A Technique for Digital Information Broadcasting Using SCA Channels

Harry R. Anderson, P.E.
Consulting Engineer
P. O. Box 3682
Quincy, Illinois 62305

Ronald C. Crane
3 Com Corp.
1390 Shorebird Way
Mountain View, California 94043

Abstract: This paper describes a simple technique using the SCA (Subsidiary Communications Authorization) channel authorized for use in FM and TV broadcasting to provide a one-way digital transmission channel for teletext-type service. The channel is transparent to data format. Preliminary field test results for a 9600 bit/second channel are also presented which show average error rates of less than 1 in 10^6.

1. Introduction and Summary

With the recent introduction of teletext systems in Europe for the dissemination of information-based programming, the question of how best to implement such a service on the highly-developed broadcast resource in the United States is being addressed. Techniques similar to those employed in Great Britain using blank lines in the vertical interval of television broadcast signals are currently under experimental and regulatory investigation.

This paper describes a simple technique using the SCA (Subsidiary Communications Authorization) channel authorized for use by FM and television broadcasting to provide a teletext-type service. The data channel is completely transparent to data structure, allowing either page and line formatted transmissions, as in the current British teletext system, or a much more flexible system in which data fromatting, sorting, and retrieval is accomplished by a personal computer at the receiver location. Preliminary field test results for a 9600 bit/second system are also presented which show typical uncorrected average error rates of less than one error in 10^6 bits.

Also, considering that one way data transmission is an intermediate step to the advent of high speed, two-way data retrieval for the home, this paper briefly discusses the larger question of whether using television transmissions, with relatively sophisticated hardware and adaptive filtering, is the most suitable choice to implement a teletext service when simpler, more flexible transmission outlets are viable.

Finally, the work described in this paper was not intended as a rigorous analytical and experimental investigation of data transmission on frequency modulated channels, but rather an exploration of the application of a widely available broadcast communications channel to data transmission at moderate bit rates.

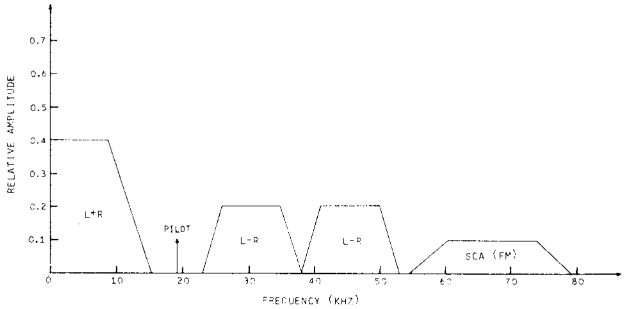

FIGURE 1 — FM BROADCAST BASEBAND SPECTRUM

2. SCA Modulation Fundamentals

2.1 Broadcast FM in the United States

Figure 1 is a diagram showing the signal baseband for FM stereo transmissions originating in the United States. The horizontal axis represents frequency in kilohertz, and the vertical axis shows relative amplitudes. For stereo transmissions, the left+right signal uses the frequency band from 0 to 15 KHz and the left-minus-right signal uses the 23 KHz to 53 KHz band. Sum and difference signals are used to maintain compatibility with monaural receivers which only see the 0 to 15 KHz band. The left-minus-right signal occupies 30 KHz of bandwidth because it is double sideband modulation of a 38 KHz subcarrier. In this modulation process, the 38 KHz subcarrier is suppressed, resulting in double sideband, suppressed carrier (DSBSC) modulation–a linear, amplitude modulation method. The detection of the DSBSC signal in the receiver must be synchronous with the originating modulation subcarrier, and therefore requires the 38 KHz subcarrier be reinserted. Doubling the frequency of the 19 KHz pilot signal in the receiver recreates the 38 KHz subcarrier, thus allowing proper synchronous detection of the left-minus-right audio information.

