ELECTROMAGNETIC COMPATIBILITY BETWEEN SPREAD SPECTRUM AND CONVENTIONAL TELEMETRY SYSTEMS: THE KEY TO A NEW ERA FOR DOD TEST RANGES

Dr. Maqsood A. Mohd
Sverdrup Technology, Inc./TEAS Group
Eglin AFB, FL 32542-5000

James J. McLaughlin, Jr.
DOD Gulf Area Frequency Coordinators Office
Eglin AFB, FL 32542-6346

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ABSTRACT

Telemetry operation is used extensively on a typical Department of Defense (DOD) test range to transfer data from an airborne transmitter to a ground receiver. The conventional telemetry systems employed are usually narrow-band systems. When a large number of airborne transmitters need to transfer data simultaneously to a ground station, a spread spectrum modulation scheme can be used. The drawback of such a scheme, however, is the large emission bandwidth required. The present frequency channeling plans in the telemetry band do not support frequency approval of large bandwidth data telemetry systems. However, a key requirement for obtaining the frequency approval can be satisfied if it can be shown that the spread spectrum modulated signal does not interfere with other systems in the same band. That is, the spread spectrum telemetry systems (SSTS's) are feasible if these systems are electromagnetically compatible with the existing narrow-band telemetry receivers (NBTR's) in their immediate environment. The electromagnetic compatibility (EMC between the SSTS transmitters and the conventional NBTR would promise the beginning of a new era for the telemetry operations on a DOD test range.

This paper develops a methodology to establish the EMC between multiple airborne transmitters of an SSTS employing the code division multiple access (CDMA) technique and a ground-based conventional NBTR on a typical DOD test range operating simultaneously in the same band. The paper calculates the electromagnetic interference (EMI) levels between the SSTS and the NBTR to establish the EMC between the two systems.

INTRODUCTION

The DOD uses the telemetry bands of 1,435 to 1,535 Megahertz (MHZ), 2,200 to 2,290 MHZ, and 2,310 to 2,390 MHZ to support critical research, development, and testing of new and improved airborne weapon systems at the national test ranges. The first two of these bands are designated primarily for telemetry and telecommand functions associated with the flight testing of aircraft, missiles, and major airborne system components. Telemetry operations associated with launching and reentry operations into the earth's atmosphere, along with orbiting operations of manned and unmanned vehicles undergoing flight tests, also use these frequency bands. Primary use of the third band is for telemetering from space research stations; aeronautical telemetering associated with launch vehicles, missiles and upper atmospheric research rockets; and on a shared-use basis with fixed and mobile line-of-sight operations.

In the three telemetry bands 1,435 to 1,535 MHZ, 2,310 to 2,390 MHZ, and 2,200 to 2,290 MHZ discrete frequency assignments are centered on frequencies at standard intervals of 1 MHZ, beginning at 1,435.5, 2,310.5, and 2200.5 MHZ, respectively, and may have authorized bandwidths of at least 1 MHZ. A maximum of 99 1-MHZ channels can potentially be assigned in the 1,435 to 1,535 MHZ frequency band and 79 1-MHZ channels would be the maximum possible in the 2,310 to 2,390 MHZ band. The third frequency band between 2,200 and 2,290 MHZ contains 89 1-MHZ narrow-band channels. Wider (e.g., 3 MHZ and 5 MHZ) bandwidth channels are available in the telemetry bands based on special applications. The three telemetry bands are used extensively at the national test ranges. In most instances, frequency scheduling is required because telemetry frequencies are shared among test missions and range users. Because of the limited spectrum available, obtaining multiple wide bandwidth telemetry frequency assignments to support a single test program is virtually impossible. For example, requirements to test 100 airborne vehicles simultaneously where each test vehicle's telemetry bandwidth exceeds 1 MHZ cannot be met with conventional approaches because of insufficient spectrum. Spread spectrum techniques can be implemented to overcome this limitation without burdening the frequency spectrum requirements. However, the EMC between the SSTS and its electromagnetic (EM) environment must be established and approval must be obtained prior to acquiring these systems.

