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5 CASE NO: A24362

RADIO SYSTEM

10 The present invention relates to a radio system, and in particular, though not exclusively, to a quasi-synchronous radio system.

15 A simplified example of a quasi-synchronous, bi-directional radio system is shown schematically in Figure 1, where a control centre 1 is connected by fixed links (A,B,C,D) to transceiver (sometimes referred to as transmitter) sites 2,3,4,5. The system of this example is bi-directional permitting two way communication between a mobile 6 and the control centre 1 via the transceivers.

20 In a quasi-synchronous system transmitter (transceiver) sites all radiate the same signal on nominally the same radio channel. Such systems are suitable for wide area coverage over a limited number of radio channels, sometimes only a single channel, and so are often adopted by police, fire and similar utility services. Geographical considerations and transmitter power
25 restrictions, for example, often mean that it is not possible to achieve coverage of the area served by such services with a single transmitter site, so the multiple transmitter site configuration of a quasi-synchronous or synchronous radio system is appropriate.

30 In a quasi-synchronous system the radio frequency carriers are within a few Hertz of each other, while the modulation imposed on the carrier remains synchronous. This is necessary because in regions where the coverage of two neighbouring transmitters overlap, a mobile will receive
35 signals from both transmitters. In such circumstances the two signals must be sufficiently synchronous not to destructively interfere. In a synchronous radio system where the signals radiated from all transmitters are



identical in all respects and in particular are transmitted on the same frequency, the same circumstances may occur.

In a quasi-synchronous radio system the necessary accuracy of radio carrier frequency can be provided by using accurate ovened oscillators at the transmitters. The synchronisation of the modulated signals between neighbouring transmitters requires, typically, an accuracy of:

AM systems: maximum amplitude differential 3dB
10 maximum phase differential 30°
or $0.018f_0$ -
whichever is greater -
(worst case 50 microseconds)

FM systems: maximum amplitude differential 2dB
15 maximum phase differential 10° or $0.007f_0$
whichever is greater
(worst case 20 microseconds)

To achieve this degree of matching it is necessary that the amplitude and phase transfer functions of fixed links between the control centre and its transmitters differ by no more than these limits across the audio band (300Hz-3400Hz). One solution to this problem is to use fixed radio links between the control centre and the transmitters at either VHF or microwave frequencies. These introduce constant delay and can be equalised relatively easily for any differences in their path lengths. Analogue land lines have also been used, but equalisation becomes more of a problem and performance can be poor.

It would be advantageous to be able to use a digital data network to provide the links, for example the Megastream (registered trade mark) service offered by British Telecom which provides customers with 2.048Mb/s digital paths between pairs of sites. Other examples of digital data networks which could be used are Kilostream (registered trade mark) and ISDN (Integrated Services



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Digital Network). By connecting appropriate multiplexers at each end, the digital bearer can be used to carry a variety of traffic, including digital coded audio signals. In general with such digital data networks the connection is not direct, but is provided through a trunk network, with customer access being via a local exchange. A characteristic of such networks is that traffic can reach its destination via more than one route, and the network has the ability to re-route traffic to accommodate equipment failures, traffic fluctuations, etc.

This dynamic re-routing facility is such that there is an uncertainty in the propagation delay which will be experienced by a signal travelling between two network terminations. The variation can be of the order of milliseconds which therefore, apparently, rules out any possibility of using such networks to support quasi-synchronous radio directly.

According to a first aspect the invention provides a radio system comprising : a central source of signals for transmission; a plurality of radio transmitters, each connected to the central source by a digital data transfer link each having a respective transfer delay; means for injecting into a channel of a transfer link a test signal at intended predetermined times, means for determining the travel time of the test signal over a link by establishing the difference between arrival time and the intended predetermined time of transmission, and means for adjusting the transfer delay to at least one of the transmitters to equalise the transfer delays to the transmitters, so that signals from the central source can be transmitted from the transmitters substantially in time synchronism, characterised in that there is correction means for measuring a transmit delay between the intended predetermined transmission time and the actual time of transmission of the test signal, and for sending the length



of the transmit delay over the transfer link, so that the adjustment of transfer delay can be corrected to take account of the transmit delay.

Preferred embodiments of the invention will now be described by way of example and with reference to the accompanying drawings wherein:

Figure 1 is a general schematic diagram of a simplified example of a quasi-synchronous radio system;

Figure 2 is a schematic block diagram of a quasi-synchronous radio system of the preferred embodiment of the invention;

Figure 3 is a timing diagram illustrating the operation of the system of Figure 2;

Referring to Figure 2, the system of the preferred embodiment has a control centre 10, which is a source of and destination for signals, connected to a multiplexer A(51) and thence to a digital data network 52, shown exemplarily as a 2Mb/s Megastream network. Also connected to the data network are further multiplexers (Mux) B, C, D and E(56) at transmitters 13, 14, 15 & 16 at various geographical locations. A test signal source 54, with associated clock 55, is also connected via the multiplexer 51 to the digital data network 52. The digital data network 52, serves four transmitters sites 53, each of which has a respective multiplexer 56, an output of which is connected to a variable delay line 57 which in turn is connected to a respective site transmitter, and a delay measuring unit 58 with associated clock 59, which unit is connected to receive an output from the respective multiplexer 56 and connected to provide a control output to the respective variable delay line 57.

The operation of the system will now be described in general terms. An analogue signal is fed over the digital network 52 to the various sites 13 to 16. These transmissions are multiplexed on the 2.048Mbps digital data



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stream (ie. Megastream), which connects each multiplexer in the network. The path length between each site and the control centre will vary according to the path taken.

The preferred embodiment of the invention works to
5 correct for these path differences, as follows. At pre-defined intervals, such as the start of every minute or every second, the test signal source 54 at the control centre 10 site applies a test signal (either analogue or digital) to the four test channels, 1-4. At each
10 transmitter site the time of arrival of the test signal is identified, and the corresponding propagation time from the control centre is determined. Additional delays are then built into the respective signal paths at each transmitter site, such that the aggregate delay between the control
15 centre and any transmitter is the same.

The maximum delay through digital networks is defined, and the aggregate delay would be chosen to accomodate this. Thus, for example, if the maximum delay through the data network were known to be 8ms, an aggregate delay of 10ms
20 might be appropriate. Then if the delay to multiplexer 2 was 3ms, T2 would be set as 7ms, etc.

This measurement and compensation process would be repeated at regular intervals to accomodate any changes in propagation delay brought about by re-routing within the
25 digital data network.

The operation of the preferred embodiment will now be described in greater detail with reference to figure 3. The clock 55, associated with the control centre 10, and each of the clocks 59, at the various transmitter sites,
30 synchronously generate a precise time marker, shown respectively as 60 and 61 in figure 6, at predetermined intervals, eg every minute or every second. The time marker is a pulse of 20 μ s duration.

As soon as possible following the generation of the
35 time marker, for example at the start of the next clock



cycle, a test signal is transmitted by the test signal source 54 to each of the transmitter sites via the digital data network 52. The delay between occurrence at the control centre 10 of the time marker 60 and the start of transmission of the test signal is termed the "transmit" delay. The transmission of the test signal is followed by a transmission from the control centre to each of the transmitter sites of the length of the transmit delay. This information is transmitted by means of a data packet comprising a 16 bit header forming the test signal followed by an 8 bit field containing the value of the length of the transmit delay.

At each transmitter site at the instant local time marker 61 is generated the delay measuring unit 58 starts a timer. These timers measure the delay before the test signal arrives at each site, and this measured delay is the propagation delay of the data network plus the transmit delay as shown in figure 3.

In order to determine the propagation delay itself the delay measuring unit 58 awaits the transmission of the length of the transmit delay, which follows each test signal, and then subtracts this transmit delay from the measured delay.

It is important for an accurate determination of the propagation delay that the transmit delay is included in the delay calculation because the generation of the time markers is unlikely to be synchronous with the digital data network. This means that not taking the transmit delay into account could result in an error in the propagation delay of up to one bit period of the test signal channel e.g. if the test signal was transmitted via a 64k bit/s channel this would be 15.625µs, which is a significant error.

