Development of Highly Flexible Broadband Networks Incorporating Wavelength Division Multiplexing and Sub-carrier Division Multiplexing in a Hybrid Radio/Fiber Distribution System

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ABSTRACT
A radio over fiber distribution system incorporating both SCM and WDM technologies is presented. The SCM signal contains five 155 Mbit/s data channels, centered around 18.5 GHz with 450 MHz spacing. This signal is directly modulated onto three high-speed lasers with emission frequencies spaced by 50 GHz. Bragg filters are employed at the receiver base station in order to both demultiplex the required optical channel, and ensure that the detected signal is single side band (in order to overcome dispersion limitations on the link). Our results show negligible degradation in system performance for the demultiplexing of the WDM signal compared with the back-to-back performance curves.
Keywords: hybrid radio-fiber systems, Subcarrier Multiplexing, Wavelength Division Multiplexing, Single Sideband Modulation.

1. INTRODUCTION

As the demand for broadband mobile services such as video-on-demand and mobile computing increases, so does the need to develop high capacity mobile communication networks which are capable of delivering broadband signals to remote areas "over the air". Microwave and millimeter wave fiber/radio systems are a very attractive option to realize such broadband networks. In these hybrid radio/fiber systems, the microwave or millimeter wave data signals are modulated onto an optical carrier at a central location, and then distributed to remote base stations using optical fiber. The base stations then transmit the microwave/millimeter-wave signals over small areas using microwave antennas [1-3]. Such an architecture should prove to be highly cost efficient, since it allows sharing the transmission and processing equipment (remotely located in the central control station) between many base stations. Within these microwave and millimeter wave radio networks it is also expected that the available bandwidth will be divided into a number of frequency channels for signal distribution. This use of multiple RF carrier distribution (known as sub-carrier multiplexing (SCM)) is normally required in high capacity multi-path environments in order to overcome multi-path fading effects, and it thus important for simplifying the complexity of the radio links and the management of the available spectral bandwidth [4]. In addition to the use of SCM, it is also expected that hybrid radio/fiber distribution networks may employ wavelength division multiplexing (WDM) in order to allow different base stations to be fed with a common optical fiber [4-6]. In such a system, an optical filter at the base station will be required to select one of the wavelength channels carrying a specific SCM data signal.

The main difficulties with the development of such hybrid radio/fiber systems employing SCM and WDM technologies is the cost and complexity of the data generation at the receiver, and the demultiplexing at the base station. One of the main problems encountered is the need for an optical single side band (SSB) signal at the base-station in order to overcome dispersion effects in the transmission fiber [7]. Previous work in this area has used either complex signal generation techniques to produce optical SSB signals, followed by simple optical filtering at the base station [4,5], or a complicated demultiplexing technique using a Fabry-Perot etalon and an array waveguide grating to select out just one carrier and one side-band from the WDM/SCM signal [6].

In this paper we use the simplest of all techniques to generate the optical microwave signal for use in a hybrid radio/fiber distribution system, namely direct modulation of a laser diode with the SCM microwave data signal. We also use the WDM technique to generate a 50 GHz separated 3-channel optical double side band (DSB) signal. Although the optical signals are DSB, we demonstrate that by the correct use of a simple Bragg filter at the receiver base-station, we can not only select out one of the wavelength channels, but also eliminate one the sidebands in order to overcome dispersion effects in the transmission fiber. Our results show a negligible power penalty when demultiplexing one of the SCM data signals from the 3-channel optical DSB signal, using the Bragg filter. We also show that our filtering technique is successful in overcoming dispersion effects due to the DSB nature of the generated data signal.

