Title: HBRE OPTIC SYSTEM FOR ANALOGUE COMMUNICATION BETWEEN A FIRST STATION AND A SECOND STATION COMPRISING AN ANTENNA UNIT

Abstract: A communication system has a first device, a second device and at least one optical fibre. The first device has an electrical node and an optical node, and the second device has an optical node, an antenna and circuitry for electrically driving the antenna according to signals received at the optical node. The optical fibre links the optical nodes of the first and second devices and the system is configured to permit analogue communication to the antenna from the first device. The circuitry of the second device includes processing means connected to receive commands sent from the first device over the optical fibre for controlling said circuitry.
before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments.

For two-letter codes and other abbreviations, refer to the “Guidance Notes on Codes and Abbreviations” appearing at the beginning of each regular issue of the PCT Gazette.
The present invention relates to a communication system, an optical communication system, to a method of setting up an antenna unit, to a method of setting up a laser transmitter, to a method of controlling a laser transmitter, to a method of controlling an optical communication system and to a method of operating a transmission system.

Digital communication systems are known in which packets of external data are carried using optical fibres as the transmission medium between stations. It is known in such systems to transfer command or monitoring data over the optical fibre—referred to herein as "internal data"—to enable housekeeping or diagnostic communication between stations. Such communication uses the optical fibre as a "dumb pipe" and usually requires complex software in the stations to identify which packets of data are of this type and which packets of data are for external use. The internal data are carried as digital data since the whole communication system is digital; imperfections due to the transmission media are usually catered for by pulse regeneration circuitry in the relevant stations.

It is also known to communicate using radio-over-fibre, namely transmission of optical signals representing modulated or un-modulated RF waves over an optical fibre. RF signals that may be transmitted in this way include, for example, those from mobile radios, cordless telephones, cellular mobile telephones and wireless LAN-enabled devices.

Among the advantages of radio over fibre (ROF) are the facts that optical fibres afford high data transfer rates, and are relatively immune from electrical noise or intrusion.
Wireless networks that allow digital communication between a central unit such as a server and plural wireless devices, via one or more antenna units, are well known. The wireless devices may for example be laptop computers. The antenna units may each be disposed in different rooms or on different floors of a building to provide communication between the wireless devices and a server.

Yet other wireless networks may convey signals typically signals originating outside the network between base or hub units and plural antenna units, typically located in different areas of a building or other facility. Such systems are called distributed antenna systems (DAS). Some DAS use, as transmission medium, one or more optical fibres, carrying baseband digital signals - i.e. digital signals that are not modulated on a carrier- to send digital data over optical fibres. This means that optical radiation carried by the fibre corresponds to on/off electrical signals- the optical radiation may be provided by on/off switching of a light source such as an LED, but is more likely to be provided by switching the output between two defined "on" levels. The optical fibre part of the system is dedicated to digital transmission as it responds to, for example, transitions in level at known clock intervals rather than being versatile enough to respond to signals whose form is arbitrary - e.g. analogue signals, or digital signals modulated on an RF carrier. To achieve this, A/D conversion of arbitrary signals- e.g. signals that may be either analogue or digital- may be provided before the resulting signals are applied to a laser launching light into the fibre; at the antenna end, the digital pulses from the fibre are D/A converted. Demodulation for example to an LF. may be needed before A/D conversion, with re-modulation of the LF. regenerated at the D/A converter before radiation from the antenna.
A typical example of such a system will be described later herein with respect to Fig1.

It is also known to transmit analogue, or signals of arbitrary form, as ROF using single-mode optical fibre (SMF). SMF provides easier conditions for RF than multimode fibre (MMF) because MMF has intermodal dispersion that limits data rates and/or transmission distance. However, there may be situations where use of MMF is desirable. Indeed where pre-installed fibres are to be used, these may be MMF, and on cost grounds alone it may be necessary to use those fibres rather than replacing with SMF. In turn, this may allow relatively relaxed coupling tolerances and reduced system-wide installation and maintenance costs.

As is known to those skilled in the art, optical fibres are specified by a modal bandwidth, e.g. 500 MHz.km. Again, as is known in the art, typically for MMF the modal bandwidth is specified in terms of frequency times length and represents the guaranteed performance for an over-filled launch condition, measured under pulse conditions. In this example the performance is such that for 1 km of fibre, a bandwidth of 500 MHz is guaranteed. However, for 2 km, only 250 MHz is guaranteed. The limitation is largely due to modal dispersion, which results in perceived smearing of a pulse due to the different group delays of different transmission modes in the fibre. Other launch conditions have been found to give rise to guaranteed transfer of digital signals (where transition information is sufficient for signal reconstitution) beyond the modal bandwidth limit. The present applicants have identified that optical fibres, especially pre-installed MMFs, can be used in versatile systems that carry arbitrary signals - for example 3G mobile phone signals - with acceptable signal performance even where fibre defects exist. At least some MMFs
respond to restricted mode launch, as has been shown by EVM (error vector magnitude) measurements on different fibres with different restricted modes.

It has been proposed to use restricted mode techniques to guarantee the modal bandwidth of an MMF to allow transition data of digital optical signals to be conveyed at relatively high bit rates for longer lengths.

The present inventors proposed in WO 2004/056019 to carry signals of arbitrary form over MMFs, and identified that by using restricted mode launches selected for particular fibres, a capability exists to provide fidelity in amplitude, phase or amplitude and phase information despite various defects in the fibres concerned.

More specifically, the present inventors have proposed a radio over fibre system in which the fibre carries optical signals corresponding to electrical signals that comprise information modulated onto RF carriers. The system can carry optical information corresponding to GHz-frequency range modulated signals for km, and still allow for good fidelity.

