APPENDIX A: DATA COLLECTION SYSTEM

In order to efficiently measure STIC performance and received signal power over a wide geographical area, a mobile data collection system was employed. The data collection system consisted of a van with both the STIC receiver and FM signal power measurement. GPS receivers were employed by both systems allowing the simultaneous collection of signal power, STIC performance, time, and location.

The STIC receiver and power measurement systems were installed in a van. The single FM antenna, shared between the STIC and FM power measurement systems, was a quarter wavelength monopole mounted on a 132-cm diameter circular ground plane. The antenna was set at a nominal height of 79 cm and adjusted for a minimum voltage standing wave ratio (VSWR) at 98.5 MHz. The VSWR was reduced to 1.5:1 by impedance matching the antenna. The antenna and ground plane were mounted on a roof rack about 13 cm above the roof of the van. The gain of the antenna was 1.5 dBi. The feed from the antenna was connected to an RF power splitter where it was routed to the FM stereo receiver (STIC system) antenna terminal and to the spectrum analyzer (FM signal power measurement system). Also mounted on the roof of the van were two GPS receiver antennas, one for each system. The STIC system has provisions for receiving and recording GPS data along with the error data. An additional GPS antenna and receiver were used with the signal power measurement system in order to continue the reception of GPS data while the STIC system was out of synchronization. They also were used to record an independent estimate of position. Each system employed a PC dedicated to system control, configuration, and data collection. The entire system was powered by a portable generator that was towed behind the van.

A.1 Data Collection - STIC

When operating in BER mode, the STIC transmitter continuously sends a pseudorandom noise (PN) data sequence. The receiver compares the incoming sequence to the transmitted sequence (stored internally at the receiver) and computes and stores system performance data. A system data record was stored every $T_i/72$ seconds where T_i was the interleaver time (5.76 seconds for the x1 interleaver). A data record consists of the following fields:

- time,
- speed,
- frame identification number,
- channel error count,
- packet count,
- latitude,
- heading,
- synchronization value,
- bit error count,
- packet errors,
- longitude,
- synchronization flag,
- byte count,
- Viterbi errors, and
- system parameter mask.

For the purposes of the NTIA/ITS test program, not all of the fields are relevant. All were collected, however, in order to maintain compatibility with software routines that MITRE provided. The processing of this data is explained in Appendix B.

A.2 Data Collection - Signal Power

The signal power data collection system consisted of an HP 8562A Spectrum Analyzer, Trimble PAC II GPS receiver, and a laptop PC. The spectrum analyzer was configured to operate in the detector sample mode, at a center frequency of 98.5 MHz, span of 0 Hz, resolution and video bandwidths of 300 kHz and a sweep time of 30 seconds. In this configuration, the spectrum analyzer displays and stores received power as a function of time in a 300-kHz bandwidth centered at 98.5 MHz. The sweep data were sampled and stored as a series of 601 data points. The 30-second sweep time yields a 20-Hz sampling rate. The PC alternately collects time and location data from the GPS receiver and power measurements from the spectrum analyzer. The data collection PC first queries the spectrum analyzer for the current set of received power data. At the end of each 30-second sweep, the data collection PC then queries the GPS receiver for the current time and location. These values are stored to the data collection hard disk. This cycle repeats continuously until a command was given to cease. At that time, the system continued to operate until the current sweep was finished and saved and a final GPS time and location estimate were received and stored. The received signal power data file format was as follows:

```
data header,
time, latitude, longitude, power[0], power[1], power[600],
time, latitude, longitude, power[0], power[1], power[600],
………
………
………
………
time, latitude, longitude, power[0], power[1], power[600],
time, latitude, longitude.
```

APPENDIX B: DATA-PROCESSING METHODOLOGY

Data collection was performed by two independent systems. However, the data files from each system ultimately needed to be combined in order to correlate received signal power to STIC performance. The STIC system collected GPS location, GPS time, and STIC performance data. The FM power measurement system collected GPS location, GPS time, and signal power as a function of time (and therefore location). The time resolution of each GPS system was 1 second.

