64QAM TRANSMISSION OF DIGITAL DATA OVER CABLE AND ALTERNATE MEDIA

Joseph B. Waltrich
Manager, Advanced Television Systems
Jerrold Communications
2200 Byberry Rd.
Hatboro, PA 19040

ABSTRACT

Transmission of compressed digital data is a compromise between data rate and signal robustness. In a relatively benign transmission medium such as cable, an efficient modulation technique, such as 64QAM, can be used to optimize the information rate and, therefore, the channel capacity. This paper discusses the results of 64QAM transmission testing. Bit error rates are measured and correlated with channel impairments. The effects of error correction and adaptive equalization are investigated.

BACKGROUND

It has been demonstrated that compressed digital video can be transmitted over cable as a 16QAM signal. However, 16QAM transmission limits the maximum data rate to somewhat less than 20 Mb/s in a 6 MHz channel. The information rate (i.e. - the amount of useful data which can be transmitted) is even lower due to the data overhead which must be added for error correction. In a relatively benign environment such as cable, a significant increase in channel capacity can be obtained by using a more efficient modulation technique in conjunction with error correction which is more appropriate for the medium. 64QAM is one such modulation technique.

A comparison of the efficiency of 16QAM and 64QAM is shown in Table 1. The information rate shown in the table is based on the DigiCipher compression algorithm which is capable of compressing up to 5 NTSC signals into a 13.46 Mb/s data stream. If a low overhead error correction is used in conjunction with 64QAM modulation, it is possible to transmit a total information rate of 26.92 Mb/s or up to 10 NTSC signals in 6 MHz.

Table 1 Comparison of 1QAM and 64QAM

	16QAM	64QAM
Information Rate (Mb/s)	13.46	26.92
Error Correction (Mb/s)	6.05	2.34
Total Data Rate (Mb/s)	19.51	29.26
NTSC Signals in 6 MHz	5	10

DigiCipher, as transmitted via satellite, is a QPSK signal with 2 - 5 NTSC signals modulated on each transponder phase. Therefore, the use of 64QAM for transmission over cable would permit the operator to send the contents of an entire satellite transponder in 6 MHz.

Since the results of previous tests with 16QAM were encouraging [1], it was decided to conduct a series of channel characterization tests to determine the feasibility of using 64QAM.

TEST SYSTEM DESCRIPTION

A block diagram of the test system is shown in Fig. 1. A pseudorandom data generator, internal to the digital modulator, is used as the data source. The digital modulator is capable of generating and transmitting data with both trellis coding and Reed Solomon error correction or with either or both of these error correction techniques disabled. This flexibility permits testing to determine the optimum error correction technique for use in cable transmission.

The IF output of the digital modulator is a double sideband suppressed carrier AM signal centered at 44 MHz with a 3 dB bandwidth of 4.88 MHz. The output is up-converted to the appropriate cable channel using the RF section of a Jerrold Commander VI modulator. The digital RF signal is combined with other cable channels and sent over the system in the normal manner.

At the receiving site, the RF signal is converted to IF using a frequency agile down converter. In order to insure low phase noise, the down converter's local oscillator input was supplied by a HP8644 frequency synthesizer. Spectral purity of the L.O. was maintained by a tunable bandpass filter at the output of the device.

The digital demodulator incorporates display capability for readout of errored seconds. Both raw errors and coded errors are displayed. The errored second data is also output to an RS-232 port in order to permit data logging using a personal computer. The demodulator also contains a 64 tap adaptive equalizer for correction of multipath and group delay effects. The values of the adaptive equalizer coefficients are also output on the serial data port in order to provide data on the nature and extent of echoes resident in the system under test. The PC software is structured such that the error data and the adaptive equalizer coefficients can be stored in separate ASCII files for off-line printout.

TEST RESULTS:

Initial tests were conducted with the system in a back-to-back configuration at the headend. For this test, the RF signal was taken directly from the -20 dB monitor output of the Commander VI modulator. The digital signal level was about 8 dBmV. In this configuration, the bit error rate prior to correction was about 3×10^{-4}. The coded bit error rate remained at zero over a 12 hour test period.

The first sytem test was conducted over two fiber optic links plus a 23 trunk cascade, terminating in a bridger and one tap. Test duration was 15 hours. The digital signal was transmitted on channel A-3 (102-108 MHz). Analog carrier/noise and CTB in the channel were 44 dB and -63 dBc, respectively. Digital signal level at the end of the drop was 7 dBmV. Digital carrier/noise ratio was about 32 dB. The average raw BER was 3.4×10^{-4}. A total of 7 errored seconds were logged during the course of the test run, resulting in an average coded BER of 1.4×10^{-7}. There was no loss of signal during this test. The system operated without errors for 99.99% of the time. It should be noted that there was some interference from FM carriers, resulting in about a 20 dB C/I ratio.

