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(54) **Title:** COMMUNICATIONS APPARATUS

(57) **Abstract:** A receiver for use in a communications system comprising a transmitter. The receiver comprising storage means for storing data representing characteristics of the channel impulse response of the transmission channel between a predetermined transmitter and the receiver. The receiver further comprising discriminating means for discriminating received signals emanating from the predetermined transmitter, from signals emanating from another source, on the basis of data stored in said storage means.

COMMUNICATIONS APPARATUS

The present invention relates to a communications apparatus, and particularly although not exclusively a communications apparatus which utilises ultra-wide band electromagnetic pulses. The present invention also relates to a method for determining the position of at least one structure within a predetermined space.

Electromagnetic radiation has been used to provide wireless communications since the late 19th century. Early communications used 'spark transmitters' which generated pulses having a wide frequency spectrum. The pulses were detected at a receiver located at a distance from the transmitter. A problem associated with spark transmitters is the difficulty of discriminating between signals originating from different transmitters. This problem was circumvented by Marconi in 1901 with the introduction of a tuned frequency filter. The system developed by Marconi used a carrier wave of a predetermined frequency which was modulated by data to be carried. This system allows discrimination between signals transmitted from different transmitters by tuning a frequency filter at the receiver to detect a desired carrier wave frequency and exclude other carrier wave frequencies.

Narrow-band communications systems based upon carrier frequencies and tuned filters are in widespread use around the world. Ultra-wide band signals i.e. signals of the type generated by the spark transmitter system have not been widely adopted due to the difficulty of providing selectivity between signals generated by different transmitters. Ultra-wide band signals have been used in specialised applications, for example sub-surface radar for detecting gas pipes and anti-personnel mines. Typically, in these applications a particular advantage such as ground penetration is sufficient to outweigh the lack of selectivity provided by the ultra-wide band signal.

In recent years the electromagnetic spectrum has become increasingly full with communications transmissions, for example, radio transmissions, military transmissions, mobile telephone transmissions, and so on, to the extent that there are very few useful frequencies left unused. Thus there are insufficient frequency bands available to accommodate new radio communications services demanding very high bandwidth. For example it would be most desirable to have a wireless equivalent of USB2 which operates at a data rate of 480Mb/s and Firewire (IEEE1394) which operates at a data rate of 400Mb/s. Furthermore, existing wireless communications such as Wireless LAN (WLAN) operate at a relatively low data rate which is imposed by the narrowband environment in which they work. This has reduced the attractiveness of WLAN as a communications protocol.

For the reasons outlined above, there has been a resurgence of interest in ultra-wide band communications. Ultra-wide band communications extend over a wide band of frequencies. The term ultra-wide band is generally used to refer to a signal which has a bandwidth greater than 25% of its centre frequency, for example 3.5 to 4.5 GHz would just qualify. Most systems use a wider bandwidth than this, typically 2 to 8 GHz, although some systems may use bandwidth which extends beyond 8 GHz. For example, in February 2002 the Fedral Communications Commission (FCC) in the USA allocated a spectrum between 3.1GHz and 10.6GHz for UWB communications. It is expected that the European regulatory authorities will follow suit.

Since the power of ultra-wide band transmissions is spread over a wide range of frequencies, they do not disrupt narrow band communications. The problem that applied to ultra-wide band transmissions in the late 19th century however remains, i.e. there is currently no suitable way of discriminating between transmitters.

Many of the techniques which are used to control access in narrowband systems are not applicable in an ultra-wide band environment. For example, Frequency Division Multiple Access (FDMA) is only applicable to narrow band systems. Time Division Multiple Access (TDMA) wherein a central controller provides timeslots to individual transmitters is clearly only applicable to centrally controlled systems, and can not be used in an area in which two networks operate simultaneously if these two networks are to have independent central controllers.

Conventional Code Divisional Multiple Access (CDMA) systems rely on power control to limit interference between users, and therefore can be operated only in centrally controlled systems, not in networks in which control is distributed between various transmitters within the network. Given the need for a central controller, CDMA can not be used in unlicensed applications.

EP1065807 (Alcatel) describes a narrow band CDMA type cellular network in which connection messages are interchanged between mobile transmitters and a base station. Collisions between connection messages occur when the base station receives connection messages from two transceivers within a single time slot. Such collisions are resolved using a "rake" receiver and a correlator, which correlates multiple signals arising as a result of for example signals being received along direct and reflected signal paths.

None of the known access control mechanisms can be successfully employed in a UWB environment where control is distributed.

It is an object of the present invention to provide a communications system which obviates or mitigates at least one of the above disadvantages.

According to a first aspect of the present invention there is provided a receiver for use in a communications system comprising a transmitter, the receiver comprising:

storage means for storing data representing characteristics of the channel impulse response of the transmission channel between a predetermined transmitter and the receiver; and

discriminating means for discriminating received signals emanating from the predetermined transmitter, from signals emanating from another source, on the basis of data stored in said storage means.

The term Channel Impulse Response (CIR) of a transmission channel between a transmitter and a receiver is herein used to mean the relationship between an impulse transmitted by the transmitter and signals received by the receiver as a result of transmission of that impulse.

The characteristics of the channel impulse response may be timings between signals received by the receiver as a result of transmission of that impulse.

The other source could be for example another authorised transmitter, or noise generated by a source such as an internal combustion engine, or could be an unauthorised transmitter attempting to send unauthorised information or a jamming signal.

The invention is advantageous because it allows the receiver to discriminate between pulses arriving from different transmitters, even where the transmitted signals are otherwise indistinguishable. This allows the receiver to receive pulses transmitted simultaneously by more than one transmitter, instead of requiring each transmitter to transmit only when all other transmitters are not transmitting.

The receiver may comprise computing means to compute the data representing characteristics of the channel impulse response of the transmission channel between the predetermined transmitter and the receiver. The computing means may include means for comparing signals received from the predetermined transmitter with a predetermined training sequence of impulses to compute the data representing the channel impulse response. The predetermined training sequence may comprise data encoded using a predetermined code.

The discriminating means may comprise a memory having a series of memory locations, reception of a pulse may be recorded in a respective one of the memory locations, and reception of successive pulses may be recorded in locations spaced apart in the series in proportion to the delay between the successive pulses.

The receiver may comprise means to apply a threshold to receive signals so as to discard signals having an amplitude lower than a predetermined threshold. The receiver may be part of a transceiver.

The invention also provides a communications system comprising at least one receiver as set out above, and at least one transmitter.

The invention further provides a method for discriminating at a receiver between signals transmitted from a predetermined transmitter and signals which have been transmitted by another source, wherein data representing characteristics of the channel impulse response of the transmission channel between a predetermined transmitter and the receiver is stored at the receiver and signals emanating from the predetermined transmitter are discriminated from signals emanating from another source on the basis of the stored data.

The data representing the channel impulse response of the transmission channel between the predetermined transmitter and the receiver may be computed by correlating signals received from the predetermined transmitter with a predetermined training sequence of impulses to determine the data representing the channel impulse response. The predetermined training sequence may comprise data encoded using a predetermined code.

The receiver may comprise a memory having a series of memory locations, reception of a pulse may be recorded in a respective one of the memory locations, and reception of successive pulses may be recorded in locations spaced apart in the series in proportion to the delay between the successive pulses.
Signals emanating from the predetermined transmitter and received by the receiver may be correlated with the stored data representing the channel impulse response of

the transmission channel between the predetermined transmitter and the receiver to obtain the signal originally transmitted by the predetermined transmitter.

According to a second aspect of the present invention there is provided a method for determining the position of at least one structure within a predetermined space, using first and second transceivers located within the predetermined space, the method comprising:

transmitting a first signal from the first transceiver and receiving signals reflected from the at least one structure in response to transmission of the first signal at the first transceiver and at the second transceiver;

transmitting a second signal from the second transceiver and receiving signals reflected from the at least one structure in response to transmission of the second signal at the second transceiver; and

generating information indicative of the position of the at least one structure on the basis of the signals received at the said first and second transceivers.

At least one of the first and second transceivers may includes a receiver according to the first aspect of the present invention.

A threshold may be applied to signals received by the first and second transceivers to discard signals having an amplitude lower than a predetermined threshold.

The method may further comprise moving at least one of the first and second transceivers within the predetermined spaces; transmitting a further signal from at least one of the first and second transceivers, receiving reflections of said further signal at each of the first and second transceivers, and generating further information indicative of the position of the at least one structure on the basis of said received reflections of the said further signal. The method may comprise generating composite information indicative of the position of the at least one structure on the basis of the generated information and said further information.

One of the first and second transceivers may be moveable within the predetermined space. The other of the first and second transceivers may be stationary within the predetermined space.

Characteristics of signals received by one of the first and second transceivers may be communicated to the other of the first and second transceivers.

The signals transmitted by the first and second transceivers are preferably ultra-wide band signals. The first and second transceivers may operate independently.

The structure may be a wall, and the predetermined space may be a room. The information indicating the position of the structure may be generated using characteristics which the predetermined space is expected to exhibit.

The method may further comprise using the information indicative of the position of the at least one structure within the predetermined space to generate a graphical representation of said predetermined space. The graphical representation is displayed to a user by means of a headset.

The invention also provides a system for determining the position of at least one structure within a predetermined space comprising:

a first transceiver having means to transmit a first signal and means to receive signals reflected from the at least one structure in response to transmission of the first signal;

a second transceiver having means to transmit a second signal and means to receive signals reflected from the at least one structure in response to transmission of the first signal and the second signal;

means for generating information indicative of the position of the at least one structure on the basis of the signals received at the said first and second transceivers.

Embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic illustration of a communications system which is operated in accordance with the invention;

Figures 2A and 2B are schematic illustrations of signals received by a transceiver in response to a transmission by another transceiver, in the communications system of figure 1;

Figure 3 is a logic circuit schematically illustrating a process for identifying a predetermined transceiver in the communications system of figure 1;

Figure 4 is an illustration of signals received by a transceiver in response to a transmission by a transceiver in a communications system in accordance with the present invention;

Figure 5 is a schematic illustration of an environment in which a method in accordance with the second aspect of the present invention may be operated to obtain information about the environment;

Figure 6 is an illustration showing how distances between transceivers and a wall in figure 5 are calculated;

Figure 7 is a schematic illustration of a different environment in which a method in accordance with the second aspect of the present invention may be operated to obtain information about the environment; and

Figures 8 to 12 are schematic illustrations of an irregular room in which a method in accordance with the second aspect of the present invention may be operated to obtain information as to the location of walls of the room.