The frequency approval process for equipment is the key to minimizing and documenting the potential impact of EMI and ensuring EMC between systems. Gaining frequency allocation approval for spread spectrum systems presents challenges for the users and the national level approving authorities. Standardized criteria are not available for this purpose. A thorough analysis of EMC between an SSTS and an NBTR is needed to evaluate the impact of SSTS's on the EM environment. A better understanding of the impact of an SSTS on an NBTR by the user and the approving authorities is the key to open new opportunities for telemetry applications and begin a new era for the DOD test ranges. A preliminary analysis is presented in this paper to establish the spread spectrum system will not adversely impact the operation of any other system in its intended EM environment.

EMC BETWEEN CDMA BASED SSTS AND NBTR

Spread spectrum modulation techniques such as the CDMA can be implemented to satisfy a test program requirement for multiple wide bandwidth channels. In the CDMA technique each data stream from the airborne platform is modulated directly with a different and unique pseudo noise (PN) code. This results in a large radiated bandwidth for each data stream. The advantage of modulating the data stream with different and unique PN codes is that while all the radiated bandwidths occupy the same spectrum and the center frequency, they can operate simultaneously without any cochannel interference. That is, the CDMA technique would allow multiple users to simultaneously use the same telemetry band without interference. It would allow selective addressing between possible users, provide co-band interference rejection, low density power spectra for signal hiding, and screening from eavesdroppers. The CDMA would allow applications that are not possible with conventional signal formats. Thus, the implementation of SSTS with techniques like CDMA would open new vistas for the range telemetry operations. The telemetry spectrum’s use could be enhanced without jeopardizing any user.

The following paragraphs present a methodology (illustrated with an example) to establish the EMC between an SSTS using the CDMA technique and a conventional NBTR. The EMI levels are computed to establish the EMC between the SSTS and the NBTR.

SSTS SPECTRUM ARCHITECTURE FOR 100 DATA STREAMS

Consider an SSTS that uses a direct spread modulation scheme and has 100 airborne transmitters. An implementation architecture based on optimum use of bandwidth, data link margin, and hardware complexity is shown in figure 1. The scheme is implemented using 4 center frequencies with 25 transmitters for each frequency; each transmitter occupies the same bandwidth and each uses a unique code in the CDMA mode. If the chip rate results in a 3-decibel (dB) bandwidth of 16 MHZ, then a guard band of 4 MHZ would cause a net bandwidth requirement of 20 MHZ. In the CDMA technique, multiple data streams from various transmitters are simultaneously transmitted on a single RF. Unique PN codes differentiate each data stream. Each telemetry data stream may originate from a different platform. A 20-MHZ bandwidth in the telemetry band (e.g., the upper S band 2,310 to 2,390 MHZ) is needed for each of the CDMA transmitters, requiring a total of 80 MHZ for 100 airborne vehicles. As discussed earlier, obtaining this bandwidth is virtually impossible for standard broadcast techniques. The calculations in the following paragraphs

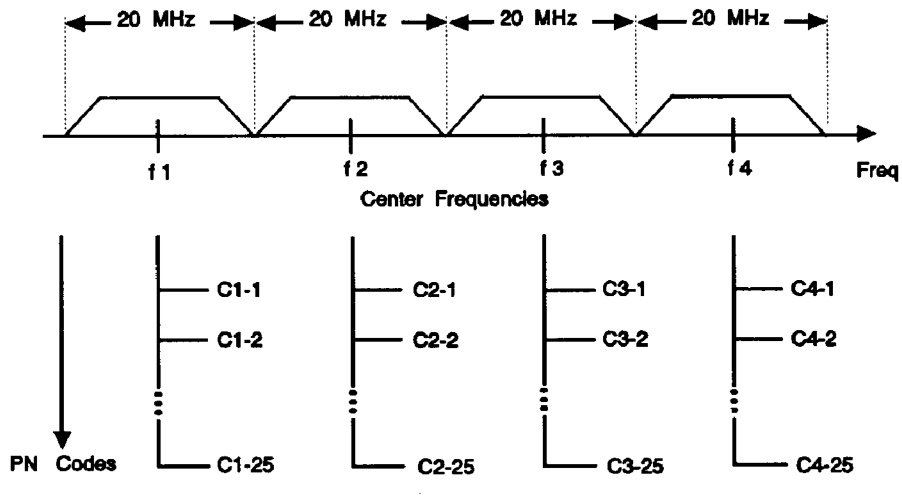

Figure 1. SSTS Spectrum Architecture for 100 Data Streams

illustrate an SSTS using the CDMA technique does not interfere with the NBTR operating simultaneously in the same band on a typical test range.

