Receiver Design for Wavelength Division Multiplexed Optical Networks Employing Subcarrier Multiplexing Techniques

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Abstract: *This paper describes a receiver for Wavelength Division Multiplexed (WDM) optical networks that employs Subcarrier Multiplexing (SCM) techniques to implement the control channels. The control channels operate in the 1 GHz to 2 GHz band.*

1. Introduction

Optical Wavelength Division Multiplexing (WDM) technology has emerged as the dominant technique used in the realisation of all-optical networks. In wavelength agile networks, by assignment of wavelengths to the network transmitters and receivers, it is possible to embed a virtual topology in a physical network [1]. This requires the use of tuneable components (tuneable transmitters and/or receivers) featuring short tuning times as well as a scheme to co-ordinate the use of a limited number of wavelengths. A variety of control protocols has been proposed to carry out such control functions. Conventional access protocols such as token ring and Carrier Sense Multiple Access/Collision Detection (CSMA/CD), show poor performance as the propagation delay becomes greater than the packet length. To exploit the high throughput possible with WDM networks, a typical approach is to use a common signalling wavelength shared by all nodes. However, this approach suffers from several disadvantages. Firstly, each node requires a second laser to transmit the control packets, resulting in a substantial increase in the cost of optoelectronics per node. Secondly, as the number of nodes increases, the density of the control packets grows proportionally creating severe contention for the control channel. Furthermore, the data rate of the control channel must increase as the density of the traffic increases, forcing the control channel to transmit at Gbit/s rates. One way to avoid these difficulties is to use the Subcarrier Multiplexing (SCM) technique to implement the control channels. This approach eliminates the need for a second laser at each node, and alleviates the control channel contention problem by channelising the control packets. As such, the control channel rate is kept low, typically in the 10-100 Mbits/s range, making it feasible to process the control data with low cost silicon technology.

This paper describes the receiver design for a WDM optical networks that employs Subcarrier Multiplexing (SCM) techniques for control channels implementation.

2. Overall receiver design

The receiver described here is used in the demonstrator of the DAWN (Dynamically Allocated Wavelength WDM Network) project [2]. The DAWN architecture is based on the use of a reflective semiconductor optical amplifier (RSOA). The main components of a transmitter of each node are the RSOA and a tuneable optical filter. Each node receives a signal comprising a comb of reference wavelengths and selects one of the wavelengths by appropriately setting the optical filter. The received signal travels along the RSOA where it is amplified, modulated and reflected back to the network.

Besides providing gain, this simple scheme has the advantage of facilitating wavelength monitoring and control at the controlling node. The control information is subcarrier multiplexed and superimposed on the baseband payload. Direct detection is employed because of its reduced cost. The receiver section consists of an optical fixed optical filter, followed by a PIN based receiver and an amplifier.

