TESTING AND EVALUATION OF THE SUBCARRIER TRAFFIC INFORMATION CHANNEL

John F. Mastrangelo and Wayne R. Rust*

In support of the Federal Highway Administration of the United States Department of Transportation, the Institute for Telecommunication Sciences has completed a laboratory and field test program designed to independently evaluate the performance of an FM subcarrier-based traveler information broadcast system. This system was developed by the MITRE Corporation to investigate the use of FM subcarriers for the broadcast of traffic data to vehicles on highways. The testing and evaluation program measured the Subcarrier Traffic Information Channel (STIC) system performance both in the laboratory and when installed in the subcarrier channel of a commercial FM broadcast station. STIC performance was measured and evaluated in a variety of reception environments in order to assist in the future prediction of STIC coverage in areas of the United States that differ dramatically in terrain and population density.

Key words: Advanced Traffic Information Systems (ATIS); FM broadcast subcarrier; Intelligent Transportation Systems (ITS); propagation measurements; propagation predictions; Subcarrier Traffic Information Channel (STIC) system

1. INTRODUCTION

The United States Department of Transportation (DOT) established the Intelligent Transportation System (ITS) program to use advanced computer, electronics, and communications technologies to improve the effectiveness of the nation's highway system. The goals are to provide travel planning and management, traveler information, energy conservation, and advanced vehicle control to highway users. The Federal Highway Administration (FHWA) contracted the MITRE Corporation to investigate the use of FM subcarriers for the broadcast of traffic data to vehicles on highways to support ITS. In response to this contract, MITRE developed the Subcarrier Traffic Information Channel (STIC) waveform and prototype STIC system to evaluate the potential use of the existing FM broadcast infrastructure to broadcast traffic information. The National Telecommunications and Information Administration/Institute for Telecommunication Sciences (NTIA/ITS) was contracted by the FHWA to perform independent analysis and additional laboratory and field testing of the STIC system. NTIA/ITS measured the STIC system performance when installed in the subcarrier channel of a commercial FM broadcast station. STIC performance was evaluated in a variety of reception environments: urban high-rise, urban low-rise, rural mountain, and rural plains.

---

* The authors were formerly with the Institute for Telecommunication Sciences, National Telecommunications and Information Administration, U.S. Department of Commerce, Boulder, CO 80303-3328.

2. STIC SYSTEM DESCRIPTION

The STIC system is a proof-of-concept prototype developed by the MITRE Corporation under the sponsorship of the ITS program. The prototype is intended to demonstrate the ability to broadcast high-speed digital data using the existing commercial FM broadcast radio infrastructure.

The STIC system is an FM subcarrier-based data transmission and reception system. It is designed to achieve reliable communications in the multipath and fading environment associated with very high frequency (VHF) mobile receivers. To achieve that end, the STIC system uses high levels of signal processing and error correction. The key characteristics of the waveform are:

- 72.2-kHz center frequency,
- 20-kHz bandwidth,
- π/4 DQPSK with square root raised cosine filtering,
- ½-rate convolutional code (mitigation of random errors),
- Reed-Solomon (228,243) block code (mitigates burst errors and provides error detection),
- convolutional interleaving (to randomize burst errors), and
- 18.05-kbps channel data rate, >8-kbps information data rate.

The prototype STIC system consists of a transmitter subsystem and receiver subsystem. The STIC transmitter subsystem consists of the STIC subcarrier generator and a personal computer (PC). The PC is used to control and configure the subcarrier generator and generate messages for transmission. The subcarrier generator is enclosed in a single rack-mounted chassis. It connects directly to the subcarrier input port of an FM broadcast exciter. The STIC receiver subsystem consists of an FM car stereo receiver (modified to demodulate the subcarrier signal), a Global Positioning System (GPS) antenna, the STIC receiver (which also functions as a GPS receiver), a hand-held data terminal, a data collection PC, and the STIC power supply and harness.