Having accurately measured the propagation delay of the digital data network to each transmitter site,

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additional delays are then inserted into each signal path by each of the delay lines 57 at the transmitter sites. These additional delays are calculated by each delay measuring unit 58 so as to give a total delay between the
5 control centre and each transmitter of a predetermined value (this value being the same at each transmitter site) which is known to exceed the longest possible transfer delay of the network.

The additional delays inserted by the delay lines can
10 be generated by any convenient method but are preferable generated by passing the digital voice samples carried by the data network through a shift register which operates at a constant rate, but whose length can be varied according to the delay required. Thus, for example if the shift
15 register operated at 1 MHz, a delay of $N\mu s$ could be introduced by passing all audio signal samples through N stages of the shift register.

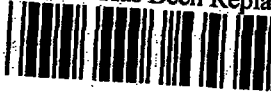
The described embodiment employs separate channels for user data and the test signal. Alternatively, the same channel could be used for both by using time division multiplexing of that channel. In this case the transmit delay would, significantly, be the period between occurrence of the time marker and the time slot for the test signal.

The time markers 60, 61 can be generated by clocks 59 whose synchronism is maintained by any convenient method, but are preferable generated by clocks whose synchronism is maintained via a global positioning satellite (GPS).

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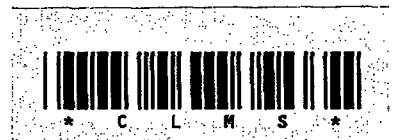


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CLAIMS

1. According to a first aspect the invention provides a radio system comprising : a central source of signals for transmission; a plurality of radio transmitters, each connected to the central source by a digital data transfer link each having a respective transfer delay; means for injecting into a channel of a transfer link a test signal at intended predetermined times, means for determining the travel time of the test signal over a link by establishing the difference between arrival time and the intended predetermined time of transmission, and means for adjusting the transfer delay to at least one of the transmitters to equalise the transfer delays to the transmitters, so that signals from the central source can be transmitted from the transmitters substantially in time synchronism, characterised in that there is correction means for measuring a transmit delay between the intended predetermined transmission time and the actual time of transmission of the test signal, and for sending the length of the transmit delay over the transfer link, so that the adjustment of transfer delay can be corrected to take account of the transmit delay.
2. A radio system as claimed in claim 1, wherein the means for adjusting is operable to adjust the delay of each of the transfer links to be at least equal to the longest transfer delay of the system.
3. A radio system as claimed in claim 1 wherein the means for adjusting is operable to adjust the delay of each of the transfer links to be equal to a predetermined limit.





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4. A radio system as claimed in claim 3, in which the predetermined limit is greater than the longest transfer delay of the system.
5. A radio system as claimed in any previous claim, wherein the delay adjusting means comprises a variable length shift register.
6. A radio system as claimed in claim 5 wherein the shift register operates at a constant rate.
7. A radio system as claimed in any preceding claim wherein each of the central source and radio transmitters has a clock for generating time markers at the intended predetermined times.
8. A radio system as claimed in claim 7 wherein each of the clocks is maintained in synchronism with each of the other clocks via a global positioning satellite.
9. A radio system as claimed in claim 7 or 8 wherein the correction means comprises means for measuring the transmit delay between the generation of a time marker and the transmission of the test signal.
10. A radio system as claimed in any preceding claim wherein the length of the transmit delay is measured at the control centre and is transmitted to the transmitters after the test signal.
11. A quasi-synchronous bi-directional radio system for communicating with a mobile station comprising:
 - a control centre for sourcing signals to, and receiving signals from, mobile stations; a plurality of outlying transceivers for relaying the signals between the





control centre and the mobile stations; for each transceiver a respective link connecting the control centre and the transceiver, and a delay equalizer for equalizing the delay in transfer of signals from the control centre over the links to the transceivers so that the transceivers transmit signals in quasi-synchronism or in synchronism.

12. A method of operating a radio system in which a signal for transmission is disseminated from a central source to a plurality of transmitters at separate sites, comprising the steps of:

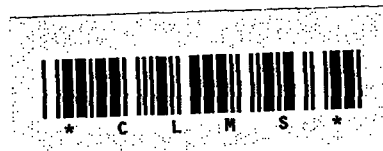
(a) determining the time of transfer of the signal from the central source to each of the transmitter sites, and

(b) delaying the transfer of the signal to at least one of the transmitters, to equalize the transmission times.

13. A radio system substantially as herein described, and with reference to the drawings.

14. A quasi-synchronous radio system substantially as herein described, and with reference to the accompanying drawings.

15. A method of operating a radio system substantially as herein described, and with reference to the accompanying drawings.



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ABSTRACT

A radio system has a control centre 10 for providing signals for transmission to a plurality of radio transmitters (13, 14, 15 & 16) each connected to the central source by a digital data link (12). A delay equaliser (11) measures the variable transfer delay of each data link and adjusts the transfer delay of the transfer links to equalise the transfer delays to transmitters, so that the signals from the control can be transmitted from the transmitters substantially in time synchronism.

Figure 2

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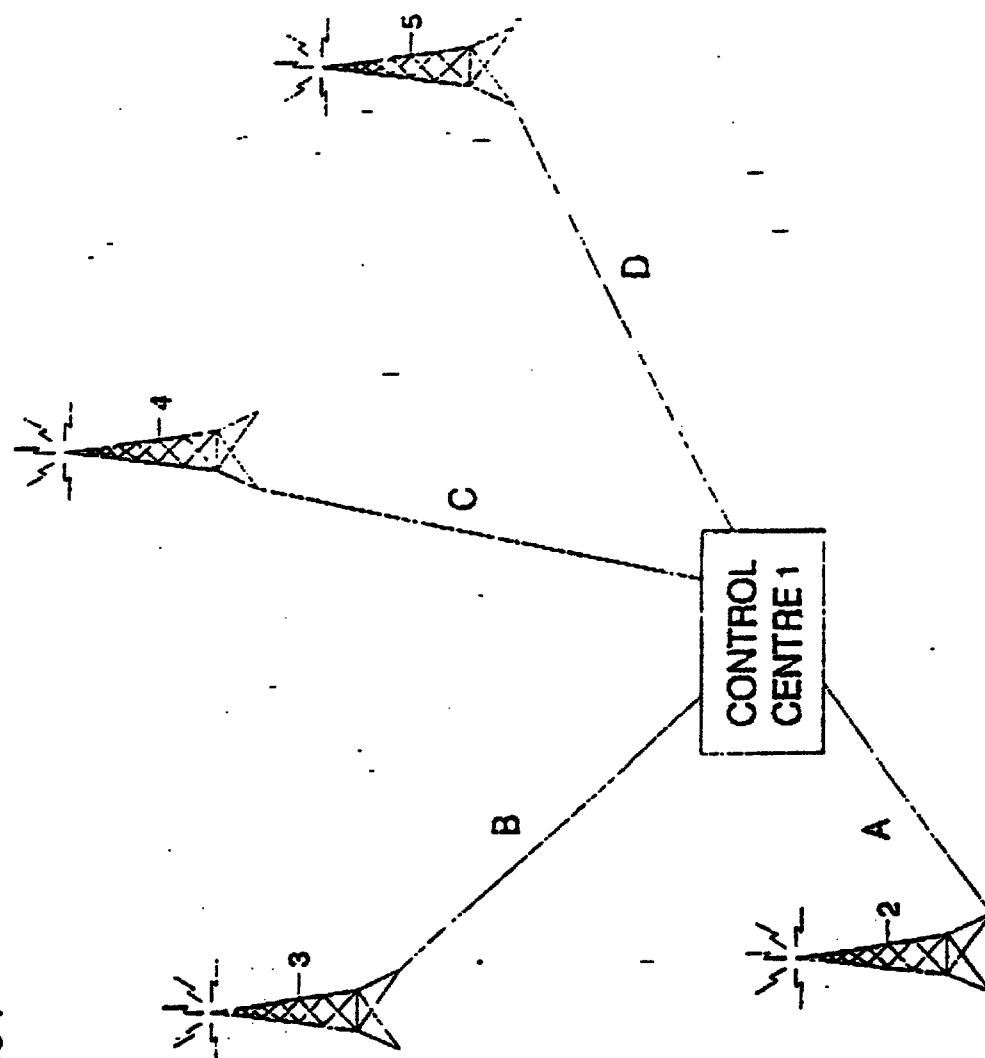