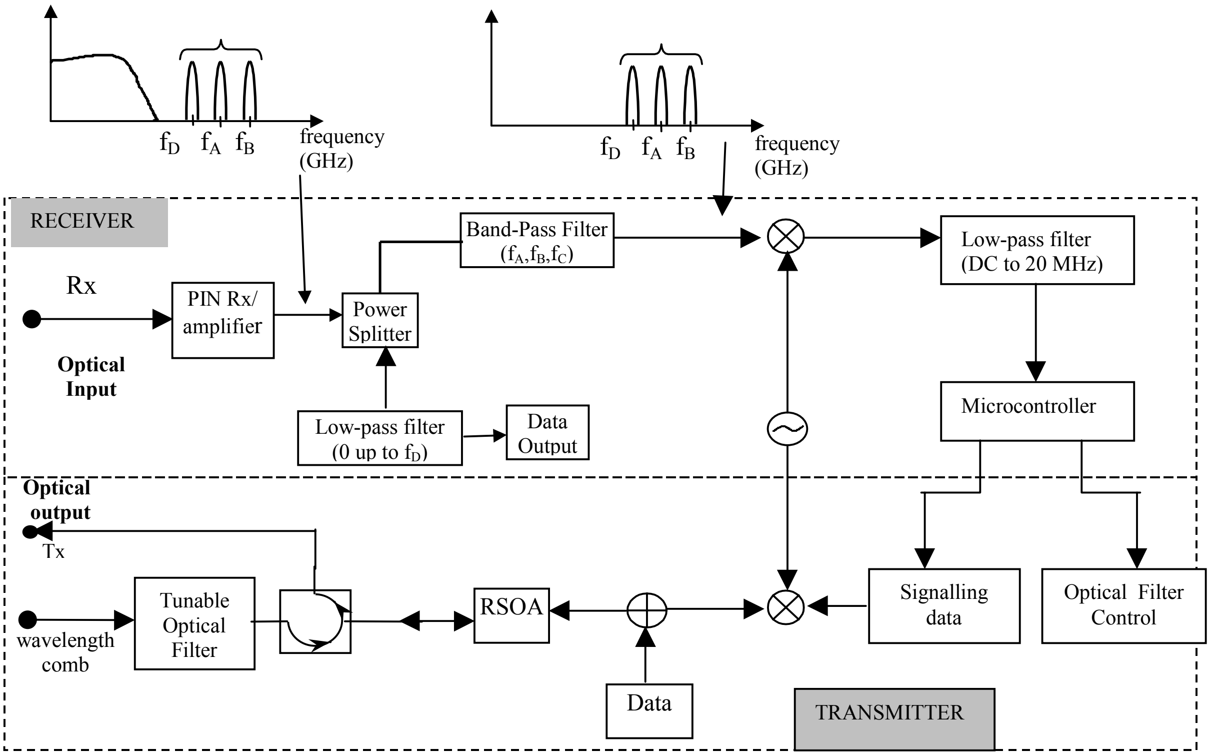


Figure 1: Detailed implementation of a user node

At the transmitter section, a parallel 8-bit control header is converted to serial data by a digital control circuit implemented using a micro controller. From the control header 3 bits are reserved for the identification of the node to be contacted, 3 bits for the identification of the receive node and the rest are not used. The control bit stream modulates a subcarrier frequency. Then, the data is added to the modulated subcarrier and the resulting signal is used to modulate the RSOA.

The DAWN demonstrator consists of 3 user nodes and a controlling node, each user node being identified by a subcarrier frequency. Taking into account harmonic and intermodulation distortions, appropriate values for the subcarrier frequencies were chosen to be 1.7, 1.8 and 1.9 GHz. The receiver front end comprises a PIN photodiode and an amplifier of bandwidth up to 2 GHz. By appropriate filtering of the received signal, the data is separated from the signalling information. The signalling information is retrieved by mixing with a locally generated carrier obtained using a frequency synthesiser.

3. Microstrip filter design

In this section we detail the implementation of the band-pass and low pass filters, as well as, the combination of the two filters as shown in figure 2

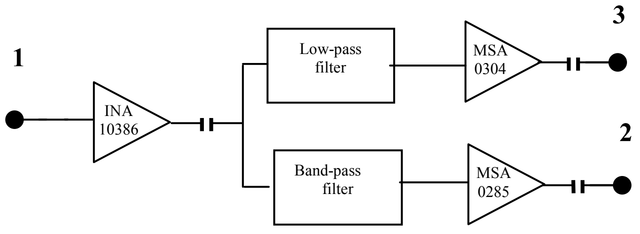
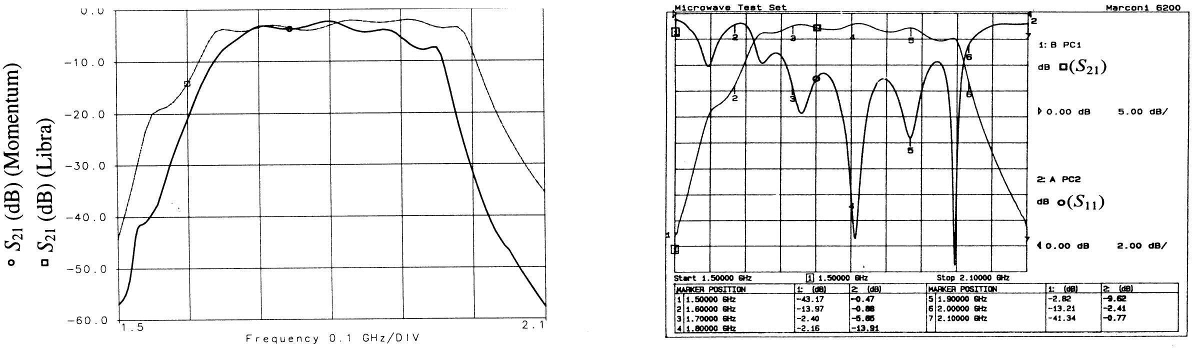