There is a problem however in such systems in that additional communications links may be needed to convey digital control information over the system, or to convey diagnostic commands and setting parameters. This may apply during operation but may also apply for example during system set-up.

According to a first aspect of the invention, there is provided a communication system comprising a first device, a second device and at least one optical fibre, the first device having an electrical node and an optical node, the second device having an optical node, an antenna and circuitry for electrically driving the antenna according to signals received at the optical node, and the optical fibre
linking the optical nodes of the first and second devices, the system being configured to permit analogue communication to the antenna from the first device, wherein the circuitry of the second device includes processing means connected to receive commands sent from the first device over the optical fibre for controlling said circuitry.

The first device may have means for providing commands for the second device, the means including a frequency modulation device and a controller for dynamically selecting a modulation frequency of the frequency modulation device to avoid frequencies of said signals.

In another aspect there is provided a communication system comprising a first device, a second device and at least one optical fibre, the first device having an electrical node and an optical node, the second device having an optical node, an antenna and circuitry for electrically driving the antenna according to signals received at the antenna, and the optical fibre linking the optical nodes of the first and second devices, the system being configured to permit analogue communication from the antenna from the first device, wherein the circuitry of the first device includes processing means connected to receive commands sent from the first device over the optical fibre for controlling said circuitry.

The second device may have means for providing commands for the first device, the means including a frequency modulation device and a controller for dynamically selecting a modulation frequency of the frequency modulation device to avoid frequencies of said signals received at the antenna.

The first device may comprise an electro-optical transducer for receiving electrical signals from the electrical node and converting into corresponding optical signals for output at said optical node for transmission by said optical
fibre, and an opto-electrical transducer for receiving optical signals input to the
optical node from the optical fibre and converting into corresponding electrical
signals for output at said electrical node.

Each device may include transmission means responsive to the parameters of
traffic being carried by the system, and operable to cause communication in
such a way as to not interfere with the traffic.

The second device may comprise an opto-electrical transducer for receiving
optical signals input to the optical node thereof from the optical fibre and
converting into corresponding electrical signals for output at said antenna via
said circuitry, and an electro-optical transducer for receiving electrical signals
from the antenna via said circuitry and converting into corresponding optical
signals for output at said optical node for transmission by said optical fibre.

The system may be configured to carry signals modulated on an RF carrier.

The circuitry may include demodulating means for extracting signals
containing said commands from said corresponding electrical signals in said
second device.

The circuitry may include power amplifier means for driving said antenna.

The circuitry may include signal amplifier means for receiving signals from
said antenna and for driving said electro-optical transducer in accordance
therewith.

According to a further aspect of the invention, there is provided a
communication system comprising a first device, a second device and at least
one optical fibre, the first device having an electrical node and an optical node,
the second device having an optical node, an antenna and circuitry for electrically driving the antenna according to signals received at the optical node, and the optical fibre linking the optical nodes of the first and second devices, the system being configured to permit analogue communication to the antenna from the first device, wherein the circuitry of the second device includes processing means connected to receive commands sent from the first device over the optical fibre for controlling said circuitry, each device having a respective laser for converting electrical signals into optical signals for output at the respective optical node to the fibre, and a respective photodiode for converting optical radiation received at the fibre into respective electrical signals.

In an embodiment, the first device has means for generating digital command signals, and a processing circuit for modulating the digital command signals onto an RF carrier, the second device has demodulating circuitry for extracting signals containing said commands from electrical signals in said second device.

The circuitry of the second device may include one or more of power amplifier means for driving said antenna, signal amplifier means for receiving signals from said antenna and for modulating the output of the laser of the second device in accordance therewith, bias circuitry for driving said laser and RF power monitoring means.

The command signals may be commands to adjust parameters of said circuitry.

The command signals may be commands causing readout of parameters of said circuitry in the form of a digital representation thereof, and the second device may include means for modulating data corresponding to the digital representation onto an RF carrier for application to the laser of the second
device whereby the parameters are transmitted via the fibre and demodulating circuitry of the first device to the first device.

The first device may have a processor and an external input/output to and from the processor, whereby control inputs at said external input/output may control the second device and/or parameter information may be output from said external input/output.

According to yet another aspect of the invention there is provided a method, suitable for use in a distributed antenna system, of controlling an antenna unit, wherein the antenna unit is connected to a base station via at least one optical fibre, the method comprising providing electrical control signals, modulating the control signals onto a RF carrier, converting the modulated control signals to corresponding optical signals, carrying the optical signals to at least one antenna unit over an optical fibre, converting the optical signals to corresponding electrical signals and demodulating the corresponding electrical signals to derive the control signals.

According to a still further aspect of the invention is provided a method of setting up a laser transmitter at the head end of an optical fibre communication system having a remote node including an antenna, the method comprising sensing a parameter of received signals at the remote node, modulating data indicative of the parameter onto an RF carrier to provide a modulated electrical signal and transferring optical signals corresponding to the modulated electrical signal to the head end.

According to yet another aspect of the invention there is provided a method of operating a transmission system having a first station coupled to a second station via an optical link, the method comprising: emitting a signal from the first station over the optical link such that a version of the signal is received at
the second station; determining a parameter of the received version at the second station, and in response thereto, generating a control signal indicative of the parameter at the second station; sending the control signal from the second station to the first station over the optical link; and using the control signal in the first station to control the first station.

The first station may be controlled by the control signal to modify transmission parameters of the first station.

The control signal may be used to improve the correspondence between the received version of the signal and the emitted signal.