A subsequent test was run over a 15.25 mile AML link. Test duration was about 2 hours, with a total of 8 errored seconds, yielding an average coded BER of 1.6×10^{-5}. The average raw BER was 7.4×10^{-5}, resulting in 99.85% error free operation. The errors which occurred during this test were due to phase noise in the AML hardware. Phase noise, measured at 10 KHz from an unmodulated carrier, ranged from -70 dBc/Hz to -103 dBc/Hz. The received signal level was 27 dBmV, with a digital carrier/noise ratio of 40 dB.

The third test was run over a 24 trunk cascade plus two taps plus considerable internal wiring to the receiving site (a hotel room). Received signal level and digital carrier/noise were -3 dBmV and 22 dB, respectively. The test duration was about 51 hours, during which loss of signal occurred for 65 seconds, resulting in a system availability of 99.96%. The loss of signal may have been due to an intermittent failure of the down converter's power supply which was corrected for subsequent tests.

The final test was run over a cascade of 41 trunk amplifiers plus two line extenders and a total of 22 taps. The digital signal was transmitted on channel 58 (96-102 MHz). Test duration was 19.5 hours. The digital signal level was 11 dBmV. Analog C/N was 41 dB. No CTB or CSO were present on the channel. Average raw BER was 1.3×10^{-4}. There were zero coded errors during the duration of the test. Digital C/N at the start of the test was 32 dB, improving to 36 dB at the conclusion of the test run. This may be attributed to a 50 degree change in ambient temperature on the system during the test period.

Information on reflections and group delay, may be derived from the adaptive equalizer coefficient values. Ten bit coefficients are used in the equalizer, providing a coefficient range of ±512. In order to provide headroom, the equalizer is initialized by setting the 20th tap of the in-phase section to 384 and all other coefficients to zero. The coefficient values transmitted via the serial port are those values obtained after the equalizer has converged.

Adaptive equalizer impulse response plots are shown in Figs. 2 - 5. These plots show the absolute value of the impulse response in dB relative to the initial value of the non-zero (20th) tap. The information presented in these figures shows the results of equalization of both system echoes and group delay as well as correction of deviations from ideal impulse response in the system filters. Group delay in the test hardware was on the order of 6-700 nS and was chiefly due to the IF filter. Fig. 2 shows echo amplitude and phase data for the system in the back-to-back configuration.

The data presented in Figs. 3 - 5 indicates that echoes which were present on all of the subsystems tested were relatively short. If one defines significant tap amplitudes as those exceeding -30 dB, then only about 14 taps of the adaptive equalizer showed significant changes relative to the back-to-back impulse response shown in Fig. 2. This implies that system echoes which were corrected by the equalizer were relatively short. This is not inconsistent with the results of previous analyses and testing [2], [3].

Since the channels used for these tests were at the low end of the cable spectrum, it may be assumed that system echo amplitudes were near worst-case conditions due to near-minimum attenuation in the cable. Nevertheless, the performance of the adaptive equalizer was such as to compensate for the effects of all echoes without much difficulty.

CONCLUSIONS:

Judging from the results obtained to date, 64QAM appears to be feasible for cable transmission. The problems encountered in transmission over AML are indicative of the need for careful design of phase locked loops in both the digital transmission and AML hardware. Adaptive equalization appears to be capable of handling echoes and group delay in both the cable system and the transmission equipment. Additional laboratory and field testing is required in order to determine more conclusively the effects of system impairments.

REFERENCES:

[1] J. Waltrich, J. Glaab, "Digital transmission in 16QAM Format Over Cable and Alternate Media", IBC Technical Papers, July, 1992.

[2] J. Glaab, M. Muller, M. Ryba, J. Waltrich, "The Impact of Microreflections on Digital Transmission Over Cable and Alternate Media", NCTA Technical Papers, 1992.

[3] R. Prodan, "Performance of Digital Transmission Techniques for Cable Systems", NCTA Technical Papers, 1992.

