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Direct Fiber Optic Transmission of a Wideband Multi-Carrier Microwave Signal Spectrum to and from Satellite Earth Station Antennas

J. W. Carlin
J. E. Bowers
A. C. Chipaloski
S. Boodaghians

AT&T Bell Laboratories
Holmdel, New Jersey 07733

ABSTRACT

High speed semiconductor lasers and detectors are used to transmit the 500 MHz bandwidth C-band microwave signal spectrum to and from a satellite earth station antenna over a low loss optical fiber. The optical system introduces ≈1 dB or less of degradation for both low spectral density QPSK signals and high spectral density FM video signals present in typical satellite transmission systems. For FM video signals, the signal to noise after AM conversion and transmission over 20 km of fiber was 55 dB. The 20 km fiber system degraded the signal to noise ratio by 1 dB. Similar results were obtained for digital signals where 20 km of fiber caused a 1 dB reduction in the available E_b/N_o for the digital system.

Introduction

Satellite communication systems provide a cost effective means for obtaining point to multi-point video and data communication networks. Coaxial cable or waveguide runs are usually used to interconnect a C-band (6/4 GHz) or Ku-band (14/11 GHz) earth station antenna to terminal equipment located in a nearby equipment shelter or building. Losses in the cable or waveguide limit the interconnection distance to 100 m or less if the transmission frequencies are above 4 GHz. Optical fiber has two or more orders of magnitude less loss than such microwave cable systems, and the possible transmission distances extend to 50 kilometers or more without amplification or regeneration if the satellite spectrum can be used to directly modulate the light intensity in the fiber. Directly modulated multi-longitudinal mode lasers[1], single mode fiber, and PIN photodetectors[2] or avalanche photodetectors (APDs)[3] were used to transmit the composite satellite signal spectrum directly at the microwave transmission frequency.

System Description

A schematic drawing of the experiment is shown in Fig. 1. A 10 meter antenna was used to transmit or receive the 6 or 4 GHz signals from the AT&T Telstar T-302 satellite. A typical composite received signal spectrum is shown in Fig. 2. The 500 MHz bandwidth is partitioned into twelve, 40 MHz channels for each polarization; FM Video, digital and telemetry signals are marked on Fig. 2. The difficulty of transmitting the entire satellite signal spectrum over a fiber optic link can be appreciated from this figure. There are several different modulation formats and the spectral density levels differ by as much as 15 dB. A major concern is the effect on the low level FDMA (Frequency Division Multiple Access) digital signal of laser intensity noise and intermodulation distortion (IMD) from the high level FM video signals.

The laser was a multilongitudinal mode 1.3 μm constricted mesa laser[1] with a 3 dB bandwidth of 14.6 GHz at a bias current of 100 mA. Light from the laser was coupled into single mode optical fiber using a lensed tip on the fiber. The fiber has a loss of 0.45 dB(optical)/km at 1.3 μm. The zero dispersion wavelength (1.3μm) was close to the center wavelength of the lasers used, but no attempt was made to tune the wavelength of the lasers to the

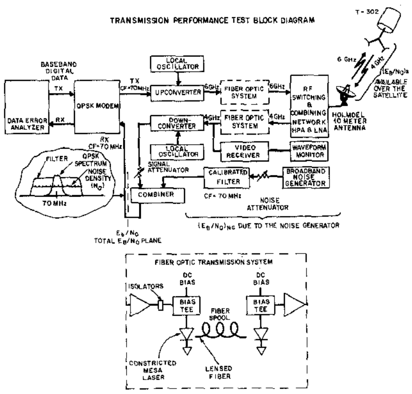

Fig. 1 Schematic diagram of the satellite signal transmission experiment. For the digital error rate experiment, a test signal was transmitted to the satellite. Existing nonencoded video signals were used for the video characterization.

zero of dispersion. The lasers had typically 3 to 4 longitudinal modes, spaced 9 Å apart.

Two photodetectors were used: a PIN InGaAs back-illuminated detector[2] with a 3 dB bandwidth of 22 GHz, a quantum efficiency of 50 percent, and a leakage current of 10 nA at the bias voltage of 4V, and an avalanche photodetector (APD)[3] with a gain bandwidth product of 45 GHz and a maximum 3 dB bandwidth (at low gain) of 7 GHz. The total microwave to optical to microwave conversion loss of the fiber optic system for a 20 km

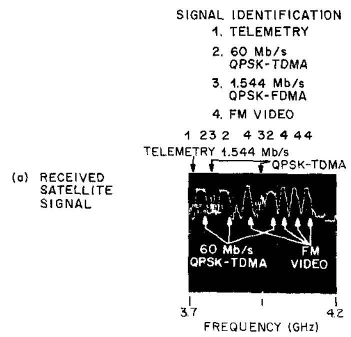

Fig. 2 Spectrum of the received satellite signal.

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length of fiber was 45 dB for a constricted-mesa laser without facet coating, a lensed fiber, and a PIN detector. Using an APD decreased the system conversion loss to 25 dB at 45V bias.