In a yet further aspect, there is provided a communication system comprising a first device, a second device and at least one optical fibre, the first device having an electrical node, an optical node, and circuitry for driving the optical node in response to signals received at the electrical node, the second device having an optical node, and an electrical node, and the optical fibre linking the optical nodes of the first and second devices, the system being configured to permit analogue communication to the second device from the first device, wherein the circuitry of the first device includes processing means connected to receive commands sent from the second device over the optical fibre for controlling said circuitry.

The second device may have an antenna connected to the electrical node of the second device.

The antenna may be physically remote from the fibre, and may be connected to circuitry interfacing with the fibre via conductive means. Amplifiers, for example buffers for impedance conversion may be provided.
Embodiments of the invention will now be described by way of example with reference to the drawings of which:

Fig. 1 is a schematic diagram of a known system for transmitting digital signals over optical fibre;

Fig. 2 is a schematic diagram of a communication system embodying the invention;

Fig. 3 shows a block schematic diagram of an example of an optical module for use in the system of Fig. 2; and

Fig. 4 shows a partial block diagram of processing circuits of the base unit and antenna unit of Fig. 1.

Referring to Fig. 1, an example of a known optical communication system 1100 has a base unit 1120 connected to an antenna unit 1140 via first and second multimode optical fibres 1105 and 1115 defining respective transmission directions. The system 1100 is configured to transfer signals outward from the base unit 1120 to the antenna unit 1140 over the first fibre 1105 and to transfer signals inward from the antenna unit 1140 to the base unit 1120 over the second fibre 1115.

The base unit 1120 has an electrical input/output node 1101 connected to a first processing circuit 1110 having an electrical output 1103a and an electrical input 1113a. The electrical output 1103a is connected to the input of a laser diode 1103, having an optical output 1103b. The base unit 1120 also has a photodetector 1113, having an optical input and providing electrical signals to the electrical input 1113a of the first processing circuit 1110.

The antenna unit 1140 has a photodetector 1107 having an electrical output 1107a. The electrical output 1107a is connected to the electrical input of a
second processing circuit 1130 also having an electrical output 1117a and an electrical input/output node 1130a. The electrical input/output node 1130a couples to an antenna 1150. The electrical output 1111a is connected to the input of a laser diode 1117.

Turning to the fibres 1105, 1115, the optical output 1103b of the laser diode 1103 of the hub unit 1120 is coupled to the first fibre 1105, at one end thereof. The other end of the first fibre 1105 is coupled to the optical input 1107b of the photodetector 1107 of the antenna unit 1140. The laser diode 1117 of the antenna unit 1140 couples to the second fibre 1115 at one end thereof. At the other end thereof the second fibre 1115 is coupled to the optical input 1113b of the photodetector 1113 of the base unit 1110.

In use, signals, e.g. GSM signals are received at the electrical input/output node 1101 of the base unit 1110, for example from a base transceiver station.

Referring now to Fig 4, an example of a processing circuit 1110 has a crystal oscillator 402 having its output connected to one input of a mixer 401, to whose other input is connected the electrical input/output node 1101. The demodulated output of the mixer 403 is fed to an A/D converter 403, whose output forms control signals 1103a for the laser diode 1103.

Returning to Fig 1, the control signals 1103a are used for controlling the bias current to the laser diode 1103. In the described embodiment the laser diode 1103 is directly modulated by the control signals at the output 1103a. It will however be understood that the optical output of the laser diode 1103 may not cycle between the on and off states but instead may cycle between two different intensity levels in response to digital signals at the input 1101.
Light is launched from the laser diode 1103 into the first multimode optical fibre 1105 using a centre launch in this particular embodiment. However it is has been previously found that it may be possible to allow higher data rates to pass through the fibre if an off-centre launch, chosen for the fibre concerned, is used. Such a launch which can provide a desired limited set of modes in the fibre may be used to overcome modal dispersion.

Light travels through the first fibre 1105 and is incident upon the photodetector 1107 of the antenna unit 1140. The electrical output 1107a of the photodetector 1107 is provided to the processing circuit 1130 of the antenna unit 1140.

Returning to Fig 4, the electrical output signals 1107a are fed to a D/A converter 411. The analogue output of the D/A converter 411 is fed as on input to a modulator 412, to whose other input is fed the output of a crystal oscillator 413. Synchronising information may be derived from the D/A converter so that the oscillator output is synchronous with that of the oscillator of the base unit. The output of the modulator 412 forms the electrical output 1150d of the antenna unit, so that the signals at the antenna 1150 correspond to those received at input 1101. Similar considerations apply to signals received at the antenna 1150 and destined for the output 1101.

The length of the optical fibres 1105-1115 is typically restricted by the modal bandwidth in conjunction with the data rate. Thus, if high speed data are required to be carried by the optical fibres 1105-1115, then the pulse smearing effect of the different excitation modes in the fibres restricts the total fibre length over which the data can be carried with good fidelity.
Referring to Fig. 2, an optical communication system 200 has a base unit 225 connected to one antenna unit 240 via first and second multimode optical fibres 205 and 215 defining respective transmission directions, and to a like antenna unit 240a via further MMFs 205a, 215a. The system 200 is configured to transfer signals outward from the base unit 225 to the antenna unit 240 over the first fibre 205 and to transfer signals inward from the antenna unit 240 to the base unit 225 over the second fibre 215. Similar considerations apply to the second antenna unit 240a.