3. LABORATORY EVALUATION

The goals of the laboratory testing were to familiarize the NTIA/ITS engineers with the operation of the STIC system before embarking on the field-testing program, verify adjacent subcarrier and entertainment signal compatibility by measuring the occupancy bandwidth of the STIC signal, and determine the baseline performance under the best possible operating conditions in preparation for field testing. Extensive compatibility testing of the STIC waveform with an audio program or other subcarrier systems was not performed due to time and equipment constraints. The primary purpose of the STIC laboratory performance testing was to measure the system error rates vs. received signal power. Error performance for the STIC system consisted of three performance metrics: channel error rate (CER), bit error rate (BER), and packet error rate (PER). Each of these was measured and recorded for a range of received signal power levels.

3.1 Laboratory Testing

Laboratory testing was used to characterize the idealized system error performance (CER, BER, and PER) as a function of the received power level. The received power level is a metric closely associated with radio area coverage. The ultimate goal of the field test program was to predict STIC performance in different geographic environments (i.e., system coverage) by using either known or predicted received signal power levels.

The STIC system can operate in message mode and BER mode. In message mode, the STIC transmits a user-specified message. This message can be generated via the keyboard, a previously stored file, a modem, or any other input device. The message mode was not used during the NTIA/ITS testing. In BER mode, the transmitter continuously sends a BER data pattern that is known by the receiver. By comparing the received BER data pattern with the stored BER data pattern, error rate information can be computed. The STIC prototype can also perform convolutional interleaving of the transmitted data. The convolutional interleaver can operate in one of four modes; denoted x1, x2, x4, or x8. Each mode corresponds to an interleaver depth. Two of the four modes, x1 and x2, were evaluated during laboratory testing. Error performance was divided into three categories: CER, which corresponds to the actual channel error rate; BER, which is post-error-correction bit error rate; and PER, which corresponds to the packet error rate. A packet with errors is defined as a packet containing one or more bit errors. A packet consists of 1824 bits. The laboratory evaluation system is shown in Figure 1.

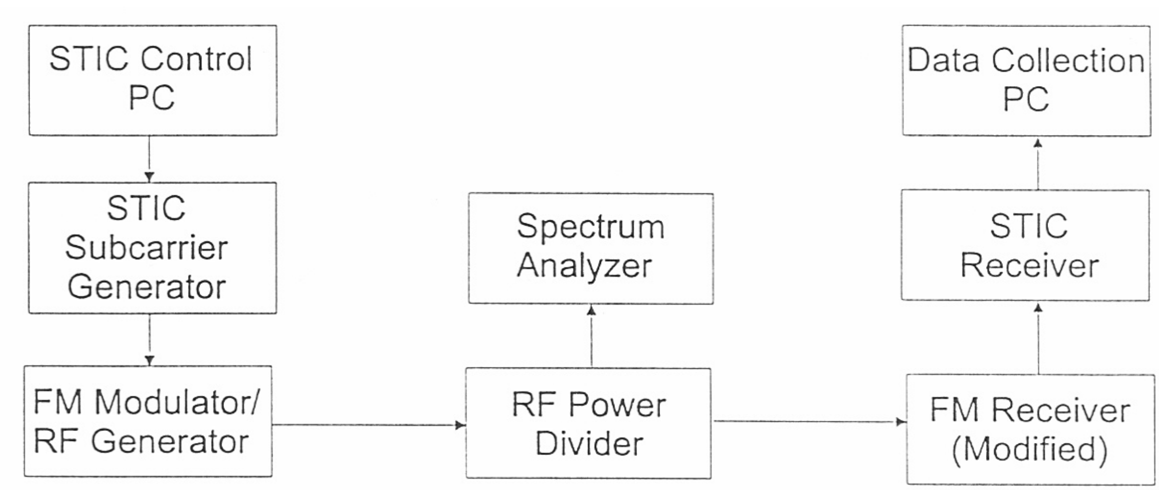

Figure 1. Laboratory test configuration for error rate testing.