Figure 1

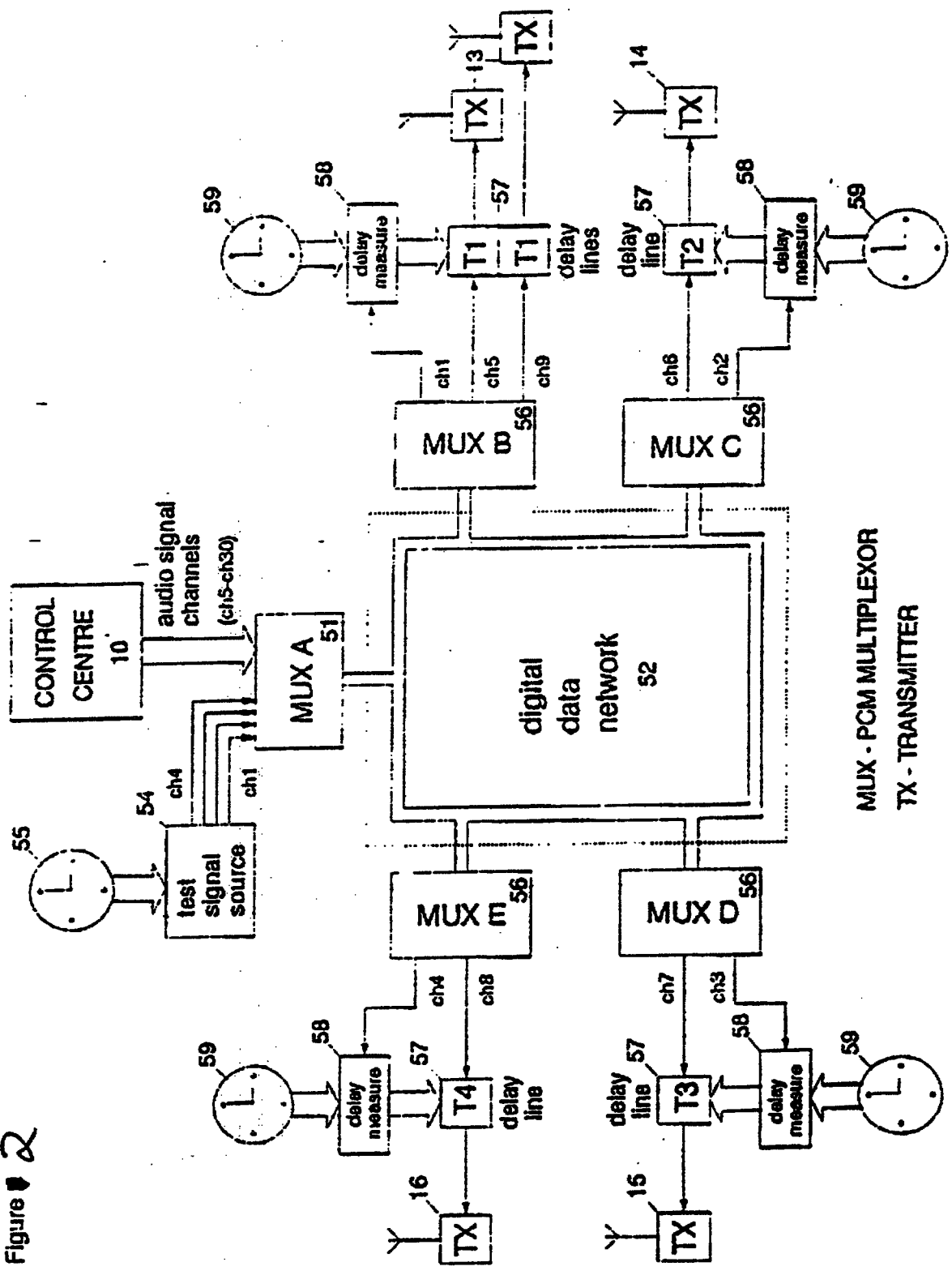
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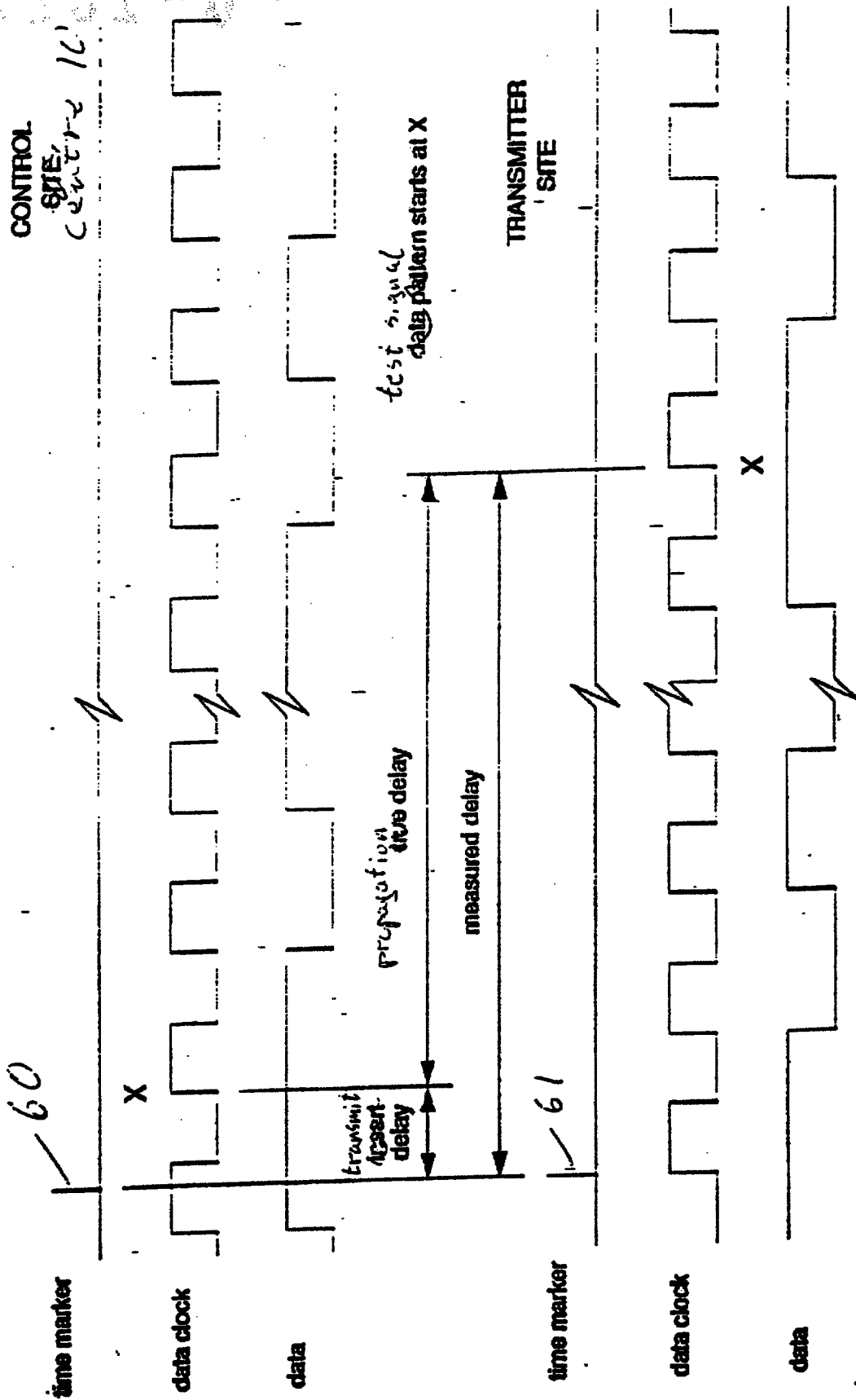
Figure 2



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Figure 3 Digital delay measurement via a synchronous data channel



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RADIO SYSTEM

The present invention relates to a radio system, and in particular, though not exclusively, to a quasi-synchronous radio system.