B.1 Signal Power Data Analysis

The signal power measurement system consisted of an FM band antenna, GPS antenna and receiver, spectrum analyzer, and data collection PC. The spectrum analyzer was used to measure available signal power, the GPS receiver to determine position and time, and the PC to collect and store spectrum analyzer and GPS data. Data from the spectrum analyzer and GPS receiver were collected periodically and stored serially in a file.

Each file entry consisted of a time, latitude and longitude reading from the GPS receiver followed by 601 power measurements from the spectrum analyzer. The 601 points corresponded to one full sweep from the analyzer, therefore a sweep time of 30 seconds yielded a power measurement every 0.05 seconds. Following guidelines recommended by Lee [1], the recommended procedure for measuring the local received power for a mobile radio system was to obtain a series of measurements over a path, from 20 to 40 wavelengths in length, sampling at least 36 times during this interval and finding the arithmetic mean of the 36-sample set. A 40-wavelength sampling interval was preferable.

A spectrum analyzer sweep time of 30 seconds was chosen such that a single sweep would be appropriate over the expected range of receiver velocities of 5 to 60 mph. Averages were computed over intervals approaching 40 wavelengths whenever possible. Only when the average speed decreased to under 5 mph did the effective sampling interval begin to approach 20 wavelengths. Given the wavelength of the broadcast signal:

$$\lambda = \frac{3\times10^{8}}{98.5\times10^{6}} = 3.05\ \textit{meters}$$

and

$$20\times\lambda = 61\ \textit{meters},\quad 40\times\lambda = 122\ \textit{meters}$$

then the lowest vehicle speed at which the measurement system would traverse 20 wavelengths in a 30-second interval was:

$$V_{\min} = \frac{61\ meters}{30\ seconds} = 2.03\ meters/second = 4.54\ miles/hour.$$

Lee also stated that at least 36 samples should be taken over the 20- to 40-wavelength interval. At a sampling rate of 20 samples/second, 36 samples were recorded in 1.8 seconds. The receiver velocity at which 40 wavelengths were traversed in 1.8 seconds is:

$$V_{\max} = \frac{122\ meters}{1.8\ seconds} = 67.8\ meters/second = 151.5\ miles/hour.$$

This implied that our sampling rate and block length were sufficient for all vehicle speeds greater than 4.5 mph and less than 150 mph.

As mentioned previously, data were recorded in 30-second blocks of data containing power levels in dBm with time, latitude, and longitude values at the beginning of each block. The time, latitude, and longitude values at the beginning of the next block were used as the end values for the previous block. When processing the data, the first value computed was the distance traversed during the 30-second scan in order to verify that the minimum 20-wavelength distance was traversed for the block. This was computed by determining the distance between the beginning and ending (latitude, longitude) pairs for the block and then converting that value to the number of wavelengths traversed. If the distance traveled for a block was less than 20 wavelengths, the data block was discarded. If the distance traveled for a block was more than 20 wavelengths, then the data block was divided into an integral number of sub-blocks using the following equation:

$$N_{sub-blocks} = \left\lfloor \frac{distance}{40 \times wavelength} \right\rfloor + 1$$

Each of these sub-blocks represented the spatial sampling of the local signal power taken over an interval of 20 to 40 wavelengths and have at least 36 samples per sub-block. The mean power value was then computed on each of the sub-blocks by computing the arithmetic mean on the logarithmic power levels (dBm) in the data [1]. Since time, latitude, and longitude information was only stored in blocks every 30 seconds and a typical sub-block was approximately 5 seconds in length, estimates of time, latitude, and longitude had to be made for each of the N sub-blocks to provide position information. This was performed by linearly interpolating between the time, latitude, and longitude measurements at the beginning and end of each measurement block and evaluating these functions at the center of each sub-block. The values of center time, center latitude, center longitude, and mean signal power in dBm were stored in a file to process either separately or in conjunction with the STIC error data.

