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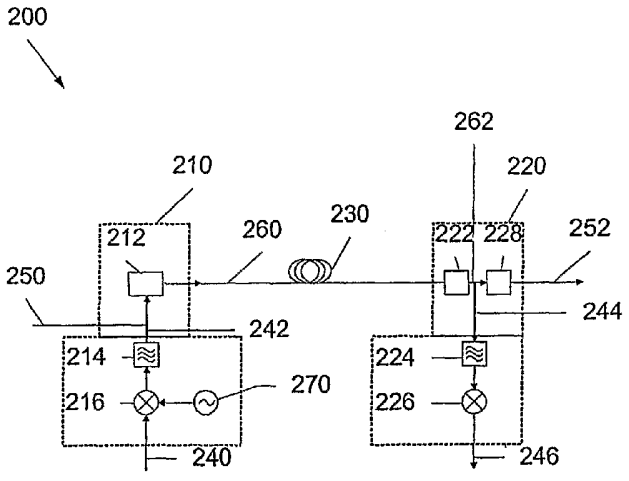

(57) Abstract: Apparatus and method for transmitting a supervisory signal for optical network applications. The apparatus includes a subcarrier transmission system configured to receive a first supervisory signal and output a second supervisory signal, and an electrical-to-optical conversion system configured to receive the second supervisory signal and. a data signal and output an optical signal. The second supervisory signal is associated with a subcarrier frequency. The data signal is associated with a data bandwidth, and the data bandwidth includes a data frequency. At the data frequency, a power density of the data signal is substantially equal to zero. A ratio of the subcarrier frequency to the data frequency ranges from 0.8 to 1, and the subcarrier frequency ranges from 2.4 GHz to 2.483 GHz.

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SYSTEM AND METHOD FOR SUBCARRIER MODULATION IN ISM BAND AS SUPERVISORY CHANNEL

Field of the Technology

The present invention relates in general to telecommunication techniques. More particularly, the invention provides a method and system for subcarrier modulation as supervisory channel. Merely by way of example, the invention is described as it applies to optical networks, but it should be recognized that the invention has a broader range of applicability.

Background of the Invention

Telecommunication techniques have progressed through the years. As merely an example, optical networks have been used for conventional telecommunications in voice and other applications. The optical networks can transmit multiple signals of different capacities. For example, the optical networks terminate signals, multiplex signals from a lower speed to a higher speed, switch signals, and transport signals in the networks according to certain definitions.

To monitor these signals, the optical networks often track the flow of data through various nodes, switching sites and links. For example, the optical networks provide supervisory signals propagating with the data signals. The supervisory signals provide information for maintaining and monitoring the optical networks. Several conventional techniques have been proposed to transmit and receive such supervisory signals.

In Dense Wavelength Division Multiplexing (DWDM) systems, the supervisory signals are transmitted in a separate channel at a wavelength outside of the data band. For example, the supervisory channel is either at 1510 nm or 1620 nm outside the wavelength band for data signal transmissions. The data band is usually in the range of 1530 nm to 1562 nm for C-band or 1570 nm to 1610 nm for L-band. This transmission method may be a good solution if majority of the wavelength channels are deployed and the cost of the supervisory channel is shared by all data channels. But in many practical situations, especially in metro area Wavelength Division

Multiplexing (WDM) applications, only a few channels are usually deployed. In these cases, the cost of a separate WDM supervisory channel becomes significant, and the solution is usually not cost effective.

Another method of carrying supervisory signals uses the Frequency Division Multiplexing (FDM) mechanism. The FDM method transmits the supervisory signals by subcarrier transmissions. The supervisory signals and the data signals are usually generated by the same transmitters and share the same wavelengths. The subcarrier frequency of the supervisory channel is outside of the bandwidth of the data signals. For example, the subcarrier frequency equals about 3 GHz for a base band data rate up to 2.5 Gbps. To accommodate the high subcarrier frequency, the transmitters and receivers need to have a frequency response higher than one for transmitting only the data signals. Non-standard and high cost components are usually used. For example, a separate, higher speed, receiver may be used to detect the supervisory channel signal.

Similarly, the supervisory signals can be transmitted with a low frequency subcarrier or "pilot tone." Lowering the subcarrier frequency to the kHz or MHz range reduces the cost of components and the difficulty of implementation, but the performance of the supervisor signal is usually degraded.

Hence it is highly desirable to improve techniques for transmitting and receiving supervisor signals.

Summary of the Invention

The present invention relates in general to telecommunication techniques. More particularly, the invention provides a method and system for subcarrier modulation as supervisory channel. Merely by way of example, the invention is described as it applies to optical networks, but it should be recognized that the invention has a broader range of applicability.

According to one embodiment of the present invention, an apparatus for processing a supervisory signal for optical network applications includes a subcarrier transmission system configured to receive a first supervisory signal and output a second supervisory signal, and an electrical-to-optical conversion system configured to receive the second supervisory signal and a first data signal and output a first

optical signal. Additionally, the apparatus includes an optical-to-electrical conversion system configured to receive the first optical signal and output a first electrical signal and a second data signal, and a subcarrier reception system configured to receive the first electrical signal and output a third supervisory signal. The second supervisory signal is associated with a first subcarrier frequency. The first data signal is associated with a first data bandwidth, and the first data bandwidth includes a first data frequency. At the first data frequency, a power density of the first data signal is substantially equal to zero. A ratio of the first subcarrier frequency to the first data frequency ranges from 0.8 to 1. The first optical signal is associated with a perturbation to the first data signal, and the perturbation is smaller than or equal to 1 dB. The first optical signal is associated with a signal-to-noise ratio related to the first supervisory signal, and the signal-to-noise ratio being larger than or equal to 20 dB. The first supervisory signal is associated with a first subcarrier data rate larger than 1 Mbps.

According to another embodiment of the present invention, an apparatus for processing a supervisory signal for optical network applications includes a subcarrier transmission system configured to receive a first supervisory signal and output a second supervisory signal, and an electrical-to-optical conversion system configured to receive the second supervisory signal and a first data signal and output a first optical signal. Additionally, the apparatus includes an optical-to-electrical conversion system configured to receive the first optical signal and output a first electrical signal and a second data signal, and a subcarrier reception system configured to receive the first electrical signal and output a third supervisory signal. Moreover, the apparatus includes an optical system coupled to the electrical-to-optical conversion system and the optical-to-electrical conversion system. The second supervisory signal is associated with a first subcarrier frequency, and the first data signal is associated with a first data bandwidth. The first data bandwidth includes a first data frequency, and at the first data frequency a power density of the first data signal is substantially equal to zero. A ratio of the first subcarrier frequency to the first data frequency ranges from 0.8 to 1.

According to yet another embodiment of the present invention, a method for processing a supervisory signal for optical network applications includes receiving a

first supervisory signal, processing information associated with the first supervisory signal, and outputting a second supervisory signal based on at least information associated with the first supervisory signal. Additionally, the method includes receiving the second supervisory signal and a first data signal, processing information associated with the second supervisory signal and the first data signal, and outputting a first optical signal based on at least information associated with the second supervisory signal and the first data signal. Moreover, the method includes receiving the first optical signal, processing information associated with the first optical signal, and outputting a first electrical signal and a second data signal based on at least information associated with the first optical signal. Additionally, the method includes receiving the first electrical signal, processing information associated with the first electrical signal, and outputting a third supervisory signal. The second supervisory signal is associated with a first subcarrier frequency, and the first data signal is associated with a first data bandwidth. The first data bandwidth includes a first data frequency, and at the first data frequency a power density of the first data signal is substantially equal to zero. A ratio of the first subcarrier frequency to the first data frequency ranges from 0.8 to 1.

According to yet another embodiment of the present invention, an apparatus for transmitting a supervisory signal for optical network applications includes a subcarrier transmission system configured to receive a first supervisory signal and output a second supervisory signal, an electrical-to-optical conversion system configured to receive the second supervisory signal and a first data signal and output a first optical signal. The second supervisory signal is associated with a first subcarrier frequency, and the first data signal is associated with a first data bandwidth. The first data bandwidth includes a first data frequency, and at the first data frequency a power density of the first data signal is substantially equal to zero. A ratio of the first subcarrier frequency to the first data frequency ranges from 0.8 to 1.

According to yet another embodiment of the present invention, an apparatus for receiving a supervisory signal for optical network applications includes an optical-to-electrical conversion system configured to receive a first optical signal and output a first electrical signal and a second data signal, and a subcarrier reception system configured to receive the first electrical signal and output a third supervisory signal.

The subcarrier reception system includes a band pass filter associated with a first subcarrier frequency, and the second data signal is associated with a first data bandwidth. The first data bandwidth includes a maximum data frequency. A ratio of the first subcarrier frequency to the maximum data frequency ranges from 0.8 to 1.

