UPSTREAM NOISE AND BIT-ERROR RATE ANALYSIS OF AN OPERATIONAL ONE-WAY SYSTEM CONVERTED TO TWO-WAY OPERATION

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INTRODUCTION

A. As an industry, we have spent many years perfecting the art of building analog RF wideband communications systems. Although the meaning of the term "wideband" takes on a new meaning every few years, and the technology of RF circuit design may still be more black art than science, still we have become fairly comfortable with this discipline. Now, however, we have witnessed the marriage or perhaps elopement of digital data processing with our broadband RF analog cable systems. What will be the ultimate issue of this union cannot be fully determined at this time, however, it can be said that it is here to stay. Cox Cable has responded to this stimulus by the development of its Tandem T-16 based INDAX system. INDAX, which is an acronym for INteractive DAta eXchange system, is a versatile, modularly expandable interactive data system for subscriber services and is based upon the multi-processor, fully load-sharing Tandem T-16 system. Communications between this central processor and the user terminals occurs over dedicated bandwidth on the subscriber cable. The basic data transmission rate for all INDAX communications is 28 KBS. This occurs in two different modes. A number of 28 KBS channels are set aside for what is essentially one-way common user communications. In this mode, data items of common interest, such as sport briefs, stock market reports, news and the like are constantly cycled. A subscriber may tap into one of these 28 KBS channels at any time without requiring a unique response from the INDAX processor. The second mode of operation is a two-way interactive process, which once again is implemented over dedicated bandwidth on the cable. This service also operates at 28 KBS, but in a different manner. After extensive investigation Cox has determined that the most efficient implementation for this kind of service is a packetized system utilizing carrier sense multiple access with collision detection, commonly called CSMA-CD protocol. With this technique, all communications occur in standard digital packets in a listen-before-transmit mode. This is the CSMA portion of the protocol. The CD, or collision detection, means that the transmitter listens to see if another transmitter came up at exactly the same time. If so, a random time is delayed before attempting to retransmit. Utilizing this process, the INDAX two-way interactive system achieves a 70% efficiency.

B. Cox has installed and is now operating INDAX in a very large test area in our San Diego system. However, before this occurred, Cox wished to determine two very important things. First, what kind of bit error rate environment would our INDAX system be working into in San Diego and what distribution would those errors take; and second, would the inclusion of digital data and the possible carrier collision in a CSMA-CD type system have any adverse effect on adjacent video channels. From the engineering standpoint, we felt that San Diego was a good choice because the system, although well maintained, is not new and is very typical for systems of its age, size and construction. After an initial examination of the typical spectrum on the plant, we knew that we would never be accused of testing INDAX in a pristine laboratory environment. Not a "worst case" perhaps, but certainly representative.

With this introduction, let me now proceed with a description of the test.

TEST STRUCTURE

A. The portion of the INDAX market area chosen for the test is as shown on this slide. We arbitrarily designated the trunk amplifier at this location as the headend and chose a subscriber point downstream through an eleven amplifier cascade. These sites were primarily chosen for the convenience of the test and observational personnel. The headend for the San Carlos area is located atop Cowles Mountain and requires a 4-wheel drive vehicle to approach. We were not convinced that our rental cars were adequate for the climb, nor that we were up to the attempt. Our choice proved to be good as there was considerable bouncing back and forth between each end of the test sample. The test supervisor was Mr. Claude Baggett, Manager of Advanced Systems Engineering for Cox in Atlanta. The chief test engineer was Mr. Paul Workman, Chief Engineer for Cox's subsidiary in San Diego. Assisting were Mr. Gilles Vrignaud of Catel Corporation, Mr. Mark Dineson of Sytek Corporation, and Messrs. Bob Celuska and Dan Barton, technicians from the San Diego system.

B. This slide shows a block diagram of the test set-up. Note that with frequency translators at both ends of the test sample we were able to vary the amplifier cascade in eleven amplifier increments out to a 44 amp cascade, which we did. We used Sytek, Inc. Tverter frequency translators, the new Catel Prentice FM system FSK modem, and an Amdax Model 740 Bi-Ø modem. Test equipment included the Avantek 2000 Analyzer, H.P. 141 Spectrum Analyzer, Instrument Flight Regul. Receiver Corporation, Model FM/AM-1000A Transceiver, and the Astrocom Corporation AC-1900 data test set.