Referring to figure 1, there is illustrated a room 1, containing three transceivers A, B, C. In the following description, it is assumed that transceivers A and B are transmitting data which is received by transceiver C. It will be appreciated that the system could be operated such that A and B are transmitters without reception capability, while C is a receiver without transmission capability. When transceiver A emits an electromagnetic pulse representing a data containing signal, the pulse propagates outwards in all directions. Some of these directions of propagation are illustrated in figure 1. The transceiver C which is acting as a receiver will receive the signal transmitted from transceiver A along the direct path indicated by line A1, and also by reflections of the signal from walls of the room 1. These reflections are indicated by lines labelled A2 to A5 in figure 1.

Figure 2A schematically shows the signals received by the transceiver C following transmission of a single pulse signal by transceiver A. The received signal comprises an initial pulse P1 which corresponds to the direct propagation of the pulse from transceiver A to transceiver C along path A1, and a series of subsequent pulses P2, P3, P4, and P5, which correspond to pulses which emanate from the transceiver A and are reflected from walls of the room 1 along paths A2, A3, A4 and A5, to reach the transceiver C. Pulse P5 follows pulses P1, P2, P3, and P4 after a delays T1, T2, T3 and T4 respectively. It should be noted that figure 2A is schematic and is not intended to correspond exactly to the separation between received pulses which would occur in the environment of Figure 1. Figure 2A shows that in the environment of Figure 1, the initial pulse P1 travelling along path A1 is of higher energy that the detected reflected pulses.

If transceiver B transmits a signal to transceiver C, this will propagate directly from transceiver B to the transceiver C. Additionally, the pulse will be reflected from the walls of the room 1, and the reflected pulses will also be received by the transceiver C. A schematic representation of the pulses received by the transceiver C is shown in

Figure 2B. Again, this illustration is schematic and is not intended to correspond to the dimensions of the room 1 shown in figure 1.

It can be seen from Figure 2A and Figure 2B that each time a single pulse is emitted by transceiver A, transceiver C receives a characteristic train of pulses i.e. the pulse which has propagated directly to the transceiver C together with an associated series of reflected pulses. The received pulse train represents what is known as the Channel Impulse Response (CIR) of the communications channel between the transceiver A and the transceiver C. Provided that neither the transceiver A nor the transceiver C are moved within the room 1, and there is no other change to the environment of room 1, the form of the pulse train will remain unchanged. Similarly, each time the transceiver B transmits a pulse, this will result in a different characteristic pulse train being received at transceiver C, which is related to the relative locations of the transceivers B, C. When the transceiver C receives a series of pulses, the form of the characteristic pulse train may be used to discriminate between pulses received from transceiver A and pulses received from transceiver B.

To allow transceiver C to discriminate between signals transmitted from transceiver A and signals transmitted from any other source, transceiver C must carry out an initialisation procedure with each transceiver A, B. This initialisation procedure results in transceiver C storing data which is subsequently used to discriminate between transceiver A, transceiver B and any other source.

An initialisation procedure to allow transceiver C to discriminate signals transmitted from transceiver A from those transmitted by all other signal sources is now described. Transceiver A sends a pulse train (known to both transmitter and receiver) to the transceiver C. This is hereinafter referred to as a training sequence. The training sequence may be sent at the request of the transceiver C or alternatively when the transceiver A is switched on, as part of a start-up procedure. The pulse train received by the transceiver C in response to transmission of the training sequence will be the convolution of the training sequence and the CIR of the communications channel between the transceiver A and the transceiver C. The transceiver C cross-correlates the received pulse train with the known training sequence, and can thereby recover the CIR of the transmission channel between the transceiver A and the transceiver C. Data representing this CIR is stored for future reference. Thus, transceiver C can now differentiate between data received from transceiver A and other signal emitting sources within the environment with the resolution described below. Initialisation may be achieved even in the presence of many other (random) transmitters.

When data is to be sent from the transceiver A to the transceiver C, the transceiver A sends an information bearing sequence to the transceiver C. This sequence is unknown to the receiver. The receiver cross-correlates the received pulse train with the CIR (recorded in the initialisation phase) and recovers the transmitted sequence. If the information is carried in the intervals between transmitted pulses (i.e if data is encoded using pulse position modulation, PPM), the data is recovered from the intervals of the recovered data sequence. If there is additional amplitude and/or phase modulation, then the pulses identified as coming from the desired transmitter must be demodulated in a further stage.

Interception of communication as described above by an unauthorised third party or eavesdropper is difficult to effect. The third party has three possible methods of intercepting data:

- It can be very lucky and correctly guess the training sequence (which could be changed every day, hour, minute, etc.), and thereby correctly obtain the CIR and intercept future communications; or
- It can set up parallel correlators for all possible training sequences and keep them permanently ready for the relatively short time within which the training sequence is transmitted; or
- It can perform auto-correlation on the received pulse train and try to recover the CIRs of all the transmitters present by higher-order statistical analysis.

The first option has a very low probability of success, while the other two impose "orders-of-magnitude" higher computational requirements on the eavesdropper than the intended recipient. Thus, the invention provides relatively secure communication between the transmitter and the receiver.

Possible initialisation methods are now described in further detail. The initalisation may be based upon a training sequence comprising a series of pulses at for example 50ns intervals. Transceiver C is then configured to perform during initialisation a correlation of the received signal with that training sequence. Using this initialisation process, a problem arises during initialisation if two transceivers A, B start sending training sequences of pulses at 50 ns intervals at the same time. This problem is avoided by making the transceivers A, B pick a random number from a set comprising for example ten random numbers between 501 and 1000. During initialisation the transceiver to be initialised chooses one of these numbers, n, and transmits a regular series of pulses at intervals of n×100 ps, i.e. between 10 and 20 MHz repetition rate. Friendly receivers have ten parallel correlators, comparing the incoming pulse stream with itself delayed by each of the "allowed" values. The new user will be picked up after transmitting a few tens of pulses, i.e. after a few microseconds. In contrast, an intending eavesdropper, who knows everything about the system except today's choice of ten random numbers, must have 500 correlators to be sure of catching a new user. The transceiver C identifies the characteristic pulse trains by correlating received signals at the intervals defined by the known set of numbers. If the transceiver C does not manage to determine the form of the characteristic pulse train associated with transceiver A it will be necessary to repeat the initialisation process.

The training sequences need not be a series of regularly spaced pulses, but may instead be more complex. For example, a simplex code a few hundred ns in duration may be used. Where this is done the transceiver is provided with a copy of the code prior to initialisation, and constantly correlates received signals against the simplex code to monitor for a new transmitter (several simplex codes may be used to reduce the possibility of two transmitters transmitting the code simultaneously). The term simplex code is intended to mean a code for which an autocorrelation of the code will yield only one peak, the remainder of the auto correlation having a magnitude which corresponds to the inverse of the code length. It will be appreciated that codes other than simplex codes may be used in some embodiments of the invention.

Transceiver A may transmit identification data which is stored at the transceiver C and associated with any pulse trains received from the transceiver A. This identification data is required by higher layers of the communications system. However, the present invention does not rely upon this identification data to discriminate between transceiver A and other signal sources within the communications system.

Transceiver B is initialised in the same way as transceiver A, although it should be noted that the initialisation of transceiver B may take place while transceiver A is being initialised, or when transceiver A is in communication with another transceiver. Indeed, the initialisation of transceiver B can take place even in the presence of signals from other UWB communications systems, and from pulse sources which are not even communications devices.

When initialisation of transceiver A and transceiver B has been completed, both transceivers A and B may transmit data either separately or simultaneously as described above. Again, communication can occur in the presence of background noise emanating from other UWB communications systems, or pulse sources which are not communication devices.

The CIR data for each transceiver which is stored during the initialisation process described above, may be used to set a second correlator which has a single bit output and which is used to identify transceivers. Whilst this second correlator may check for numerous delays it has a single bit output (single output channel correlator) and in this text is thus termed a comparator means.

If the comparator means is set as described above, each received pulse and its associated characteristic pulse train is replaced at the receiver by a single bit defining that a pulse was sent (at a specific time) and all other input information may be ignored.

A set of comparator means may be operated in parallel, each comparator being configured to correlate the data and compare it with a single stored CIR associated with a particular transceiver.

Whilst the comparator is termed single bit (as it outputs a 1 only when a characteristic pulse train recognition has occurred for a particular transceiver), there may be a means of indicating a measure of confidence associated with the output bit. In other words, the output may include a multibit number defining how well the input signal matched the characteristic pulse train. This allows means of error correction, and also provides a means for monitoring movement of a transceiver as described further below.

Figure 3 schematically illustrates operation of the comparator described above. Referring to Figure 3 an AND Gate 3 has multiple inputs I_1 to I_5. The AND gate is arranged to produce an output pulse when all of the five inputs are high, and otherwise to produce no output. During initialisation the signal received from a given transceiver, for example the signal received from transceiver A as shown in Figure 2A, is used to initialise the AND gate. Inputs I_2 to I_5 are provided with delay lines D_2 to D_5. The delay lines are configured to correspond to the time measured in reverse from the final pulse of the pulse train shown in Figure 2 to the first pulse of the pulse train. Referring to Figure 2A and Figure 3, delay line D_5 is set to delay input signals by time period T1. Similarly delay line D_4 is set to delay input signals by time T2, the delay line D_3 is set to delay signals by time T3, and delay line D_2 is set to delay signals by time T4. There is no delay line provided on input I_1. When an input signal comprising a train of pulses is received it is passed to the inputs I_5 to I_1, and if the input signal includes the pulse train shown in Figure 2A then this will result in all of the inputs of the AND gate downstream of the delay lines D_1 to D_5 going high simultaneously, thereby causing the AND gate to emit an output pulse. This will occur every time the characteristic pulse train is received at the receiver, i.e. for each pulse transmitted by transceiver A.