The described stereo transmission standard is specified in detail in the FCC Rules, thus requiring all FM stations transmitting stereo programming to use this system. The FCC Rules also allow the frequencies between 53 KHz and 75 KHz to be used for another transmission channel, the SCA subcarrier.

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2.2 The SCA Channel

By the FCC Rules[1], the SCA signal must be frequency modulated rather than amplitude modulated as in the case of the left-minus-right subchannel. In frequency modulation, the message is conveyed by the frequency of the signal rather than by its amplitude. For pure FM transmissions, the amplitude of the signal is constant at all times. The SCA subcarrier frequency with no modulation is typically placed at 67 KHz for stereo stations. A negative modulating voltage would lower the frequency; a positive modulating voltage would increase the frequency. The difference between the instantaneous frequency and the center frequency of 67 KHz is the deviation. The peak voltage (positive or negative) transmitted through the SCA channel will cause a peak deviation, which in the case of a time varying signal such as music or voice, occurs only occasionally. The FCC requires that the instantaneous frequency never fall outside the range of 53 KHz to 75 KHz. For an SCA channel with a rest (no modulation) frequency of 67 KHz, the maximum symmetrical deviation is ±8 KHz.

In addition to the instantaneous frequency limits, the FCC also requires that no interference be caused to the normal stereo transmissions. The specification is that any signal resulting from the SCA which is in the range of 0 to 53 KHz must be 60 dB below the main channel audio signal at its maximum amplitude. The maximum allowed amplitude of the subcarrier is already 20 dB below this maximum, therefore, any SCA-caused signals between 0 and 53 KHz must be 40 dB below the SCA subcarrer level. This restriction of no interference to the stereo transmission affects both the allowed SCA frequency deviation and the energy spectrum of the message used to modulate the SCA subcarrier.

2.3 Information Capacity of an SCA Channel

Given a transmission channel with a certain bandwidth and signal-to-noise ratio, it is possible to determine an upper limit on data rate (bits/second) and associated error rate (errors/bit). A commonly used relationship knows as the Hartley-Shannon law[2], states that the information capacity of a channel, C, is related to the channel bandwidth and signal-to-noise ratio by the following equation:

$$C = B \log_2 (S/N + 1) \text{ bits/second}$$

B — Channel bandwidth in Hz
S/N — Ratio of signal power to noise power in channel

For an SCA channel, measured results show that a bandwidth of 5 KHz and a signal power to noise power ratio of 1000 (30 dB) are readily achievable. Using these numbers, a maximum transmission rate of 50,000 bits/second is possible. However, to approach this speed, modulation techniques which use a combination of both amplitude and phase encoding of the signal are necessary.

It should be pointed out that the channel transmission rate and the useful message rate for the channel are not the same. There are typically overhead bits which are used for framing, addressing, and error checking.

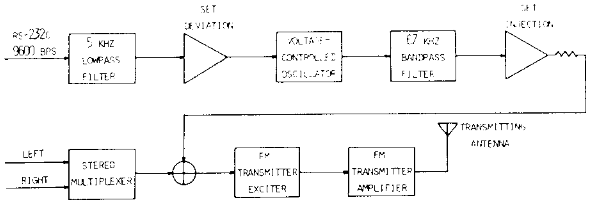

FIGURE 2 — BLOCK DIAGRAM OF SCA MODULATOR AND FM TRANSMITTER

2.4 Channel Modulation

Simple FSK (frequency shift keying) was chosen for the modulation technique to simplify the detection circuitry in the receiver. The derived channel provides a single digital path with flat response from DC to 5 KHz. Signalling is asynchronous (no recovered clock) at 9600 bits/second. In the FM baseband channel, 63 KHz represents a logic 0 and 71 KHz represents a logic 1. Thus, the deviation is ±4 KHz. the data is band-limited by a 5 KHz low pass filter before modulation of the 67 KHz subcarrier. The frequency modulated subcarrier is also passed through a 61 KHz to 73 KHz bandpass filter before it is added to the main transmission channel. These two stages of filtering limit the rate of change of frequency within the passband (consistent with limited bandwidth of PLL receivers) and limit the spectral energy outside the SCA 53 KHz to 75 KHz spectrum to achieve compliance with the FCC rules.