B.2 STIC Data

The STIC data collection system consisted of a specially modified FM stereo receiver, STIC receiver and laptop PC. As described in Appendix A, the STIC system recorded a data record every 80 milliseconds.

The data in this file needed to be associated with the signal power data file in order to correlate error rates with signal power. Each signal power measurement was computed over a time interval between 4.5 and 30 seconds in length, depending on the velocity of the vehicle. Each entry in the signal power file consisted of start time, center time, stop time, center latitude, center longitude, and signal power. The start and stop times were used to select STIC data file entries that occurred during a particular signal power measurement interval.

For each signal power measurement there was an associated start and stop time. The start and stop times were used to select entries from the STIC data file. These data were then used to compute CER, BER, and PER for the current signal power measurement. The error ratios were computed as follows:

$$CER = \frac{\sum_{t=start\ time}^{stop\ time} channel\ errors}{2 \times 8 \times {}^{243}\!/_{228} \times \sum_{t=start\ time}^{stop\ time} byte\ count}$$

$$BER = \frac{\sum_{t=start\ time}^{stop\ time} bit\ errors}{8 \times \sum_{t=start\ time}^{stop\ time} byte\ count}$$

$$PER = \frac{\sum_{t=start\ time}^{stop\ time} packet\ errors}{\sum_{t=start\ time}^{stop\ time} packet\ count}$$

Depending on the environment, the STIC system occasionally lost synchronization; i.e., became inoperable while the STIC system attempted to regain sync with the transmitter. During these times, no data were written to the data collection PC as there were no BER data being received by the STIC. During the time that the STIC system was out of sync, there were no data entries in the STIC data file. Therefore, during these times, the sums were not formed and the error rates were assigned default values of CER = BER = 0.5 and PER = 1.

These three error ratios were computed for each signal power measurement and stored to a new file now consisting of the following fields:

- center time,
- center latitude,
- center longitude,
- signal power,
- CER,
- BER, and
- PER.

This data file was used to develop a number of graphs. The type of plots generated for each environment (rural plains, rural mountain, urban low-rise, and urban high-rise) were:

- mean error rates (CER, BER, PER) vs. signal power,
- mean error rates (sync data only) vs. signal power,
- median error rates vs. signal power,
- percentile PER vs. signal power,
- percentile PER (sync data only) vs. signal power,
- mean error rates vs. distance from transmitter,
- cumulative error rates vs. error rate,
- scatter plot of CER vs. signal power,
- scatter plot of PER vs. signal power,
- received power vs. distance from transmitter,
- measurement count vs. signal power, and
- measurement count vs. distance from transmitter.

Additional plots comparing the four environments were:

- mean PER vs. signal power for four environments,
- mean PER vs. signal power for four environments (sync data),
- percentile PER vs. signal power for four environments, and
- percentile PER vs. signal power for four environments (sync data).

REFERENCES

[1] W.C.Y. Lee, “Estimate of local average power of a mobile radio signal,” *IEEE Trans. Veh. Technol.,* VT-34, No.1, pp. 22-27, Feb. 1985.

APPENDIX C: CONVERSION OF RECEIVED SIGNAL POWER TO ELECTRIC FIELD STRENGTH

Throughout this report, STIC performance has been reported as a function of received signal power. In some cases, electric field strength is a more useful parameter with which to correlate system performance. Fortunately, received signal power can easily be converted to electric field strength. The pertinent components of the signal power measurement system are shown in the Figure C-1.