A practical embodiment of that which is schematically illustrated in Figure 3, particularly suitable for receiving sparse data, is now described. The time intervals between received pulses may be measured by a timing circuit of the type described in International Patent Specification No. WO99/21063, application no. PCT/GB98/03093, the content of which is incorporated herein by reference. Where this is done, the time intervals may be represented by writing a 1 into a first memory location, then skipping 'n' memory locations and writing another 1 into the next memory location, such that the 'n' memory locations indicates the elapsed time between received pulses. The value 'n' is measured by starting a timer when a pulse is received and stopping this timer when the next pulse is received. This measured time value can then be added to the current value of the memory pointer to determine the memory location in which reception of the next pulse should be recorded. Thus the time intervals are stored by incrementing a memory pointer to indicate the time interval.

To determine whether a signal has been received from for example transmitter A, each time a 1 is written to memory, the set of preceding addresses which correspond to the temporal separations of the characteristic pulse train for transceiver A are interrogated. If all of the addresses contain a 1 then the input is deemed to have come from transceiver A. It will be appreciated that the results of this interrogation could be input to an AND gate, the output of which could be used to perform the discrimination. The memory may be a re-circulating buffer, with addresses more than N memory locations away from the current memory locations being overwritten, where N represents a time period longer than those to be monitored. This overwriting procedure is appropriate given the sparse nature of pulses which are received.

Figure 4 illustrates the CIR of a communication channel between two transceivers. As is typical in radio communications applications, the CIR comprises a small number (up to five or six) of dominant echoes, interspersed with a large number of much weaker ones. The data illustrated in Figure 4 was measured with 1 ns resolution using a network analyser sweeping over 2 GHz. It can be seen that 90% of the energy is contained in five paths, spread over 100 ns of delay. Therefore a transmitter sending a pulse on average every 50ns produces five pulses of 100 ps duration at the receiver and occupies the channel for ~1% of the time.

In a preferred embodiment of the invention coding of data is provided by time pulse position modulation, i.e. by controlling the intervals between pulses as described above. It will be readily apparent to those skilled in the art that other modulation techniques can be used in embodiments of the present invention. These include PSK, PAM, QAM etc.

The rate at which data may be received by a transceiver is determined by the temporal resolution at which pulses may be discriminated from one another by the transceiver. The temporal resolution of the transceiver depends upon the reciprocal of the bandwidth and the signal to noise ratio. For the frequency band discussed above, a temporal resolution of the order of $\frac{1}{(10.6-3.1)\times 10^9} = 133ps$ is possible Thus, given a bandwidth of 3.1GHz to 10.6GHz it is not unreasonable to expect temporal resolution of about 100ps.

Since discrimination between transceivers is based upon CIR characteristics, which in turn are based upon the location of the transmitters, the transmitters must be spaced apart in order that they can be discriminated. The spatial separation of the transmitters that is required to allow discrimination is dependent upon the temporal resolution of the receiver. Where the embodiment of the invention uses pulses of around 100 picoseconds (this corresponds to a bandwidth of 10 GHz), and is able to resolve the time of arrival of the pulses at the transceiver receiver to an accuracy of 100 picoseconds (as above), this will correspond to the propagation of an electro-magnetic signal by a distance of approximately 3cm. This means that a transmitter located more than 3cm away from for example transceiver A will cause a different characteristic pulse train to be received and resolved by the transceiver C.

Some embodiments of the invention may include means to monitor the movement of a transceiver, or changes in the environment, such as an object obstructing a path between one transceiver and another. Such monitoring ensures that such movement and such changes do not cause any failure of the communication. In one embodiment, a characteristic pulse train which comprises a series of 100ps pulses will be interpreted as being transmitted by transceiver A if each pulse arrives at the 'correct' time or within ±100ps, thus allowing for some change in distance between transceiver A and transceiver C. If some of the pulses arrive at the 'correct' time 90% of the time and at +100ps 10% of the time then this is deemed to be acceptable. If however one of the pulses arrives at +100ps 90% of the time then this is interpreted as a change of the characteristic pulse train (assumed to be caused by movement of the transceiver A, movement of the transceiver C or some change in the environment surrounding A and C), and the characteristic pulse train stored at the transceiver C in relation to transceiver A is updated accordingly. Generally, when movement of the transceiver A occurs the time delays associated with several of the pulses of the pulse train will be modified. These are updated simultaneously.

The present invention also has particular applicability in wireless interactive television and other consumer applications. Specifically, in such wireless systems high data rate radio communication is required between devices within a house, and this communication must be able to occur in one house without affecting similar devices which may be operated in a neighbour's house. The discrimination provided by the present invention allows such communication to take place.

Ultra-wide band pulses in the visible, or close or adjacent to visible, optical spectrum may be used in embodiments of the present invention.

Since the invention determines identity based upon the spatial location of the transmitter and receiver, the invention does not require the use of handshaking, signature signals or a common clock. This is advantageous because it means that signalling may be truly randomised. The invention does not use a central communications hub, i.e. any transmitter may transmit a signal to any receiver without passing that signal via a central communications hub. This is advantageous because it eliminates the possibility that communications could be disabled by damage to the central communications hub.

Embodiments of the present invention may be used to obtain details of features such as walls within an environment, and these details may be used to form a map of the environment. The manner in which the present invention obtains details of features within an environment is now described.

Referring to figure 5, there is illustrated an environment comprising a wall 2. Two transceivers P, Q can be used to determine the location of that wall as is now described. Initially transceiver P transmits a signal and part of that signal is transmitted as is schematically illustrated by arrow T1. This part of the signal is reflected from the wall 2 and received by the transceiver P. This reflection is schematically indicated by an arrow R1. By knowing the time difference between the time at which the signal is transmitted from transceiver P and the time at which the reflected signal is received by transceiver P, the transceiver P can compute the distance y_1. In the present example, this time between transmission and reception is measured to be 33.3ns. Thus, given that electromagnetic radiation travels at a speed of about 3 x 10^8 ms^{-1}, the distance travelled by the part of the signal transmitted by the transceiver P and received by the transceiver P can be calculated as:

$$33.3\times10^{-9}\times3\times10^{8}=9.99\text{m}$$

Given that the received signal has travelled from transceiver P to the wall 2 and back again, the distance from the transceiver P to the wall is half the total distance travelled. That is, y_1 is approximately equal to 5m.

Similarly, transceiver Q transmits a signal, and part of that signal is transmitted in the direction schematically indicated by arrow T2. This part of the signal is reflected from the wall 2 and received by the receiver Q. This reflection is schematically indicated by an arrow R2. The time between transmission of this signal from Q and reception of the reflected signal at Q is 100ns. Therefore, in the manner described above with reference to transceiver P, it can be determined that y_2 is 15m.

When either transceiver P or transceiver Q transmits a pulse, the other transceiver receives two pulses, a first pulse by direct transmission, and a second pulse by reflection from the wall 2. For the purposes of the present example, only transmissions from P to Q will be considered, although it will be appreciated that similar calculations could be performed on the basis of pulses transmitted from Q to P.

When transceiver P transmits a single pulse signal, transceiver Q receives a first pulse schematically illustrated by arrow T3, and a second pulse (reflected from the wall 2) which is schematically illustrated by arrows T4. The transceiver Q can measure the time difference between reception of the first and second pulses, and thereby determine the difference between the length of the path denoted by the arrow T3, and the path denoted by the arrows T4. In this case, the pulse represented by the arrow T3 arrives after 74.54ns, and the pulse represented by the arrows T4 arrives after 94.28ns. Thus, there is a time difference of 19.75ns between reception of the two pulses which can be measured by the transceiver Q. Given that all pulses are travelling at $3\times10^{8}\,\mathrm{ms}^{-1}$, it can be deduced that the difference in path length between the path denoted by the arrow T3 and the path denoted by the arrows T4 is 5.92m. As described below, given knowledge of y_1 and y_2, and the difference d between the paths T3 and T4 between the transceivers P and Q, the distance x (representing the spacing between P and Q in a direction parallel to the wall 2) can be calculated. Given that y_1 is calculated by the transceiver P and y_2 and d are calculated by the transceiver Q it will be appreciated that communication must occur to centralise the gathered information. This can either by achieved by the transceiver P sending its information to transceiver Q, or by transceiver Q sending its information to transceiver P, or by both transceivers P, Q sending their information to a central processor which is to calculate x on the basis of the gathered information.

It will be appreciated that, for example, the transceiver P must be able to distinguish between reflections of signals that it has transmitted and signals received from transceiver Q directly or after reflection. This can be achieved using the method described with reference to figures 1 to 4.

Referring to figure 6, it can be seen that that $d''=d''_1+d''_2$, and therefore d, the difference in path lengths, is given by the equation:

$$d = d''-d' \qquad (1)$$

Given knowledge of the values of y_1, y_2 and d, it is possible to calculate x. Figure 6 shows the directions in which parts of signals transmitted by the transceivers P and Q travel, together with construction lines (shown as broken lines) which are used for the purposes of calculation. From Figure 6, using Pythagoras' theorem on the triangle P, Q, R it can be seen that:

$$d' = \sqrt{x^2 + (y_2 - y_1)^2} \qquad (2)$$

Simiarly, using Pythagoras' theorem on the triangle P, R, S it can be seen that:

$$d'' = \sqrt{x^2 + (y_1 + y_2)^2} \qquad (3)$$

Substituting equations (2) and (3) into equation (1) gives:

$$\sqrt{x^2 + (y_1 + y_2)^2} - \sqrt{x^2 + (y_2 - y_1)^2} = d \qquad (4)$$

For ease of working:

$$\begin{aligned} &\text{Let A} = (y_2 - y_1)^2 \\ &\text{Let B} = (y_1 + y_2)^2 \end{aligned} \qquad (5)$$

Substituting the definitions (5) into equation (4) and simplifying gives:

$$\begin{aligned}
&\sqrt{x^2 + B} - \sqrt{x^2 + A} = d \\
&(x^2 + B) + (x^2 + A) - 2\sqrt{x^2 + B}\sqrt{x^2 + A} = d^2 \\
&2x^2 + A + B - d^2 = 2\sqrt{x^2 + B}\sqrt{x^2 + A} \\
&2x^2 + A + B - d^2 = 2\sqrt{(x^2 + B)(x^2 + A)} \\
&2x^2 + A + B - d^2 = 2\sqrt{(x^4 + (A + B)x^2 + AB)} \\
&(2x^2 + (A + B - d^2))^2 = 4(x^4 + (A + B)x^2 + AB) \\
&4x^4 + 4x^2(A + B - d^2) + (A + B - d^2)^2 = 4x^4 + (A + B)4x^2 + 4AB \\
&4x^2(A + B - d^2) - (A + B)4x^2 = 4AB - (A + B - x^2)^2 \\
&-4d^2x^2 = 4AB - (A + B - d^2)^2
\end{aligned}$$

$$x = \sqrt{\frac{(A + B - d^2)^2 - 4AB}{4d^2}} \qquad (6)$$

Thus, given that A and B can be determined by substituting calculated values of y_1 and y_2 into the definitions (5), the value of x can then be determined from equation (6) above. Where d=5.92m as in the example of figure 5 described above, equation (6) determines that x=20m.