TEST PROCEDURE

With this equipment, we were able to observe the following test factors:

A. Amplifier Cascade, as previously stated.

B. Data Rate, up to 19.2 KBS.

C. Modulation Scheme.

D. Signal Input Levels from a maximum of 15 dB below video through the error threshold and below (35 dB down from video.)

E. Carrier Collision.

At a data transfer rate of 19.2 KBS, to measure to a 10^{-8} error rate takes a minimum of 1-1/2 hours per test run. Since we wanted to make measurements with two different amplifier cascades, two different modulation schemes at 4 levels, a total of 16 tests were required at 1-1/2 hours each. In fact, as we gained experience with this testing, we found that several of these data points were unnecessary, since the communication scheme was far more robust than first believed. As a result of this, only the threshold areas needed to be investigated for definition. The tendency of the modems were to hang on until the signal passed below sync lockup threshold, then drop out at once. If timing were provided through an alternate source, data transmission would have been possible to a much worst S/N.

Based on findings that the maximum cascade which we were able to achieve exceeded the minimum requirements for threshold operation, we proceeded with the following special tests to get a better feel for operation of data transmission with multiple modem technologies.

The modems previously mentioned incorporated three methods of modulation. They were: FSK, FM and Bi-Phase. The purpose of these special tests were to determine the effect of collisions with other data carriers in the cable TV RF spectrum as well as to determine the impact on the bit error rate during such collisions. This was accomplished by using a CW generator and zero beating it with the data carrier which was transmitted at a level 15 dB down from video signal reference. The amplitude of the injected carrier was varied from a level equal to the transmitter carrier to a level 12 dB below the transmitted data carrier with the following findings:

With the data carrier 12 dB greater than the interfering carrier, there was no change in the BER. As the interfering data carrier level was increased, the bit error rate increased to the point when the interfering carrier was 7 dB below the data carrier level at which point the system totally failed. The results of comparing this with the three different modem modulation techniques indicated that the superior decoding capabilities of the bi-phase was able to hold a higher bit error rate than was the FSK or the FM, however, all three still failed at the 7 dB level.

With regard to spurious signal generation due to the collision of data carriers is precisely controlled, all spurious signals fell within the expected bandpass of the data channel and were greater than 60 dB down in adjacent channel spectrum.

Another question which was quite frequently asked and which we sought an answer to was whether the bit error rate would be proportionate to the data rate on the system. Given the limitations of the modems we had available to use at the time of the test, we varied the data rates from 300 baud to 29 Kbaud, holding other parameters in the system constant and found no measurable difference in bit error rates. While it can be argued that burst noise impacting higher speed data rates can affect a higher instantaneous bit error rate, the statistical average always came out consistent.

Another test which we accomplished was to check the bit error rates on the cable TV system as a function of carrier-to-noise ratio. This was accomplished by reducing the output carrier level of the transmitted modems under test. The findings are shown on this slide. As you will notice, at the time of this test, a consistent knee in the bit error rate showed up between 27 and 30 dB down from peak video carrier on the cable TV system. The sharpness of this knee was dependent on the method of modulation and de-modulation used in the system with bi-phase having the sharpest knee.

Since these tests were initially made, we have proceeded to complete the design of the overall INDAX system in its analog and digital forms and have had additional opportunities to test this newly designed hardware in the San Diego system.

Our initial concerns were that a converted two-way operational system could be kept free of spurious signals in the return path. We have since found that normal good trouble-shooting procedures in keeping equipment aligned and connectors tightened has been sufficient to supply a 44 dB carrier-to-noise ratio for the upstream signal path with approximately 200 miles of plant activated.

The present system in San Diego has not been modified for bridger switching nor have the drop cables been replaced for higher RFI integrity. Based on our earlier tests, our requirements had called for a 10^{-8} bit error rate using a 33 dB carrier-to-noise ratio as a design parameter. It is apparent, based on these tests and later operational findings, that this was a conservative design goal.

Several areas of interest have come out of the testing and development of the RF portion of this design. The method of modulation, modulation index, and pre-modulation requirements that would give a noise-free narrow band data transmission system. It has been shown in our tests that Manchester and bi-phase modulation coding schemes offer superior data recovery capabilities. It is not clear at this time that a data recovery system requires the complex overhead of these modulation schemes in order to work effectively. The use of a pre-modulation filter in FSK and FM modulation allows for the compression of the data in the RF spectrum and is shown to be a very valuable trade-off. It has not been found that wide band FM adds any significant performance to the operation of the data system.

As INDAX and other cable based data transmission schemes move forward in the near future, additional data will be gathered and will help in bringing this technology into reality.