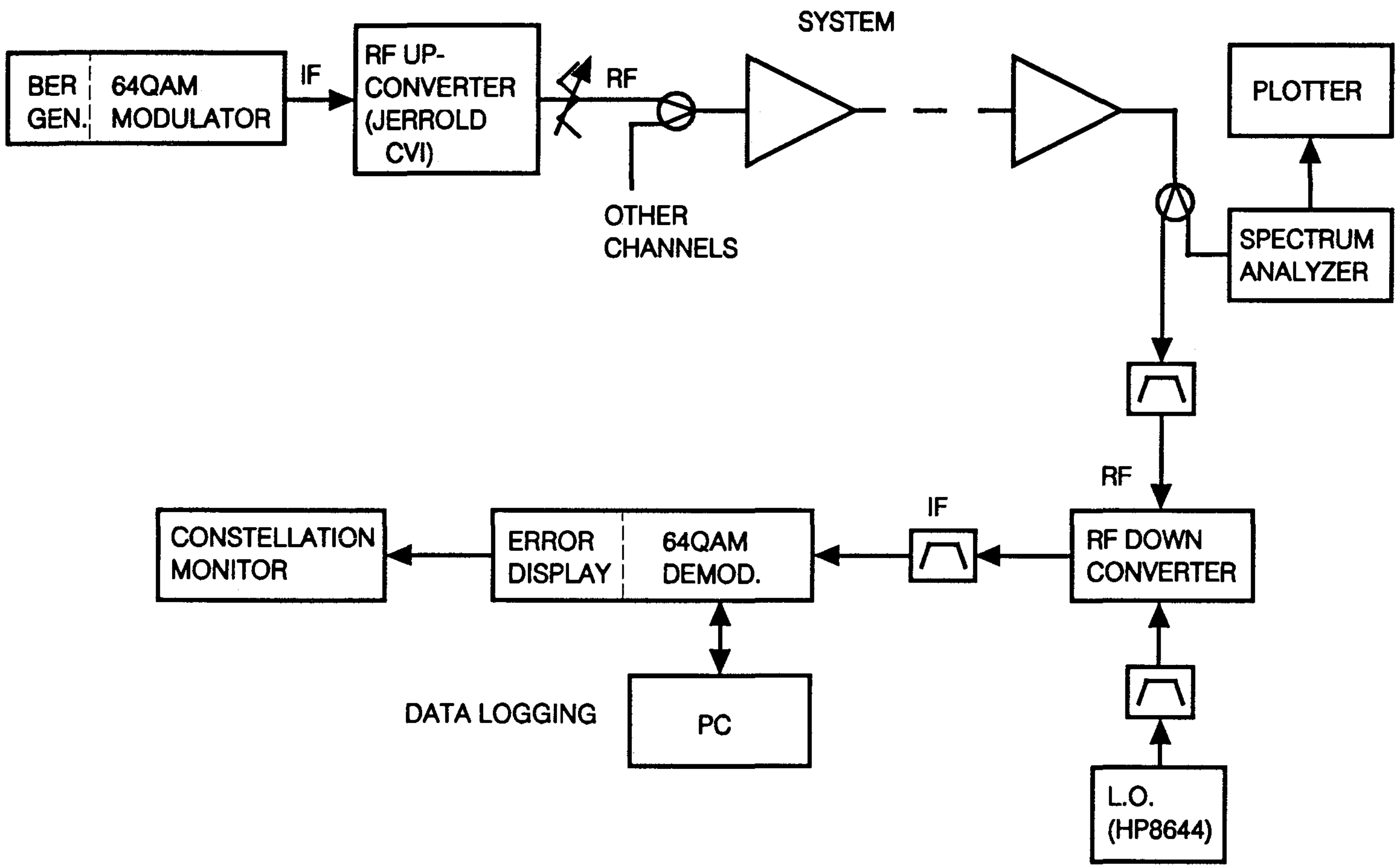

FIG. 1 - 64QAM CHANNEL CHARACTERIZATION - BLOCK DIAGRAM

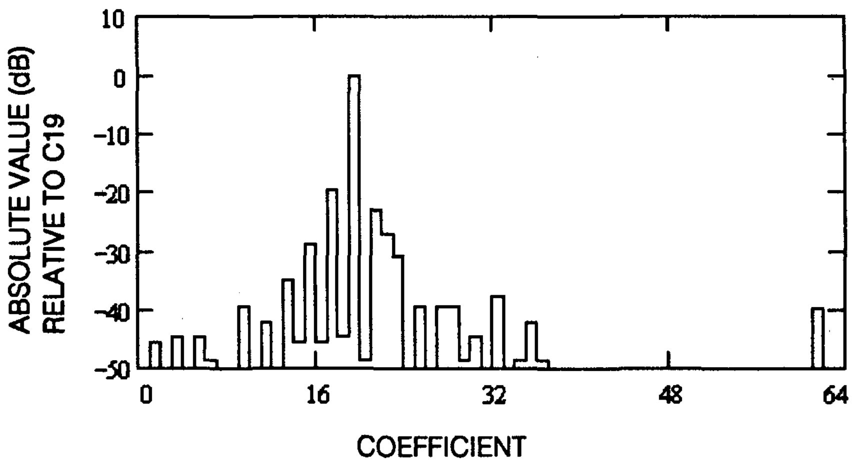

FIG. 2 - ADAPTIVE EQUALIZER IMPULSE RESPONSE - BACK TO BACK THROUGH RF LINK

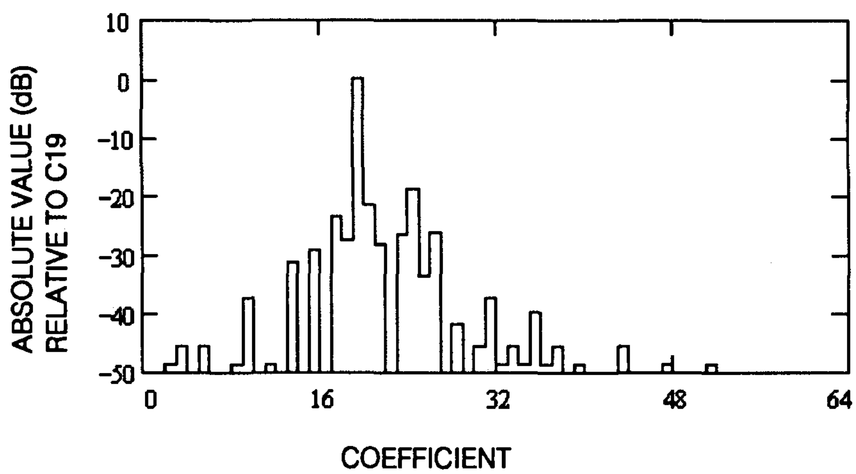

FIG. 3 - ADAPTIVE EQUALIZER IMPULSE RESPONSE 