A simplified example of a quasi-synchronous, bi-directional radio system is shown schematically in Figure 1, where a control centre 1 is connected by fixed links (A, B, C, D) to transceiver (sometimes referred to as transmitter) sites 2, 3, 4, 5. The system of this example is bi-directional permitting two way communication between a mobile 6 and the control centre 1 via the transceivers.

In a quasi-synchronous system transmitter (transceiver) sites all radiate the same signal on nominally the same radio channel. Such systems are suitable for wide area coverage over a limited number of radio channels, sometimes only a single channel, and so are often adopted by police, fire and similar utility services. Geographical considerations and transmitter power restrictions, for example, often mean that it is not possible to achieve coverage of the area served by such services with a single transmitter site, so the multiple transmitter site configuration of a quasi-synchronous or synchronous radio system is appropriate.

In a quasi-synchronous system the radio frequency carriers are within a few Hertz of each other, while the modulation imposed on the carrier remains synchronous. This is necessary because in regions where the coverage of two neighbouring transmitters overlap, a mobile will receive signals from both transmitters. In such circumstances the two signals must be sufficiently synchronous not to destructively interfere. In a synchronous radio system where the signals radiated from all transmitters are

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identical in all respects and in particular are transmitted on the same frequency, the same circumstances may occur.

In a quasi-synchronous radio system the necessary accuracy of radio carrier frequency can be provided by using accurate ovened oscillators at the transmitters. The synchronisation of the modulated signals between neighbouring transmitters requires, typically, an accuracy of:

AM systems: maximum amplitude differential 3dB
maximum phase differential 30°
or $0.018f_0$ -
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(worst case 50 microseconds)

FM systems: maximum amplitude differential 2dB
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To achieve this degree of matching it is necessary that the amplitude and phase transfer functions of fixed links between the control centre and its transmitters differ by no more than these limits across the audio band (300Hz-3400Hz). One solution to this problem is to use fixed radio links between the control centre and the transmitters at either VHF or microwave frequencies. These introduce constant delay and can be equalised relatively easily for any differences in their path lengths. Analogue land lines have also been used, but equalisation becomes more of a problem and performance can be poor.

It would be advantageous to be able to use a digital data network to provide the links, for example the Megastream (registered trade mark) service offered by British Telecom which provides customers with 2.048Mb/s digital paths between pairs of sites. Other examples of digital data networks which could be used are Kilostream (registered trade mark) and ISDN (Integrated Services

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Digital Network). By connecting appropriate multiplexers at each end, the digital bearer can be used to carry a variety of traffic, including digital coded audio signals. In general with such digital data networks the connection is not direct, but is provided through a trunk network, with customer access being via a local exchange. A characteristic of such networks is that traffic can reach its destination via more than one route, and the network has the ability to re-route traffic to accommodate equipment failures, traffic fluctuations, etc.

This dynamic re-routing facility is such that there is an uncertainty in the propagation delay which will be experienced by a signal travelling between two network terminations. The variation can be of the order of milliseconds which therefore, apparently, rules out any possibility of using such networks to support quasi-synchronous radio directly.

According to a first aspect the invention provides a radio system comprising : a central source of signals for transmission; a plurality of radio transmitters, each connected to the central source by a digital data transfer link each having a respective transfer delay; means for injecting into a channel of a transfer link a test signal at intended predetermined times, means for determining the travel time of the test signal over a link by establishing the difference between arrival time and the intended predetermined time of transmission, and means for adjusting the transfer delay to at least one of the transmitters to equalise the transfer delays to the transmitters, so that signals from the central source can be transmitted from the transmitters substantially in time synchronism, characterised in that there is correction means for measuring a transmit delay between the intended predetermined transmission time and the actual time of transmission of the test signal, and for sending the length

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of the transmit delay over the transfer link, so that the adjustment of transfer delay can be corrected to take account of the transmit delay.

Preferred embodiments of the invention will now be described by way of example and with reference to the accompanying drawings wherein:

Figure 1 is a general schematic diagram of a simplified example of a quasi-synchronous radio system;

Figure 2 is a schematic block diagram of a quasi-synchronous radio system of the preferred embodiment of the invention;

Figure 3 is a timing diagram illustrating the operation of the system of Figure 2;

Referring to Figure 2, the system of the preferred embodiment has a control centre 10, which is a source of and destination for signals, connected to a multiplexer A(51) and thence to a digital data network 52, shown exemplarily as a 2Mb/s Megastream network. Also connected to the data network are further multiplexers (Mux) B, C, D and E(56) at transmitters 13, 14, 15 & 16 at various geographical locations. A test signal source 54, with associated clock 55, is also connected via the multiplexer 51 to the digital data network 52. The digital data network 52, serves four transmitters sites 53, each of which has a respective multiplexer 56, an output of which is connected to a variable delay line 57 which in turn is connected to a respective site transmitter, and a delay measuring unit 58 with associated clock 59, which unit is connected to receive an output from the respective multiplexer 56 and connected to provide a control output to the respective variable delay line 57.

The operation of the system will now be described in general terms. An analogue signal is fed over the digital network 52 to the various sites 13 to 16. These transmissions are multiplexed on the 2.048Mbps digital data

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stream (ie. Megastream), which connects each multiplexer in the network. The path length between each site and the control centre will vary according to the path taken.

The preferred embodiment of the invention works to correct for these path differences, as follows. At pre-defined intervals, such as the start of every minute or every second, the test signal source 54 at the control centre 10 site applies a test signal (either analogue or digital) to the four test channels, 1-4. At each transmitter site the time of arrival of the test signal is identified, and the corresponding propagation time from the control centre is determined. Additional delays are then built into the respective signal paths at each transmitter site, such that the aggregate delay between the control centre and any transmitter is the same.

The maximum delay through digital networks is defined, and the aggregate delay would be chosen to accomodate this. Thus, for example, if the maximum delay through the data network were known to be 8ms, an aggregate delay of 10ms might be appropriate. Then if the delay to multiplexer 2 was 3ms, T2 would be set as 7ms, etc.

This measurement and compensation process would be repeated at regular intervals to accomodate any changes in propagation delay brought about by re-routing within the digital data network.

The operation of the preferred embodiment will now be described in greater detail with reference to figure 3. The clock 55, associated with the control centre 10, and each of the clocks 59, at the various transmitter sites, synchronously generate a precise time marker, shown respectively as 60 and 61 in figure 6, at predetermined intervals, eg every minute or every second. The time marker is a pulse of 20 μ s duration.

As soon as possible following the generation of the time marker, for example at the start of the next clock

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cycle, a test signal is transmitted by the test signal source 54 to each of the transmitter sites via the digital data network 52. The delay between occurrence at the control centre 10 of the time marker 60 and the start of transmission of the test signal is termed the "transmit" delay. The transmission of the test signal is followed by a transmission from the control centre to each of the transmitter sites of the length of the transmit delay. This information is transmitted by means of a data packet comprising a 16 bit header forming the test signal followed by an 8 bit field containing the value of the length of the transmit delay.

At each transmitter site at the instant local time marker 61 is generated the delay measuring unit 58 starts a timer. These timers measure the delay before the test signal arrives at each site, and this measured delay is the propagation delay of the data network plus the transmit delay as shown in figure 3.

In order to determine the propagation delay itself the delay measuring unit 58 awaits the transmission of the length of the transmit delay, which follows each test signal, and then subtracts this transmit delay from the measured delay.