It is also possible to provide a synchronous channel by encoding the information sent through the 5 KHz channel in such a way that a clock can be recovered. Two methods are immediately available: Manchester coding and MFM (Miller) coding. Both techniques require a 9600 baud (signalling element transitions/second) channel. Manchester encoding is simpler, but requires 2 transitions per bit, giving only a 4800 bits/second data rate. MFM coding requires slightly more circuitry, but takes only 1 transition per bit giving a data rate of 9600 bits/second.

Although synchronous modulation techniques could be used with this data channel at some additional cost, this paper deals only with the characteristics of the asynchronous 9600 bit/second channel.

3. Modulator Implementation

3.1 Modulator

Figure 2 is a block diagram of the SCA modulator. The input port is a common RS-232C interface which accepts asynchronous data at 9600 bits per second. The 9600 baud asynchronous signal is sent through a low pass filter in order to attenuate the high frequency components in the data waveform. Several designs have been used for this filter and its parameters appear to be noncritical. Successful designs have been 4 pole active Butterworth filters which are essentially flat from DC to 5 KHz, with a 3 dB cutoff frequency of 5.2 KHz and 18 dB attenutation at 10 KHz. The measured variation in time delay is ±10

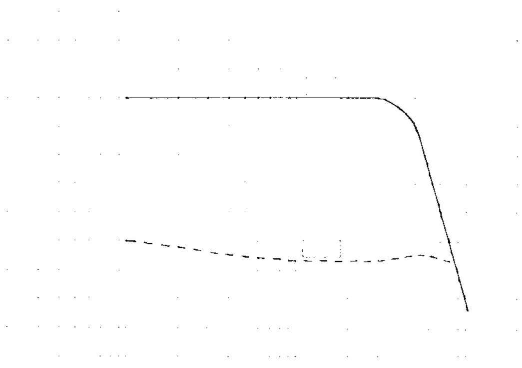

FIGURE 3 — SCA CHANNEL RESPONSE

microseconds from 150 Hz to 5 KHz. Its response is shown in figure 3.

Following the lowpass filter, the amplitude is adjusted to set the subcarrier deviation and the signal is then applied to a voltage controlled oscillator (VCO) which produces the FSK modulated signal centered at 67 KHz. Initial tests of the output spectrum and later tests of performance in the field indicate that a deviation of ±4 KHz is sufficient FM modulation depth. The VCO is operated in the linear mode, such that its sweep rate is limited by the input filter. This prevents step changes in frequency from appearing at the input of the receiver as well as reducing out of band components at the output of the VCO.

Observations have been made of the output of the VCO using a spectrum analyzer designed for this frequency range. This spectrum analyzer has the capability of storing and displaying the maximum amplitude of the signal components as it sweeps across a set frequency band. Using as a data source a character generator which cycles through all 256 possible 8 bit characters and delivers them at 9600 bits per second, the maximum amplitude of the VCO output frequency spectrum was stored for several minutes. Over this period of time, it is reasonable to expect that the maximum amplitudes of all possible output spectra would be recorded. The results of this test show the amplitude of the SCA components below 53 KHz were approximately 35 dB below the unmodulated SCA subcarrier level. As stated before, the FCC Rules require the level of such components to be 40 dB or more below the SCA level, if the SCA occupies the maximum allowed 10% of the main channel modulation (injection level). Additional filtering is therefore required after the VCO in order to comply with the FCC Rules. The amount of filtering required, at least 5 dB, is easily achieved with the 2 pole bandpass filter indicated in figure 2. This filter, as built, achieves 8 to 10 dB of attenuation at 53 KHz while maintaining adequate phase and frequency response through the frequency band where the significant SCA energy resides. Figure 4A and 4B show the maximum spectral amplitudes stored over a 15 minute period at the output of the bandpass filter using the test data modulation source described above.