According to yet another embodiment of the present invention, a method for transmitting a supervisory signal for optical network applications includes receiving a first supervisory signal, processing information associated with the first supervisory signal, and outputting a second supervisory signal based on at least information associated with the first supervisory signal. Additionally, the method includes receiving the second supervisory signal and a first data signal, processing information associated with the second supervisory signal and the first data signal, and outputting a first optical signal based on at least information associated with the second supervisory signal and the first data signal. The second supervisory signal is associated with a first subcarrier frequency, and the first data signal is associated with a first data bandwidth. The first data bandwidth includes a first data frequency, and at the first data frequency a power density of the first data signal is substantially equal to zero. A ratio of the first subcarrier frequency to the first data frequency ranges from 0.8 to 1.

According to yet another embodiment of the present invention, a method for receiving a supervisory signal for optical network applications includes receiving a first optical signal, processing information associated with the first optical signal, and outputting a first electrical signal and a second data signal based on at least information associated with the first optical signal. Additionally, the method includes receiving the first electrical signal, processing information associated with the first electrical signal, and outputting a third supervisory signal. The processing information associated with the first electrical signal includes filtering the first electrical signal, and the filtering the first electrical signal is associated with a first subcarrier frequency. The second data signal is associated with a first data bandwidth, and the first data bandwidth includes a maximum data frequency. A ratio of the first subcarrier frequency to the maximum data frequency ranges from 0.8 to 1.

Many benefits are achieved by way of the present invention over conventional techniques. For example, certain embodiments of the present invention use a

subcarrier frequency that is slightly lower than the maximum frequency of the frequency band of the data signal 250 or 450. The subcarrier power spectrum overlaps with the tail of the data power spectrum. The data power density at the tail is substantially lower than that at a low frequency. For example, the low frequency is in the range of kHz or MHz. Some embodiments of the present invention provide a subcarrier signal that shares with the data signal some or all of the optical-to-electrical signal converter, the electrical-to-optical signal converter, and other optical-to-electrical or electrical-to-optical conversion components. Certain embodiments of the present invention significantly lower costs for transmitting and receiving supervisory signals. Some embodiments of the present invention provide a low data power density at f_{SC}. The supervisory signal has a high signal to noise ratio and can be transmitted at a high data rate. For example, the data rate is higher than 1 Mbps. Certain embodiments of the present invention provide a subcarrier modulation with a low amplitude. The main data channel suffers from only a small perturbation. For example, the perturbation in optical power is smaller than 1 dB. Some embodiments of the present invention provide a simple configuration and an easy implementation.

According to yet another embodiment of the present invention, an apparatus for processing a supervisory signal for optical network applications includes a subcarrier transmission system configured to receive a first supervisory signal and output a second supervisory signal, an electrical-to-optical conversion system configured to receive the second supervisory signal and a first data signal and output a first optical signal, and an optical-to-electrical conversion system configured to receive the first optical signal and output a first electrical signal and a second data signal. Additionally, the system includes a subcarrier reception system configured to receive the first electrical signal and output a third supervisory signal, and an optical system coupled to the electrical-to-optical conversion system and the optical-to-electrical conversion system. The second supervisory signal is associated with a first subcarrier frequency. The first data signal is associated with a first data bandwidth, and the first data bandwidth includes a first data frequency. At the first data frequency, a power density of the first data signal is substantially equal to zero. A ratio of the first subcarrier frequency to the first data frequency ranges from 0.8 to 1, and the first subcarrier frequency ranges from 2.4 GHz to 2.483 GHz.

According to yet another embodiment of the present invention, a method for processing a supervisory signal for optical network applications includes receiving a first supervisory signal, processing information associated with the first supervisory signal, outputting a second supervisory signal based on at least information associated with the first supervisory signal, and receiving the second supervisory signal and a first data signal. Additionally, the method includes processing information associated with the second supervisory signal and the first data signal, outputting a first optical signal based on at least information associated with the second supervisory signal and the first data signal, receiving the first optical signal, and processing information associated with the first optical signal. Moreover, the method includes outputting a first electrical signal and a second data signal based on at least information associated with the first optical signal, receiving the first electrical signal, processing information associated with the first electrical signal, and outputting a third supervisory signal. The second supervisory signal is associated with a first subcarrier frequency. The first data signal is associated with a first data bandwidth, and the first data bandwidth including a first data frequency. At the first data frequency, a power density of the first data signal is substantially equal to zero. A ratio of the first subcarrier frequency to the first data frequency ranges from 0.8 to 1, and the first subcarrier frequency ranges from 2.4 GHz to 2.483 GHz.

According to yet another embodiment of the present invention, an apparatus for transmitting a supervisory signal for optical network applications includes a subcarrier transmission system configured to receive a first supervisory signal and output a second supervisory signal, and an electrical-to-optical conversion system configured to receive the second supervisory signal and a data signal and output an optical signal. The second supervisory signal is associated with a subcarrier frequency. The data signal is associated with a data bandwidth, and the data bandwidth includes a data frequency. At the data frequency, a power density of the data signal is substantially equal to zero. A ratio of the subcarrier frequency to the data frequency ranges from 0.8 to 1, and the subcarrier frequency ranges from 2.4 GHz to 2.483 GHz.

According to yet another embodiment, an apparatus for receiving a supervisory signal for optical network applications includes an optical-to-electrical conversion system configured to receive an optical signal and output an electrical signal and a

data signal, and a subcarrier reception system configured to receive the electrical signal and output a supervisory signal. The subcarrier reception system includes a band pass filter associated with a subcarrier frequency. The data signal is associated with a data bandwidth, and the data bandwidth includes a data frequency. At the data frequency, a power density of the data signal is substantially equal to zero. A ratio of the subcarrier frequency to the data frequency ranges from 0.8 to 1, and the subcarrier frequency ranges from 2.4 GHz to 2.483 GHz.

The present invention has various advantages. Certain embodiments of the present invention provide high performance at low cost. Some embodiments of the present invention use RF transmitters and receivers that are commercially available for wireless communications. For example, the wireless communications are conducted in the ISM band. The RF transmitters and receivers include integrated circuit (IC) chips. These IC chips can offer excellent performance at low price for optical communications.

Various additional objects, features and advantages of the present invention can be more fully appreciated with reference to the detailed description and accompanying drawings that follow.

Brief Description of the Drawings

Figure 1 is a simplified conventional optical network connection;

Figure 2 is a simplified optical network connection according to an embodiment of the present invention;

Figure 3 is a simplified conventional optical network connection;

Figure 4 is a simplified optical network connection according to another embodiment of the present invention;

Figure 5 is a simplified power spectrum of a data signal and a supervisory signal according to an embodiment of the present invention.

Figure 6 is a simplified power spectrum of a subcarrier signal and a simplified band limiting characteristic of a band pass filter according to an embodiment of the present invention;

Figure 7 is a simplified conventional diagram for signal transmission and reception in ISM band;

Figure 8 is a simplified optical network connection according to yet another embodiment of the present invention;

Figure 9 is a simplified optical network connection according to yet another embodiment of the present invention.

Embodiments of the Invention

The present invention relates in general to telecommunication techniques. More particularly, the invention provides a method and system for subcarrier modulation as supervisory channel. Merely by way of example, the invention is described as it applies to optical networks, but it should be recognized that the invention has a broader range of applicability.

At low frequency, subcarrier modulation can be used as supervisory channel. The subcarrier frequency overlaps with the main data spectrum, so the latter acts as a high-level noise source to subcarrier signals. Limited by the high spectral density of data signals, the low-frequency subcarrier modulation usually supports a transmission rate for the supervisory signals only in the kbps range. For example, the supervisory channel has a transmission rate of 9.6 kbps. In modern optical networks, the terminal nodes often require communications faster than kbps.

Figure 1 is a simplified conventional optical network connection. An optical network connection 100 includes a transmitter system 110, a receiver system 120, and an optical link 130. The transmitter system 110 includes an electrical-to-optical signal converter 112. The receiver system 120 includes an optical-to-electrical signal converter 122 and a clock and data recovery system 124. The optical-to-electrical signal converter receives a data signal 140. At the transmitter system 110, the data signal is converted into an optical signal 142. The optical signal 142 is transmitted through the optical link 130 and then received by the receiver system 120. For example, the optical link 130 includes optical fibers. At the receiver system 120, the optical signal 142 is converted to an electrical signal 144, which often contains signal distortions. These signal distortions are reduced by the clock and data recovery system 124. The clock and data recovery system 124 generates a data signal 146, which is substantially a replica of the data signal 140.

