MICROWAVE MULTIPLEXING TECHNIQUES FOR WIDEBAND LIGHTWAVE DISTRIBUTION NETWORKS

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ABSTRACT

The use of microwave subcarriers is a promising new approach for providing wideband services in the subscriber network. Optical communications systems that carry 60 FM video channels in the 2.7 to 5.2 GHz band and 20 100 Mb/S FSK video channels in the 2 to 6 GHz band will be described. A hybrid system which carries a 140 Mb/s baseband signal plus 60 FM video channels will also be described.

The use of microwave subcarriers is a promising new approach for providing wideband services to the subscriber over optical fiber networks (1,2). This paper will review the system design principles for such systems with attention focused on the transmission of multiple video channels to the subscriber, and it will describe systems which carry 60 FM video channels multiplexed on carriers in the 2.7–5.2 GHz band and 20 frequency shift-keyed (FSK) 100 Mb/s digital video channels in the 2–6 GHz band. In addition, a hybrid system which carries a 100 Mb/s baseband signal plus 60 FM video channels will also be described. These systems illustrate the enormous capacity microwave-multiplexed optical systems have for providing wideband services.

Figure 1 shows the basic system diagram for a microwave-multiplexed optical system. A large number of microwave carriers are power combined, and the composite signal is used to intensity modulate a high-speed 1.3 μm InGaAsP laser. At 5 mW dc bias, the vapor phase regrown buried heterostructure lasers (3) used in these experiments have average 3 dB bandwidths of 11 GHz. The microwave carrier is conveniently generated with a voltage controlled oscillator (VCO) which can be directly modulated with either the baseband analog video signal or a digitized video signal.

After transmission through conventional single-mode fiber, the signal is detected with a high-speed InGaAs PIN photodiode (4) and amplified with a low-noise 2–8 GHz microwave amplifier with a 3 dB noise figure. In the case of FM video transmission, the signal can be downconverted with a mixer and demodulated with a low-cost commercial satellite earth station video receiver. The FSK digital signal can be recovered using a two-stage downconversion and a delay line discriminator.

The carrier-to-noise ratio (CNR) of these systems is dominated by the thermal noise of the amplifier. Thus

$$CNR = (mI)^2 R/(2\, NF\, kT\, B), \qquad (1)$$

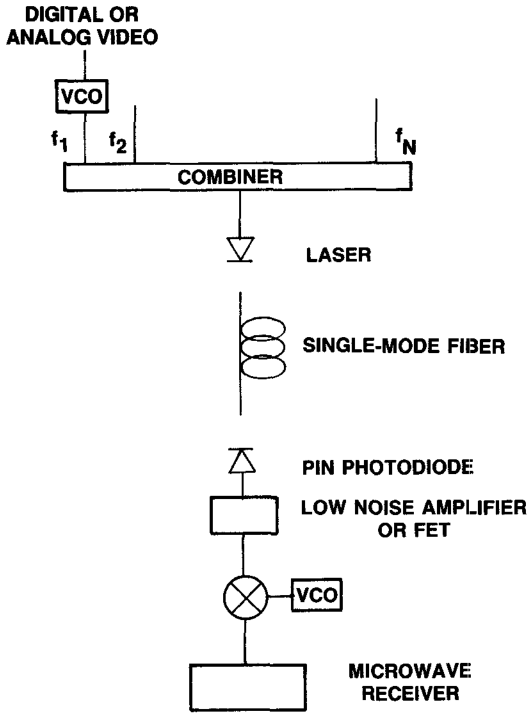

Figure1. Microwave subscriber multiplexing.

where m is the modulation index per channel, I is the dc photocurrent, R is the 50 Ω load, NF the amplifier noise figure, kT the thermal energy, and B the receiver bandwidth, which is 30 MHz for FM transmission and 120 MHz for 100 Mb/s FSK transmission. FM video transmission requires a 16.5 dB CNR to achieve a 56 dB weighted SNR (5). A 10^{-9} BER can be achieved with a 16 dB CNR for FSK transmission if a separate local oscillator (6) is used. For the system reported here, the use of a delay line discriminator eliminates the need for a carrier recovery circuit but increases the required CNR to 19 dB.

From Eq. (1) one sees that for the FM video system, a signal, mI, of only 0.63 μA/channel is required for a 56 dB weighted SNR. For a dc photocurrent of 30 μA, which is a value that is easily achieved in a wideband network, this corresponds to a modulation depth of only 2.1%/channel. For a 100 Mb/s FSK system, a modulation depth of 5.4%/channel is required for a 10^{-9} BER.

Because of the small modulation depth/channel, the noise introduced by the second- and third-order modulation products is completely negligible (1). The effect of laser-relative intensity noise is also negligible if it is kept below –135 dB/Hz. This value is generally obtainable in the 2–8 GHz band for the VPR-BH lasers used provided there is minimal optical feedback to the laser.

Figure 2 shows the measured CNR and SNR for transmission of 60 FM video channels over 18 km of single-mode optical fiber (7). The total optical loss of the link is 8 dB, and there is an extra 4 dB loss introduced at the photodiode to simulate system margin. As can be seen, a 56 dB weighted SNR is achieved with a 16.5 dB CNR and a modulation depth of 2%/channel.