The base unit 225 has a first electrical input/output node 201, an electrical input node 202 and an electrical output node 203, an optical output 205b and an optical input 215b. The base unit 225 contains a first processing circuit 210 to which the first electrical input/output node 201 is connected, a second processing circuit 265 having a first output 266 and a first input 267 coupled respectively to the electrical input node 202 and the electrical output node 203, and a digital input/output 268. The digital input/output 268 of the second processing circuit 265 is connected to a third processing circuit 260, which is also connected to the first processing circuit 210 via a two-way link 261. The first processing circuit 210 has a further input 211 and an output 212 connected respectively as input to and output from optical modules 220, 220a. The electrical input node 202 and the electrical output node 203 are also connected to the optical modules 220, 220a. The first electrical input/output node 201 is adapted to carry digital signals to and from the first processing circuit 210, which in this embodiment is a microprocessor. The electrical input node 202 and electrical output node 203 are, in this embodiment, connected to receive and respectively send analogue signals. They are shown as directly connected to the optical modules 220, 220a, but there may of course be circuitry interposed for example, buffer circuits, level changing circuits and the like.
Referring now to Fig. 3, an embodiment of an optical module 230 consists of two portions, an optical transmitter portion 100a and an optical receiver portion 100b. Each portion is provided with its own power supply VccT, VeeT for the transmitter portion 100a and VccR, VeeR for the receiver portion 100b. In the present embodiment, these are not connected together within the transceiver device 100, so as to reduce crosstalk between transmitter portion 100a and receiver portion 100b. In other embodiments, connection of the power supplies to one another within the transmitter device is made. The transceiver 100 also has a digital processing section 190, described later herein.

The optical transmitter portion 100a has a laser 120. In this embodiment, the laser 120 is a DFB (Distributed Feedback) laser. In other embodiments, the laser is a directly modulated FP (Fabry Perot) laser, VCSEL (Vertical Cavity Surface Emitting Laser), LED (light emitting diode) or EML (Externally Modulated Laser) or other appropriate optical source. The laser 120 is connected to an optical fibre 205, 205a - see Fig. 2 - for transferring the resultant optical radiation to a remote location.

Interface between the laser 120 and the fibre may be effected in a number of ways. In one family of embodiments, where the optical fibre is a multimode fibre, the aim is to achieve a restricted mode set in the fibre. To this end, one subset of embodiments uses a standard laser diode, or the like, and uses optical components configured and arranged to provide the desired modal launch. In one embodiment of this subset, the launch is offset from the fibre centre, so as to provide reduced low order modes and reduced high order modes. In another embodiment the launch is a centre launch to give rise to mainly low order modes. In another subset, there is used a laser diode that has an output or set of outputs selected to provide a desired mode pattern. For example a reduced set of high and low order modes may be achieved by providing a laser diode
having a radiation null at the centre of its emission facet and radiation outputs circularly disposed around that centre.

The laser 120 is operated by a laser bias circuit 121, including a two-input first amplifier 110 having an inverting input 101, a non-inverting input 102 and an output 103, an npn bipolar transistor 140 having its emitter coupled to a the transmitter lower power supply voltage Veet via a current source resistor 150, and a monitor photodiode 130. The collector of the transistor 140 is connected to the cathode of the laser 120 via inductance 113. The inductance serves to block RF from creating noise on the dc laser current bias. The monitor photodiode 130 has its anode connected to VccT and its cathode connected to the inverting input 101.

Input signals 202 are applied on an RF carrier to the input node 161 of a conditioning circuit 160. The conditioning circuit 160 processes the RF signals to cause them to be of suitable amplitude and frequency to modulate the laser, and has an output 163 connected directly to the cathode of the laser diode 120. The RF signal is superimposed onto the dc optical signal in such a way as to maintain linearity of the signal to be transmitted. This is achieved by maintaining the correct depth of modulation current as controlled by the conditioning circuit 160. No A/D conversion is effected — i.e. the variations in laser radiation substantially correspond to those of the input signal.

The monitor photodiode 130 captures light from the rear facet 129 of the laser, and is connected to the inverting input 101 of the bias amplifier 110. In conjunction with the first amplifier 110 and current source 150 the monitoring photodiode 130 forms a feedback loop to maintain a constant current through the monitor photodiode 130. If the power output from the laser 120 drops (for example due to a rise in temperature) the current of the monitor photodiode 130
falls in like fashion. The inverting input 101 to the first amplifier 110 falls causing the output 103 to rise. This in turn provides additional base current to the transistor 140 increasing current to the laser 120.

A transmit disable input 155 is hard-wired input to the conditioning circuit 160 and the first amplifier 110. When a logical low level is applied at the disable input 155, the output 103 of the amplifier 110 is pulled down to VeeT to disable the laser 120, and the conditioning circuit is tristated to isolate it.

The receiver portion 100b has a receiver photodiode 170 having sufficient bandwidth to detect the RP signal in question from the return fibre (not shown). The receiver photodiode 170 has its cathode connected to VccR and its anode connected to VeeR via a bias resistor 172, and to the input 173 of a second amplifier 175, in this embodiment. In this embodiment the second amplifier 175 includes an automatic gain control loop. In other embodiments, the output from the receiver photodiode 170 may be sufficiently large to not require amplification, and sufficiently constant not to require AGC.

The second amplifier 175 has an output 177 that is connected as input 181 to a buffer 180. This in turn has an output 183, providing an analogue RF output to electrical output 203 of Fig. 2. The buffer includes logic circuitry for providing an output indicating loss of signal (LOS) when no light is received or the level is too low for detection. This LOS signal may be used by the host as a warning for instance that the fibre is broken.

The digital processing section 190 forms a system management block for handling a digital interface and itself contains memory. Digital optical monitoring (DOM) is a means of the device holding information about itself
and performance. It holds both static and dynamic data. The static data can be date code, part number, manufacturer, serial number.

In the present embodiment, the dynamic data, which may be for example laser conditions, temperature etc, is read and loaded into an in-module memory location and then accessed externally via a 2-wire interface 211,212- see Fig. 2. This memory can also be used to hold information relating to manufacturer, parts numbers etc.