Experimental Results

Signals transmitted over the satellite link were used to determine in practice how much degradation the optical system introduces. The first experiment examined the effect of the optical system on large bandwidth FM video signals after transmission over the satellite. The FM video signals occupy the entire 36 MHz bandwidth of one transponder (see Fig. 2) with a peak deviation frequency of approximately 11 MHz and a baseband bandwidth of 4 MHz. The second experiment examined the optical system effect on low level QPSK digital signals after transmission over the satellite. The downlink received power spectral density of the digital signals in Fig. 2 is approximately 10 to 18 dB lower than the FM video spectral density.

It was anticipated that 3rd order IMD products from the high level FM video carriers due to laser non-linearities would degrade the signal to noise or E_b/N_o ratio of the lower level digital signals. To determine the best operating point for the laser, a two tone measurement of the fiber optic system IMD levels was made. The results of the measurement are given in Fig. 3. From Fig. 3, it can be seen that the best compromise between IMD noise and laser intensity noise occurs if the microwave power level at the laser input is between 0 and -10 dBm. In the experimental results discussed in the following the microwave drive power was approximately -3 dBm and the laser dc bias current was 70 mA.

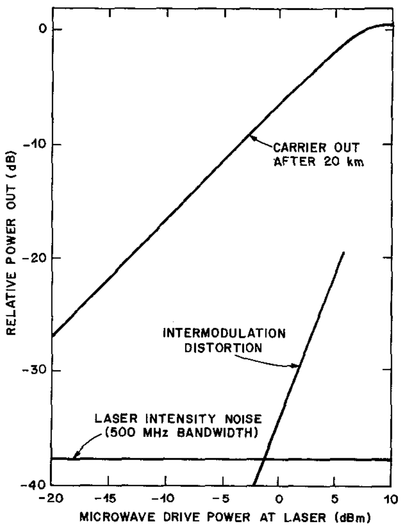

Fig. 3 Third Order Intermodulation Distortion Levels - vs. Laser input power for a 20 km Fiber Transmission System. Laser bias current 70 mA.

The satellite system performance was first determined with no fiber system. The video carrier to noise ratio in a 36 MHz bandwidth (BW) at the input to the laser in Fig. 1 was 16 dB. The measured video S/N ratio at the waveform monitor was 56 dB without the fiber system.

On inserting a 45 dB attenuator after the low-noise amplifier LNA in Fig. 1 (equivalent to the conversion loss of our 20 km fiber system) the S/N ratio decreased to 55 dB. When the attenuator was replaced by a constricted-mesa laser, 20 km of fiber and a PIN detector, the S/N ratio was the same, 55 dB. This indicates the major fiber system degradation is that due to the fiber system conversion loss. The dependence of S/N ratio on transmission distance is shown in Fig. 4 for PIN and APD detectors. For 50 km transmission with a PIN detector, the fiber loss, 45 dB (electrical), was now so large that the thermal noise of the preamp following the detector dominated the noise level. Since the APD has 20 dB more gain than the PIN, the SNR was greatly improved by using an APD for the longest distances.

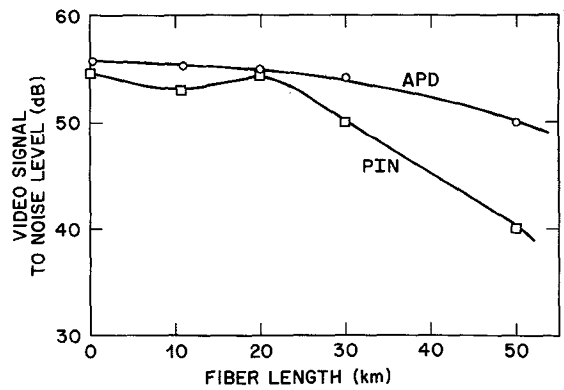

Fig. 4 Signal to noise level of the FM video signal as a function of fiber transmission lengths for PIN and APD photodetectors. Laser bias: 70 mA, APD Voltage, 39V, PIN Voltage: 4V, Microwave drive level: -3 dBm.

Transmission characteristics for digital 3.1 Mb/s QPSK FDMA carriers were also obtained as shown in Fig. 1. In this case the fiber transmission system was used to route the 3.1 Mb/s QPSK carrier to the high-power amplifier (HPA) on the uplink or to transmit the composite 500 MHz received satellite spectrum to the downconvertor on the downlink. A measurement of the system bit error rate vs. E_b/N_o where E_b is the bit energy and N_o the noise density ratio was performed by adding a calibrated amount of