The concept is demonstrated with an example of 25 airborne vehicles simultaneously transmitting on the same channel of a 20-MHZ bandwidth in the upper S band (2,310 to 2,390 MHZ).

CALCULATION OF EMI LEVELS DUE TO SSTS TRANSMITTERS

Figure 2 shows the SSTS transmitters are deployed on range A and the other user is at range B. In the worst case scenario, the SSTS transmitter is assumed to be at the edge of the test range A, 8 kilometers from the range B NBTR antenna.

An SSTS transmitter presumably has an onmidirectional antenna and an effective radiating power (ERP) of 10 milliwatts (mw). If the losses due to atmosphere and multipath are ignored, the interference power received by the NBTR (P_R can be computed by the following equation:

$$P_R = P_T + G_T + G_R + 20 \log (c/f) - 20 \log(4\pi D) \quad (1)$$

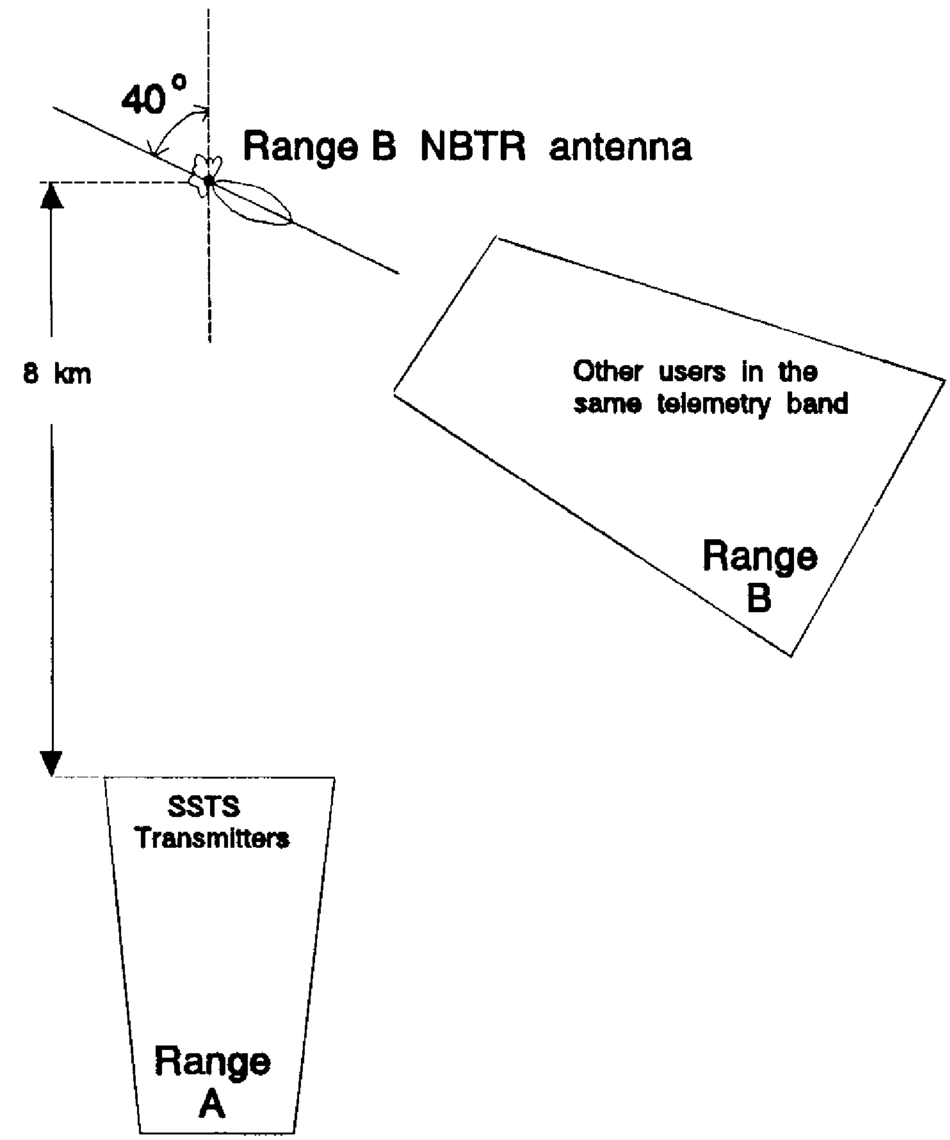

Figure 2. Telemetry Sites at a Typical Test Range

where

P_T	=	SSTS transmitter power
G_T	=	SSTS transmit antenna gain
G_R	=	NBTR receiver antenna gain
c	=	Velocity of light in meters/second
f	=	Frequency of RF waves
D	=	Spatial separation between SSTS transmitter and NBTR in meters

The transmitter ERP is 10 mw; therefore,

$$P_T + G_R = 10 \text{ dBm} \tag{2}$$

A typical NBTR has a 15-foot parabolic dish antenna with a 3-dB beamwidth of 2º, a boresight gain of 40 dB, and the side lobe levels of at least 35 dB below the main beam beyond 35º from the boresight. Under the very unlikely event of another user of the same band wishing to operate simultaneously on a nearby test range (range B), range resources scheduling will ensure the narrow beam antenna of the NBTR will be directed away from the airborne vehicles carrying the SSTS transmitters. Therefore, the SSTS transmitters will never be within the main lobe of the narrow beam NBTR antenna. Consequently, side lobe gain is used for interference calculations.