It is important for an accurate determination of the propagation delay that the transmit delay is included in the delay calculation because the generation of the time markers is unlikely to be synchronous with the digital data network. This means that not taking the transmit delay into account could result in an error in the propagation delay of up to one bit period of the test signal channel e.g. if the test signal was transmitted via a 64k bit/s channel this would be 15.625µs, which is a significant error.

Having accurately measured the propagation delay of the digital data network to each transmitter site,

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additional delays are then inserted into each signal path by each of the delay lines 57 at the transmitter sites. These additional delays are calculated by each delay measuring unit 58 so as to give a total delay between the control centre and each transmitter of a predetermined value (this value being the same at each transmitter site) which is known to exceed the longest possible transfer delay of the network.

The additional delays inserted by the delay lines can be generated by any convenient method but are preferable generated by passing the digital voice samples carried by the data network through a shift register which operates at a constant rate, but whose length can be varied according to the delay required. Thus, for example if the shift register operated at 1 MHz, a delay of $N\mu s$ could be introduced by passing all audio signal samples through N stages of the shift register.

The described embodiment employs separate channels for user data and the test signal. Alternatively, the same channel could be used for both by using time division multiplexing of that channel. In this case the transmit delay would, significantly, be the period between occurrence of the time marker and the time slot for the test signal.

The time markers 60, 61 can be generated by clocks 59 whose synchronism is maintained by any convenient method, but are preferable generated by clocks whose synchronism is maintained via a global positioning satellite (GPS).

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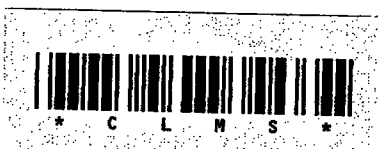
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REPLACEDCLAIMS

1. According to a first aspect the invention provides a radio system comprising : a central source of signals for transmission; a plurality of radio transmitters, each connected to the central source by a digital data transfer link each having a respective transfer delay; means for injecting into a channel of a transfer link a test signal at intended predetermined times, means for determining the travel time of the test signal over a link by establishing the difference between arrival time and the intended predetermined time of transmission, and means for adjusting the transfer delay to at least one of the transmitters to equalise the transfer delays to the transmitters, so that signals from the central source can be transmitted from the transmitters substantially in time synchronism, characterised in that there is correction means for measuring a transmit delay between the intended predetermined transmission time and the actual time of transmission of the test signal, and for sending the length of the transmit delay over the transfer link, so that the adjustment of transfer delay can be corrected to take account of the transmit delay.

2. A radio system as claimed in claim 1, wherein the means for adjusting is operable to adjust the delay of each of the transfer links to be at least equal to the longest transfer delay of the system.

3. A radio system as claimed in claim 1 wherein the means for adjusting is operable to adjust the delay of each of the transfer links to be equal to a predetermined limit.



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4. A radio system as claimed in claim 3, in which the predetermined limit is greater than the longest transfer delay of the system.

5. A radio system as claimed in any previous claim, wherein the delay adjusting means comprises a variable length shift register.

6. A radio system as claimed in claim 5 wherein the shift register operates at a constant rate.

7. A radio system as claimed in any preceding claim wherein each of the central source and radio transmitters has a clock for generating time markers at the intended predetermined times.

8. A radio system as claimed in claim 7 wherein each of the clocks is maintained in synchronism with each of the other clocks via a global positioning satellite.

9. A radio system as claimed in claim 7 or 8 wherein the correction means comprises means for measuring the transmit delay between the generation of a time marker and the transmission of the test signal.

10. A radio system as claimed in any preceding claim wherein the length of the transmit delay is measured at the control centre and is transmitted to the transmitters after the test signal.

11. A quasi-synchronous bi-directional radio system for communicating with a mobile station comprising:

a control centre for sourcing signals to, and receiving signals from, mobile stations; a plurality of outlying transceivers for relaying the signals between the



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control centre and the mobile stations; for each transceiver a respective link connecting the control centre and the transceiver, and a delay equalizer for equalizing the delay in transfer of signals from the control centre over the links to the transceivers so that the transceivers transmit signals in quasi-synchronism or in synchronism.

12. A method of operating a radio system in which a signal for transmission is disseminated from a central source to a plurality of transmitters at separate sites, comprising the steps of:-

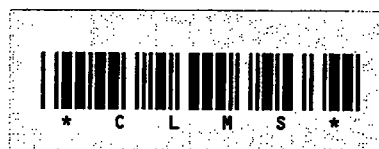
(a) determining the time of transfer of the signal from the central source to each of the transmitter sites, and

(b) delaying the transfer of the signal to at least one of the transmitters, to equalize the transmission times.

13. A radio system substantially as herein described, and with reference to the drawings.

14. A quasi-synchronous radio system substantially as herein described, and with reference to the accompanying drawings.

15. A method of operating a radio system substantially as herein described, and with reference to the accompanying drawings.



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ABSTRACT

RADIO SYSTEM

A radio system has a control centre 10 for providing signals for transmission to a plurality of radio transmitters (13, 14, 15 & 16) each connected to the central source by a digital data link (12). A delay equaliser (11) measures the variable transfer delay of each data link and adjusts the transfer delay of the transfer links to equalise the transfer delays to transmitters, so that the signals from the control can be transmitted from the transmitters substantially in time synchronism.

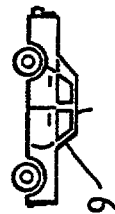
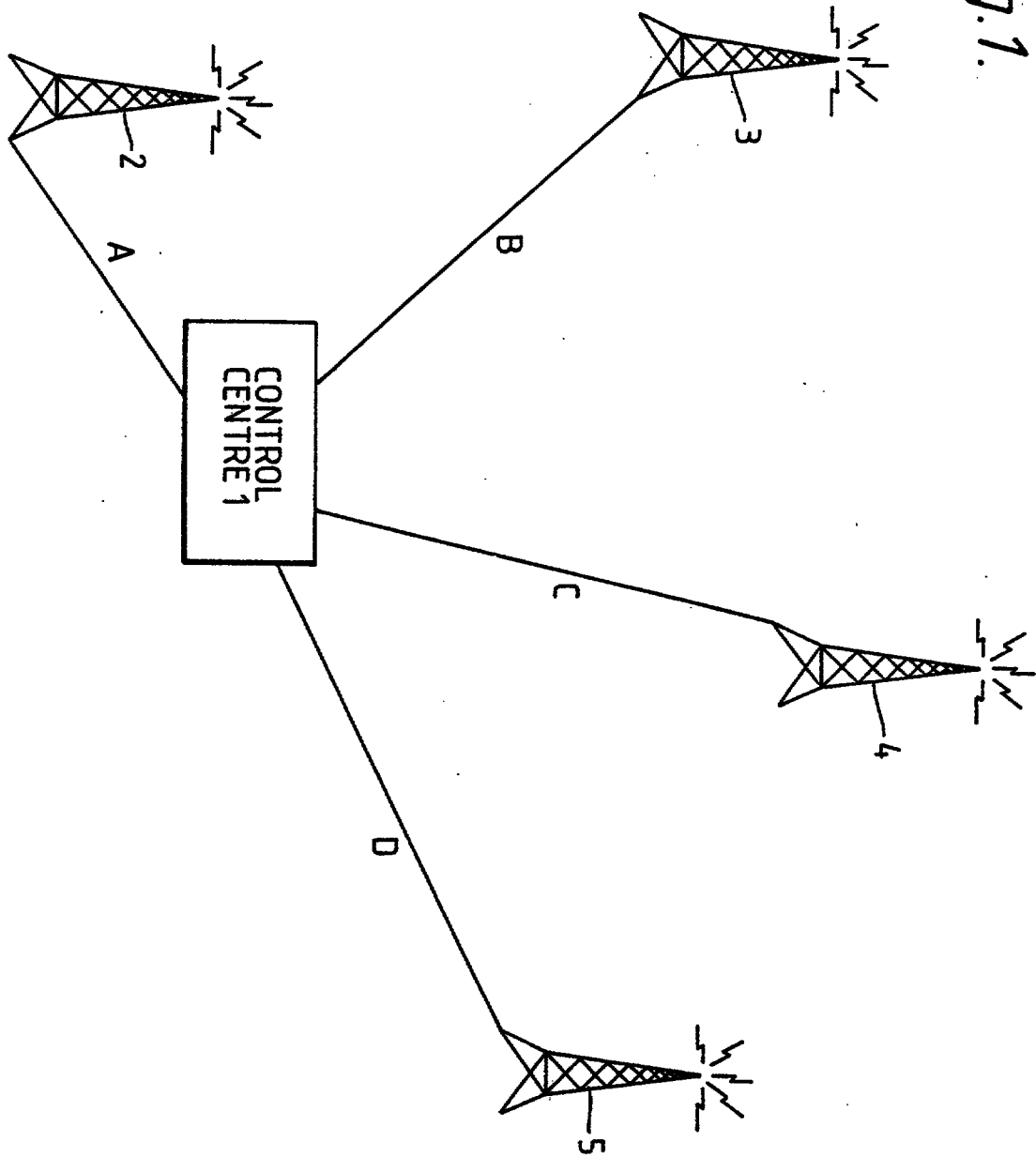
FIG. 2