Figure 2 is a simplified optical network connection according to an embodiment of the present invention. The diagram is merely an example, which should not unduly limit the scope of the present invention. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. An optical connection 200 includes a transmitter system 210, a receiver system 220, and an optical link 230. The transmitter system 210 includes an electrical-to-optical signal converter 212, an RF band pass filter 214, and an RF modulator 216. The receiver system 220 includes an optical-to-electrical signal converter 222, an RF band pass filter 224, an RF demodulator 226, and a clock and data recovery system 228. For example, the RF band pass filter 214 and the RF modulator 216 form a subcarrier transmitter system. In another example, the RF band pass filter 224 and the RF demodulator 226 forms a subcarrier receiver system. Although the above has been shown using systems 210, 212, 214, 216, 220, 222, 224, 226, 228, and 230, there can be many alternatives, modifications, and variations. Some of the systems may be combined. Other systems may be added to the optical connection 200. Depending upon the embodiment, one or more of the systems may be replaced. Further details of these systems are found throughout the present specification and more particularly below.

The RF modulator 216 receives a supervisory signal 240 and modulates an RF source 270. For example, the supervisory signal 240 is generated by a control circuit. In another example, the RF source 270 has a frequency of about 2.4 GHz. At the RF modulator 216, the RF signal is modulated according to the base band supervisory signal 240. The modulation format can be Amplitude-Shift Keying (ASK), Frequency-Shift Keying (FSK), or Phase-Shift Keying (PSK). The modulated subcarrier signal then passes the RF band pass filter 214. The RF band pass filter 214 has a center frequency substantially equal to that of the RF source 270, and a transmission bandwidth substantially equal to the supervisory signal bandwidth.

At the electrical-to-optical signal converter 212, a data signal 250 is combined with the subcarrier signal 242. The combined signal is converted into an optical signal 260. For example, the frequency of the subcarrier signal 242 falls within the frequency response range of the electrical-to-optical signal converter 212. In another example, the electrical-to-optical converter 212 has a frequency response range up to 2.5 Gbps. In yet another example, the electrical-to-optical signal converter 212 is an

analog system, whose output signal level is proportional to the input signal level. The optical signal 260 is a superposition of the optical power corresponding to the data signal 250 and the optical power corresponding to the subcarrier signal 242. The ratio between the subcarrier signal 242 and the data signal 250 in terms of optical power is in the range of 1% to 10%. This ratio is often referred to as subcarrier modulation depth.

The optical signal 260 is transmitted through the optical link 230 and received by the receiver system 220. For example, the optical link 230 includes optical fibers. At the receiver system 220, the optical signal 260 is converted to an electrical signal 262 by the optical-to-electrical signal converter 222. A portion 244 of the signal 262 passes through the RF band pass filter 224 and enters the RF demodulator 226. The RF band pass filter allows only the signal frequency components around the subcarrier frequency to pass, and rejects substantially all other frequency components. At the RF demodulator 226, the band passed signal is demodulated through Amplitude-Shift Keying (ASK), Frequency-Shift Keying (FSK), or Phase-Shift Keying (PSK). The RF demodulator 226 then outputs a base band supervisory signal 246. The supervisor signal 246 is substantially a replica of the supervisory signal 240. For example, the supervisory signal 246 is sent to a control circuit. Additionally, the other portion of the signal 262 is received by the clock and data recovery system 228. The clock and data recovery system 228 reduces signal distortions and generates a data signal 252. The data signal 252 is substantially a replica of the data signal 250.

Figure 3 is a simplified conventional optical network connection. An optical network connection 300 includes a transmitter system 310, a receiver system 320, and an optical link 330. The transmitter system 310 includes a laser source 312 and an electrical-to-optical signal modulator 314. The receiver system 320 includes an optical-to-electrical signal converter 322 and a clock and data recovery system 324. The laser source 312 provides a Continuous Wave (CW) light 380 to the electrical-to-optical signal modulator 314. For example, the laser source 312 includes a laser diode. The modulator modulates the CW light 380 with a received data signal 340 and converts the received data signal 340 into an optical signal 342. The optical signal 342 is transmitted through the optical link 330 and then received by the receiver system 330. For example, the optical link 330 includes optical fibers. At the receiver

system 330, the optical signal 342 is converted to an electrical signal 344, which often contains signal distortions. These signal distortions are reduced by the clock and data recovery system 324. The clock and data recovery system 324 generates a data signal 346, which is substantially a replica of the data signal 340.

Figure 4 is a simplified optical network connection according to another embodiment of the present invention. The diagram is merely an example, which should not unduly limit the scope of the present invention. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. An optical connection 400 includes a transmitter system 410, a receiver system 420, and an optical link 430. The transmitter system 410 includes a laser source 412, an electrical-to-optical signal modulator 414, an RF band pass filter 416, and an RF modulator 418. For example, the laser source 412 includes a laser diode. The receiver system 420 includes an optical-to-electrical signal converter 422, an RF band pass filter 424, an RF demodulator 426, and a clock and data recovery system 428. For example, the RF band pass filter 416 and the RF modulator 418 forms a subcarrier transmitter system. In another example, the RF band pass filter 424 and the RF demodulator 426 forms a subcarrier receiver system. Although the above has been shown using systems 410, 412, 414, 416, 418, 420, 422, 424, 426, 428, and 430, there can be many alternatives, modifications, and variations. Some of the systems may be combined. For example, the laser source 412 and the electrical-to-optical signal modulator 414 are combined. Other systems may be added to the optical connection 400. Depending upon the embodiment, one or more of the systems may be replaced. Further details of these systems are found throughout the present specification and more particularly below.

The RF modulator 418 receives a supervisory signal 440 and modulates an RF source 470. For example, the supervisory signal 440 is generated by a control circuit. At the RF modulator 418, the RF signal is modulated according to the base band supervisory signal 440. The modulation format can be Amplitude-Shift Keying (ASK), Frequency-Shift Keying (FSK), or Phase-Shift Keying (PSK). The modulated subcarrier signal then passes the RF band pass filter 416. The RF band pass filter 416 has a center frequency substantially equal to that of the RF source 470, and a transmission bandwidth substantially equal to the supervisory signal bandwidth.

The laser source 412 receives the subcarrier signal 442 and generates a laser signal 480. The subcarrier signal 442 modulates the intensity of the laser signal 480. For example, the laser source 412 includes a laser diode. The laser signal is provided to the electrical-to-optical signal modulator 414. The modulator 414 modulates the laser signal with a received data signal 450 and converts the received data signal 450 into an optical signal 452. For example, the subcarrier signal 442 has a frequency ranging from 2.4 to 2.5 GHz, which falls within the frequency response range of the laser source 412 and the electrical-to-optical signal modulator 414. In yet another example, the subcarrier modulation depth is in the range of 1% to 10%.

The optical signal 452 is transmitted through the optical link 430 and received by the receiver system 420. For example, the optical link 430 includes optical fibers. At the receiver system 420, the optical signal 452 is converted to an electrical signal 462 by the optical-to-electrical signal converter 422. A portion 464 of the signal 462 passes through the RF band pass filter 424 and enters the RF demodulator 426. The RF band pass filter allows only the signal frequency components around the subcarrier frequency to pass, and rejects substantially all other frequency components. At the RF demodulator 426, the band passed signal is demodulated through Amplitude-Shift Keying (ASK), Frequency-Shift Keying (FSK), or Phase-Shift Keying (PSK). The RF demodulator 426 then outputs a base band supervisory signal 466. The supervisor signal 466 is substantially a replica of the supervisory signal 440. For example, the supervisor signal 466 is sent to a control circuit. Additionally, the other portion of the signal 462 is received by the clock and data recovery system 428. The clock and data recovery system 428 reduces signal distortions and generates a data signal 454. The data signal 454 is substantially a replica of the data signal 450.

As discussed above and shown in Figures 2 and 4, the data signals 250 and 450 act as noise to the subcarrier signals 240 and 440 respectively. At the subcarrier frequency, the spectral density of the data signals 250 and 450 is substantially lower than the spectral density of the subcarrier signals 240 and 440 respectively.