As shown in figure 2 the angle between the SSTS transmitter and the NBTR antenna is 40º in azimuth; therefore, the NBTR antenna gain G_R is calculated as follows:

$$G_R = 40 \text{ dB} - 35 \text{ dB}$$
$$G_R = 5 \text{ dB}$$
$$20 \log (c/f) = -18 \text{ dB}$$
$$20 \log (4\pi D) = 100 \text{ dB}$$

Substituting the previous results into equation 1 yields

$$P_R = 10 + 5 - 18 - 100 \tag{3}$$
$$P_R = -103 \text{ dBm}$$

CALCULATION OF INTERFERENCE THRESHOLD OF NBTR

The interference threshold for an NBTR is developed based on the bandwidth relationship between the NBTR and the SSTS transmitter. An NBTR with a -3 dB Intermediate Frequency (IF) bandwidth less than the -3 dB emission bandwidth of the SSTS transmitter has a noise-like interference response. Conversely, when the NBTR bandwidth exceeds the SSTS transmitter bandwidth, an undistorted response is predicted for SSTS transmitter interference.

In this example the transmitters and receivers are assumed to operate in the upper S band and the -3 dB IF bandwidth of the NBTR presumably does not exceed the -3 dB emission bandwidth (16 MHZ) of SSTS transmitters. The first case of noise-like response in the NBTR is discussed in the following paragraphs.

The telemetry sites at a typical test range use either a Microdyne 1200 MRA or MRC telemetry receiver in the upper S band (2,310 to 2,390 MHZ). From the data sheets of these receivers the worst case noise figure is 10 dB. Therefore, the noise floor of the Microdyne 1200 receivers is calculated using KTBF values as follows:

$$K = 1.38 \times 10^{-23} J/K^{o}$$
$$T = 290^{o}\ K$$
$$B = 5 \times 10^{6}\ Hz$$
$$F = 10\ dB$$

Therefore,

$$\text{NBTR noise floor} = KTBF = -97\ dBm \quad (4)$$

The minimum detectable signal (MDS) (before the AGC circuit starts functioning) is about 3 to 6 dB above the noise floor. Therefore, the (worst case) MDS level for the NBTR is as follows:

$$\begin{aligned} \text{NBTR MDS} &= -97\ dBm + 3\ dB \\ &= -94\ dBm \end{aligned} \quad (5)$$