2. EXPERIMENTAL SET-UP

The experimental set-up used is presented in Fig. 1. A 155 Mbit/s NRZ data stream from an Anritsu pattern generator is initially passed through a 117 MHz low pass filter to minimize the bandwidth of the data signal. The

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resulting signal is then mixed with five RF carriers centered at 18 GHz (with a channel spacing of 450 MHz) to generate five BPSK data signals. The SCM signal is subsequently split into three ways and used to directly modulate three high-speed single mode laser diodes from NTT Electronics. The lasers used are DFB multiple-quantum-well devices with threshold currents around 25 mA, and 3 dB electrical bandwidths in excess of 18 GHz. The central wavelengths of the three lasers are all around 1550 nm, but this can be slightly altered and set to specific wavelengths by temperature control of the diodes. The operating wavelengths chosen for the three lasers are 1549.9, 1550.3, and 1550.7 nm.

With each of the three lasers biased around 60 mA, the SCM signal is applied to each of the transmitters. The optical outputs are then combined using an optical coupler, and selection of one of the optical data channels is carried out using a Bragg filter in conjunction with an optical circulator. The Bragg filters used are designed specifically for WDM systems with 50 GHz spacing, and have reflection bandwidths of around 0.35 nm. After selection of one the optical wavelength channels the signal is then detected using a 50 GHz pin diode. In a complete radio/fiber system the output signal of the detector would be transmitted through an RF antenna to the mobile network stations where the data is received by down-converting the incoming signal using a local oscillator. However, in our experiment we have concentrated on the optical part of the system, hence the down conversion takes place after the photodiode by mixing the SCM data signal with an 18.5 GHz local oscillator. The down-converted signal (central channel of the 5-channel RF data signal) is then passed through a low-pass filter to ensure that only the required base-band signal is examined using the 50 GHz oscilloscope and error analyser.

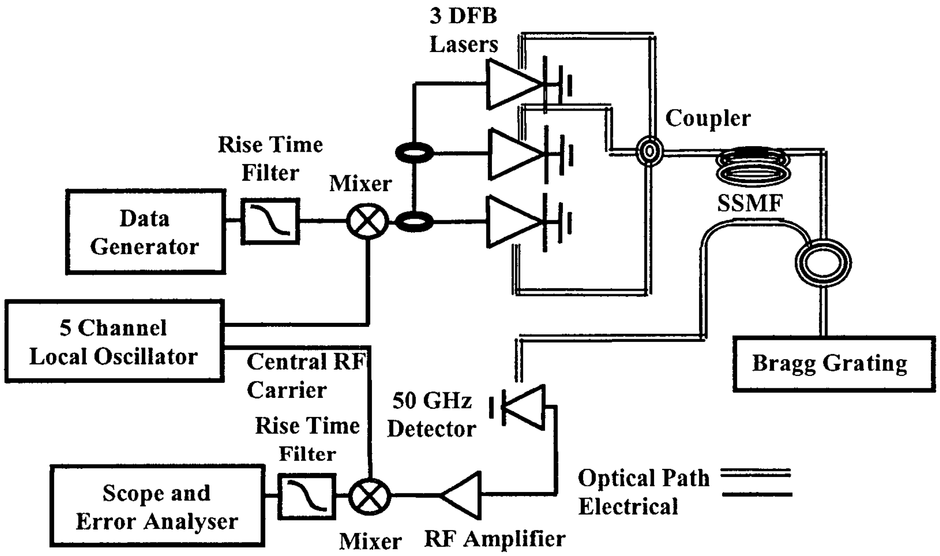

Figure 1. Experimental set-up for hybrid radio/fibre distribution system employing SCM and WDM technologies.

3. EXPERIMENTAL RESULTS

Figure 2(a) displays the 3-channel optical data signal after passing through the optical coupler. In order to select out only one carrier and one side-band of the central optical channel the Bragg filter is positioned such that the central carrier is at the longest wavelength that is correctly reflected by the Bragg filter.