In certain embodiments as shown in Figures 2 and 4, the data signal 250 or 450 is transmitted in the form of Non-Return to Zero (NRZ) format. According to the NRZ format, the binary 0 corresponds to -1.0 volt and the binary 1 corresponds to +1.0 volt

at the output 262 or 462 of the optical-to-electrical signal converter 222 or 422 respectively. The average power of the data signal 250 or 450 is then

$$P_{DATA} = \frac{1.0^2}{R} \quad \text{(Equation 1)}$$

where R is the output load impedance of the optical-to-electrical signal converter 222 or 422. For example, R is equal to about 50 ohms. The data signal 250 or 450 is superposed with a subcarrier signal 240 or 440 with the following format:

$$V_{SC}(t) = A_{SC} \times \sin(2\pi \times f_{SC} \times t + \varphi) \quad \text{(Equation 2)}$$

where V_{SC}, A_{SC} and f_{SC} are voltage, amplitude, and frequency of the subcarrier signal 240 or 440 respectively. φ represents a constant phase, and t represents time. The subcarrier signal 240 or 440 can be transmitted through Amplitude-Shift Keying (ASK) by the modulation of A_{SC}, Frequency-Shift Keying (FSK) by the modulation of f_{SC}, or Phase-Shift Keying (PSK) by the modulation of φ. For FSK or PSK, A_{SC} is a constant. The average power of subcarrier signal is given by

$$P_{SC} = \frac{0.5 \times A_{SC}^2}{R} \quad \text{(Equation 3)}$$

To reduce perturbation to the data signal 240 or 440, the subcarrier signal 240 or 440 is limited to cause no more than $\pm 20\%$ broadening of the "0" and "1" levels at the output 262 or 462. Specifically,

$$A_{SC} = 20\% \times 1.0 = 0.2 \text{ (volt)} \quad \text{(Equation 4)}$$

The above perturbation usually causes 1 dB "eye" penalty as commonly used in telecommunication industry. The 1dB "eye" penalty usually causes the sensitivity of a receiver to degrade by 1dB. Correspondingly, the maximum power of the subcarrier signal 240 or 440 is given by

$$P_{SC} = \frac{0.5 \times 0.2^2}{R} = 2\% \times P_{DATA} \quad \text{(Equation 5)}$$

Hence the maximum power of the subcarrier signal 240 or 440 should be no more than 2% of the average power of the data signal 250 or 450. With this limitation on the subcarrier modulation, the maximum subcarrier data rate is determined by the Signal-to-Noise Ratio (SNR) limit.

For in-band subcarrier transmission, the subcarrier frequency is within the frequency band of the data signal 250 or 450. The spectrum of the data signal 250 or

450 acts as a noise to the subcarrier signal 240 or 440. The SNR of the subcarrier signal is therefore given by the ratio between the spectral density of the subcarrier signal and the spectral density of the data signal.

Figure 5 is a simplified power spectrum of a data signal and a supervisory signal according to an embodiment of the present invention. The power spectrum in Figure 5 may be implemented with the system 200 or 400 as shown in Figure 2 or 4 respectively. Figure 5 is merely an example, which should not unduly limit the scope of the present invention. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. For example, the data signal is in the NRZ format. The data rate of the date signal is 2.5 Gigabits per second (Gbps). The data power density decreases with increasing frequency and falls to almost zero at about 2.5 GHz. To select the subcarrier signal, an RF band pass filter 224 or 424 is used with a -3dB transmission bandwidth substantially equal to the subcarrier data rate as follows.

$$\Delta f_{SC} = R_{SC} \qquad \text{(Equation 6)}$$

where Δf_{SC} is the -3dB transmission bandwidth of the RF band pass filter 224 or 424, and R_{SC} is the subcarrier data rate. The RF band pass filter 224 or 424 allows the subcarrier signal and a portion of the data signal to pass through. The passed portion of the data signal acts as a noise causing degradation in the subcarrier signal. In the frequency domain, the subcarrier signal power passing the band pass filter is given by

$$P_{SC} \approx \rho_{SC}(f_{SC}) \times R_{SC} \qquad \text{(Equation 7)}$$

where P_{SC} is the subcarrier power, and $\rho_{SC}(f_{SC})$ is the subcarrier power density at the subcarrier frequency. Also in the frequency domain, the noise power from the data signal passing the band pass filter is

$$P_N \approx \rho_{DATA}(f_{SC}) \times R_{SC} \qquad \text{(Equation 8)}$$

P_N is the noise power, and $\rho_{DATA}(f_{SC})$ is the noise power density at the subcarrier frequency. The SNR for the subcarrier signal is then given by

$$SNR = \frac{P_{SC}}{P_N} = \frac{\rho_{SC}(f_{SC})}{\rho_{DATA}(f_{SC})} = \frac{P_{SC}}{R_{SC} \times \rho_{DATA}(f_{SC})} \qquad \text{(Equation 9)}$$

SNR is inversely proportionate to the subcarrier data rate R_{SC}. As shown in Figure 5, when subcarrier frequencies are in the range of kHz or MHz, the spectral density ρ_{DATA} can be approximated as follows.

$$\rho_{DATA}(f_{SC}) \approx \rho_{DATA}(0) \quad \text{(Equation 10)}$$

Additionally, the total data signal power, P_{DATA}, is equal to the integration of ρ_{DATA} in the frequency space. From Figure 5, it can be seen that this is approximately given by

$$P_{DATA} \approx \rho_{DATA}(0) \times 0.5 \times R_{DATA} \quad \text{(Equation 11)}$$

where R_{DATA} is the main data rate for the data signal. With Equations 9-11 and Equation 5, the SNR for the subcarrier signal is derived as

$$SNR = \frac{P_{SC}}{R_{SC} \times P_{DATA}/(0.5 \times R_{DATA})} = 1\% \times R_{DATA}/R_{SC} \quad \text{(Equation 12)}$$

For high quality detection, SNR should equal at least 20 dB for certain embodiments. Specifically,

$$SNR = 100 \quad \text{(Equation 13)}$$

Hence the subcarrier data rate R_{SC} and the main data rate R_{DATA} have the following relation:

$$R_{SC} \leq 10^{-4} \times R_{DATA} \quad \text{(Equation 14)}$$

Equation 14 provides the limitation on the subcarrier data rate in order to satisfy both Equations 4 and 13. Equations 4 is usually required for high quality detection of data signal, and Equations 13 is usually required for high quality detection of subcarrier signal. To simultaneously transmit both data and subcarrier signals, both conditions should usually be satisfied. For example, the main data rate equals 2.5 Gbps, and the subcarrier data rate should be no higher than 250 kbps. In another example, the main data rate equals 100 Mbps, and the maximum subcarrier data rate should be no higher than 10 kbps.

In contrast, when the subcarrier frequency is increased from the range of kHz or MHz to the range of GHz, e.g., 2.4 GHz, the maximum subcarrier data rate can be significantly improved. For example, as shown in Figure 5, the noise power density at f_{SC} = 2.4 GHz is about 26 dB lower than that at f_{SC} in the range of kHz-MHz, i.e., $\rho_{DATA}(2.4\ GHz) = 10^{-2.6}\ \rho_{DATA}(0)$. As a result, the SNR is 26 dB higher for a given subcarrier data rate according to Equation 9, and the maximum subcarrier data rate can be increased to about 100 Mbps to obtain the desired 20 dB SNR. Alternatively, if the maximum subcarrier data rate is not used, the subcarrier modulation depth and the perturbation to the data signal may be reduced.

Figure 6 is a simplified power spectrum of a subcarrier signal and a simplified band limiting characteristic of a band pass filter according to an embodiment of the present invention. The diagram is merely an example, which should not unduly limit the scope of the present invention. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. The subcarrier signal has a power spectrum 610. For example, the power spectrum 610 is associated with a data rate of 1 Mbps at a subcarrier frequency of 2.41 GHz. The RF band pass filter has a band limiting characteristic 620. For example, the band limiting characteristic 620 has a Full-Width Half-Maximum (FWHM) equal to 1.6 MHz centered at 2.41 GHz. The RF band pass filter can be used as the RF band pass filter 214, 224, 416, or 424.

As discussed above and further emphasized here, Figures 5 and 6 are merely examples, which should not unduly limit the scope of the present invention. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. For example, the data power density falls to almost zero at a frequency equal to, lower than, or higher than 2.5 GHz. The subcarrier frequency is selected to be a certain percentage of the frequency at which the data power density falls to almost zero. For example, the percentage ranges from 80% to 100%.

According to another embodiment of the present invention, a method for processing a supervisory signal for optical network applications includes receiving a first supervisory signal, processing information associated with the first supervisory signal, and outputting a second supervisory signal based on at least information associated with the first supervisory signal. Additionally, the method includes receiving the second supervisory signal and a first data signal, processing information associated with the second supervisory signal and the first data signal, and outputting a first optical signal based on at least information associated with the second supervisory signal and the first data signal. Moreover, the method includes receiving the first optical signal, processing information associated with the first optical signal, and outputting a first electrical signal and a second data signal based on at least information associated with the first optical signal. Additionally, the method includes receiving the first electrical signal, processing information associated with the first electrical signal, and outputting a third supervisory signal. The second supervisory signal is associated with a first subcarrier frequency, and the first data signal is

associated with a first data bandwidth. The first data bandwidth includes a first data frequency, and at the first data frequency a power density of the first data signal is substantially equal to zero. A ratio of the first subcarrier frequency to the first data frequency ranges from 0.8 to 1.