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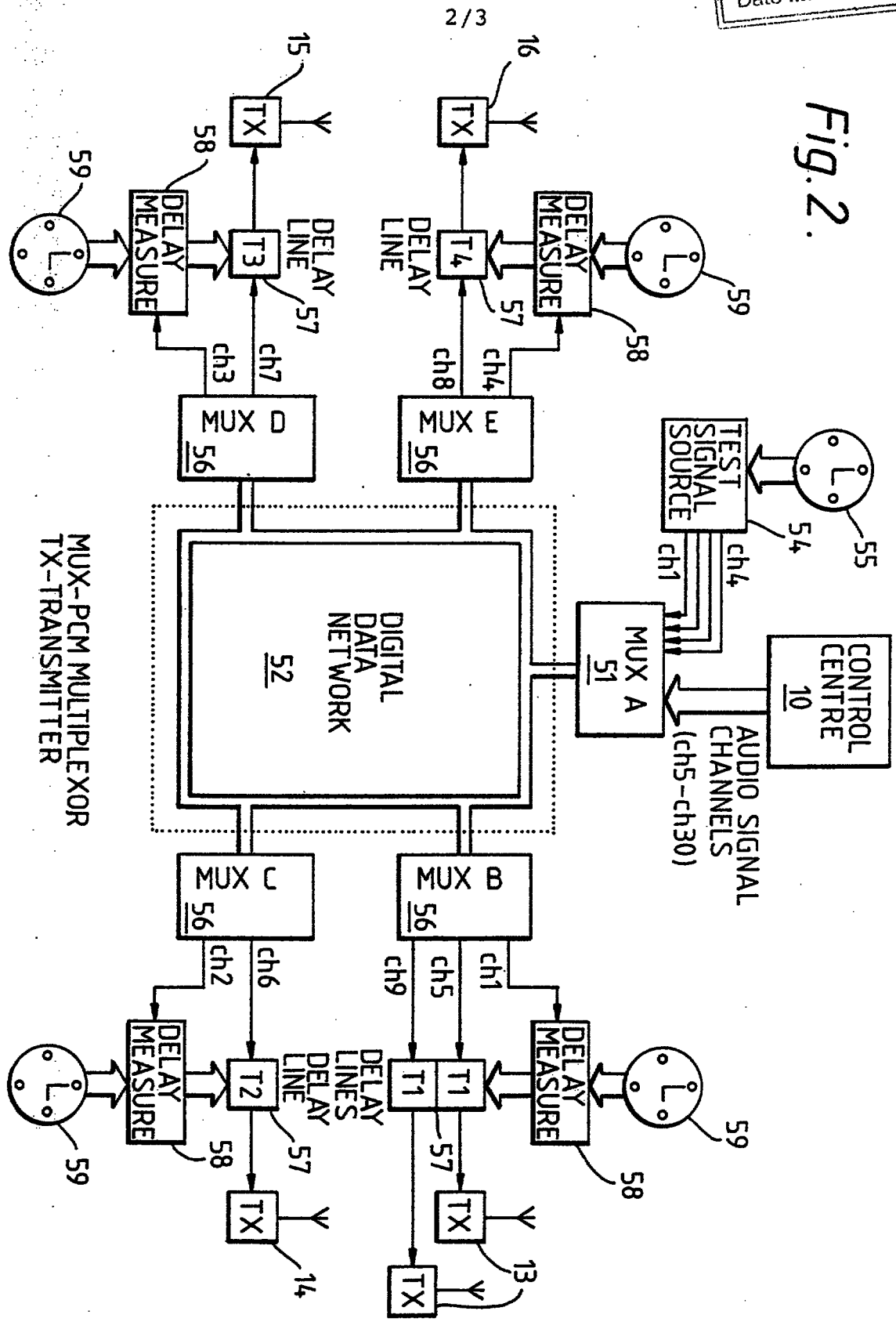
Fig.1.



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Fig. 2.



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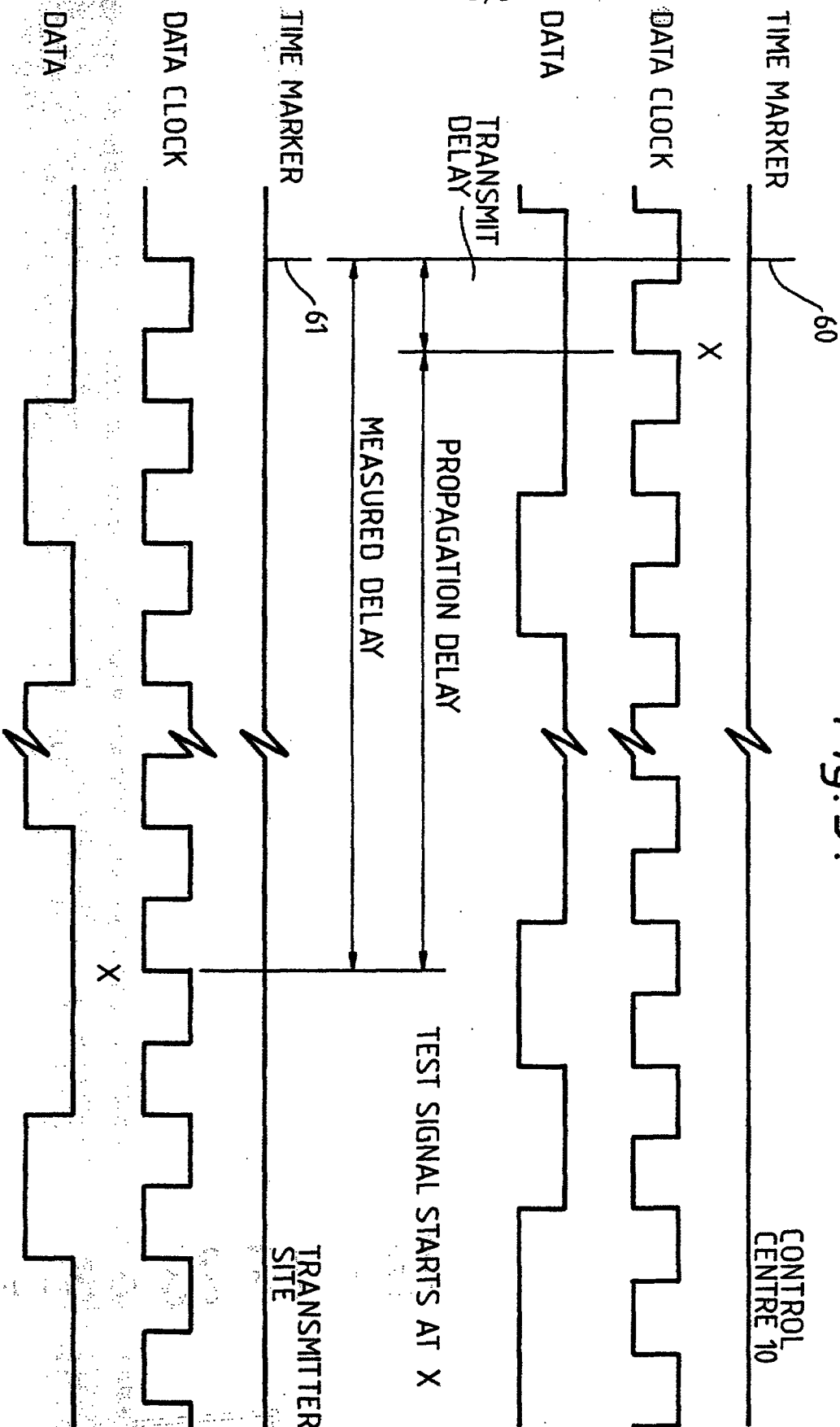


Fig. 3.