CALCULATION OF NET EMI SAFETY MARGIN (SM) OF NBTR

The SM between the NBTR receiver noise floor and the interference signal due to the SSTS transmitter is

$$\begin{aligned} \text{SM (noise floor)} &= \text{NBTR noise floor} - P_R \\ &= -97\ dBm + 103\ dBm \\ &= 6\ dB \end{aligned} \quad (6)$$

The SM between the NBTR MDS level and the interference due to the SSTS transmitter is

$$\begin{aligned} \text{SM (MDS)} &= \text{NBTR MDS} - P_R \\ &= -94\ dBm + 103\ dBm \\ &= 9\ dB \end{aligned} \quad (7)$$

Therefore, the interference due to the SSTS transmitter at the NBTR will be at least 6 dB below the noise floor and at least 9 dB below the MDS level.

CALCULATION OF SSTS POWER SPECTRAL DENSITY

Equation 8 shows how the power spectral density (PSD) of the SSTS transmitter can be calculated. This equation shows the PSD of SSTS transmitters is less than that required by IRIG-106-86 and National Telecommunications and Information Administration (NTIA) power level limits for transmitters of greater than 1 MHZ bandwidth.

$$PSD = P_T + G_T - 10 \log(BW) \qquad (8)$$

where

P_T = SSTS transmitter power
G_T = SSTS transmit antenna gain
BW = SSTS transmitter -3 dB bandwidth

$$PSD = (10 \text{ mw}/16 \text{ MHZ})$$

$$PSD = -27.2 \text{ dBm}/3 \text{ kHz} \qquad (9)$$

The IRIG-106-86 and NTIA maximum power level limit requirement is -25 dBm/3 kHz. The SSTS transmitter power is lower than the maximum PSD power level limit (-25 dBm/kHz) specified in IRIG-106-86 and NTIA specifications.

CONCLUSION

Insufficient spectrum availability in the telemetry bands makes the simultaneous data telemetry from several airborne platforms impossible. Spread spectrum modulation can be exploited to overcome this limitation. An example of an SSTS that uses a CMDA technique and has 100 airborne transmitters is considered for concept demonstration.

PSD and EMI levels from an SSTS transmitter are calculated for a typical test range environment. The calculations show the SSTS transmitter using the CDMA technique is not a source of interference over the entire bandwidth of 20 MHZ, to any of the NBTR's operating on a typical test range. The NBTR considered in the example is a Microdyne 1200. Thus, the EMC analysis concludes the SSTS transmitters will not jeopardize the test range operations and other users within the same telemetry band. That is, the SSTS is practical and feasible in the existing EM environment on a typical test range.

The EMC analysis presented in this paper evaluates the impact of an SSTS on the test range EM environment. Such an evaluation with a better understanding of the results both by the users and the approving authorities is the key to enhance the use of the telemetry spectrum, support simultaneous co-band data telemetry operations for a large number of users, and also provide co-band interference rejection for all the users. This essentially promises the beginning of a new era for the DOD test ranges.

REFERENCES

1. Radio Frequency Spectrum Management, AF Regulation 700-14, 3 July 1989.

2. Manual of Regulations and Procedures for Federal Radio Frequency Management, U.S. Dept. of Commerce, National Telecommunications and Information Administration, September 1991.

3. Mohd, Maqsood A., “Frequency Allocation Analysis of Subminiature Telemetry Technology Transmitter.” A technical report, TEAS Reference Number 9000802-70U, submitted to MSD/AGI, March 1989.

4. Murphy, Robert A., “Advancements in Subminiature Telemetry Technology.” Technical Proceedings, Test Technology Symposium IV, Johns Hopkins University, pp. 639-640, April 1991.

5. McLaughlin, Jr., James J., and Maqsood A. Mohd. “Establishing EMC between Spread Spectrum and Narrow-band Telemetry Systems: The Key to Obtain Frequency Spectrum Assignment.” 1992 EMC Expo Technical Record, EMCT Expo 92, EMC Technology Magazine, Gainesville, VA, pp. 237-241, May 1992.