According to yet another embodiment of the present invention, a method for transmitting a supervisory signal for optical network applications includes receiving a first supervisory signal, processing information associated with the first supervisory signal, and outputting a second supervisory signal based on at least information associated with the first supervisory signal. Additionally, the method includes receiving the second supervisory signal and a first data signal, processing information associated with the second supervisory signal and the first data signal, and outputting a first optical signal based on at least information associated with the second supervisory signal and the first data signal. The second supervisory signal is associated with a first subcarrier frequency, and the first data signal is associated with a first data bandwidth. The first data bandwidth includes a first data frequency, and at the first data frequency a power density of the first data signal is substantially equal to zero. A ratio of the first subcarrier frequency to the first data frequency ranges from 0.8 to 1.

According to yet another embodiment of the present invention, a method for receiving a supervisory signal for optical network applications includes receiving a first optical signal, processing information associated with the first optical signal, and outputting a first electrical signal and a second data signal based on at least information associated with the first optical signal. Additionally, the method includes receiving the first electrical signal, processing information associated with the first electrical signal, and outputting a third supervisory signal. The processing information associated with the first electrical signal includes filtering the first electrical signal, and the filtering the first electrical signal is associated with a first subcarrier frequency. The second data signal is associated with a first data bandwidth, and the first data bandwidth includes a maximum data frequency. A ratio of the first subcarrier frequency to the maximum data frequency ranges from 0.8 to 1.

The present invention has various advantages. Certain embodiments of the present invention use a subcarrier frequency that is slightly lower than the maximum

frequency of the frequency band of the data signal 250 or 450. The subcarrier power spectrum overlaps with the tail of the data power spectrum. The data power density at the tail is substantially lower than that at a low frequency. For example, the low frequency is in the range of kHz or MHz. Some embodiments of the present invention provide a subcarrier signal that shares with the data signal some or all of the optical-to-electrical signal converter, the electrical-to-optical signal converter, and other optical-to-electrical or electrical-to-optical conversion components. Certain embodiments of the present invention significantly lower costs for transmitting and receiving supervisory signals. Some embodiments of the present invention provide a low data power density at f_{SC}. The supervisory signal has a high signal to noise ratio and can be transmitted at a high data rate. For example, the data rate is higher than 1 Mbps. Certain embodiments of the present invention provide a subcarrier modulation with a low amplitude. The main data channel suffers from only a small perturbation. For example, the perturbation in optical power is smaller than 1 dB. Some embodiments of the present invention provide a simple configuration and an easy implementation.

Figure 7 is a simplified conventional diagram for signal transmission and reception in ISM band. A system 700 includes an RF transmitter 710, an RF receiver 720, and antennas 730 and 740. For example, the RF transmitter 710 converts a base-band signal 750 to a RF signal 752. The RF signal 752 has a carrier frequency ranging from 2.4 GHz to 2.483 GHz. For example, this frequency range is the unlicensed Industrial, Scientific, and Medical (ISM) band in the United States. In another example, the RF transmitter 710 includes an RF transmitter chip in ISM band. The RF signal 752 is radiated by the antenna 730 to the air, which serves as the transmission medium. The transmitted RF signal is received by the antenna 740. For example, the antenna 740 is located at a distance, such as several meters to several hundred meters, away from the antenna 730. In response, the antenna 740 outputs an RF signal 754 to the RF receiver 720. The RF receiver 720 converts the RF signal 754 to a base-band signal 756. For example, the RF receiver 720 includes an RF receiver chip in ISM band. In another example, the communication between the antennas 730 and 740 are bi-directional. The RF receiver 710 is part of an RF transmitter/receiver pair, and the RF transmitter 720 is part of an RF transmitter/receiver pair.

Figure 8 is a simplified optical network connection according to yet another embodiment of the present invention. The diagram is merely an example, which should not unduly limit the scope of the present invention. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. A system 800 includes a transmitter system 810, a receiver system 820, and an optical link 830. The transmitter system 810 includes an electrical-to-optical signal converter 812 and an RF transmitter 870. The receiver system 820 includes an optical-to-electrical signal converter 822, an RF receiver 880, and a data recovery system 828. Although the above has been shown using components 810, 812, 820, 822, 828, 830, 870, and 880, there can be many alternatives, modifications, and variations. Some of the components may be combined. Other components may be added to the system 800. Depending upon the embodiment, one or more of the component may be replaced. Further details of these components are found throughout the present specification and more particularly below.

The RF transmitter 870 receives a supervisory signal 840 and converts the supervisory signal 840 to an RF signal 842. In one embodiment, the RF signal 842 is a subcarrier signal. In another embodiment, the RF signal 842 has a carrier frequency ranging from 2.4 GHz to 2.483 GHz. For example, the carrier frequency is in the ISM band. In yet another embodiment, the supervisory signal 840 is generated by a control circuit. In yet another embodiment, the RF transmitter 870 serves as a subcarrier transmission system. In yet another embodiment, the RF transmitter 870 includes the RF transmitter 710. For example, the RF transmitter 870 can be that used for Wi-Fi, Bluetooth, and/or wireless USB. In another example, the RF transmitter 870 uses a modulation format of Amplitude-Shift Keying (ASK), Frequency-Shift Keying (FSK), or Phase-Shift Keying (PSK).

At the electrical-to-optical signal converter 812, a data signal 850 is combined with the subcarrier signal 842. The combined signal is converted into an optical signal 860. For example, the frequency of the subcarrier signal 842 falls within the frequency response range of the electrical-to-optical signal converter 812. In another example, the electrical-to-optical converter 812 has a frequency response range up to 2.5 Gbps. In yet another example, the electrical-to-optical signal converter 812 is an analog system, whose output signal level is proportional to the input signal level. The

optical signal 860 is a superposition of the optical power corresponding to the data signal 850 and the optical power corresponding to the subcarrier signal 842. For example, the superposition is linear. The ratio between the subcarrier signal 842 and the data signal 850 in terms of optical power is in the range of 1% to 10%. This ratio is often referred to as subcarrier modulation depth.

The optical signal 860 is transmitted through the optical link 830 and received by the receiver system 820. In one embodiment, the optical link 830 includes optical fibers. For example, the optical fibers serve as the transmission medium, and the transmission distance is up to several hundred kilometers. At the receiver system 820, the optical signal 860 is converted to an electrical signal 862 by the optical-to-electrical signal converter 822. A portion 844 of the electrical signal 862 is received by the RF receiver 880. For example, the RF receiver 880 includes a band pass filter. The RF receiver 880 extracts a subcarrier signal from the portion 844, and converts the subcarrier signal to a supervisory signal 846. In one embodiment, the RF receiver 880 serves as a subcarrier reception system. In another embodiment, the RF receiver 880 includes the RF receiver 720. For example, the RF receiver 880 can be that used for Wi-Fi, Bluetooth, and/or wireless USB. In another example, the RF receiver 880 uses a demodulation format of Amplitude-Shift Keying (ASK), Frequency-Shift Keying (FSK), or Phase-Shift Keying (PSK). The supervisor signal 846 is substantially a replica of the supervisory signal 840. For example, the supervisory signal 846 is sent to a control circuit. Additionally, the other portion of the signal 862 is received by the clock and data recovery system 828. The clock and data recovery system 828 reduces signal distortions and generates a data signal 852. The data signal 852 is substantially a replica of the data signal 850.

Figure 9 is a simplified optical network connection according to yet another embodiment of the present invention. The diagram is merely an example, which should not unduly limit the scope of the present invention. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. A system 900 includes a transmitter system 910, a receiver system 920, and an optical link 930. The transmitter system 910 includes a laser source 912, an electrical-to-optical signal modulator 914, and an RF transmitter 970. For example, the laser source 912 includes a laser diode. The receiver system 920 includes an optical-to-electrical signal

converter 922, an RF receiver 990, and a clock and data recovery system 928. Although the above has been shown using components 910, 912, 914, 920, 922, 928, 930, 970 and 990, there can be many alternatives, modifications, and variations. Some of the components may be combined. For example, the laser source 912 and the electrical-to-optical signal modulator 914 are combined. Other components may be added to the system 900. Depending upon the embodiment, one or more of the components may be replaced. Further details of these components are found throughout the present specification and more particularly below.