In order to simulate the STIC subcarrier signal imposed onto a commercial FM carrier, the STIC signal was modulated using a Fluke 6062A synthesized RF signal generator. The signal generator carrier frequency was set to 100.5 MHz and the FM modulation sensitivity was adjusted for an injection level of 10% for the STIC signal. The carrier frequency was chosen for minimal commercial broadcast energy in the surrounding frequency band. Additionally, the laboratory testing was conducted in the NTIA/ITS screen room to minimize the reception of spurious RF signals. The RF output of the signal generator was connected to a power divider. The output power of the RF generator was varied using a precision output attenuator contained in the generator. One output of the power divider was routed to a spectrum analyzer for signal power measurements and the other output was routed to the modified FM stereo receiver. The hand-held data terminal and data collection PC were connected to the STIC receiver. The hand-held data terminal was used to configure the STIC receiver and the PC was used to collect and store error information. Laboratory testing of the STIC system consisted of two parts: bandwidth occupancy and error rate testing.

3.2 Laboratory Measurement Results

3.2.1 Bandwidth Occupancy Measurements

The STIC waveform was designed to be compatible with the entertainment signal, the 57-kHz Radio Broadcast Data System (RBDS) and the 92-kHz subcarrier channel. This required that the STIC signal power (when injected at 10%) be suppressed by at least 60 dB relative to the carrier level at 62 and 82 kHz. Examination of the STIC signal power spectrum (Figure 2) displayed in the