It will be appreciated that in a practical embodiment, it may be more efficient to calculate the value of x using numerical analysis instead of the analytical approach set out above.

By transmitting a signal from each of transceivers P, and Q and measuring the times described above, the distances y_1, y_2 and x shown in figures 5 and 6 can be calculated. Thus the transceivers P and Q can deduce that there is a wall extending between them at a distance of 5m from P and a distance of 15m from Q, and that P′ is 20m from Q in a direction parallel to that wall.

However, two ambiguities remain. Firstly, there is a "mirror image" ambiguity. The system gives exactly the same result when the wall is in the position shown in figure 5 with P and Q below the wall, as when the wall is on the other side of the transceivers P and Q such that P and Q are above the wall. Both possible scenarios are retained until further measurements resolve the ambiguity.

Secondly, there is a "rotational" ambiguity. The system has no information about the direction of the wall relative to any external reference such as "compass North". Any angular rotation of the entire scene, including P, Q and the wall, will give the same result.

The rotational ambiguity can be resolved by taking a second measurement after one of the transceivers P, Q has moved a small distance. The new measurement will place the moved transceiver in a slightly different position relative to the other transceiver and relative to the wall. The vector denoting the movement of the moved transceiver represents the direction of motion. The entire scene can now be fixed with respect to this direction, which for many applications is the most important direction for the user to be able to orient him/herself relative to his/her surroundings. E.g. in a "head-up" display used in many virtual reality applications, the scene may be rotated so that the direction of motion is shown as a vertical arrow, as this is commonly understood to mean "straight ahead".

However, the "mirror image" ambiguity remains. We still have two possible scenes "reflected" through the line defined by the vector denoting movement of the moved transceiver. This ambiguity can be resolved by taking a third measurement, after one or other of the transceivers P, Q has moved a further small distance in any direction different from the original direction. Suppose transceiver P has turned slightly to the left before making the third measurement. Then the "correct" scene will show P turning to the left, whereas the "mirror image" scene will show P turning to the right. This resolves the ambiguity provided that transceiver P knows which way it has turned.

If the transceiver making movements is a human being, he/she will know which way he/she has turned. If it is a robot, it will usually be carrying some sort of motion sensors, e.g. wheel rotation counting, as part of its control functions, and the readings from these can be used. If P is attached to an object without motion sensors, e.g. for tracking purposes, then some sort of motion detection, such as accelerometers, may be required to assist in the resolution of the "mirror image" ambiguity.

If the method of the invention is not being used for communication, but instead solely to determine properties of an environment, then movements may be consciously made, perhaps at the instruction of a transceiver, so as to obtain the necessary data to perform the necessary calculations.

It will be appreciated that the foregoing description involving only a single wall represents a simple application of the method of the invention. It will usually be necessary to determine characteristics of more complex environments (e.g. rooms). An example is now presented where two walls are to be located.

Referring to figure 7, there is illustrated an environment containing two walls 3, 4 which are positioned at right angles to one another. The environment again contains two transceivers P, Q. When a signal is transmitted by transceiver P, the signal is transmitted in all directions, and parts of the signal travel in the directions indicated by arrows T5, T6, T7, T8 and T9. The part of the signal travelling in the direction of arrow T5 is reflected from the wall 3 back to the transceiver P as is indicated an arrow R5. Similarly, the part of the signal travelling in the direction of arrow T6 is reflected from the wall 4 back to the transceiver P as is indicated by an arrow R6. The part of the signal travelling in the direction of the arrow T7 travels directly from P to Q. The part of the signal travelling in the direction of arrows T8 is reflected from the wall 3 for transmission to the receiver Q. Similarly the part of the signal travelling in the direction of the arrows T9 is reflected from the wall 4 for transmission to the receiver Q.

When a signal is transmitted by transceiver Q, the signal is transmitted in all direction. Parts of the signal travel in the directions indicated by T10, and T11. The part of the signal travelling in the direction of arrow T10 is reflected from the wall 3 back to the transceiver Q as is indicated an arrow R10. Similarly, the part of the signal travelling in the direction of arrow T11 is reflected from the wall 4 back to the transceiver Q as is indicated by an arrow R11. It will be appreciated that parts of the signal transmitted by Q will also travel directly and by reflection from the transceiver Q to the transceiver P, however these parts of the signal need not be considered for the purposes of the following example.

From figure 7, it can be seen that when a pulse is transmitted by the transceiver P two pulses R5, R6 are received by transceiver P. These pulses can be used to determine the distance between the transceiver P and the walls 3, 4. Additionally, for each pulse transmitted by the transceiver P, a series of three pulses T7, T8, T9 are received by transceiver Q. Transceiver Q can use reception of these three pulses to determine the relative time delays between the three signal transmission paths T7, T8 and T9. These three pulses will therefore make it possible to generate two time delay values at transceiver Q.

When a pulse is transmitted by the transceiver Q two pulses R10, R11 are received by transceiver Q. These pulses can be used to determine the distance between the transceiver Q and the walls 3, 4.

Thus transmission of a pulse by transceiver P allows P to generate two distance values and Q to generate two distance values (from the measured time difference values). Transmission of a pulse by transceiver Q allows Q to generate two distance values. Thus, six distance measurements are available which may be used to determine the relative positions of the two transceivers. That is, the six values may be used to determine four unknowns (the x and y co-ordinates of each of P and Q), implying that a soluble system of equations can be created. It may be convenient, for example, to measure the positions of the transceivers P, Q relative to an origin O shown on figure 7. Some ambiguities will again exist (the positions could be reflected through a line passing through the origin at 45degrees to both walls, and the environment could be rotated), but by moving at least one transceiver as described above, these ambiguities can be resolved.

It will be appreciated that to generate data indicative of the location of the wall 2 in figures 5 and 6 and the walls 3, 4 in figure 7, data collected by both transceivers must be communicated to one transceiver, such that the one transceiver has the information collected by both transceivers and can determine the location of the wall(s).

The foregoing examples have been concerned only with determining the location of a single wall or two walls which join at right angles. It will be appreciated that if the invention is to be used in a real building, considerably more complex environments will be encountered, including rooms with non-square corners, and curved walls. In a real application, the system will operate by hypothesis testing. On entering a building, for example, a user will select "indoor" from a menu provided by a device including one of the transceivers of the foregoing description. The device will then know that rectangular rooms are far more likely than irregular shapes. It will therefore test whether the data (received pulse intervals) can be fitted to the patterns expected in a rectangular room first. If this is not possible, it will then test more complex shapes. It should be noted that, as the number of transceivers, and/or the number of reflecting surfaces (walls) increases, the number of intervals which can be measured increases more quickly than the number of unknown distances required to map the environment.

It is believed that the vast majority of commonly experienced environments can be mapped using a network comprising only two or three transceivers.

Examples of a more complex environment than those presented previously are now discussed. Referring to figures 8 to 12, there is illustrated an irregularly shaped room, made up of four walls 5, 6, 7, 8. The room contains three transceivers L, M, N, and it is desired to obtain details of the location of the walls 5, 6, 7, 8 using these transceivers, however as will be shown below, three transceivers located in stationary positions as illustrated can not determine the location of the wall 8.

Referring to figure 9, reflections of signals transmitted by the pair of transceivers M, N are illustrated. As discussed below, only direct and single reflection paths will be considered. It can be seen that each of the transceivers M, N receives a direct reflection of its own signal from each of the three walls 5, 6, 7, and each of the transceivers receives a signal transmitted by the other transceiver by a direct path and by three reflected paths, one for each of the walls 5, 6, 7. Thus, using only transceivers M, N at least some information as to the location of each of the walls 5, 6, 7 relative to the transceivers M, N can be obtained, in the manner described above with reference to figures 5, 6 and 7.

Referring to figure 10, reflections of signals transmitted by the pair of transceivers L, N against the walls 6, 7 is illustrated. It can be seen that each of the transceivers L, N receives a direct reflection of its own signal from each of the two walls 6, 7, and each of the transceivers receives a signal transmitted by the other transceiver by a direct path and by two reflected paths, one for each of the walls 6, 7. Thus, using only transceivers L, N at least some information as the location of each of the walls 6, 7 relative to the transceivers L, N can be obtained. This can be combined with information obtained using the pair of transmitters M, N (as shown in figure 8) to provide a fuller picture of the environment.

Referring to figure 11, reflections of signals transmitted by the pair of transceivers L, M against the walls 6, 7 is illustrated. It can be seen that each of the transceivers L, M receives a direct reflection of its own signal from each of the two walls 6, 7, and each of the transceivers receives a signal transmitted by the other transceiver by a direct path and by two reflected paths, one for each of the walls 6, 7. Thus, using only transceivers L, M at least some information as to the location of each of the walls 6, 7 relative to the transceivers L, M can be obtained. This can be combined with information obtained using the pairs of transmitters M, N and L, N to provide a fuller picture of the environment.

