.=1
Q S=1
BASE Sends Query with Seq. No.=1
Q S=2
BASE Sends Query with Seq. No.=1
Q S=3
BASE Receives Response with Seq. No.=1
R S=1 ID
MOBILE Receives Query with Seq. No.=1
Q S=1
MOBILE Sends Response with Seq. No.=1 and ID
R S=1 ID
BASE
MOBILE
T
Tp
T
T TOTAL

FIG. 13

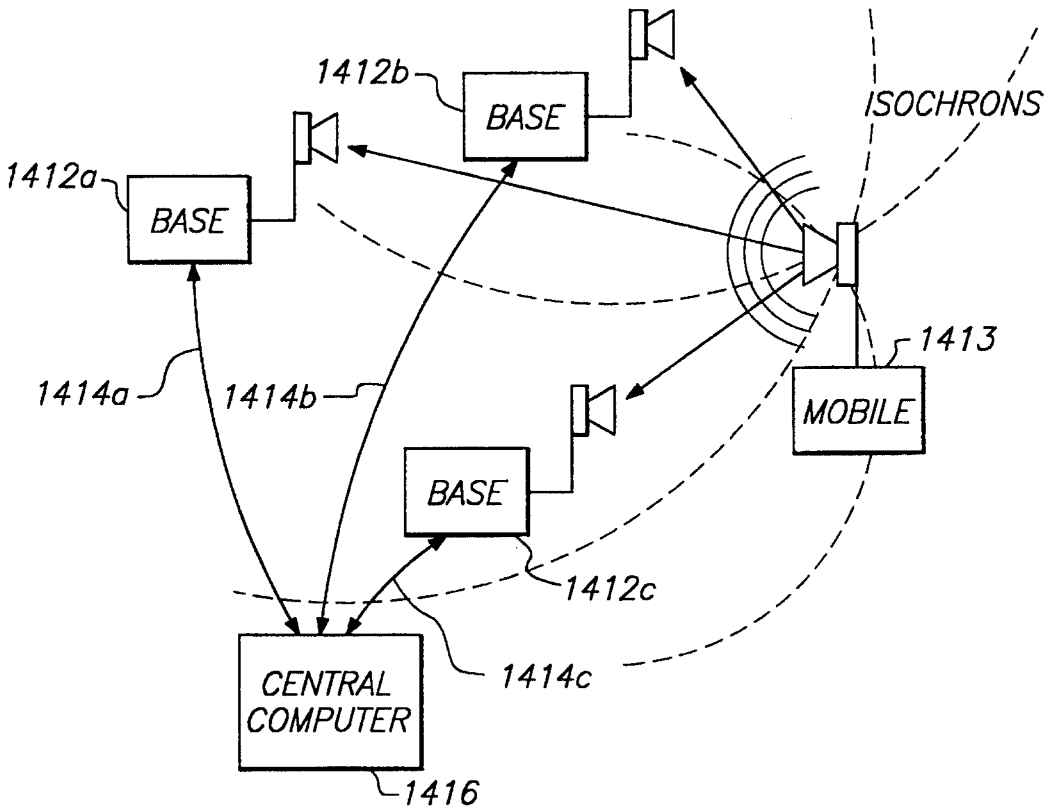

1412b
BASE
ISOCHRONS
1412a
BASE
1413
1414a
1414b
MOBILE
BASE
1412c
1414c
CENTRAL
COMPUTER
1416

FIG. 14

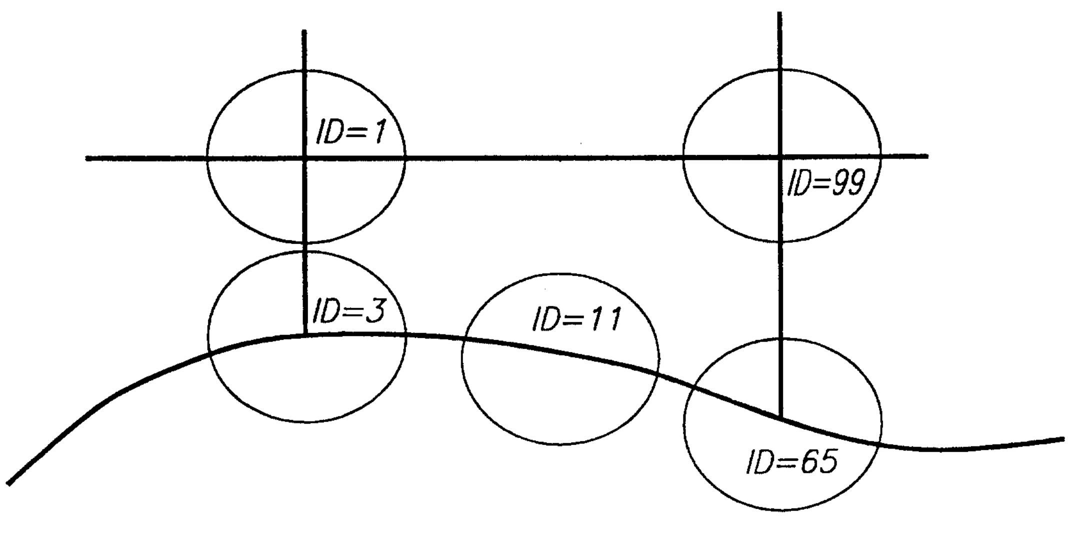
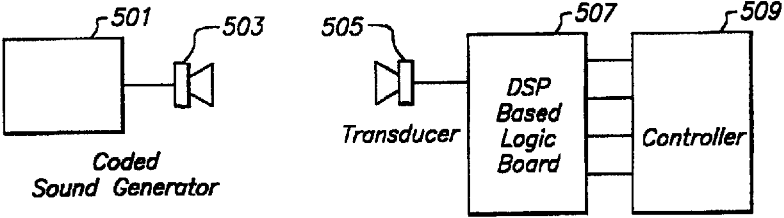

ID=1
ID=99
ID=3
ID=11
ID=65

FIG. 15


501
503
Coded
Sound Generator
505
Transducer
507
DSP
Based
Logic
Board
509
Controller