Figure 2: Filtering at the DAWN receiver

The band pass filter was implemented in microstrip using a parallel-coupled structure [3], this structure was chosen over the end- or edge-coupled structures because : i) the length of the filter is approximately reduced by half, ii) an almost symmetrical frequency response is obtained with the first spurious response at three times the centre frequency and iii) a much larger gap between adjacent microstrips is permitted, thereby simplifying the manufacturing process. The number of resonators determines the order of the filter.
The filter dimensions, based on odd and even mode impedance calculations, were obtained using commercially available design tools. The filter dimensions were further optimised, to account for edge effects and undesired coupling, by studying its behaviour using the simulators "Momentum" and "Libra".

The band-pass filter was specified to have a Butterworth response with a 1.8 GHz centre frequency, 1 dB attenuation at 1.8 ±0.15 GHz and > 35 dB attenuation at 1.5 and 2.1 GHz

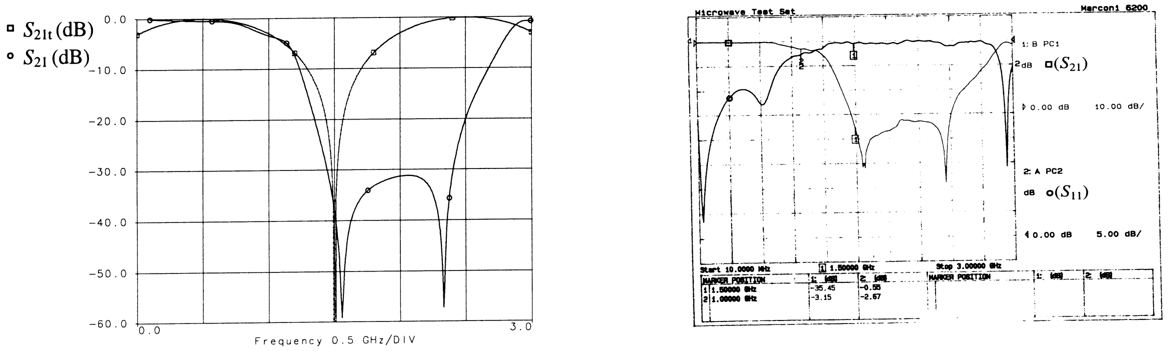


MARKER	POSITION	1: (dB)	2: (dB)
1	1.50000 GHz	-43.17	-0.47
2	1.60000 GHz	-13.97	-0.88
3	1.70000 GHz	-2.40	-5.85
4	1.80000 GHz	-2.16	-13.91
5	1.90000 GHz	-2.82	-9.62
6	2.00000 GHz	-13.21	-2.41
7	2.10000 GHz	-41.34	-0.77

(a) (b)

Figure 3: (a) Momentum and Libra results for the response S_{21} of the band-pass filter, (b) Measured S_{21} and S_{11} response

Figure 3(b) shows that the target design specifications were fully accomplished. Comparing the measured results with data obtained with Libra it can be seen that there is a very good match between the predicted responses and the measured data. The passband is indeed centred at 1.8 GHz, and the filter behaviour is exactly as predicted.
The receiver low pass filter (RLPF), was designed to give, in combination with an identical the transmitter filter, a raised cosine filter with a roll-off factor of 50%. The frequency response is given by: $H_r(f)=\sqrt{H(f)}$, where $H_r(f)$ is the transfer function of a raised cosine filter with a roll-off factor of 50%.