RADIO SYSTEM

The present invention relates to a radio system, and in particular, though
5 not exclusively, to a quasi-synchronous radio system.

A simplified example of a quasi-synchronous, bi-directional radio system is shown schematically in Figure 1, where a control centre 1 is connected by fixed links (A,B,C,D) to radio transmitter sites 2,3,4,5. (In a bidirectional system such as this example, the radio transmitters may be referred to as transceivers, and in this
10 specification the term "transmitter" includes transceivers). The system of this example is bi-directional permitting two way communication between a mobile station 6 and the control centre 1 via one of the radio transmitters 2, 3, 4, 5.

In a quasi-synchronous system, radio transmitter (transceiver) sites all radiate the same signal on nominally the same radio channel. Such systems are
15 suitable for wide area coverage over a limited number of radio channels, (sometimes only a single channel), and so are often adopted by police, fire and similar utility services. Geographical considerations, radio transmitter power restrictions, and other factors, often mean that it is not possible to achieve coverage of the area served by such services with a single radio transmitter site,
20 so a multiple radio transmitter-site configuration of a quasi-synchronous or synchronous radio system is appropriate.

In a synchronous radio system the signals radiated from all radio transmitters are identical in all respects (and in particular, they are transmitted on the same frequency). In a quasi-synchronous system the radio carrier frequencies
25 of different radio transmitters are within a few Hertz of each other. In both cases the modulation imposed on the carrier is synchronous. This is necessary because in regions where the coverage of two neighbouring radio transmitters overlap, a mobile station will receive signals from both radio transmitters. In such circumstances the two signals must be sufficiently synchronous not to
30 destructively interfere.

In a quasi-synchronous radio system the necessary accuracy of radio carrier frequency can be provided by using accurate ovened oscillators at the

transmitters. The synchronisation of the modulated signals between neighbouring radio transmitters typically requires the following accuracy:

AM systems: maximum amplitude differential 3dB

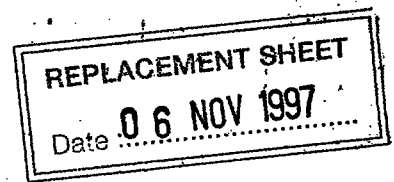
- 5 maximum phase differential 30° , or $0.018f^\circ$
(whichever is greater; worst case 50 microseconds)

FM systems: maximum amplitude differential 2dB

- maximum phase differential 10° , or $0.007f^\circ$
10 (whichever is greater; worst case 20 microseconds)

To achieve this degree of matching it is necessary that the amplitude and phase transfer functions of fixed links between the control centre and its radio transmitters differ by no more than these limits across the audio band
15 (300Hz-3400Hz). One solution to this problem is to use fixed radio links between the control centre and the radio transmitters at either VHF or microwave frequencies. These introduce constant delay and can be equalised relatively easily for any differences in their path lengths. Analogue land lines have also been used, but equalisation becomes more of a problem and performance can be poor.

- 20 It would be advantageous to be able to use a digital data network to provide the links, for example the Megastream (registered trade mark) service offered by British Telecommunications plc which provides customers with 2.048Mb/s digital paths between pairs of sites. Other examples of digital data networks which could be used are Kilostream (registered trade mark) and ISDN
25 (Integrated Services Digital Network). By connecting appropriate multiplexers at each end, the digital bearer can be used to carry a variety of traffic, including digital coded audio signals. In general with such digital data networks the connection is not direct, but is provided through a trunk network, with customer access being via a local exchange. A characteristic of such networks is that they
30 have the ability to re-route traffic to accommodate equipment failures, traffic fluctuations, etc. This dynamic re-routing facility is such that there is an uncertainty in the propagation delay which will be experienced by a signal



travelling between two network terminations. The variation can be of the order of milliseconds.

United States patents 4696051 and 5014344 both describe systems in which the differences in delay are measured against a common timing signal, the variations in delay relative to the signal then being compensated for in each individual link. However, these systems assume that the timing signal is itself synchronised with the digital data network. If this is not the case, the timing signal will itself be delayed by up to one bit period.

According to a first aspect the invention provides a radio system comprising : a central source of signals for transmission; a plurality of radio transmitters, each connected to the central source by a digital data transfer link, each having a respective transfer delay; means for injecting into a channel of a transfer link a test signal at intended predetermined times, means for determining the travel time of the test signal over a link by establishing the difference between arrival time and the intended predetermined time of transmission, and delay adjustment means for adjusting the transfer delay to at least one of the radio transmitters to equalise the transfer delays to the radio transmitters, so that signals originating from the central source can be transmitted from the radio transmitters substantially in time synchronism, and characterised in that there is correction means for measuring a transmit delay between the intended predetermined time of transmission from the central source of the test signal and the actual time of transmission of the test signal, and for sending the length of the transmit delay over the transfer link, so that the adjustment of transfer delay can be corrected to take account of the transmit delay.

According to a second aspect the invention provides a method of operating a radio system in which a signal for transmission is disseminated from a central source to a plurality of radio transmitters at separate sites, each connected to the central source by a digital data transfer link each having a respective transfer delay; the method comprising the steps of:

(a) injecting into a channel of a transfer link a test signal at intended predetermined times,

(b) determining the travel time of the test signal over a link by establishing the difference between arrival time and the intended predetermined time of transmission

(c) measuring a transmit delay between the intended predetermined
5 transmission time and the actual time of transmission of the test signal,

(d) sending the length of the transmit delay over the transfer link, and

(e) adjusting the transfer delay to at least one of the radio transmitters to equalise the transfer delays to the radio transmitters, so that signals originating from the central source can be transmitted from the radio transmitters
10 substantially in time synchronism.

Preferred embodiments of the invention will now be described by way of example and with reference to the accompanying drawings wherein:

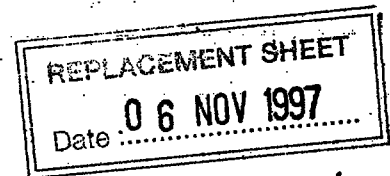
Figure 1 is a general schematic diagram of a simplified example of a quasi-synchronous radio system;

15 Figure 2 is a schematic block diagram of a quasi-synchronous radio system of the preferred embodiment of the invention;

Figure 3 is a timing diagram illustrating the operation of the system of Figure 2;

Referring to Figure 2, the system of the preferred embodiment has a
20 control centre 10, which is a source of and destination for signals, connected to a multiplexer A (51) and thence to a digital data network 52, shown exemplarily as a 2Mb/s Megastream network. Also connected to the data network are further multiplexers (Mux) B, C, D and E (56) at radio transmitters 13, 14, 15 & 16 positioned at various geographical locations. A test signal source 54, with
25 associated clock 55, is also connected via the multiplexer 51 to the digital data network 52. The digital data network 52 serves four radio transmitter sites 53, each of which has a respective multiplexer 56, an output of which is connected to a variable delay line 57 which in turn is connected to the respective site radio transmitter, and a delay measuring unit 58 with associated clock 59, which unit is
30 connected to receive an output from the respective multiplexer 56 and connected to provide a control output to the respective variable delay line 57.