The RF transmitter 970 receives a supervisory signal 940 and converts the supervisory signal 940 to an RF signal 942. In one embodiment, the RF signal 942 is a subcarrier signal. In another embodiment, the RF signal 942 has a carrier frequency ranging from 2.4 GHz to 2.483 GHz. For example, the carrier frequency is in the ISM band. In yet another embodiment, the supervisory signal 940 is generated by a control circuit. In yet another embodiment, the RF transmitter 970 serves as a subcarrier transmission system. In yet another embodiment, the RF transmitter 970 includes the RF transmitter 710. For example, the RF transmitter 970 can be that used for Wi-Fi, Bluetooth, and/or wireless USB. In another example, the RF transmitter 970 uses a modulation format of Amplitude-Shift Keying (ASK), Frequency-Shift Keying (FSK), or Phase-Shift Keying (PSK).

The laser source 912 receives the subcarrier signal 942 and generates a laser signal 980. The subcarrier signal 942 modulates the intensity of the laser signal 980. For example, the laser source 912 includes a laser diode. The laser signal is provided to the electrical-to-optical signal modulator 914. The modulator 914 modulates the laser signal with a received data signal 950 and converts the received data signal 950 into an optical signal 952. For example, the subcarrier signal 942 has a frequency ranging from 2.4 GHz to 2.483 GHz, which falls within the frequency response range of the laser source 912 and the electrical-to-optical signal modulator 914. In yet another example, the subcarrier modulation depth is in the range of 1% to 10%.

The optical signal 952 is transmitted through the optical link 930 and received by the receiver system 920. In one embodiment, the optical link 930 includes optical fibers. For example, the optical fibers serve as the transmission medium, and the transmission distance is up to several hundred kilometers. At the receiver system 920,

the optical signal 952 is converted to an electrical signal 962 by the optical-to-electrical signal converter 922. A portion 964 of the electrical signal 962 is received by the RF receiver 990. For example, the RF receiver 990 includes a band pass filter. The RF receiver 990 extracts a subcarrier signal from the portion 964, and converts the subcarrier signal to a supervisory signal 966. In one embodiment, the RF receiver 990 serves as a subcarrier reception system. In another embodiment, the RF receiver 990 includes the RF receiver 720. For example, the RF receiver 990 can be that used for Wi-Fi, Bluetooth, and/or wireless USB. In another example, the RF receiver 990 uses a demodulation format of Amplitude-Shift Keying (ASK), Frequency-Shift Keying (FSK), or Phase-Shift Keying (PSK). The supervisor signal 966 is substantially a replica of the supervisory signal 940. For example, the supervisory signal 966 is sent to a control circuit. Additionally, the other portion of the signal 962 is received by the clock and data recovery system 928. The clock and data recovery system 928 reduces signal distortions and generates a data signal 954. The data signal 954 is substantially a replica of the data signal 950.

As discussed above and further emphasized here, Figures 8 and 9 are merely examples, which should not unduly limit the scope of the present invention. One of ordinary skill in the art would recognize many variations, alternatives, and modifications. For example, the system 800 is an example of the optical connection 200. In another example, the system 900 is an example of the optical connection 400.

According to yet another embodiment of the present invention, a method for processing a supervisory signal for optical network applications includes receiving a first supervisory signal, processing information associated with the first supervisory signal, outputting a second supervisory signal based on at least information associated with the first supervisory signal, and receiving the second supervisory signal and a first data signal. Additionally, the method includes processing information associated with the second supervisory signal and the first data signal, outputting a first optical signal based on at least information associated with the second supervisory signal and the first data signal, receiving the first optical signal, and processing information associated with the first optical signal. Moreover, the method includes outputting a first electrical signal and a second data signal based on at least information associated with the first optical signal, receiving the first electrical signal, processing information

associated with the first electrical signal, and outputting a third supervisory signal. The second supervisory signal is associated with a first subcarrier frequency. The first data signal is associated with a first data bandwidth, and the first data bandwidth including a first data frequency. At the first data frequency, a power density of the first data signal is substantially equal to zero. A ratio of the first subcarrier frequency to the first data frequency ranges from 0.8 to 1, and the first subcarrier frequency ranges from 2.4 GHz to 2.483 GHz. For example, the method can be performed by the system 800 and/or the system 900.

According to yet another embodiment of the present invention, a method for transmitting a supervisory signal for optical network applications includes receiving a first supervisory signal, processing information associated with the first supervisory signal, and outputting a second supervisory signal based on at least information associated with the first supervisory signal. Additionally, the method includes receiving the second supervisory signal and a data signal, processing information associated with the second supervisory signal and the data signal, and outputting an optical signal based on at least information associated with the second supervisory signal and the data signal. The second supervisory signal is associated with a subcarrier frequency, and the data signal is associated with a data bandwidth. The data bandwidth includes a data frequency, and at the data frequency a power density of the data signal is substantially equal to zero. A ratio of the subcarrier frequency to the data frequency ranges from 0.8 to 1, and the subcarrier frequency ranges from 2.4 GHz to 2.483 GHz. For example, the method can be performed by the system 800 and/or the system 900.

According to yet another embodiment of the present invention, a method for receiving a supervisory signal for optical network applications includes receiving an optical signal, processing information associated with the optical signal, and outputting an electrical signal and a data signal based on at least information associated with the optical signal. Additionally, the method includes receiving the electrical signal, processing information associated with the electrical signal, and outputting a supervisory signal. The processing information associated with the electrical signal includes filtering the electrical signal, and the filtering the electrical signal is associated with a subcarrier frequency. The data signal is associated with a

data bandwidth, and the data bandwidth including a data frequency. At the data frequency, a power density of the data signal is substantially equal to zero. A ratio of the subcarrier frequency to the data frequency ranges from 0.8 to 1, and the subcarrier frequency ranges from 2.4 GHz to 2.483 GHz. For example, the method can be performed by the system 800 and/or the system 900.

The present invention has various advantages. Certain embodiments of the present invention provide high performance at low cost. Some embodiments of the present invention use RF transmitters and receivers that are commercially available for wireless communications. For example, the wireless communications are conducted in the ISM band. The RF transmitters and receivers include integrated circuit (IC) chips. These IC chips can offer excellent performance at low price for optical communications.

Although specific embodiments of the present invention have been described, it will be understood by those of skill in the art that there are other embodiments that are equivalent to the described embodiments. Accordingly, it is to be understood that the invention is not to be limited by the specific illustrated embodiments, but only by the scope of the appended claims.

Claims

1. An apparatus for processing a supervisory signal for optical network applications, the apparatus comprising:

a subcarrier transmission system configured to receive a first supervisory signal and output a second supervisory signal;

an electrical-to-optical conversion system configured to receive the second supervisory signal and a first data signal and output a first optical signal;

an optical-to-electrical conversion system configured to receive the first optical signal and output a first electrical signal and a second data signal;

a subcarrier reception system configured to receive the first electrical signal and output a third supervisory signal;

an optical system coupled to the electrical-to-optical conversion system and the optical-to-electrical conversion system;

wherein the second supervisory signal is associated with a first subcarrier frequency;

wherein the first data signal is associated with a first data bandwidth, the first data bandwidth including a first data frequency, at the first data frequency a power density of the first data signal being substantially equal to zero;

wherein a ratio of the first subcarrier frequency to the first data frequency ranges from 0.8 to 1;

wherein the first subcarrier frequency ranges from 2.4 GHz to 2.483 GHz.

2. The apparatus of claim 1 wherein the first optical signal is associated with a perturbation to the first data signal, the perturbation being smaller than or equal to 1 dB.

3. The apparatus of claim 1 wherein the first optical signal is associated with a signal-to-noise ratio related to the first supervisory signal, the signal-to-noise ratio being larger than or equal to 20 dB.

4. The apparatus of claim 1 wherein the first supervisory signal is associated with a first subcarrier data rate larger than 1 Mbps.

5. The apparatus of claim 4 wherein the first supervisory signal is associated with the first subcarrier data rate larger than 5 Mbps.

6. The apparatus of claim 1 wherein the first data frequency is a maximum frequency associated with the first data bandwidth.

7. The apparatus of claim 6 wherein the first data signal is associated with a non-return to zero format and a first data rate substantially equal to or smaller than 2.5 gigabits per second.

8. The apparatus of claim 7 wherein the first optical signal is associated with a perturbation related to the first data signal, the perturbation being smaller than or equal to 1 dB, the first optical signal is associated with a signal-to-noise ratio related to the first supervisory signal, the signal-to-noise ratio being larger than or equal to 20 dB.

9. The apparatus of claim 1 wherein the subcarrier transmission system comprises an RF transmitter associated with an ISM band.

10. The apparatus of claim 1 wherein the subcarrier reception system comprises an RF receiver associated with an ISM band.

11. The apparatus of claim 1 wherein:

the third supervisory signal is substantially the same as the first supervisory signal; and

the second data signal is substantially the same as the first data signal.