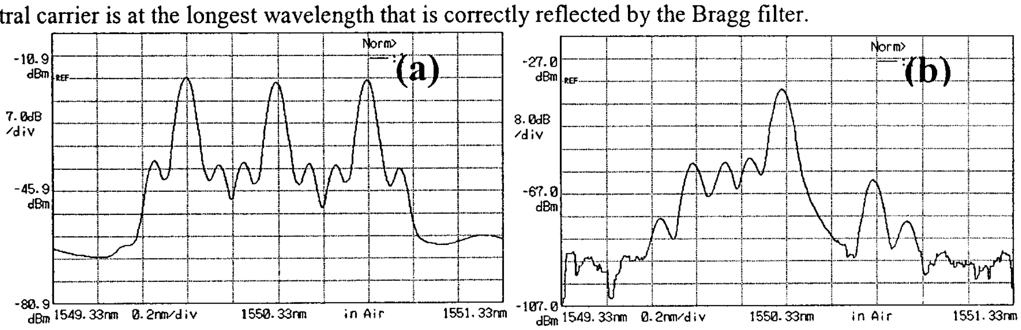

Figure 2. (a) Optical spectrum of 3-channel signal after coupler, and (b) reflected spectrum from Bragg filter showing the single side band reflected signal plus adjacent channels.

As the Bragg filter has a very sharp cut-off, this ensures that only one-side band is reflected. The reflected signal is presented in Fig. 2(b) and we can clearly see that only one-side band of the central channel is reflected by the filter. In addition, the filter also selects out one of the side-bands from the lower wavelength optical channel, and suppresses the carrier of this channel by 27 dB relative to the power in the central channel. The longer wavelength optical channel is suppressed by 33 dB relative to the central channel.

Figure 3(a) displays the received eye diagram after filtering out the central wavelength channel as described above, converting the optical signal to electrical (Fig. 3(c) displays the detected 5-channel SCM signal), and then down-converting the 18.5 GHz carrier data signal. The received power in this case is -10 dBm. To completely examine the system performance we characterized the Bit-Error-Rate vs. received optical power for the down-converted 155 Mbit/s data signal at an RF carrier frequency of 18.5 GHz. Figure 4 shows the system performance when the three optical channels are multiplexed together, and also the back-to-back performance for the central wavelength channel. We can see from this plot that the degradation is system performance is only in the order of 0.4 dB due to interference from the adjacent optical channels. The negligible effect of the channel demultiplexing is also clear from Fig. 3(a & b) that shows the received eye for the WDM system and the back-to-back case when the received power is –10dBm.

(a)
(b)
(c)

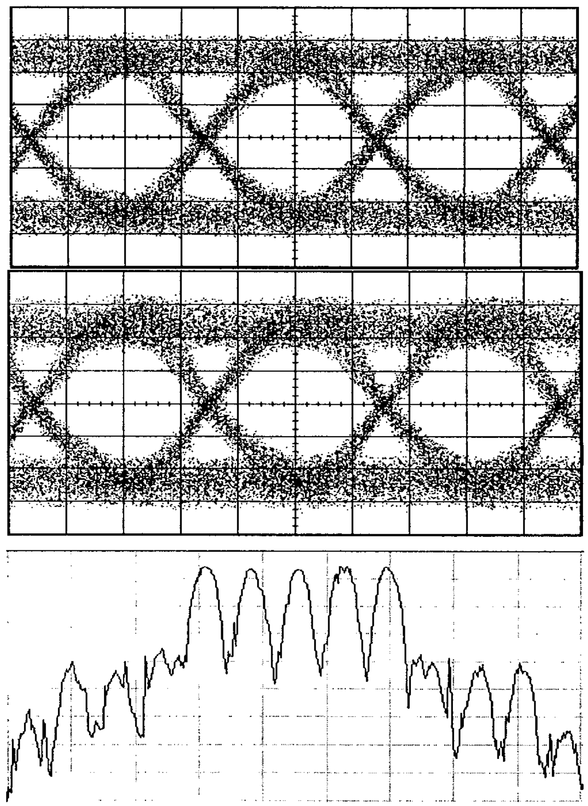

Figure 3. Received eye diagrams of 155 Mbit/s data signal after (a) demultiplexing of WDM signal, and (b) back-to-back set-up for central optical channel. (c) Electrical spectrum of detected SCM signal.