The filter is followed by a buffer amplifier and isolation resistor so that the injection of the SCA signal does not upset the function of the stereo generator or FM transmitter exciter.

While the SCA generator must not cause interference to the stereo signal, the reverse is not always true. In fact, depending on the stereo multiplex generator employed by the FM station, significant amounts of spurious energy can be generated in the frequency range where the SCA belongs. The more modern stereo generator designs are sensitive to this problem and provide for adequate suppression of the stereo signal above 53 KHz. When establishing an SCA installation, the type of stereo generator and its spurious output are factors to be considered.

4. FM Transmission Environment

4.1 Signals

The entire set of signals including the left-plus-right audio, the 19 KHz pilot tone, the left-minus-right audio, and the SCA subcarrier, after being combined, are used to frequency modulate the main FM carrier located between 88 and 108 MHz, the band designated for FM broadcasting in the United States. The FM transmitter amplifies the composite signal to a power level of from 10 watts to 50 kilowatts and directs this energy to a properly designed transmitting antenna which broadcasts it throughout the community.

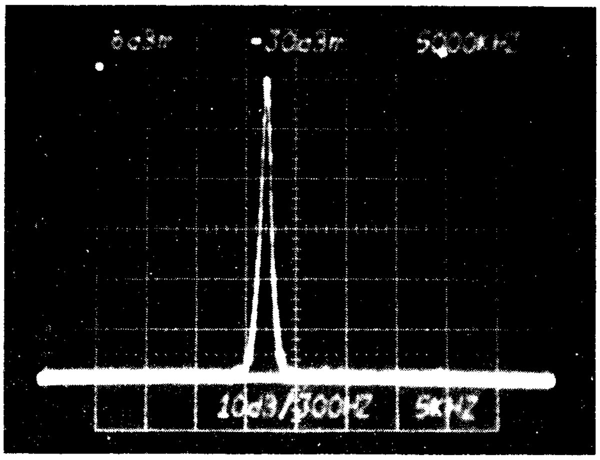

FIGURE 4A — UNMODULATED SUBCARRIER OUTPUT

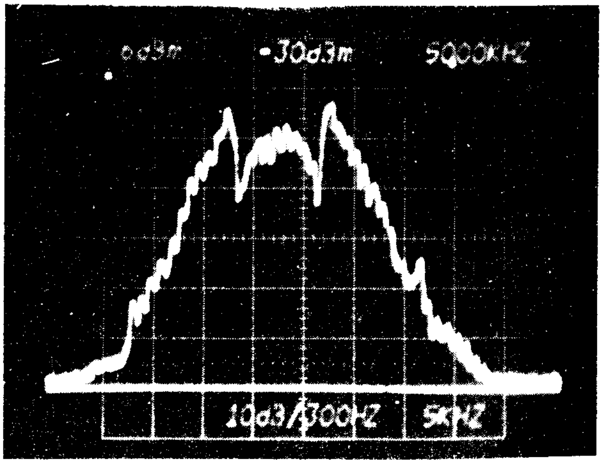

FIGURE 4B — MODULATED SUBCARRIER — MAXIMUM AMPLITUDE OVER 15 MINUTES (SEE TEXT)

Because of the frequencies involved, the transmission path for FM broadcast is primarily via space waves, i.e., electromagnetic waves propagating through space. (These should be distinguished from skywaves which propagate by reflecting off the ionosphere.) For AM broadcast stations, the daytime propagation mechanism is dominated by groundwave transmission. In areas where there is an unobstructed view of the FM transmitting antenna, space waves are not blocked by intervening objects, resulting in line-of-sight reception. When encountering an obstruction, the space wave will be partially blocked and partially refracted around the object normally producing a decrease in signal strength at the receiving location.