24 TRUNK AMPS + 2 TAPS + INTERNAL HOTEL WIRING

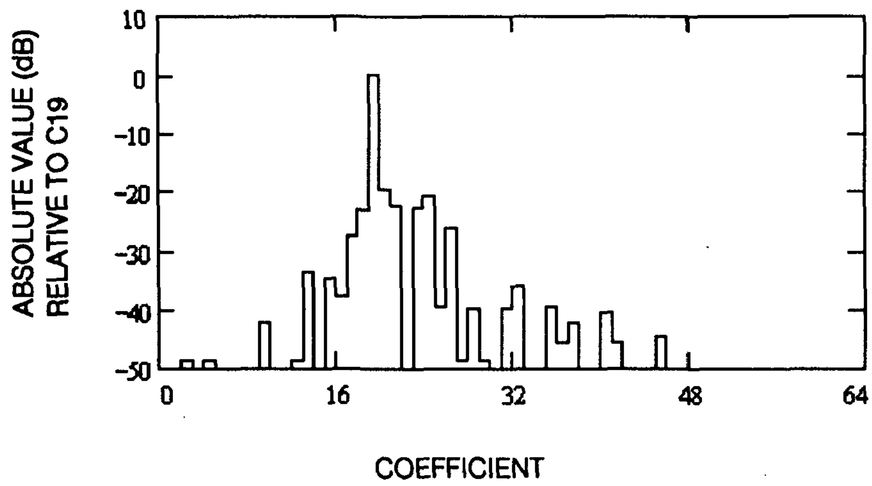

FIG. 4 - ADAPTIVE EQUALIZER IMPULSE RESPONSE
25 TRUNK AMPS + 2 LINE EXTENDERS + 22 TAPS

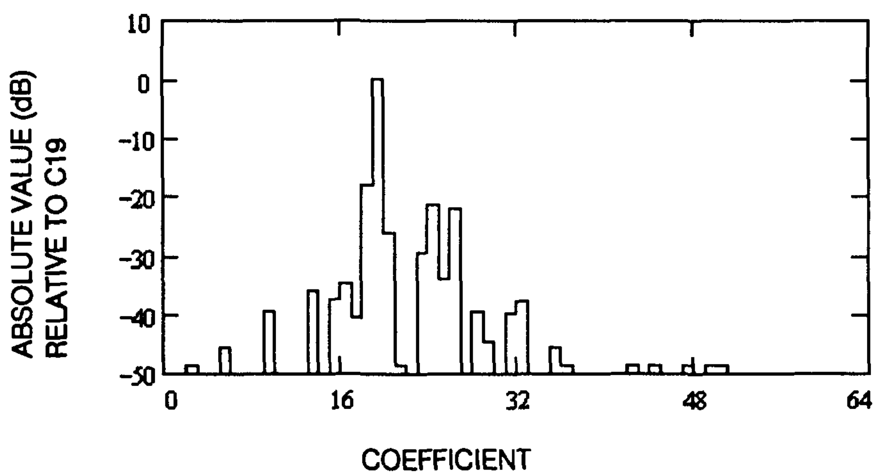

FIG. 5 - ADAPTIVE EQUALIZER IMPULSE RESPONSE
41 TRUNK AMPS + 2 LINE EXTENDERS + 26 TAPS