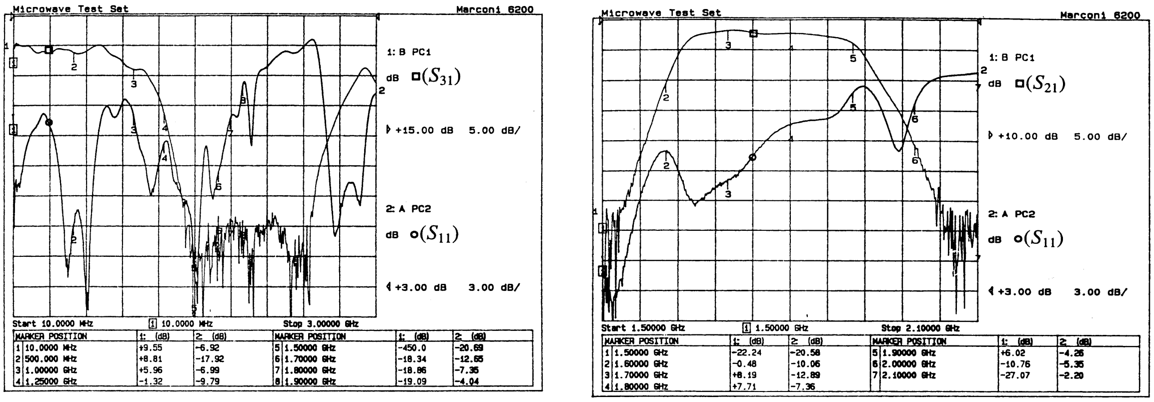
MARKER	POSITION	1: (dB)	2: (dB)
1	1.50000 GHz	-35.45	-0.55
2	1.00000 GHz	-3.15	-2.67

(a) (b)

Figure 4: (a) simulated(o) and target( ) S_{21} response of the RLPF, (b) Measured response

To design this filter we start with an all pole Butterworth low-pass filter with a 3 dB cut-off of 1 GHz, but with the addition of one or more open circuit stubs at its output. The stubs were designed to have an effective length of $\lambda/4$ at 1.5 GHz, thereby producing an effective short-circuit in the filter response and creating the required zero transmission of the RLPF. Figure 4 shows that the experimental results for the RLPF are very satisfactory. The attenuation at 1 GHz is 3.5 dB, and 35 dB at 1.5 GHz essentially providing the zero transmission required at this frequency.

Combining the two filters in one network was implemented with the aid of RF amplifiers as shown in figure 2. The low noise, INA-10386 amplifier, was chosen to drive the filters; MSA-0304 MODAMP™ and MAS-0285 MODAMP™ amplifiers were chosen to provide amplification at the output of the RLPF and band pass filter, respectively.



MARKER POSITION	1: (dB)	2: (dB)	MARKER POSITION	1: (dB)	2: (dB)
1 10.0000 MHz	+9.55	-6.92	5 1.50000 GHz	-450.0	-20.69
2 500.000 MHz	+8.81	-17.92	6 1.70000 GHz	-18.34	-12.65
3 1.00000 GHz	+5.96	-6.99	7 1.80000 GHz	-18.86	-7.35
4 1.25000 GHz	-1.32	-9.79	8 1.90000 GHz	-19.09	-4.04

MARKER POSITION	1: (dB)	2: (dB)	MARKER POSITION	1: (dB)	2: (dB)
1 1.50000 GHz	-22.24	-20.58	5 1.90000 GHz	+6.02	-4.26
2 1.60000 GHz	-0.48	-10.06	6 2.00000 GHz	-10.76	-5.35
3 1.70000 GHz	+8.19	-12.89	7 2.10000 GHz	-27.07	-2.20
4 1.80000 GHz	+7.71	-7.36			

(a) **(b)**

Figure 5: a) Low pass filter measured S_{31}, b) Band-pass filter measured S_{21}

After the introduction of the amplifiers the low-pass section of the network was re-optimised. The measured results are shown in Figure 5. Comparing this figure with Figure 4.b, it can be seen that the passband behaviour is much better with the amplifier in place, with improved gain flatness. Figure 5.a shows that the amplifier has caused a ripple of 1 dB at low frequencies. As expected, the passband gain is ~10 dB.

4. Summary

We have presented the design of receiver architecture for a WDM network employing SCM techniques to implement the control channels and discussed in detail the implementation of the receiver filtering and presented the measured characteristics.

Acknowledgement

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