Space waves also reflect off objects such as buildings, wires, light poles, and mountains. The reflected signals can propagate in such a way as to arrive at a particular receiving location delayed by some short period of time due to the longer transmission path. Depending on numerous factors including the geometry of the reflection, the frequency deviation, the incident signal phase, and the relative strength of the signals, the reflected signal can cause complete destruction of the FM transmission.[3] More recent computerized analytical investigations provide detailed estimates of audio distortion, and the more relevant problem of SCA-main channel crosstalk, as a function of multipath reflection parameters.[4]

The transmission problems which result in degraded FM stereo performance will also degrade the SCA performance. It is important to bear in mind such FM coverage limitations when considering reception of a digital or other types of SCA transmission.

5. Demodulator Implementation

5.1 Demodulator

Before the SCA demodulator can perform its function, the normal FM demodulation process must first take place. The FM receiver accepts a signal from the antenna, filters it, selects a particular FM station by mixing with a local oscillator, filters it again, and applies it to the main FM demodulator. Once the main FM demodulation is accomplished, the 88 to 108 MHz carrier has been converted back to the baseband signal shown in Figure 1, with the addition of noise, interference, and multipath degration. The normal home receiver rejects the SCA frequencies and only deals with the stereo audio signals. The SCA demodulator must do the opposite — reject the stereo audio signals and deal only with the SCA signal.

Figure 5 is a block diagram of the FM/SCA receiver. The entire FM demodulation process just described is represented in the diagram by the block labelled "FM Demodulator". The output of this block is directed to a bandpass filter which extracts the SCA frequencies. The characteristics of this filter are very important to SCA reception. Transmission has been successful with a standard 4 pole bandpass filter which attenuates the stereo signal by at least 20 dB at 53 KHz, with increasing attenuation at lower frequencies. It allows adequate phase and frequency response in the passband to achieve acceptably low SCA distortion, however a certain amount of incidental amplitude modulation occurs which is removed by a limiter which follows the filter. The phase distortion which accompanies the incidental amplitude modulation is not severe enough to cause errors in the data transmission.

The output of the limiter is routed to a phase locked loop (PLL) detector which converts the frequency shifting 67 KHz signal to a voltage proportional to input frequency. The PLL capture and lock range are optimized to accomodate the ± 4 KHz deviation which is being produced by the SCA modulator. The output of the PLL is low pass filtered again to remove any residual 67 KHz signal, and thereafter amplified to produce an RS-232C level data signal at 9600 bits/second. This signal can then be connected to any computer or terminal with an asynchronous RS-232C interface.

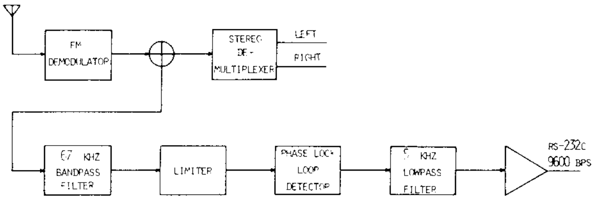

FIGURE 5 — BLOCK DIAGRAM OF SCA RECEIVER

6. Field Tests

6.1 Test Set-Up

The digital SCA transmission system as described was field tested on September 5 and 6, 1979, on station KXOA-FM in Sacramento, California. KXOA-FM operates with a radiated power of 27 KW, both horizontally and vertically polarized, with an antenna height above ground of 426 feet.

Tests were made at three types of locations. The first was within a few miles of the transmitter with no major transmission path obstructions. The second type were locations approximately 15 miles from the transmitter where local multipath reflections and some obstructions were present; these locations represents typical suburban Sacramento reception. The third location type was more than 30 miles distant with a completely terrain-obstructed transmission path.

The test equipment included the 8 bit character generator and SCA modulator already described. This equipment was set up at the transmitter site and the signal injected into the FM exciter along with the normal stereo signals. Spectrum analyzer observations of the composite output after set up confirmed compliance with pertinent FCC SCA regulations.