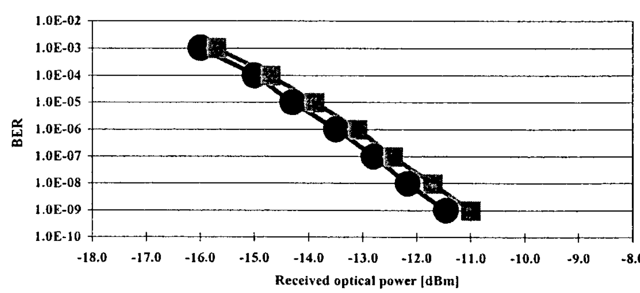

Figure 4. BER vs. received optical power for central optical channel demultiplexed from WDM system (squares), and central optical channel back-to-back (circles).

To confirm that our demultiplexing technique does indeed overcome dispersion effects in transmission fiber, we have inserted a 12 km length of standard single mode fiber after the optical coupler that combines the three wavelength signals. This fiber length has been determined to be that which minimizes the received power of the DSB optical signal due to fiber dispersion effects. Figure 5(a) displays the received eye diagram after propagation through the transmission fiber followed by demultiplexing, detection, and down-conversion of the signal. The received optical power level is –10 dBm and by comparison with the eye diagrams in Fig 3 we can see that the degradation in system performance due to the fiber is negligible. We then proceeded to position the Bragg filter such that the carrier of the central wavelength channel is at the center of the filter's reflection band. In this case the filter selects out the complete DSB optical signal, and the received eye confirms how the fiber dispersion greatly affects the system performance (Fig. 5(b)).

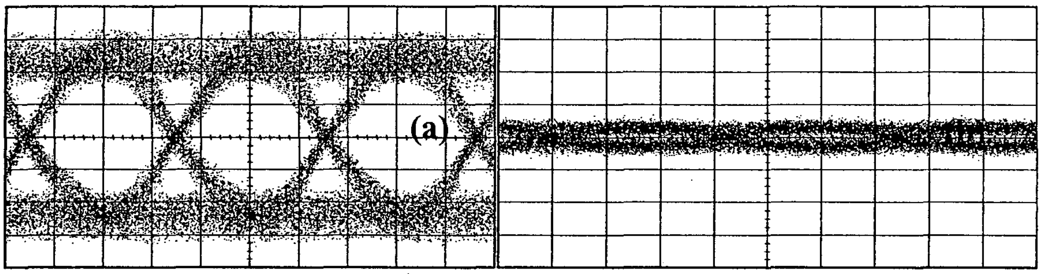

Figure 5. Received eye diagrams of 155 Mbit/s data signal after propagation of WDM/SCM signal through 12 km of standard fiber with Bragg filter positioned to (a) select single side band optical signal, and (b) select double side band optical signal.

4. CONCLUSIONS

The future development of hybrid fibre-radio systems employing both SCM and WDM technologies is highly dependent on the use of simple and efficient technologies to generate the optical microwave signals at the central station, and to demultiplex the signal at the remote base stations. In this paper we have demonstrated a hybrid WDM/SCM based radio-over-fiber distribution system employing direct modulation of the laser transmitters followed by a Bragg filter at the receiver base station. The system has been used for generation and transmission of a 5-channel SCM data signal on 3 optical wavelength channels spaced by 50 GHz. By correct positioning of the Bragg filter relative to the optical channel to be demultiplexed we can select out only the carrier and one side band in order to overcome dispersion effects in the distribution fiber. Our results show negligible degradation in system performance due to interference between the optical data channels after demultiplexing. This work shows that it may not be a necessity to generate SSB at the transmitter in a radio/fibre system incorporating WDM technology, as correct optical filtering at the receiver base station may be used to overcome system limitations imposed by DSB generation at the transmitter.

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