Referring back to figures 9, 10, and 11, it can be seen that using the transceivers M, N, no information can be determined about the form of wall 8; using the transceivers L, N, no information can be determined about the form of walls 5, 8; and using the transceivers L, M, no information can be determined about the form of the walls 5, 8. Referring to figure 12, it can be seen that the reason that no pair of transceivers L, M, N can determine information with regard to wall 8, is that the only transceiver to receive a direct reflection of its own signal from the wall 8 is transceiver L. That is, the transceivers M, N cannot determine their perpendicular distance from the wall 8. Figure 12 includes a virtual extension of the wall 8 shown as a broken line. It can be seen that the signals which approach the plane of the wall 8 at ninety degrees, hit wall 5, and are thus reflected from wall 5 away from the source transceiver. The dotted extension of the signals transmitted by the transceivers M, N is that which would be required to allow direct reflection from the wall 8. Similarly, it can be seen that the reason that the pairs of transceivers including the transceiver L can not deduce information about the wall 5, is that signals transmitted from L which approach the wall 5 at ninety degrees hit wall 8, and are thus deflected. Again, broken lines are used to show the virtual extension of the wall 5, and the path which would need to be followed by a signal which was to be transmitted from the receiver L and directly reflected back to L by the wall 5.

In the environment of figures 8 to 12, three walls will be detected. However, the properties of these walls as determined will be such that it can be deduced that the room is not triangular. In order to obtain information as to the form of the room, it will be necessary to move at least one transceiver. For example, if transceiver M moves to the position M' shown in figure 12, the pair of transceivers L, M will then determine some information as to the form of wall 8. This together with previously gathered information as to the form of the walls 5, 6, 7 may be sufficient to provide a complete picture of the room. If, not, further movement by at least one transceiver will be necessary to generate a fuller picture.

If transceivers send signals independently without a central controller, as mentioned above it will be necessary for the transceivers to operate a discrimination method so as to determine which signals emanate from themselves and which signals emanate from another transceiver. The discrimination method in accordance with the first aspect of the present invention and as described above can be used to carry out this discrimination. Discrimination is also required to overcome the effects of background noise, and this can be done using the method of the first aspect of the present invention.

If the transceivers P, Q (of figures 5 to 7) are somehow centrally controlled, for example if P acts as a master transceiver and Q acts as a slave, and communication between master and slave is carried out using conventional narrow band communication, there is no need to discriminate signals emanating from P from those emanating from Q, given that all communications are centrally controlled by transceiver P, and therefore each of the transceivers P, Q can be advised as to the source of a received signal. Similarly, if one transceiver knows the form of the signal which the other transceiver is to send, then the need for discrimination from background noise also disappears, as a predetermined transceiver can 'listen' for the signal which is to be used to obtain the necessary time delays. Thus, the embodiment of the present invention which provides information as to the locations of features within a predetermined space need not necessarily be used with the discrimination method of the first aspect of the present invention. However, combining the first and second aspects of the present invention is likely to be preferred.

It will be appreciated that the signals transmitted between transceivers to gather information about the environment can take any convenient form, and may in fact be data communications between transceivers, which are used for mapping as a subsidiary purpose.

The signals transmitted between transceivers which are used to calculate time delays are ultra-wide band signals. UWB signals are particularly appropriate given that far higher spatial resolution can be achieved, as compared with conventional narrow band signals. Specifically, using a typical ultra-wide frequency band resolution of less than ten centimetres can be obtained, while using narrow band signals, only resolutions of for example several tens of metres can be obtained.

In the foregoing description, only primary reflections have been described in response to any transmission. It will be appreciated that in any realistic situation a number of weaker echoes are also likely to be received at a receiver. These echoes can be discarded using a thresholding method whereby only signals above a minimum strength are considered. Alternatively, only the first n echoes could be used, where n is a number of for example walls which are expected.

It will be appreciated that in order to generate data indicative of the positions of structures such as walls, generally only one transceiver need move within the environment. Indeed in some circumstances no movement of transceivers is necessary to obtain the necessary information.

The description set out above concerns only the location of walls within a predetermined space. It will be appreciated that the method of the invention can be operated in three-dimensions such that floors and ceilings of various heights can be located. Furthermore, the invention is not restricted to locating only walls, but can instead be used to determine features of any object within the predetermined space. Clearly, the more information that is required to describe a space, the greater the number of signals which will need to be sent and received.

One application in which the present invention is useful is the provision of headsets for fire fighting personnel entering a smoke filled building. It would clearly be of great value to provide such personnel with a map of rooms within a building on a display within a headset. Such a map can be created using the techniques described above. All possible maps of the room which satisfy the data gathered may initially be displayed to the user using the headset display. As more data is obtained, maps which no longer satisfy the gathered data are deleted from the display until only the correct map is shown on the display. In circumstances where only one fireman is to enter a smoke filled room, he could carry a first transceiver as part of his headset, and drop a further transceiver within a heatproof container within the room. This further transceiver could then remain stationary. Signals sent between the two transceivers would then allow mapping of the room. If more than one firefighter is to enter the smoke filled room, a stationary transceiver in a heatproof box could be used as an additional transceiver, and thereby improve the quality of information generated. The signals used to map the room could be voice communication between different firefighters, which are analysed in the manner described above to identify features of the environment.

The present application also has applications in many other 'blind' environments, including search and rescue within spaces such as underground caves.

In addition to its use with UWB electromagnetic waves, the invention can also be used with ultrasonic signals. Using ultrasonic signals having microsecond pulses will obtain similar spatial resolution to that described above for picosecond UWB pulses, given that sound travels approximately one million times slower than light. Embodiments of the invention using ultrasonic pulses have underwater applications, including use by divers in environments where vision is difficult or impossible.

The present invention also has applications in many fields in which virtual reality is used, and can also be used in computer gaming and entertainment applications.

CLAIMS

1. A receiver for use in a communications system comprising a transmitter, the receiver comprising:

storage means for storing data representing characteristics of the channel impulse response of the transmission channel between a predetermined transmitter and the receiver; and

discriminating means for discriminating received signals emanating from the predetermined transmitter, from signals emanating from another source, on the basis of data stored in said storage means.

2. A receiver according to claim 1, comprising computing means to compute the data representing characteristics of the channel impulse response of the transmission channel between the predetermined transmitter and the receiver, said computing means including means for comparing signals received from the predetermined transmitter with a predetermined training sequence of impulses to compute the data representing the channel impulse response.

3. A receiver according to claim 2, wherein the predetermined training sequence comprises data encoded using a predetermined code.

4. A receiver according to any preceding claim, wherein the discriminating means comprises a memory having a series of memory locations, reception of a pulse is recorded in a respective one of the memory locations, and reception of successive pulses is recorded in locations spaced apart in the series in proportion to the delay between the successive pulses.

5. A receiver according to any preceding claim, wherein the receiver is part of a transceiver.

6. A communications system comprising at least one receiver according to any preceding claim, and at least one transmitter.

7. A method for discriminating at a receiver between signals transmitted from a predetermined transmitter and signals which have been transmitted by another source, wherein data representing characteristics of the channel impulse response of the transmission channel between a predetermined transmitter and the receiver is stored at the receiver and signals emanating from the predetermined transmitter are discriminated from signals emanating from another source on the basis of the stored data.

8. A method according to claim 7, wherein the data representing the channel impulse response of the transmission channel between the predetermined transmitter and the receiver is computed by correlating signals received from the predetermined transmitter with a predetermined training sequence of impulses to determine the data representing the channel impulse response.

9. A method according to claim 8, wherein the predetermined training sequence comprises data encoded using a predetermined code.

10. A method according to any one of claims 7, 8 or 9 wherein the receiver comprises a memory having a series of memory locations, reception of a pulse is recorded in a respective one of the memory locations, and reception of successive pulses is recorded in locations spaced apart in the series in proportion to the delay between the successive pulses.

11. A method according to any one of claims 7 to 10, wherein signals emanating from the predetermined transmitter and received by the receiver are correlated with the stored data representing the channel impulse response of the transmission channel between the predetermined transmitter and the receiver to obtain the signal originally transmitted by the predetermined transmitter.

12. A method for determining the position of at least one structure within a predetermined space, using first and second transceivers located within the predetermined space, the method comprising:

transmitting a first signal from the first transceiver and receiving signals reflected from the at least one structure in response to transmission of the first signal at the first transceiver and at the second transceiver;

transmitting a second signal from the second transceiver and receiving signals reflected from the at least one structure in response to transmission of the second signal at the second transceiver; and

generating information indicative of the position of the at least one structure on the basis of the signals received at the said first and second transceivers.

13. A method according to claim 12, wherein at least one of the first and second transceivers includes a receiver according to any one of claims 1 to 5.

14. A method according to claim 12 or 13, wherein a threshold is applied to signals received by the first and second transceivers to discard signals having an amplitude lower than a predetermined threshold.

15. A method according to claim 12, 13 or 14, further comprising, moving at least one of the first and second transceivers within the predetermined spaces; transmitting a further signal from at least one of the first and second transceivers, receiving reflections of said further signal at each of the first and second transceivers, and generating further information indicative of the position of the at least one structure on the basis of said received reflections of the said further signal.

16. A method according to claim 15, comprising generating composite information indicative of the position of the at least one structure on the basis of the generated information and said further information.

17. A method according to any one of claims 12 to 16, wherein one of the first and second transceivers is moveable within the predetermined space and the other of the first and second transceivers is stationary within the predetermined space.

18. A method according to any one of claims 12 to 17, wherein characteristics of signals received by one of the first and second transceivers are communicated to the other of the first and second transceivers.

19. A method according to any one of claims 12 to 18, wherein signals transmitted by the first and second transceivers are ultra-wide band signals.

20. A method according to any one of claims 12 to 18, wherein the signals transmitted by the first and second transceivers are ultrasonic signals.

21. A method according to any one of claims 12 to 20, wherein the first and second transceivers operate independently.

22. A method according to any of claims 12 to 21, wherein the structure is a wall, and the predetermined space is a room.

23. A method according to any preceding claim, wherein the information indicating the position of the structure is generated using characteristics which the predetermined space is expected to exhibit.

24. A method according to any one of claims 12 to 23, further comprising using the information indicative of the position of the at least one structure within the predetermined space to generate a graphical representation of said predetermined space.

25. A method according to claim 24, wherein the graphical representation is displayed to a user by means of a headset.

25 A system for determining the position of at least one structure within a predetermined space comprising:

a first transceiver having means to transmit a first signal and means to receive signals reflected from the at least one structure in response to transmission of the first signal;

a second transceiver having means to transmit a second signal and means to receive signals reflected from the at least one structure in response to transmission of the first signal and the second signal; and

means for generating information indicative of the position of the at least one structure on the basis of the signals received at the said first and second transceivers.