The receiving equipment included a very inexpensive ($60) tunable FM receiver available from a local retail outlet which had been equipped with a special output immediately after the FM demodulator section. This special output signal was than fed to the SCA demodulator where it was filtered, limited, PLL detected, and amplified, as previously described. The data output was fed to a computer which had been programmed to monitor the 8 bit character string generated at the transmitter. Since the

8 bit characters were generated in numerical sequence, the computer program at the receiver could detect and record errors by identifying characters out of sequence. The characters (asynchronous start-stop codes) contained one start bit, one stop bit, and no parity bits.

The receiving equipment was set up in a car so that it could be moved from location to location and quickly organized to monitor the transmission. In all tests, a simple, commonly available rabbit ear type antenna was used. Its position and orientation were optimized at each test location for best data reception.

6.2 Test Results

After overcoming some initial frequency drift problems, reception of the data signals was quite straightforward. In the best locations, within a few miles of the transmitter, error performance was exceptional. Transmission for several minutes without a single bit error was possible. The few errors that did occur came in short bursts which destroyed 2 or 3 characters in a row. During one monitoring period of nearly two hours, not a single transmission error occurred, all without error correcting of any kind.

At the second type of location, some 15 miles from the transmitter, adjustment of the receiving antenna for good data performance was more critical, as was fine tuning of the FM receiver. Once adjusted though, good error performance was again possible with 2 or 3 minute error-free stretches quite common. Again, errors occurred in bursts, and in one outdoor location, were obviously correlated with the movement of nearby cars and trucks which, of course, constitute local multipath degradation sources.

In the third type of location quite distant from the transmitter and behind some hills, data reception was very difficult in spite of the best antenna adjustment and receiver tuning. Neither was is possible to achieve good stereo audio reception at this location. Due to the high error rate and the simple character error detection scheme used, it was not possible to get a good idea of the type of errors which were occurring. The use of a more sophisticated FM receiver and a directional receiving antenna would improved multipath rejection in such difficult reception areas.

7. System Considerations and Applications

Figure 6 shows a diagram of how a one-way information transmission service might be established using the SCA channel. A source computer would be used to label and combine information from several different services. This computer would also establish formats for data and graphics to conform to some presentation protocol, such as that recently adopted by the Bell System.^{5}. The time-division multiplexed data stream would than be relayed to the FM transmitter site, placed on the SCA channel, and broadcast by the FM transmitter.

Reception in the home would be accomplished by a suitable FM receiver and SCA demodulator which would provide as output the data stream which originated with the source computer. The data steam would be monitored by a small computer which would interpret the data, and sort and store information which it had previously been instructed to retrieve by a user-created editing program. The stored data could than be recovered and reviewed by the user at any later convenient time. The ability to selectively store large amounts of data enables the user to quickly look over stored information of interest without placing heavy demands on the transmission system. Without local storage, and keeping the same transmission bit rate, a user would have to wait longer to see all information of interest, or the information would have to repeat more frequently, reducing the total amount of information from which to make a selection.

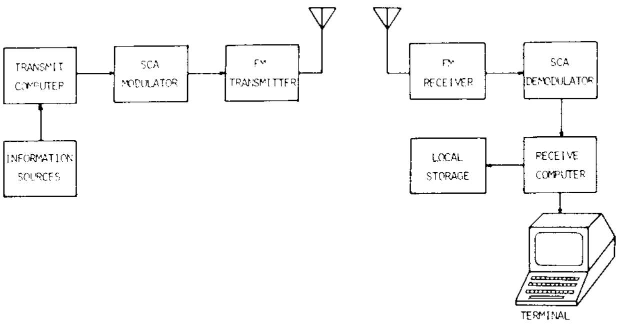

FIGURE 6 — INFORMATION TRANSMISSION SYSTEM

The following sections briefly discuss some considerations necessary to implement a one-way information transmission service.