Returning to Fig. 2, in operation a first input signal at electrical input node 202 is conveyed to the optical modules 220,220a. The signal is converted into a corresponding optical signal and output over fibre 205 to the antenna unit 240. As will later be described herein, optical signals over the second optical fibre 215 are picked up by the optical module 220 and converted into electrical signals which correspond to the analogue optical signals on the second optical fibre 215, the electrical signals being output over the second optical output 203.

The second processing circuit 265 has, as a previously been described, its first input 267 connected to the output node 203 so as to be responsive to signals that are received from the antenna unit 240. The second processing unit 265 has its output 266 connected to the input line 202 so as to be capable of sending signals to the antenna unit. The third processing unit 260 can respond to digital data from the first processing unit 210 via the input/output 261, and is programmed to respond to such signals by supplying digital signals over its input/output 268 to the second processing circuit 265. The function of the second processing circuit 265 is, in this instance, to convert the digital signals at its input 268 to radio frequency modulated signals that are capable of being carried via the optical module 220 and the first optical fibre 205 to the optical module 230 of the antenna unit 240. In the converse sense, analogue RF
signals input to the base unit from the second optical fibre 215 are demodulated by the second processing circuit 265 and output via the input/output connection 268 to the third processing circuit 260.

Control and monitoring of the optical modules 220,220a may be effected by the further input 211 and the output 212 of the first processing unit 210. This circuit may respond to commands received over the electrical input/output node 201 or to commands received from the third processing unit 260 via the input/output connection 261. Likewise, information from the optical modules 220/220a may be collected by the first processing unit 210 and output either via the electrical input/output connection 201 to external circuitry, or instead to the third processing unit 260.

The antenna unit 240 will now be described. Continuing to refer to Fig. 2, the antenna unit 240 has an optical module 230 that in the present embodiment is identical to the optical module 220 of the base unit 225, an operational circuit 243 coupled to the optical module via first and second signal lines 231, 232, a first processing circuit 235 and a second processing circuit 238. The operational circuit 243 contains an amplifier, gain control circuitry and power circuitry, as well as an RF power detector, in this embodiment. The first processing circuit 235 is connected via a two-line bus 233,234 to the optical module 230, and via a connection 236 to the operational circuit 243. The second processing circuit 238 is connected to the operational circuit 243 via a connection 239 and to the first processing circuit 235 via a connection 240. An antenna 245 is connected to the operational circuit 243.

The optical module 230 serves to receive analogue optical signals from the base unit 225 over the first optical fibre 205 and to convert these into corresponding electrical signals that are output over the first signal line 231 to
the operational circuit 243. The power circuitry of the operational circuit 243 provides the necessary power amplification to drive the antenna 245 to emit e.m. radiation. It also serves to receive analogue electrical input signals from the operational circuit 243 and to convert these into corresponding optical signals that are carried by the second optical fibre 215 to the base unit 225.

The optical module can also receive signals input to the antenna 245 via the operational circuit 243, and amplified therein by the amplifier. It serves to convert the electrical signals into optical signals for transfer via the second optical fibre 215 to the base unit 225. Such signals are then output by the base unit 225 at the electrical output node 203.

As previously mentioned, the operation circuit also includes a power detection circuit that monitors or detects received RF power. In some embodiments this function may be omitted and an output from a gain control circuit for the amplifier or the power circuitry may be used instead.

The second processing circuit 238 of the antenna unit 240 is connected to receive modulated RF signals, originating in the base unit 225 and transferred via the optical fibre 205 from the operational circuit 243 over connection 239. It is then operable to demodulate these signals to digital control signals and to output these signals to the first processing circuit 235 of the antenna unit. The first processing circuit 235 of the antenna unit 240 can then send control commands or other data as required to the optical module 230 of the antenna unit 240. As programmed or configured, the first processing circuit 235 is operable to output control commands to the operational circuit 243, for example to cause it to change its gain. The first processing circuit 235 can in some embodiments issue commands to the operational circuit 243 or to the optical module 230 to cause read-out of parameters of those devices - for
example a gain level of the operational circuit 243, a measure of RF power from the operational circuit or bias levels in the optical module 230- to the first processing circuit 235.

Then, in contrary fashion to the above, the first processing circuit 235 can output digital data indicative of the information read out from the relevant device to the second processing circuit 238 via the connection 237. The second processing circuit 238 operates to modulate the digital signals onto an RF carrier and supply this information via the operational circuit 243 to the optical module 230. There the information is transduced into corresponding optical signals and transferred to the base unit 225, where it is picked off by the second processing circuit 265 of the base unit 225.

In the presently described embodiment, the second processing circuit 265 of the base unit 225, and the second processing circuit 238 of the antenna unit are embodied as wireless USB chips. Communication between the base unit 225 and the antenna units 240, 240a can thus take place. Such communication starts by using the wireless USB chip to convert digital data into serial data, then to modulate the data onto a carrier- typically in the 2.4 GHz ISM and to output the data on an RF output line. Typical USB chips can also dynamically switch frequency to find an unused band using a complementary microprocessor (uP).

The RF output line (electrical signal) is applied to the optical module of the base unit or antenna unit respectively, and this serves to move the electrical signal into the optical domain, and apply it to the optical fibre of concern. At the receiving location along the fibre, the relevant optical module converts the optical signal into a corresponding electrical signal that is picked off by the local wireless USB chip and demodulated into a baseband digital signal.
Command information and data may be transferred using any suitable protocol; the present embodiment envisaged use of the Philips I^2^C bus protocol, with the first and third processing circuits 210,260 of the base unit 225 and the first processing unit 235 of the antenna units, as well as the optical modules 220,230 being I^2^C bus compliant.