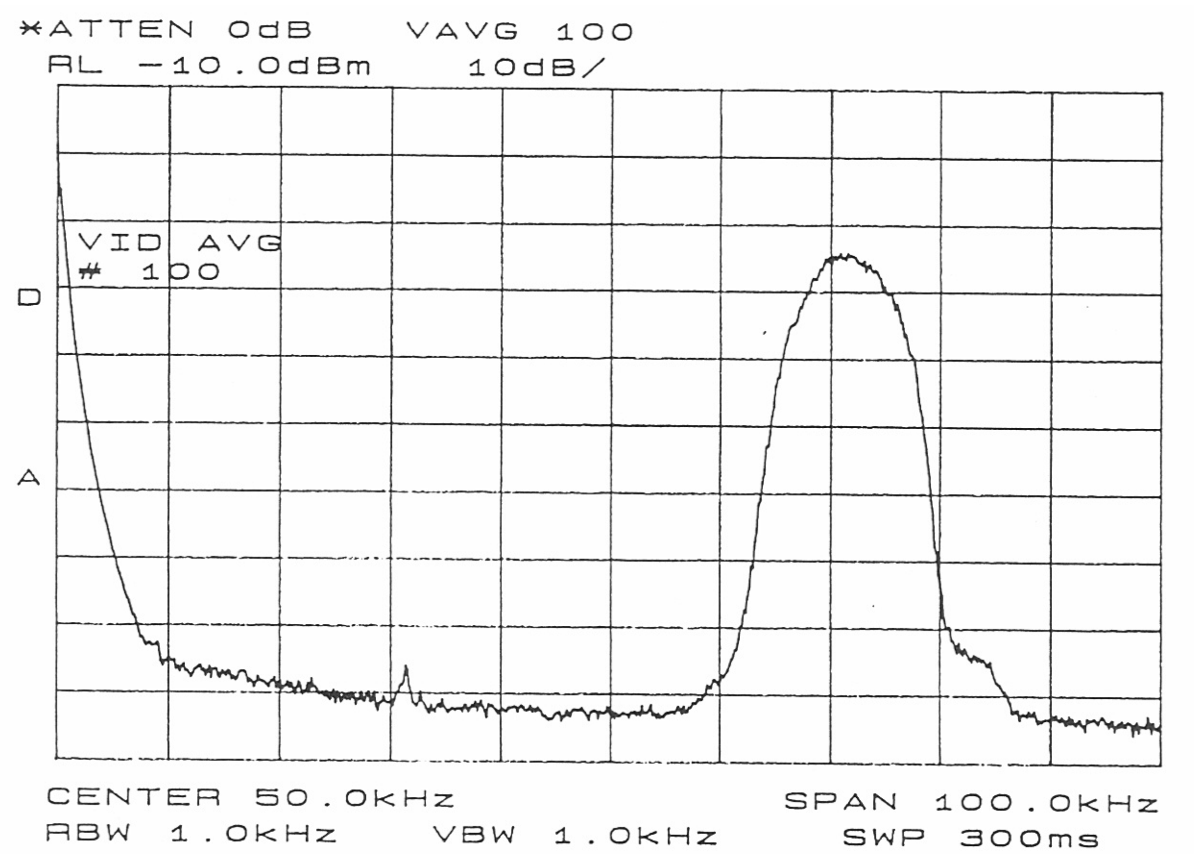

Figure 2. STIC baseband power spectrum.

spectrum analyzer plots supports this assertion, with a 6-dB bandwidth of 10 kHz and a 60-dB bandwidth of approximately 20 kHz. The out-of-band attenuation suggested that the STIC waveform did not interfere with the 57-kHz and 92-kHz subcarriers or the audio program.

3.2.2 Error Rate Performance

Error rate vs. received signal power was determined experimentally for three performance metrics and two system configurations.

For the x2 interleaver configuration (Figure 3), channel errors began to appear at power levels less than approximately -84 dBm. For channel error rates less than $1x10^{-2}$, the error-correcting codes implemented in the STIC receiver worked well and corrected 100% of the channel errors. Note that for ease of plotting, error rates less than $1x10^{-6}$ were assigned the value $1x10^{-6}$. When the received signal power level was reduced to approximately -95 dBm and the corresponding CER increased to $4x10^{-2}$, the post error-correction bit errors began to appear. The corresponding PER at this power level was approximately $1x10^{-3}$ and the post error-correction BER was $1x10^{-5}$. However, when the received power level decreased an additional 1 dB to -96 dBm, performance degraded dramatically. At -96 dBm and at a CER of roughly $5x10^{-2}$, the post error-correction BER jumped to $5x10^{-3}$ and PER increased to 0.2. By decreasing the signal power an additional 1 dB to -97 dBm, the PER increased to effectively 1.

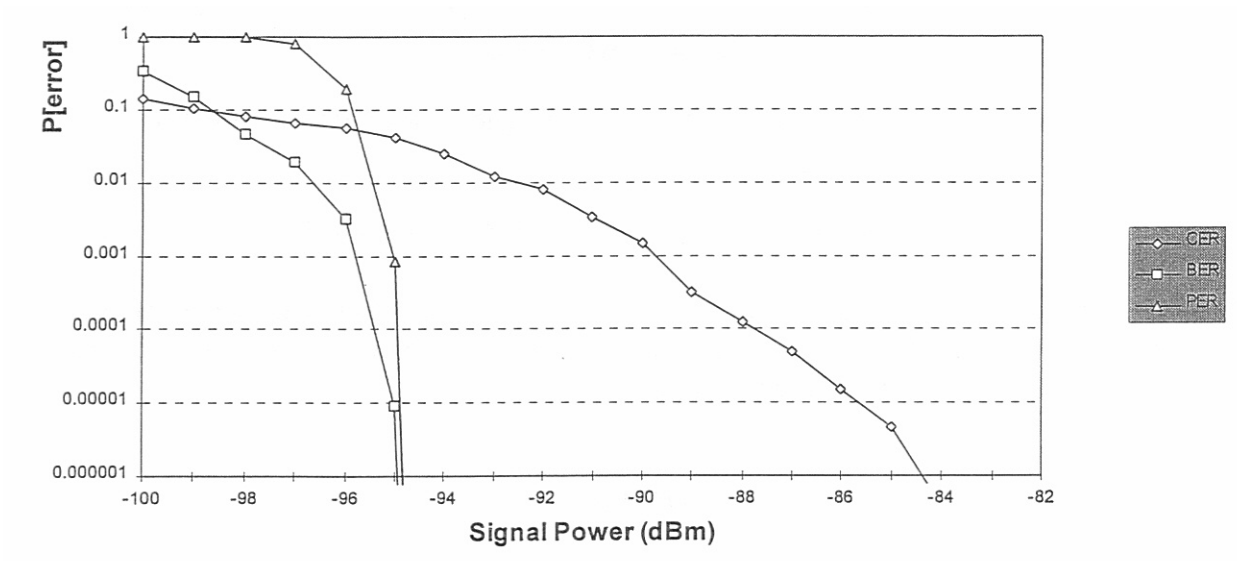

Figure 3. CER, BER, and PER vs. received signal power for x2 interleaver.