12. The apparatus of claim 1 wherein the optical-to-electrical conversion system comprises:

an optical-to-electrical signal converter configured to receive the first optical signal and configured to output the first electrical signal and a second electrical signal;

a clock and recovery system configured to receive the second electrical signal and output the second data signal.

13. The apparatus of claim 1 wherein the electrical-to-optical conversion system comprises:

a laser source configured to receive the second supervisory signal;

an electrical-to-optical modulator coupled to the laser source and configured to receive at least the first data signal and output the first optical signal.

14. The apparatus of claim 1 wherein the electrical-to-optical conversion system comprises an electrical-to-optical signal converter configured to receive the second supervisory signal and the first data signal and output the first optical signal.

15. A method for processing a supervisory signal for optical network applications, the method comprising:

receiving a first supervisory signal;

processing information associated with the first supervisory signal;

outputting a second supervisory signal based on at least information associated with the first supervisory signal;

receiving the second supervisory signal and a first data signal;

processing information associated with the second supervisory signal and the first data signal;

outputting a first optical signal based on at least information associated with the second supervisory signal and the first data signal;

receiving the first optical signal;

processing information associated with the first optical signal;

outputting a first electrical signal and a second data signal based on at least information associated with the first optical signal;

receiving the first electrical signal;

processing information associated with the first electrical signal;

outputting a third supervisory signal;

wherein the second supervisory signal is associated with a first subcarrier frequency;

wherein the first data signal is associated with a first data bandwidth, the first data bandwidth including a first data frequency, at the first data frequency a power density of the first data signal being substantially equal to zero;

wherein a ratio of the first subcarrier frequency to the first data frequency ranges from 0.8 to 1;

wherein the first subcarrier frequency ranges from 2.4 GHz to 2.483 GHz.

16. An apparatus for transmitting a supervisory signal for optical network applications, the apparatus comprising:

a subcarrier transmission system configured to receive a first supervisory signal and output a second supervisory signal;

an electrical-to-optical conversion system configured to receive the second supervisory signal and a data signal and output an optical signal;

wherein the second supervisory signal is associated with a subcarrier frequency;

wherein the data signal is associated with a data bandwidth, the data bandwidth including a data frequency, at the data frequency a power density of the data signal being substantially equal to zero;

wherein a ratio of the subcarrier frequency to the data frequency ranges from 0.8 to 1;

wherein the subcarrier frequency ranges from 2.4 GHz to 2.483 GHz.

17. The apparatus of claim 16 wherein the subcarrier transmission system comprises an RF transmitter associated with an ISM band.

18. The apparatus of claim 17 wherein the data frequency is a maximum frequency associated with the data bandwidth.

19. An apparatus for receiving a supervisory signal for optical network applications, the apparatus comprising:

an optical-to-electrical conversion system configured to receive an optical signal and output an electrical signal and a data signal;

a subcarrier reception system configured to receive the electrical signal and output a supervisory signal;

wherein the subcarrier reception system includes a band pass filter associated with a subcarrier frequency;

wherein the data signal is associated with a data bandwidth, the data bandwidth including a data frequency, at the data frequency a power density of the data signal being substantially equal to zero;

wherein a ratio of the subcarrier frequency to the data frequency ranges from 0.8 to 1;

wherein the subcarrier frequency ranges from 2.4 GHz to 2.483 GHz.

20. The apparatus of claim 1 wherein:

the subcarrier reception system includes an RF receiver associated with an ISM band;

the RF receiver includes the band pass filter associated with the subcarrier frequency.

21. The apparatus of claim 19 wherein the data frequency is a maximum frequency associated with the data bandwidth.

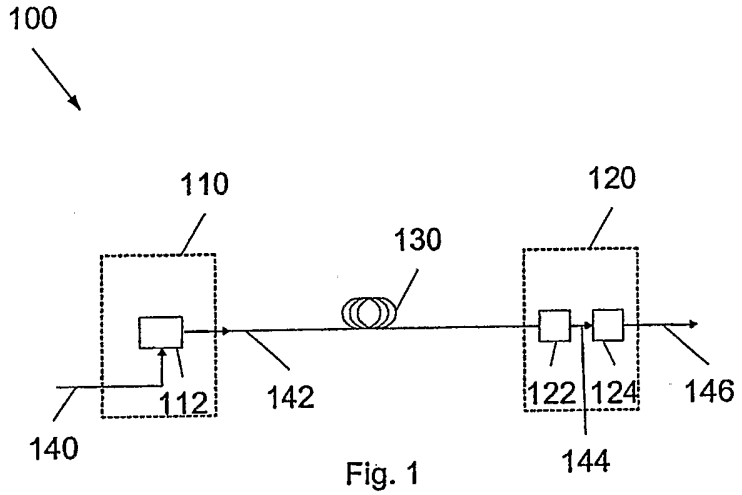
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Fig. 1

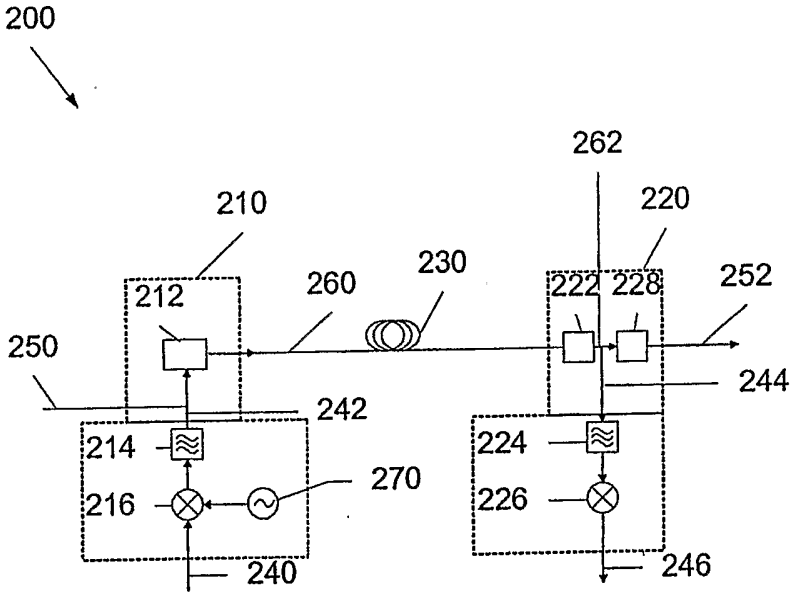
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Fig. 2

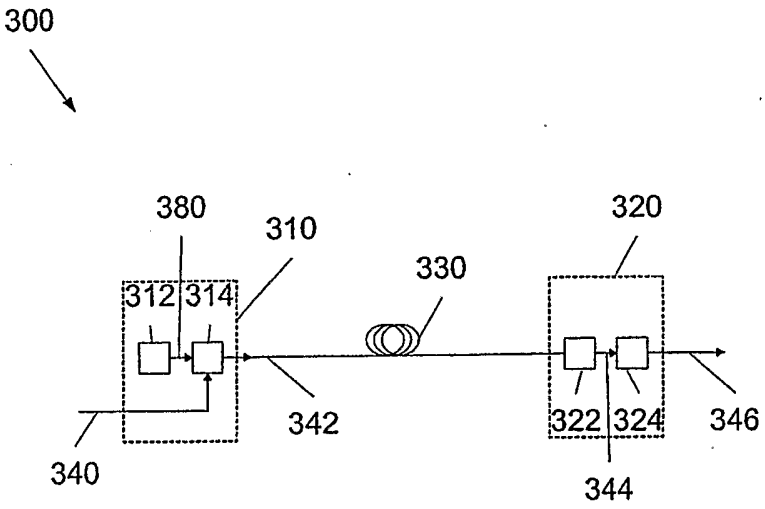
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Fig. 3

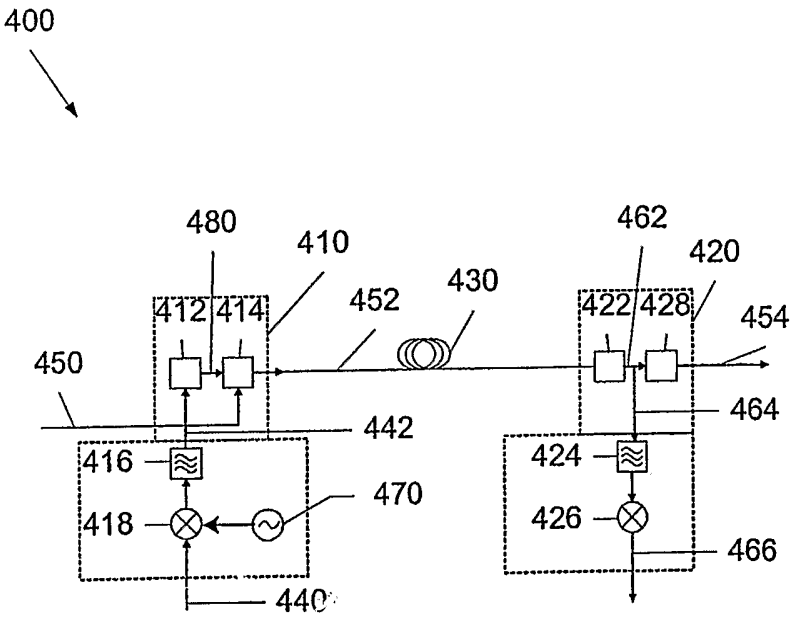
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Fig. 4