26. A system for carrying out the method of any one of claims 12 to 25.

27. A method substantially as hereinbefore described, with reference to figures 1 to 4 or figures 5 to 12 of the accompanying drawings.

28. A system substantially as hereinbefore described, with reference to figures 1 to 4 or figures 5 to 12 of the accompanying drawings.

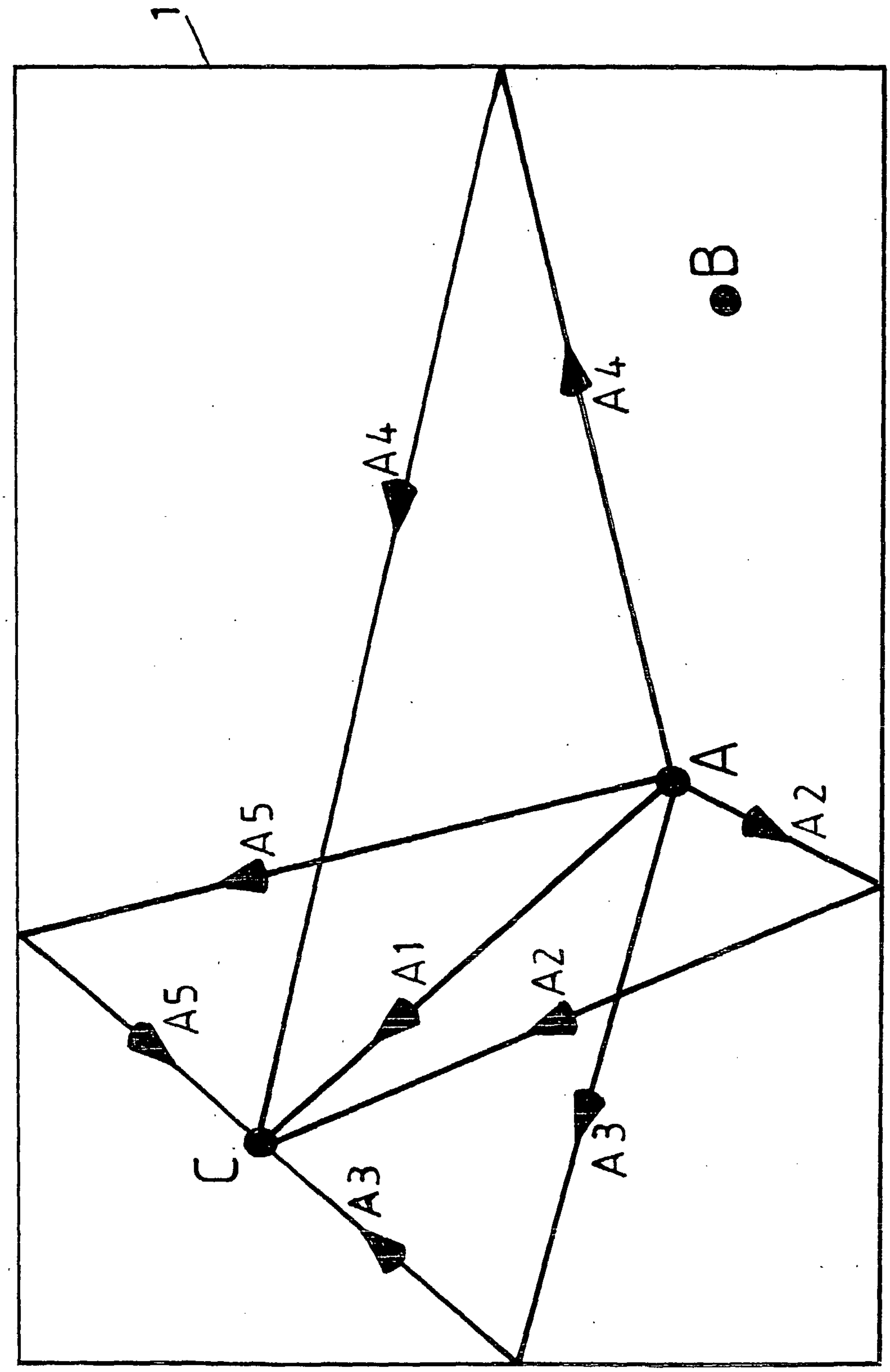

FIG. 1

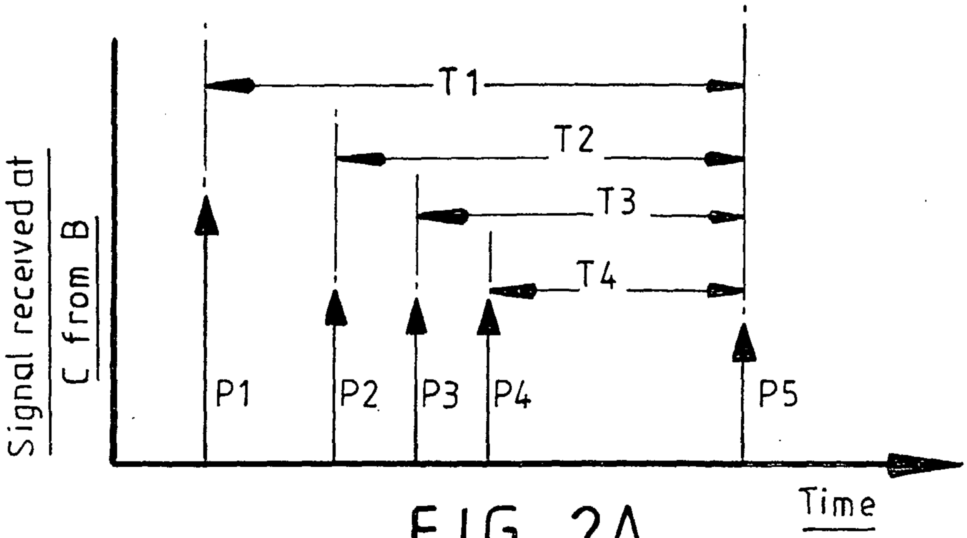

FIG. 2A

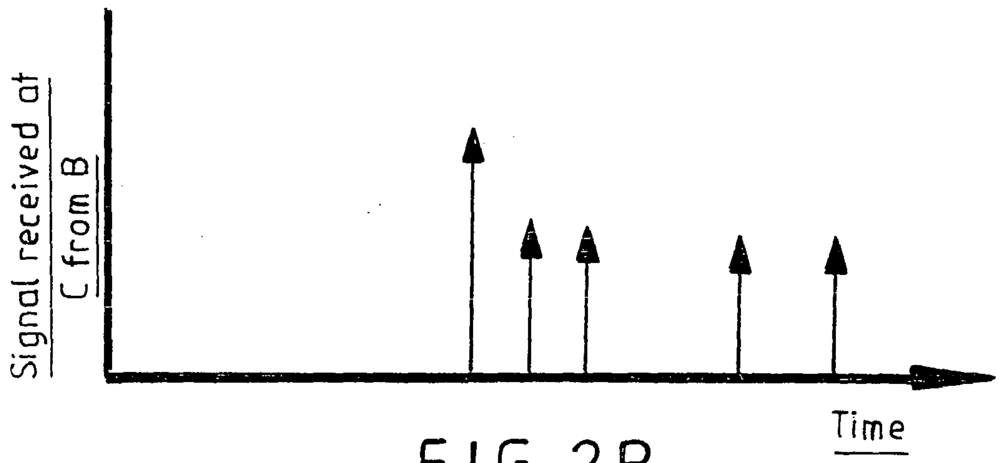

FIG. 2B

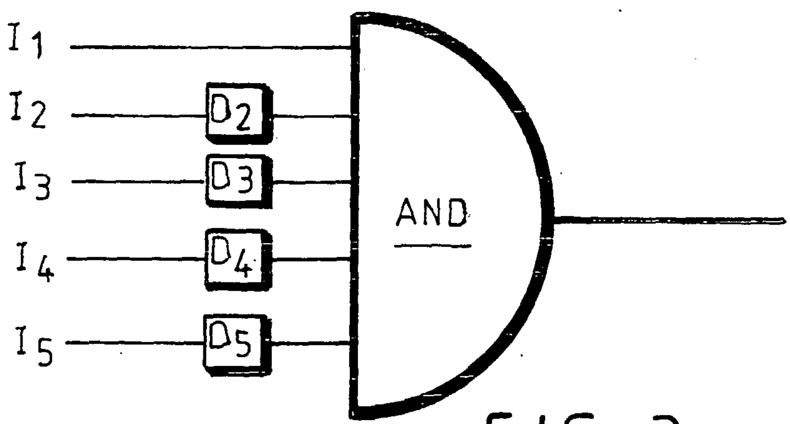

FIG. 3

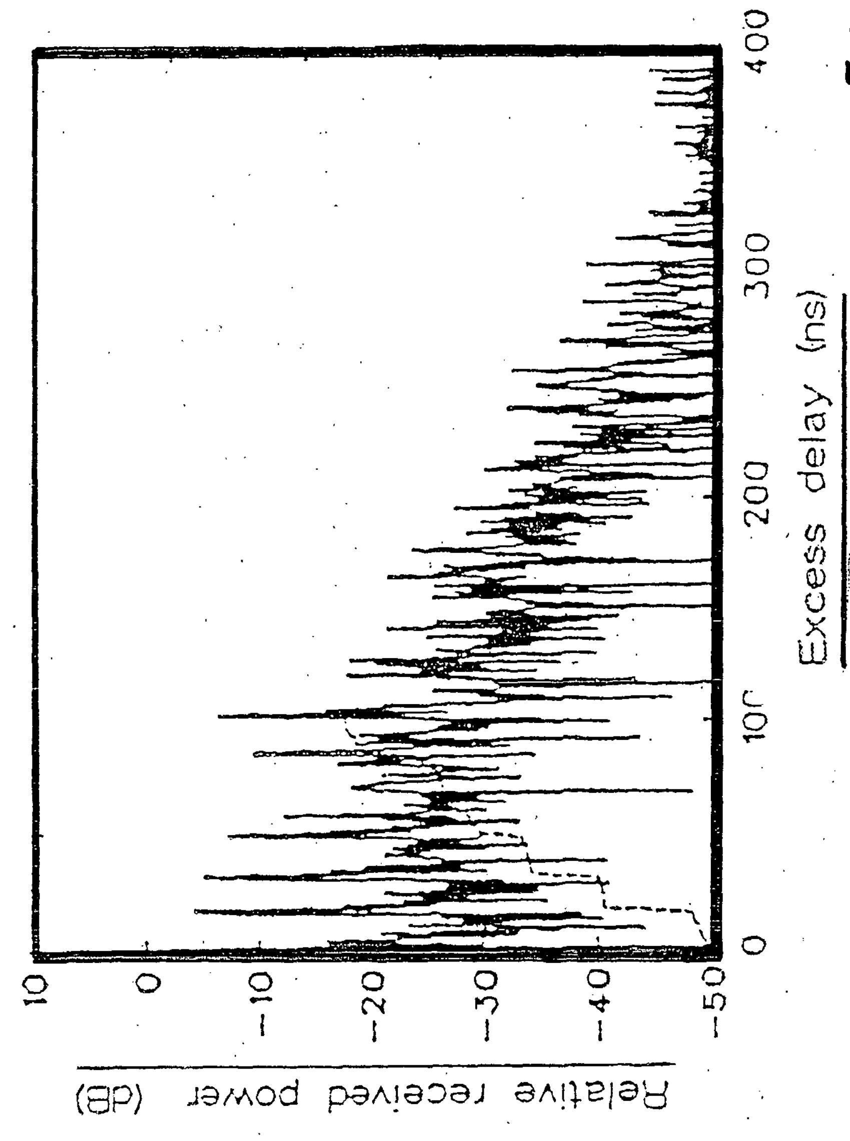
Relative received power (dB)
10
0
-10
-20
-30
-40
-50
0
100
200
300
400
Excess delay (ns)