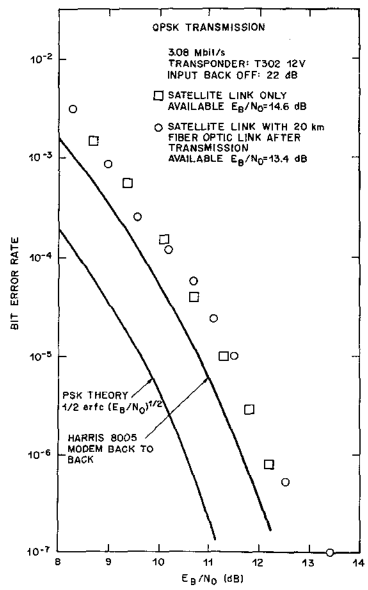

Fig. 5 Fiber transmission of downlink signal (4 GHz). Dependence of bit error rate on S/N ratio for a 3.1 Mbits/QPSK signal on channel 12V. Uplink is backed-off 22 dB from saturation. Laser bias: 70 mA, APD Voltage 39V, Microwave drive level: -3 dBm.

noise at the input to the QPSK demodulator. The levels of the FDMA carriers were set to levels which resulted in the best compromise between downlink thermal noise and satellite transponder induced intermodulation distortion.

Results with and without the fiber optic transmission system on the downlink are given in Fig. 5. The presence of the 20 km fiber transmission system in the downlink caused a 1.2 dB degradation in the available E_b/N_o for the system. This is due to the IMD and laser intensity noise introduced by the fiber system. For a 60 m fiber system the degradation in available E_b/N_o was less than .5 dB. The 1 dB increase in noise is the only degradation introduced by the fiber system as shown by the close agreement between the BER vs. E_b/N_o curves for no fiber, 60 m of fiber and 20 km of fiber in Fig. 5. The measurement accuracy for the data points in Figs. 5 and 6 is on the order of $\pm.2$ dB.

Similar results were obtained with a fiber system on the uplink as shown in Fig. 6. Here the BER vs. E_b/N_o curves are essentially identical with or without the fiber system. In this case, the overall system available E_b/N_o is not significantly degraded due to the higher C/N ratio of the uplink.

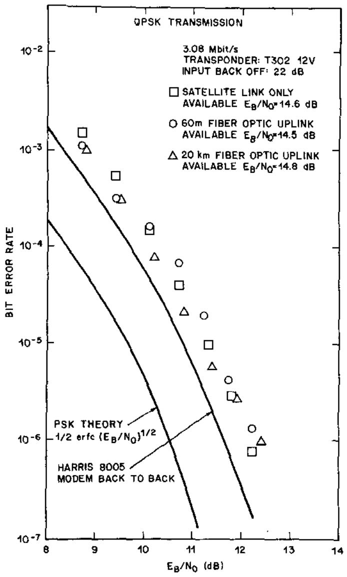

Fig. 6 Fiber transmission of uplink signal (6 GHz). Dependence of bit error rate on S/N ratio for a 3.1 Mbit/s QPSK signal on channel 12V. Same conditions as in Fig. 5.

Conclusion

In summary, a typical satellite signal spectrum, composed of 3-4 FM video signals, 1-2 60 Mbit/s QPSK signals and several 1.544 and 3.1 Mbit/s FDMA QPSK signals, can be transmitted over distances up to 20 km with a direct modulated fiber transmission system with 1 dB or less of degradation in the S/N ratio for both the video and digital signals. While we did not examine the transmission of the 60 Mbit/s QPSK signals in this paper we have previously[4] examined the transmission of a single higher bit rate signal (2 Gbit/s) at carrier frequencies from 3 to 16 GHz and found that a 10^{-9} BER could be obtained for transmission over 34 km of fiber. Hence, we believe the 60 Mbit/s signal degradation will be similar to that of the lower rate digital or video signals examined here. Transmission over 50 km of fiber is possible with a 6 dB reduction in video signal to noise ratio. The principles described here are also applicable to the transmission of Ku-band satellite signals at 11 and 14 GHz, and also to the transmission of block downconverted signals at L-band (.8-1.3 GHz). In the latter case, the system performance should be better since the laser intensity noise is smaller at lower frequencies. The IMD level is also smaller at 1 GHz than at 4 GHz.

Acknowledgement

The authors wish to thank C. Burrus, J. Campbell, A. Gnauck, W. Jan, R. Jopson, C. Julian, R. Linke, and D. Shackelford for supplying components used in this experiment.

REFERENCES

1. J. E. Bowers, B. R. Hemenway, A. H. Gnauck, and D. P. Wilt, "High Speed InGaAsP Constricted Mesa Lasers," J. Quantum Electron. QE-22, pp. 833-844 (1986).
2. J. E. Bowers, C. A. Burrus, and R. J. McCoy, "InGaAs PIN Photodetectors with Modulation Response to Millimeter Wavelengths," Electron, Lett. 21 pp. 812-814 (1985).
3. J. C. Campbell, W. S. Holden, J. F. Ferguson, A. G. Dentai and Y. K. Jhee, "A High Speed InP/InGaAsP/InGaAs Avalanche Photodiode Exhibiting a Gain Bandwidth Product of 60 GHs," Tech. Dig. IOOC-ECOC '85 (Venice, Italy) pp. 66-68, Oct. 1985.
4. J. E. Bowers, "Optical Transmission using PSK Modulated Subcarriers at Frequencies to 16 GHz," Electron. Lett 22, 1119 (1986).