It is envisaged that in some embodiments, each antenna unit can be given a unique identifier so that separate addressing, and hence control is possible. Where for example wireless USB chips are used, they may already be provided with preset identification that may be used to this end.

The command information may be used in a retroactive system using transversal or feed forward equalisers to improve received signal characteristics for example to mitigate the problems of dispersion. Non-retroactive systems may also be provided, for example where a command simply causes a new setting of an equaliser or other device at a remote station, for example in response to temperature change or another change in system parameters.

In a multi-mode (MM) fibre dispersion caused by different paths or modes of light having different propagation times through the fibre, leads to a signal broadening as it travels along the fibre giving a frequency dependant loss. As previously mentioned, dispersion can limit the frequency at which signals can be received or the length over which they can be sent.

Dispersion can also occur through different mechanisms over different transmission media (e.g. single mode fibre; copper etc).

This disclosure documents methods for electronically correcting for dispersion in a signal-versatile transmission system, hence, extending bandwidth and/or link lengths over which analogue systems can operate. In particular this
technique may be applied to distributed antenna systems used to distribute wireless signals.

In a signal-versatile link there is potentially only one narrow frequency band being transmitted.

The frequency response of the transmission media can be compensated for using a feed forward equalizer (equaliser) such as an equaliser in the form of a tapped delay line, with variable coefficients.

After being received, the distorted signal is sent into the equaliser & its frequency response is corrected for.

The equaliser consists of one or more delays with the signal tapped off at different points. The signal levels at different taps can be altered to the level that will let through the desired amount of signal & the taps are then summed together. By altering tap weights and / or delays the equaliser can be set up to give the required frequency response. In one embodiment the frequency response is set up in a way that the inverse frequency response to the transmission media is obtained; in other embodiments different frequency responses of the equaliser are achieved so as to correct for dispersion

In some embodiments a similar principle is applied to shape the signal at the base station or at the antenna unit before this is transmitted. In some of these embodiments, the equaliser is set up to a constant frequency response at the time of installation. In others the frequency response is varied in use by control signals input at the base station or respectively antenna unit where the equaliser is installed. In yet others, the equaliser is adaptive, or at least retroactively controlled by sensing the received signal at the end remote from the equaliser,
and transferring signals indicative of signal quality or of difference between desired quality and actual quality back to the end at which the equaliser is installed. Then, control circuitry acts to modify the frequency response of the equaliser to improve the received signal quality.

There are various methods in which equalisers can be set up to provide the desired frequency response.

a) In some embodiments, the response is set manually to a fixed value.

b) In another set of embodiments, a calibration routine is run on the system. In one subset of these embodiments various frequency signals are generated and sent to the transmitter. The response of the received signal at the different frequencies is measured and the filter changed to optimize this. In one embodiment this is done at set-up; in another intermittently and in yet another continuously.

c) In another set of embodiments, the amplitude of signals being transmitted over the communications link is measured before & after transmission. The resulting information is used to set up the equalizer.

d) In a further set of embodiments, a digital signal is transmitted periodically or continuously on the link. A 'mean square error' detector or other digital techniques is used as a metric for the quality of transmission.

Suitable algorithms for retroactive control of the equaliser to optimise performance or at least to mitigate defects are well known.

The system may:-

1. Use a wireless USB chip, or an RF modem, to communicate using the fall frequency spectrum, seeking unused space and frequency hopping accordingly.

   a. Communicate to the remote antenna unit for set-up.
b. Send pilot tones at the service frequency, measure power at the received end to determine fibre and system performance and make the necessary laser drive or system gain adjustments.

c. Use a wideband VCO, sweep the frequency band to determine the system freq response, optimise system gain and therefore aid system installation. Adjust transformer gain to match the fibre gain profile.

d. Dynamically adjust the laser drive conditions, in the base or antenna unit to control the fibre gain/ bandwidth profile.

e. Pick up and isolate unwanted frequencies, perform active cancellation avoiding cell de-sense.

f. Individually and uniquely address antennae.

2. Triangulate a signal using a DAS.

a. Sequencing through antennas, measuring power levels and feeding back information to the base unit.

3. Detect transmitter power levels in the antenna unit and switch in maximum attenuation when no signal is sent from the base unit to avoid noise and receiver de-sense.

4. Generate an I²C interface in the antenna unit with remote communication through a wireless USB back to the base unit.

5. DAS Dynamic frequency selection implementation within a RoF system.

It should be noted that if a frequency channel were in use, the signal carrying the data could instead be up-converted or down-converted.
A broadband RF power detector in the antenna unit can report status, such as received power levels, back via the I²C to the base unit. This information may determine the suitability of the fibre (due to inherent bandwidth or fault), or alternatively set optimal antenna location or position by sending a known power level and looking at the received power. Wireless USB chips may contain a received signal strength indicator (RSSI) but this is typically narrow band.

Inclusion of a swept RF source (VCO) in the base unit makes it possible to transmit a varying frequency un-modulated (CW) signal over fibre to the DAS, measure the received power at the antenna unit and therefore profile the system fibre bandwidth. This can be used to switch or nudge frequency a few MHz or dynamically adjust the system gain profile to compensate or avoid any deficiencies. The transmitter gain profile can also be dynamically adjusted to compensate for fibre deficiencies.

As a set-up process this can be used to profile installed fibre and report the gain/ bandwidth profile. This would be considered built in self test (BIST) within the system.

One useful feature of the wireless USB chip is that it has a unique ID. The intent is to then adopt this identifier as the antenna ID, allowing individual addressing of each antenna in a DAS system.