The operation of the system will now be described in general terms.



An analogue signal is fed over the digital network 52 to the various sites 13 to 16. These transmissions are multiplexed on the 2.048Mbps digital data stream (ie. Megastream), which connects each multiplexer in the network. The path length between each site and the control centre will vary according to the path taken. The preferred embodiment of the invention works to correct for these path differences, as follows. At pre-defined intervals, such as the start of every minute or every second, the test signal source 54 at the control centre 10 site applies a test signal (either analogue or digital) to the four test channels, 1-4. At each radio transmitter site the time of arrival of the test signal is identified, and the corresponding propagation time from the control centre is determined. Additional delays are then built into the respective signal paths at each radio transmitter site, such that the aggregate delay between the control centre and any radio transmitter is the same.

The maximum delay through digital networks is defined, and the aggregate delay should be chosen to accommodate this. Thus, for example, if the maximum delay through the data network were known to be 8ms, an aggregate delay of 10ms might be appropriate. Then if the delay to multiplexer 2 were 3ms, T2 would be set as 7ms, etc.

This measurement and compensation process would be repeated at regular intervals to accommodate any changes in propagation delay brought about by re-routing within the digital data network.

The operation of the preferred embodiment will now be described in greater detail with reference to figure 3. The clock 55, associated with the control centre 10, and each of the clocks 59, at the various radio transmitter sites, synchronously generate a precise time marker, shown respectively as 60 and 61 in figure 3, at predetermined intervals, eg every minute or every second. The time marker is a pulse of 20µs duration.

As soon as possible following the generation of the time marker, for example at the start of the next clock cycle, a test signal is transmitted by the test signal source 54 to each of the radio transmitter sites via the digital data network 52. The delay between occurrence at the control centre 10 of the time marker 60 and the start of transmission of the test signal is termed the "transmit" delay. The transmission of the test signal is followed by a transmission from the control

centre to each of the radio transmitter sites of the length of the transmit delay. This information is transmitted by means of a data packet comprising a 16 bit header forming the test signal followed by an 8 bit field containing the value of the length of the transmit delay.

5 At each radio transmitter site at the instant local time marker 61 is generated the delay measuring unit 58 starts a timer. These timers measure the delay before the test signal arrives at each site, and this measured delay is the propagation delay of the data network plus the transmit delay as shown in figure 3.

10 In order to determine the propagation delay itself the delay measuring unit 58 awaits the transmission of the length of the transmit delay, which follows each test signal, and then subtracts this transmit delay from the measured delay.

 It is important for an accurate determination of the propagation delay that the transmit delay is included in the delay calculation because the generation of the
15 time markers is unlikely to be synchronous with the digital data network. This means that not taking the transmit delay into account could result in an error in the propagation delay of up to one bit period of the test signal channel. For example, if the test signal was transmitted via a 64k bit/s channel this would be 15.625µs, which is a significant error.

20 Having accurately measured the propagation delay of the digital data network to each radio transmitter site, additional delays are then inserted into each signal path by each of the delay lines 57 at the radio transmitter sites. These additional delays are calculated by each delay measuring unit 58 so as to give an aggregate delay between the control centre and each radio transmitter of a
25 predetermined value (this value being the same at each radio transmitter site) which is known to exceed the longest possible transfer delay of the network.

 The additional delays inserted by the delay lines can be generated by any convenient method but are preferably generated by passing the digital voice samples carried by the data network through a shift register which operates at a
30 constant rate, but whose length can be varied according to the delay required. Thus, for example if the shift register operated at 1 MHz, a delay of Nµs could be introduced by passing all audio signal samples through N stages of the shift register.

The described embodiment employs separate channels for user data and the test signal. Alternatively, the same channel could be used for both, by using time division multiplexing of that channel. In this case the transmit delay could be quite significant, being the period between occurrence of the time marker and the
5 time slot for the test signal.

The time markers 60, 61 can be generated by clocks 59 whose synchronism is maintained by any convenient method, but are preferable generated by clocks whose synchronism is maintained via a global positioning satellite system (GPS).

CLAIMS

1. A radio system comprising : a central source (10) of signals for transmission; a plurality of radio transmitters (13, 14, 15, 16), each connected to
5 the central source by a digital data transfer link (1, 2, 3, 4, 5, 6, 7, 8, 9), each having a respective transfer delay; means (54) for injecting into a channel of a transfer link a test signal at intended predetermined times, means (58) for determining the travel time of the test signal over a link by establishing the difference between arrival time and the intended predetermined time of
10 transmission, and delay adjustment means (57) for adjusting the transfer delay to at least one of the radio transmitters to equalise the transfer delays to the radio transmitters, so that signals originating from the central source (10) can be transmitted from the radio transmitters substantially in time synchronism, characterised in that there is correction means (54) for measuring a transmit delay
15 between the intended predetermined time of transmission from the central source (10) of the test signal and the actual time of transmission of the test signal, and for sending the length of the transmit delay over the transfer link, so that the adjustment of transfer delay can be corrected to take account of the transmit delay.

20

2. A radio system as claimed in claim 1, wherein the delay adjustment means (57) is operable to adjust the transfer delay of each of the transfer links to be at least equal to the longest transmit delay of the system.

25

3. A radio system as claimed in claim 1 or claim 2 wherein the delay adjustment means (57) is operable to adjust the transfer delay of each of the transfer links to be equal to a predetermined limit.

30

4. A radio system as claimed in any previous claim, wherein the delay adjustment means (57) comprises a variable length shift register.



5. A radio system as claimed in claim 4 wherein the shift register operates at a constant rate.
- 5 6. A radio system as claimed in any preceding claim wherein each of the central source (10) and radio transmitters (13, 14, 15, 16) has a clock (59) for generating time markers at the intended predetermined times.
- 10 7. A radio system as claimed in claim 6 wherein each of the clocks (59) has means for maintaining it in synchronism with each of the other clocks via a global positioning satellite.
- 15 8. A radio system as claimed in claim 6 or 7 wherein the correction means (54) comprises means for measuring the transmit delay between the generation of a time marker and the transmission of the test signal.
- 20 9. A radio system as claimed in any preceding claim having means in the control centre (10) for measuring the transmit delay and transmitting the delay to the radio transmitters.
- 25 10. A radio system according to any preceding claim wherein the radio transmitters are arranged to transmit quasi-synchronously on different carrier frequencies.



11. A method of operating a radio system in which a signal for transmission is disseminated from a central source (10) to a plurality of radio transmitters (13, 14, 15, 16) at separate sites, each connected to the central source by a digital data transfer link each having a respective transfer delay; the method comprising the
5 steps of:

- (a) injecting into a channel of a transfer link a test signal at intended predetermined times,
- (b) determining the travel time of the test signal over a link by
10 establishing the difference between arrival time and the intended predetermined time of transmission
- (c) measuring a transmit delay between the intended predetermined transmission time and the actual time of transmission of the test signal,
- (d) sending the length of the transmit delay over the transfer link, and
- (e) adjusting the transfer delay to at least one of the radio transmitters
15 (13, 14, 15, 16) to equalise the transfer delays to the radio transmitters, so that signals originating from the central source (10) can be transmitted from the radio transmitters substantially in time synchronism.

12. A method according to claim 11, wherein the transfer delay of each of the
20 transfer links is adjusted to be at least equal to the longest transmit delay of the system.

13. A method according to claim 11 or claim 12, wherein transfer delay of each of the transfer links is adjusted to be equal to a predetermined limit.
25

14. A method according to claim 11, 12, or 13 wherein the length of the transmit delay is measured at the central source (10) and is transmitted to the radio transmitters (13, 14, 15, 16) after the test signal.

30 15. A method according to claim 11, 12, 13, or 14 wherein the radio transmitters transmit quasi-synchronously on different carrier frequencies.