FIG. 4

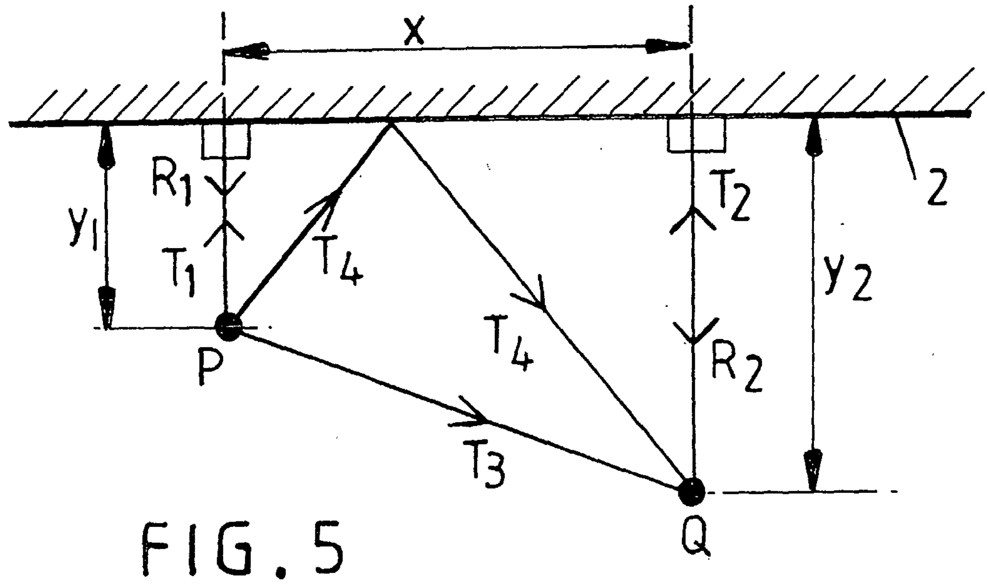

FIG. 5

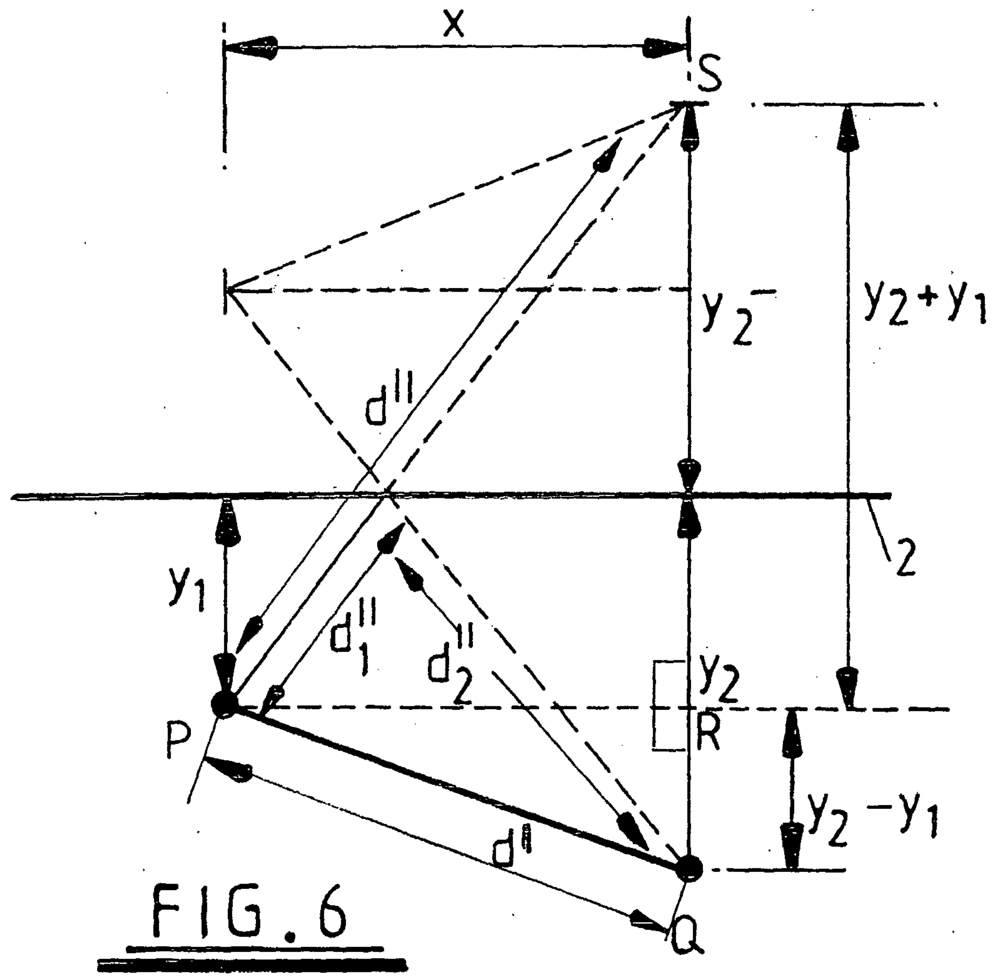

FIG. 6

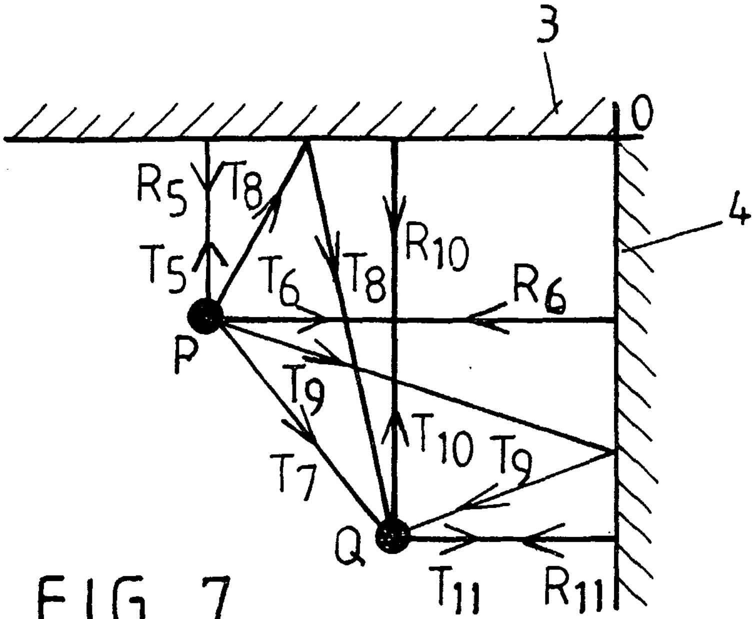

FIG. 7

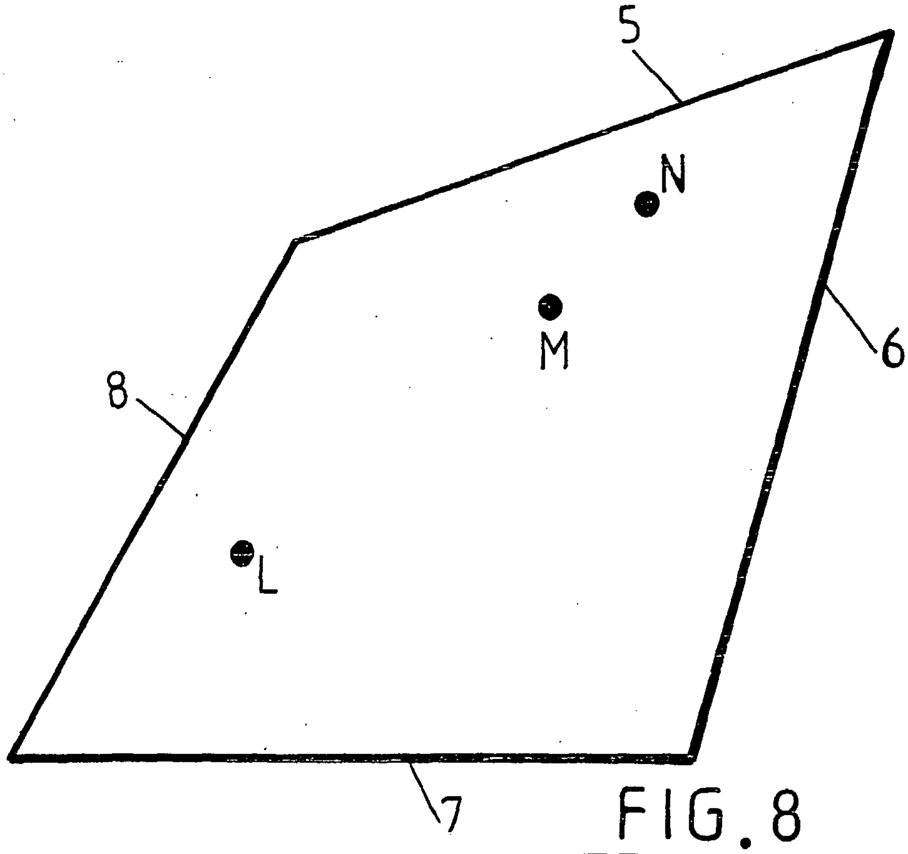