Putting together the two properties of unique addressing and power detection previously described can provide beneficial features such as triangulation or positioning of a device within the DAS system. Each antenna within range will be picking up the same signal. The signal strength from each unique antenna unit can be reported via the wireless USB and used to locate the source. A
further advantage available, if the DAS system is over-subscribed, a poor or faulty fibre could easily be detected and taken out of service, sending a maintenance alarm without necessarily producing a loss of service. Such embodiment is critically dependant upon the third party Time Division Duplexing (TDD) system.

It is possible that erroneous signals may be present and disruptive to the RoF system. This will cause noise and therefore cell shrinkage (de-sense). This may also be caused if the base unit is not transmitting when noise in the system may cause de-sense in the antenna unit. Using the wireless USB to communicate between the Hub and antenna unit, maximum attenuation can be switched in specifically to avoid noise issues. In the case of an erroneous signal the system bandwidth gain profile could be actively managed to block the signal or filters switched in to block the unwanted signal.

This also leads to the use of dynamic frequency selection (DFS) a DAS system. If a frequency is in use the communication between the base unit and antenna unit will enable dynamic movement to another, adjacent and free frequency.

Both the base unit and antenna unit have an I²C bus (2-wired interface) for internal communications. In an embodiment, the wireless USB allows extension extended to a pseudo I²C communication between the hub and antenna unit (and visa-versa). As an example the hub is acting as master requesting information. The slave needs to get this information via the wireless USB chip from the antenna unit. In the antenna unit the wireless USB chip protocol requests the data and when received sends it RoF to the base unit. The base unit would continue to poll until it is acknowledged that the information was received. Alternatively the antenna unit can become the master and write back data to the base unit when ready.
In an extension of this improvement to the gain/bandwidth of the system could be remote adjustment of the laser drive current. The bandwidth performance of MMF is critically dependent upon the laser launch conditions and therefore the drive current to the laser. The I^2C can be used to program the laser drive condition to either increase linearly on demand or to switch to an alternate and pre-determined state. The system may use a dynamic automatic change to actively adjust the laser drive condition to track dynamic fibre effects due to ageing, time, temperature or effects arising from fibre manipulation or other changes of position. Such effects include, but are not limited to dynamic fibre polarisation or modal effects. In some embodiments an automatic change to the laser drive conditions is made when a transmission error is detected due to the fibre changes. The change in drive current could happen locally in the base unit or remotely using the pseudo I^2C communication between the base unit and antenna unit.

The invention opens up many applications such as triangulation, frequency scanning of the system and system fibre, blocking of unwanted signals avoiding conflict and/or cell shrinkage and switching in a high gain block specifically to avoid de-sense when no transmission is present.

This system can also be extended to provide a pseudo I^2C bus between the base unit and antenna unit in a DAS. Dynamic frequency selection can also be implemented using feedback from the antenna unit. One use of this communication would be to enable dynamic, manual or automatic change in the laser drive conditions of optical device within the base unit or antenna unit to overcome fibre performance issues such as frequency nulls. In general the base unit or the antenna unit may initiate commands to the respective other unit.
Such changes may involve current dithering, and specifically may be selected from:

1. Movement to another and pre-determined current state, either with an increase or reduction in current.

2. Movement while monitoring the performance in some way. More linear than that described in 1.

3. Constant movement around a small and defined mean current to avoid a steady state condition.

In the above description, reference is made to "module", for example in the context of "optical module". This is for convenience and is not intended to limit the invention to modular devices, or devices that are part modular.

Embodiments may use a single fibre instead of a pair of fibres. The single fibre may use multiplex techniques to allow transfer of data in both directions, for example wavelength division multiplexing. Embodiments may use MMF or SMF.

The described embodiments are not intended to limit the scope of protection.
CLAIMS

1. A communication system comprising a first device, a second device and at least one optical fibre, the first device having an electrical node and an optical node, the second device having an optical node, an antenna and circuitry for electrically driving the antenna according to signals received at the optical node, and the optical fibre linking the optical nodes of the first and second devices, the system being configured to permit analogue communication to the antenna from the first device, wherein the circuitry of the second device includes processing means connected to receive commands sent from the first device over the optical fibre for controlling said circuitry.

2. A system as claimed in claim 1, wherein the first device comprises an electro-optical transducer for receiving electrical signals from the electrical node and converting into corresponding optical signals for output at said optical node for transmission by said optical fibre, and an opto-electrical transducer for receiving optical signals input to the optical node from the optical fibre and converting into corresponding electrical signals for output at said electrical node.

3. A system as claimed in claim 1 or 2, wherein the second device comprises an opto-electrical transducer for receiving optical signals input to the optical node thereof from the optical fibre and converting into corresponding electrical signals for output at said antenna via said circuitry, and an electro-optical transducer for receiving electrical signals from the antenna via said circuitry and converting into corresponding optical signals for output at said optical node for transmission by said optical fibre.
4. A system as claimed in any preceding claim, configured to carry signals modulated on an RF carrier.

5. A system as claimed in claim 4, wherein the circuitry includes demodulating means for extracting signals containing said commands from said corresponding electrical signals in said second device.

6. A system as claimed in claim 5, wherein the circuitry includes power amplifier means for driving said antenna.

7. A system as claimed in claim 5 or 6, wherein the circuitry includes signal amplifier means for receiving signals from said antenna and for driving said electro-optical transducer in accordance therewith.

8. A communication system comprising a first device, a second device and at least one optical fibre, the first device having an electrical node and an optical node, the second device having an optical node, an antenna and circuitry for electrically driving the antenna according to signals received at the optical node, and the optical fibre linking the optical nodes of the first and second devices, the system being configured to permit analogue communication to the antenna from the first device, wherein the circuitry of the second device includes processing means connected to receive commands sent from the first device over the optical fibre for controlling said circuitry, each device having a respective laser for converting electrical signals into optical signals for output at the respective optical node to the fibre, and a respective photodiode for converting optical radiation received at the fibre into respective electrical signals.
9. A system according to claim 8, wherein the first device has means for generating digital command signals, and a processing circuit for modulating the digital command signals onto an RF carrier, the second device has demodulating circuitry for extracting signals containing said commands from electrical signals in said second device.