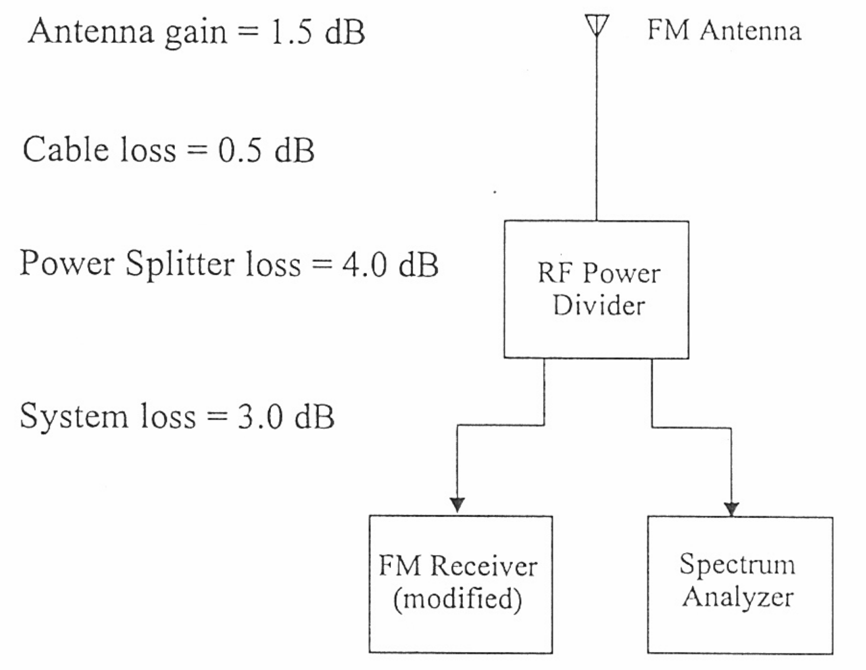

Figure C-l. FM antenna system loss.

The equation for converting received signal power to electric field strength is as follows:

$$\begin{aligned} E(dBuV/m \; &= \text{received signal power (dBm)} + 77.21 + 20 \times \log(f/10^6) \\ &- \text{antenna gain(dBi)} + \text{cable loss(dB)} + \text{divider loss(dB)}. \end{aligned}$$

Substituting the appropriate values yields:

$$\begin{aligned} E(dBuV/m) &= \text{received signal power(dBm)} + 77.21 + 39.87 - 1.5 + 0.5 + 4.0 \\ &= \text{received signal power(dBm)} + 120.1 \end{aligned}$$

APPENDIX D: COMPARISON OF PREDICTED AND RECEIVED SIGNAL POWER LEVELS

System performance predictions were made to compare with measured data of several paths collected for this report. The received signal power level versus distance data were collected and processed using the methods described in the previous appendices to determine the mean received signal power versus distance from the transmitter. The distance from the transmitter to the test vehicle was used (not the distance along the path), since none of the paths was actually a radial path from the transmitter. The measured data were available at increasing distances from the transmitter at approximately every 0.06 miles. The predictions were made to occur at these same points to compare directly with the measured data. The predictions were performed using the NTIA/ITS Communication System Performance Model (CSPM), a widely used and accepted model for performance of communication systems in the frequency range of 20 MHz to 20 GHz. Path locations at one-mile intervals of distance from the transmitter were selected for plotting. The final calculations for the predictions take into account the gain as a function of elevation angle of the receiver antenna on the test vehicle and the gain of the transmitter antenna at the radio station. The resulting data were plotted in Figures D-l and D-2 for the paths along Interstate 25 and Interstate 76, respectively. Considering that the CSPM prediction model does not openly account for losses due to vegetation or man-made structures, these figures show good agreement between actual measurements and predictions. Performance predictions can be made with confidence for other areas of the country where the coverage for the STIC system needs to be determined.