7.1 Data Formats & Overhead

The experimental system was asynchronous using start-stop codes for synchronization between the transmitter and receiver. Synchronous data formats could also be used, but some form of encoding would be necessary to facilitate clock recovery at the receiver. Some simple techniques include Manchester encoding or Miller coding (MFM), both of which are used with floppy disks.

The choice of asynchronous signalling was made for two reasons. First, most home computers have asynchronous interfaces, but do not have synchronous ones. Second, no separate clock recovery stage is needed in the receiver for asynchronous signalling since the UART (universal asynchronous receiver transmitter) in the computer performs the function on a per character basis.

7.2 Multiplexing Protocol

Some method is needed to share or subdivide a single channel among several users or services. Transmitting data in blocks and including an address (or channel number) with the block permits distinguishing the blocks of one service from those of another service.

7.3 Error Characteristics

Errors in the data stream are due to interference or noise bursts. These have the characteristic that many bits near each other are garbled, while there are long periods of error free transmission between the noise bursts. Placing the data into blocks with an error detecting code at the end of each block provides a means for the receiver to detect and reject damaged data blocks. If the transmitter transmits all blocks several times, than the receiver has an opportunity to catch an ungarbled version of the block during a repeated transmission.

Retransmission reduces overall throughput. However, with a 24 hour per day transmission schedule and a local storage system, the total information transfer is still significant. Assuming 3 transmissions for each piece of information and 20% for headers in a 960 character/second system (8 bit characters embedded in 10 bit start-stop codes and not to be confused with headers), the text transmission rate is .33 × 80% × 960 = 256 characters/second. This is roughly 6 pages (2560 char./page) per minute or 8640 pages per day.

7.4 Comments on One-Way Data Transmission

The current pursuit of establishing a teletext service in the United States is concentrating on data transmission in the television vertical interval as is done in Great Britain, with the appropriate modifications to accomodate the different line rate and bandwidth characteristics of the U.S. NTSC television standard. Considerable effort has been expended by both broadcast experimenters and hardware manufacturers to 'gear up' for an eventual FCC decision to permit regular broadcasting of such teletext transmissions.

The preliminary success of the simple SCA system set forth in this paper indicates that television vertical interval data transmission is not the only alternative. The net character transmission rate of these SCA tests is about half the rate of the current US teletext experimentation, and could conceivably be doubled using well known techniques. The lead of the British system has unfortunately narrowed the U.S. perspective. The United States has a much more technically diverse broadcasting environment, and has a correspondingly greater range of transmission alternatives for one-way data distribution.

The ultimate home information resource would be one in which high speed, two-way data retrieval is possible, either by radio, wire, or optical link. This capability is anticipated by current technological trends, and could be commonly available in 15 years, perhaps as soon as 10 years. Such a two-way system as envisioned would not be dependent on existing broadcasting outlets, but rather would be complete onto itself. In this light, a one-way, broadcast information system will eventually have a secondary role. It is therefore appropriate to develop teletext systems which require the least expensive and simplest hardware, and which serve the primary purpose of getting people accustomed to having information in electronic, machine-understandable, form.

It is suggested that the temporal, secondary nature of one-way broadcast data transmission be recognized, and that before major regulatory or financial commitments are made to television based teletext, the whole technology be evaluated as only a relatively short-term, intermediate step toward a much more versatile, two-way home information resource.

8. Conclusions

From the test results, the digital modulation technique as developed appears to be viable for the broadcast of data at 9600 bits per second while complying with all FCC technical regulations pertaining to SCA operations.

The burst errors encountered can be very effectively combatted by the use of block repetition transmission. Even so, the uncorrected error probability, P_e, for most locations was 10^{-6} or better. With a simpler error detection scheme, essentially error-free transmission should be possible at most locations where reasonably good stereo reception is now possible.

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