Behavior of the system in the x1 interleaver mode (Figure 4) was similar to the x2 mode with one exception. At signal levels of -96 dBm ± 0.5 dB, the STIC receiver would not maintain synchronization. The system would acquire the STIC signal, then immediately lose synchronization. Increasing or decreasing the power level allowed the system to regain synchronization. At this signal level, switching to the x2 mode would allow the STIC receiver to acquire the signal and maintain synchronization. This behavior did not occur at any power level during the x2 testing. MITRE personnel suggested this behavior was the result of a STIC receiver program error. The direct effects of this error on STIC field performance are unknown. However, the minimum signal power encountered during the field testing was -84 dBm, significantly greater than the -95 dBm power level at which the malfunction occurred.

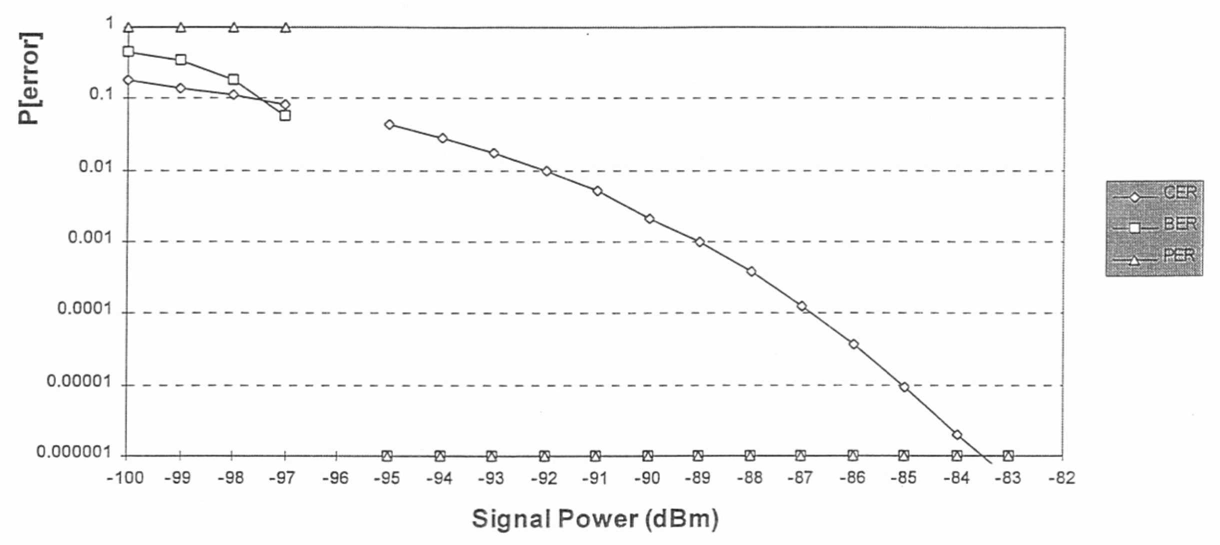

Figure 4. CER, BER, and PER vs. received signal power for x1 interleaver.

4. STIC FIELD TESTING AND EVALUATION

Once the laboratory testing of the STIC system was complete, a field test program was initiated. The primary goal of the field test program was to correlate the STIC performance with received signal level in a variety of reception environments.

4.1 STIC Installation

The following two subsections describe the installation and configuration of the STIC transmitter, STIC receiver, and signal power measurement system (Figure 5).