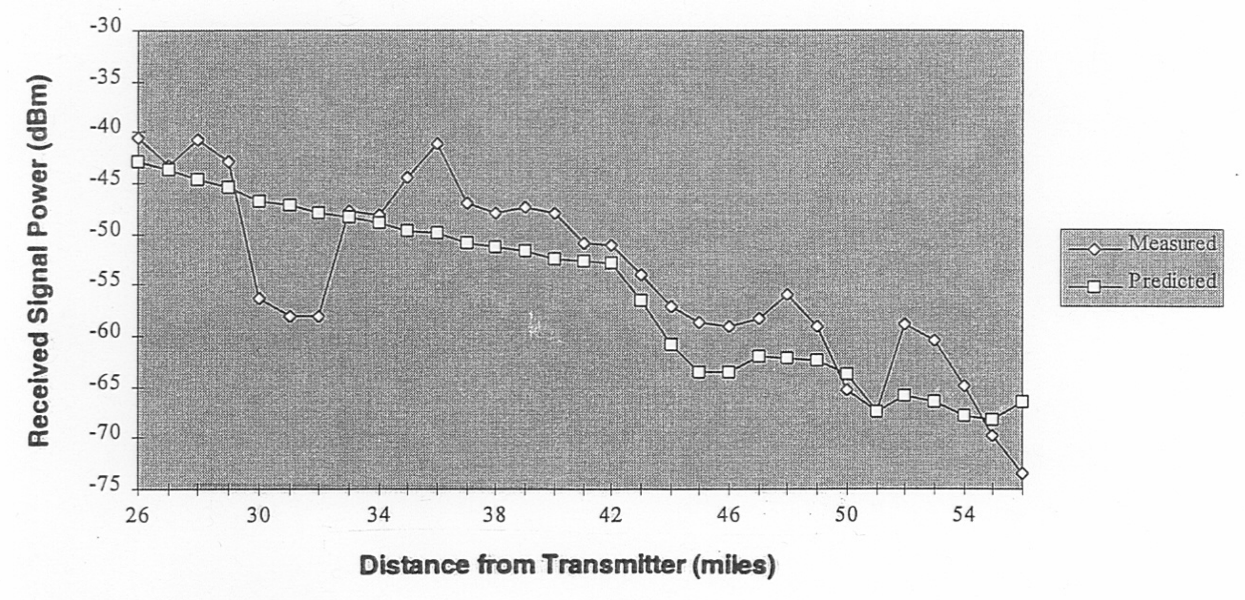

Figure D-l. Measured and predicted mean received signal power for north-bound path (along Interstate 25).

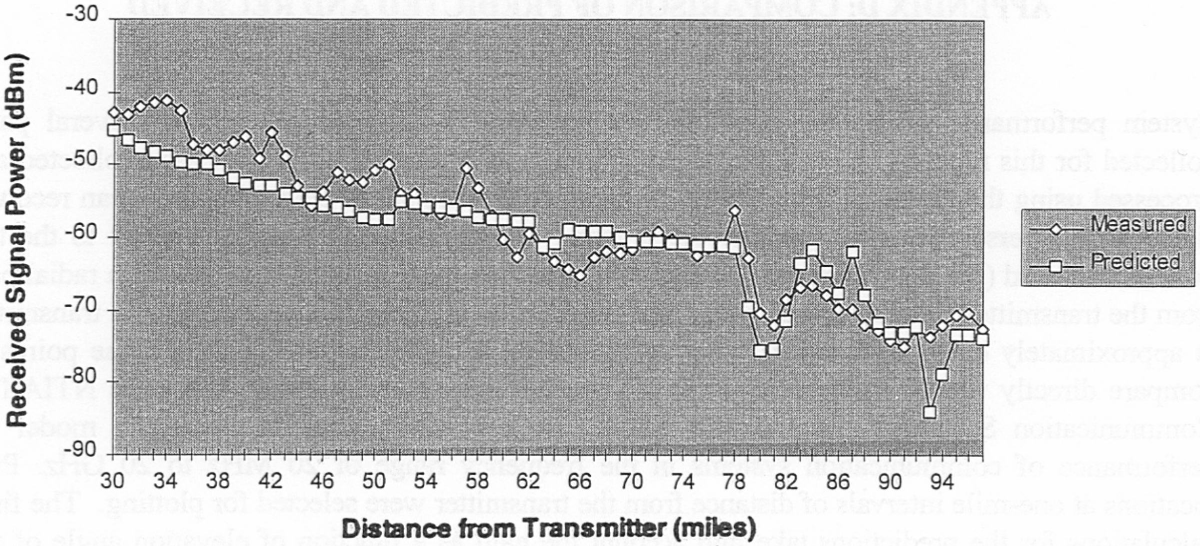

Figure D-2. Measured and predicted mean received signal power for north-east bound path (along Interstate 76).

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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.

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