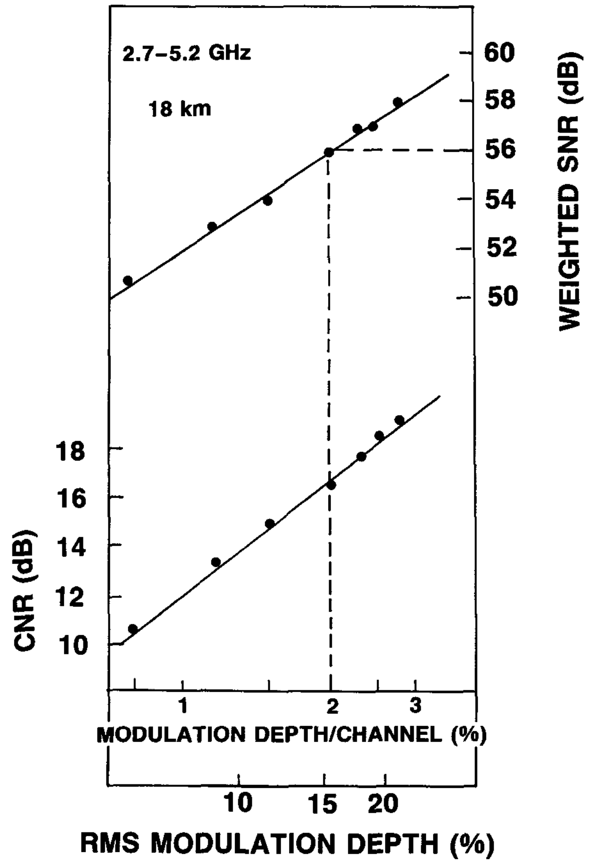

Figure 2. 60 channels FM/SCM.

Figure 3 shows the BER versus modulation depth for 100 Mb/s FSK transmission over 9 km of fiber (8). The average modulation depth for the 20 channels is 5.4±0.7%, in good agreement with the expected performance.

Some of the key advantages of wideband microwave-multiplexed systems are that they can accommodate both analog and digital transmission, and that bandwidth can be allocated in a highly flexible way to provide a multitude of services, including voice, data, analog or digital video, analog or digital audio, and high-definition video.

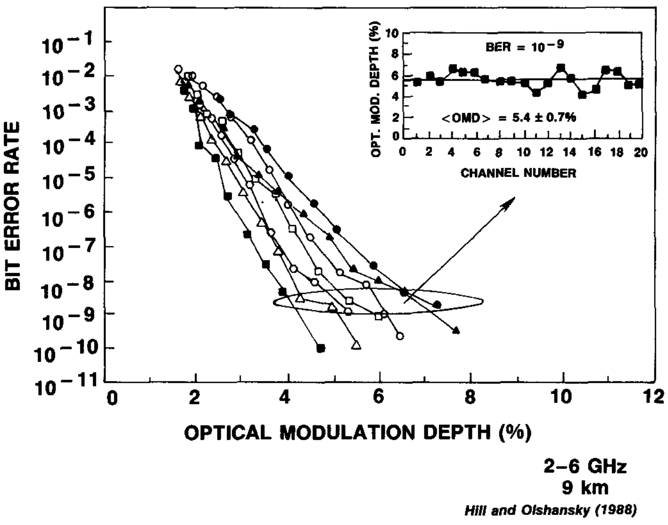

Figure 3. 20 channel 100 Mb/s FSK system.

In addition, a conventional baseband digital signal can be combined with the microwave signal to form a hybrid baseband/microwave system. To illustrate this capability, we have used commercial hybrid couplers to couple and decouple a 100 Mb/s baseband signal and the 60 channel FM video signal. Figure 4 shows the BER as a function of SNR in the 0–70 MHz band for the 100 Mb/s signal transmitted over 6 km, both with and without the presence of the 60 FM video channels.

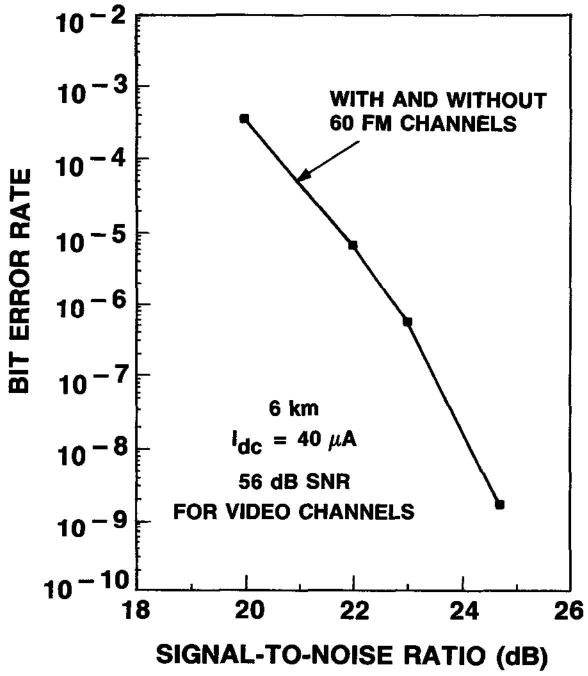

Figure 4. BER vs SNR for 100 Mb/s plus 60 FM channels.

The systems experiments presented here illustrate the enormous potential for providing wideband services to the subscriber using microwave-multiplexed optical fiber communication systems. In addition to providing a natural way to use the enormous bandwidth of optical fibers and electro-optic components, these systems allow systems designers to exploit well-developed microwave electronics to provide a wide variety of transmission services over a bandwidth as large as 10 GHz.

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