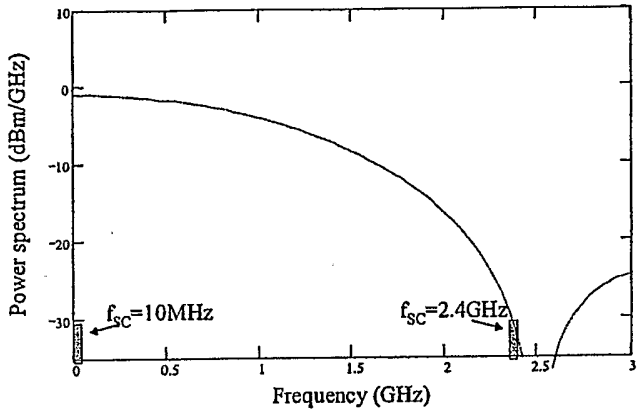

Fig. 5

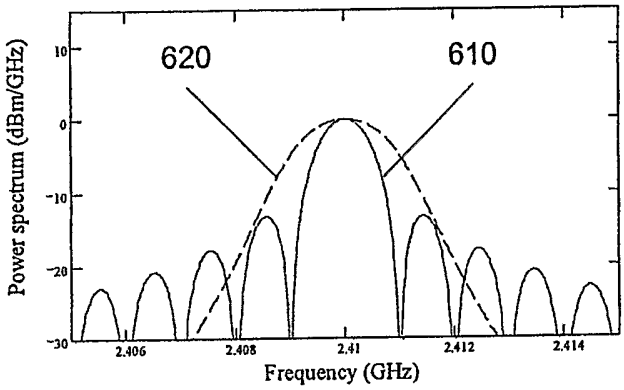

Fig. 6

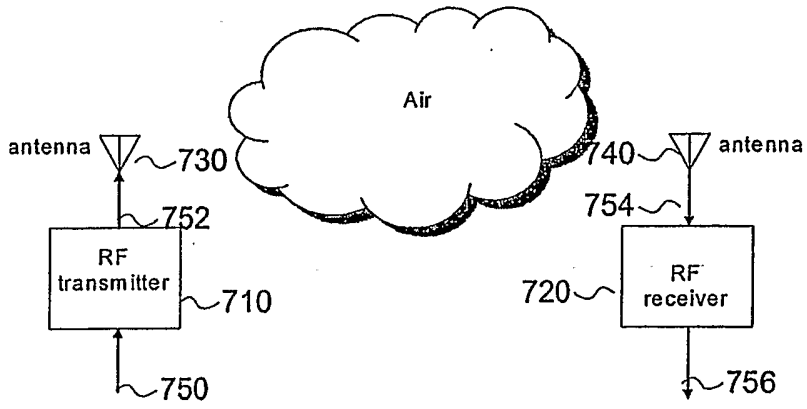

Fig. 7

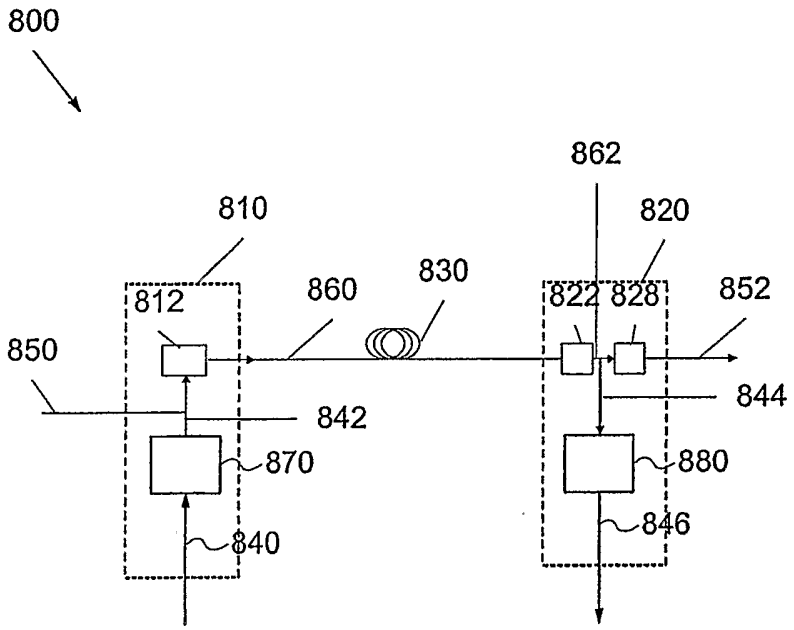
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Fig. 8

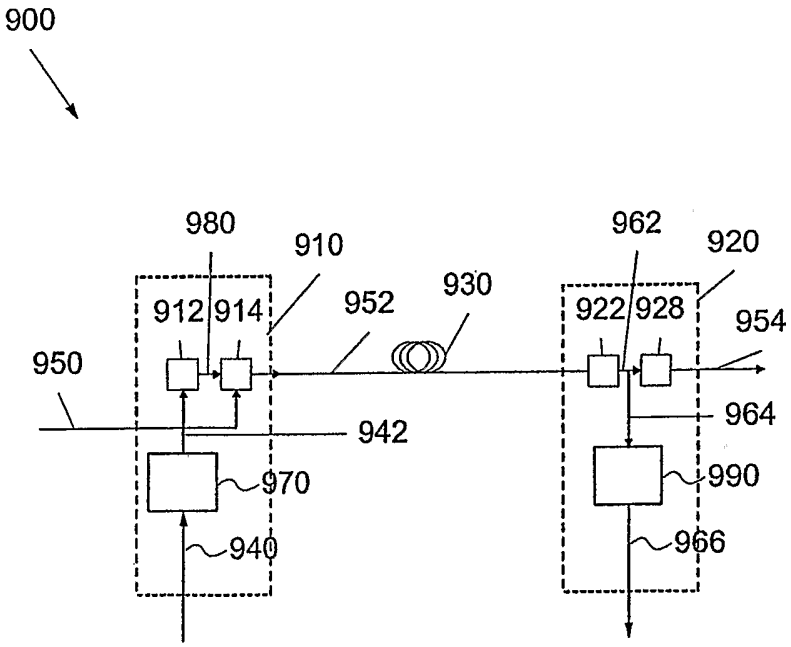
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Fig. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2005/000615

A. CLASSIFICATION OF SUBJECT MATTER

IPC[7]: H04B 10/00

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC[7]: H04B10/00 H04B10/02 H04B10/08

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI、EPODOC、PAJ、CNPAT: optical networ supervisory signal subcarrier transmission Electrical optical conversion convert SNR DWDM WDM FDM

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US B1 6639703 - (QEYT-N) QEYTON SYSTEMS AB - (CISC-N) CISCO SYSTEMS SWEDEN AB - (EGNE-I) EGNELL L 28.Oct.2003 (28.10.03) See Whole document	1-21
A	JP A 8097774 (FUIT) FUJITSU LTD 12.Apr.1996 (12.04.96) See Whole document	1-21
A	JP A 2003298540 PA - KDDI CORP 17.Oct.2003 (17. 10. 03) See Whole document	1-21

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* 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 application or patent 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

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&"document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15. Jun. 2005 (15. 06. 05)	21 · JUL 2005 (21 · 07 · 2005)
Name and mailing address of the ISA/CN The State Intellectual Property Office, the P.R.China 6 Xitucheng Rd., Jimen Bridge, Haidian District, Beijing, China 100088 Facsimile No. 86-10-62019451	Authorized officer Wang zhiyong 王智勇 Telephone No. 86-10-62084571

Form PCT/ISA /210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2005/000615

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
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		WO0055995 A1	2000-09-21
		AU200039927 A	2000-10-04
		SE9900991 A	2000-09-19
		SE516316 C2	2001-12-17
		EP1166475 A1	2002-01-02
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JP A 2003298540	2003-10-17	NONE	NONE