10. A system according to claim 8 or 9, wherein the circuitry of the second device includes one or more of power amplifier means for driving said antenna, signal amplifier means for receiving signals from said antenna and for modulating the output of the laser of the second device in accordance therewith, bias circuitry for driving said laser and RF power monitoring means.

11. A system according to claim 8, 9 or 10, wherein the command signals effect commands to adjust parameters of said circuitry.

12. A system according to any of claims 8-11, wherein the command signals are commands causing readout of parameters of said circuitry in the form of a digital representation thereof, and the second device may include means for modulating data corresponding to the digital representation onto an RF carrier for application to the laser of the second device whereby the parameters are transmitted via the fibre and demodulating circuitry of the first device to the first device.

13. A system according to any of claims 8-12, having a processor and an external input/output to and from the processor, whereby control inputs at said external input/output may control the second device and/or parameter information may be output from said external input/output.
14. A communication system according to any preceding claim, wherein the second device includes transmission means responsive to the parameters of traffic being carried by the system, and operable to cause communication in such a way as to not interfere with the traffic.

15. A communication system according to any preceding claim wherein the optical fibre in use carries signals modulated on a radio frequency carrier.

16. A method of setting up a laser transmitter at the head end of an optical fibre communication system having a remote node including an antenna, the method comprising sensing parameters of received signals at the remote node, transferring to the antenna data resulting from said sensing step and transferring corresponding data to the head end.

17. A method of controlling an optical communication system having a hub connected to plural antenna units, each having a respective antenna, via respective optical fibres, comprising transmitting control information between an antenna unit and the hub via a path including at least one optical fibre and a wireless device operatively linking circuitry of the antenna unit with its antenna.

18. A method, suitable for use in a distributed antenna system, of controlling an antenna unit, wherein the antenna unit is connected to a base station via at least one optical fibre, the method comprising providing electrical control signals, modulating the control signals onto a RF carrier, converting the modulated control signals to corresponding optical signals, carrying the optical signals to at least one antenna unit over an optical fibre, converting the optical
signals to corresponding electrical signals and demodulating the corresponding
electrical signals to derive the control signals.

19. A method of operating a transmission system having a first station
coupled to a second station via an optical link, the method comprising:
emitting a signal from the first station over the optical link such that a
version of the signal is received at the second station;
determining a parameter of the received version at the second station,
and in response thereto, generating a control signal indicative of the parameter
at the second station;
sending the control signal from the second station to the first station
over the optical link; and
using the control signal in the first station to control the first station.

20. A method according to claim 19, wherein the first station is controlled
by the control signal to modify transmission parameters of the first station.

21. A method according to claim 19 or 20, wherein the control signal is used
to improve the correspondence between the received version of the signal and
the emitted signal.

22. A communication system comprising a first device, a second device and
at least one optical fibre, the first device having an electrical node, an optical
node, and circuitry for driving the optical node in response to signals received
at the electrical node, the second device having an optical node, and an
electrical node, and the optical fibre linking the optical nodes of the first and
second devices, the system being configured to permit analogue
communication to the second device from the first device, wherein the circuitry
of the first device includes processing means connected to receive commands sent from the second device over the optical fibre for controlling said circuitry.

23. A communication system according to claim 22, wherein the second device has an antenna connected to the electrical node of the second device.
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

**INV.** H04B10/12

According to International Patent Classification (IPC) onto both national classification and IPC.

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

- H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched.

Electronic database consulted during the international search (name of database and, where practical, search terms used)

- EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
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<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No</th>
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<tbody>
<tr>
<td>X</td>
<td>WO 98/10600 A (LOCKHEED CORP [US]) 12 March 1998 (1998-03-12) abstract page 3, line 30 - page 8, line 9 figures 1,3,4</td>
<td>1-15,18, 22,23</td>
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* Special categories of cited documents:
- **A** document defining the general state of the art which is not considered to be of particular relevance
- **E** earlier document but published on or after the international filing date
- **L** document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- **O** document referring to an oral disclosure, use, exhibition or other means
- **P** document published prior to the international filing date but later than the priority date claimed

**D** Further documents are listed in the continuation of Box C

**See patent family annex**

**Date of the actual completion of the international search**

23 April 2007

**Date of mailing of the international search report**

04/07/2007

**Name and mailing address of the ISA/**

European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HI Rijswijk TBI (+31-70) 340-2040, TX: 31 651 epc nl, Fax: (+31-70) 340-3016

**Authorized officer**

ROLAN CISNEROS, E
This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.: because they relate to subject matter not required to be searched by this Authority, namely

2. Claims Nos.: because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee

3. As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims, it is covered by claims Nos. 1-15, 18, 22, 23

Remark on Protest

- The additional search fees were accompanied by the applicant's protest
- No protest accompanied the payment of additional search fees

Form PCT/ISA/21 0 (continuation of first sheet (2)) (January 2004)
This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-15, 18, 22, 23

Method and system for analogue communications between a first station and a second station comprising an antenna unit; control of said antenna unit by means of commands sent from the first station

2. claim: 16

A method of setting up a laser transmitter at the head end of an optical fibre communication system having a remote node including an antenna

3. claim: 17

A method of controlling an optical communication system having a hub connected to plural antenna units

4. claims: 19-21

A method of operating a transmission system having a first station coupled to a second station via an optical link
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