FIG. 8

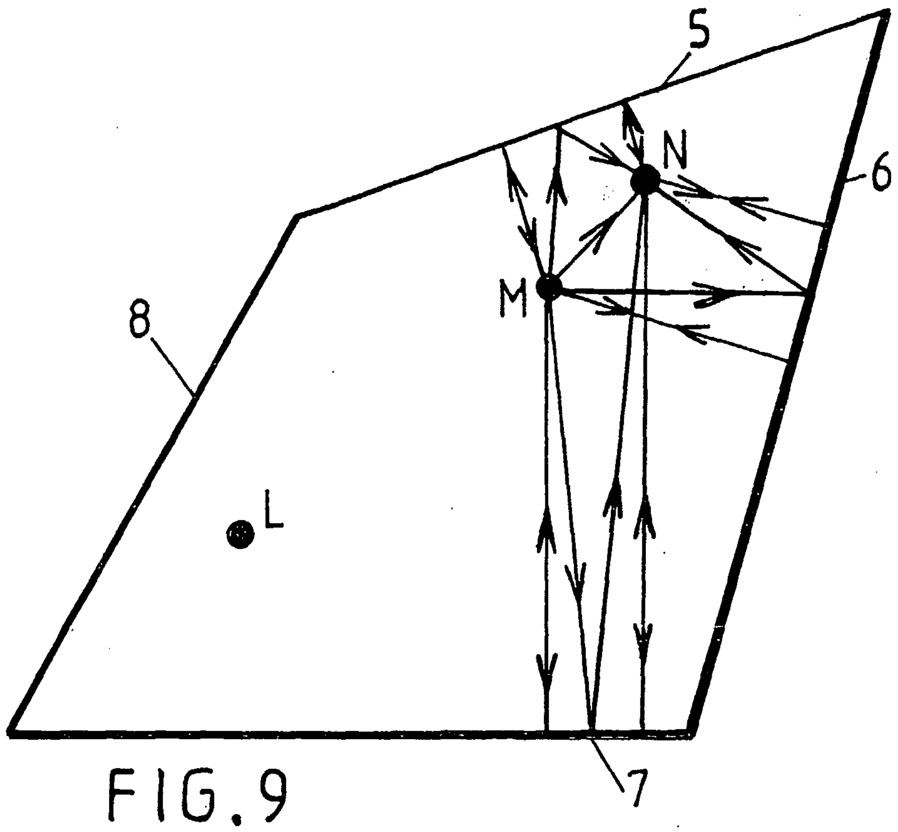

FIG.9

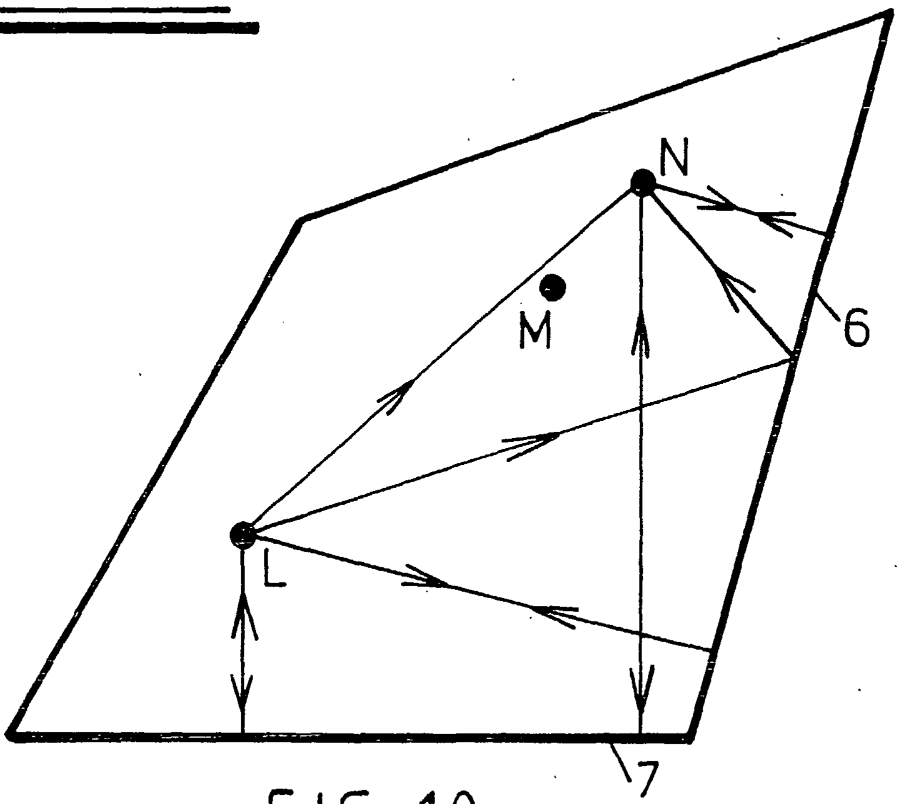

FIG.10

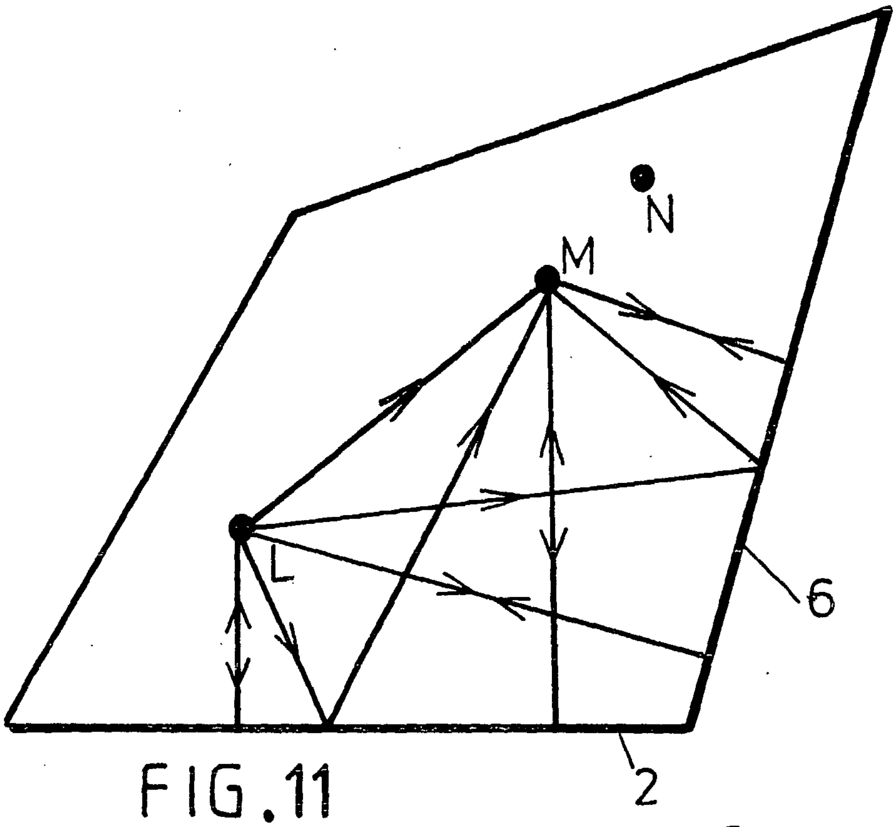

FIG.11

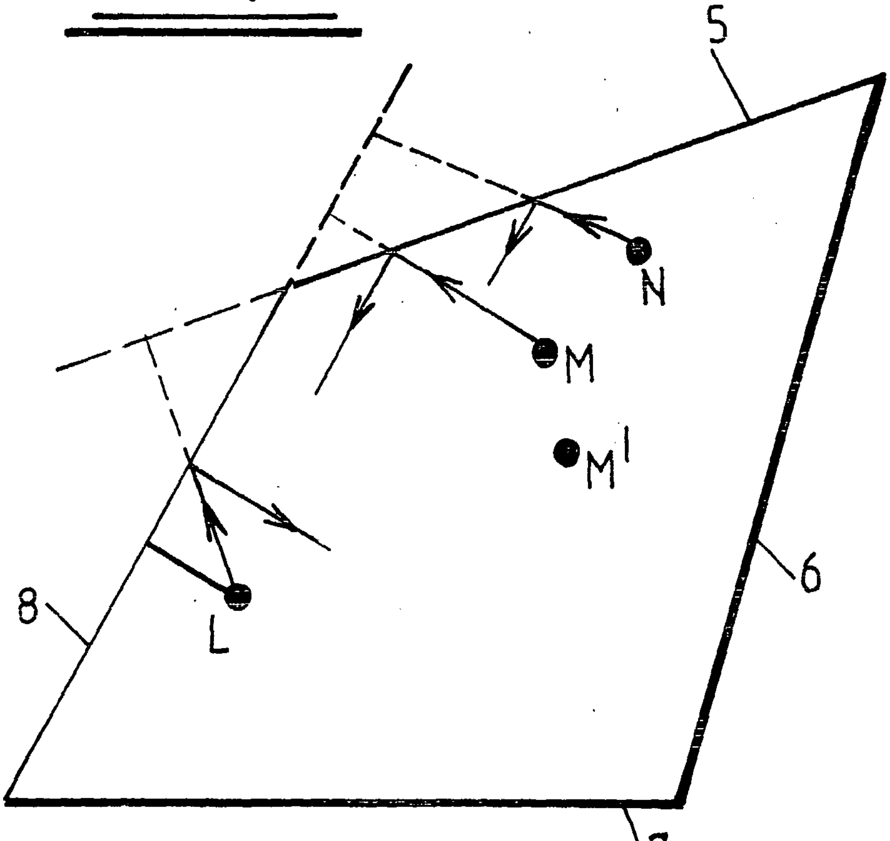

FIG.12