A Study on the Co- and Adjacent Channel Protection Requirements for Mobile Satellite ACSSB Modulation

JOHN T. SYDOR, Mobile Satellite Program, Communications Canada

COMMUNICATIONS RESEARCH CENTRE
3701 Carling Avenue
PO Box 11490, Station 'H'
Ottawa, Ontario, Canada K2H 8S2

ABSTRACT

Samples of speech modulated by NBFM (cellular) and ACSSB radios were subjected to simulated co- and adjacent channel interference environments typical of proposed FDMA mobile satellite systems. These samples were then listened to by a group of evaluators whose subjective responses to the samples were used to produce a series of graphs showing the relationship between subjective acceptability, C/No, C/I, and frequency offset. The results show that in a mobile satellite environment, ACSSB deteriorates more slowly than NBFM. The co- and adjacent channel protection ratios for both modulation techniques were roughly the same, even though the mechanism for signal deterioration is different.

INTRODUCTION

Previous studies conducted by the Communications Research Centre (CRC) have shown that ACSSB is a robust modulation technique capable of providing high quality voice communications in low C/No mobile satellite propagation environments (Ref. 1). The next logical step was to examine ACSSB performance under conditions of co- and adjacent channel interference. Understanding how ACSSB behaves under such conditions would provide mobile satellite engineers with design parameters and give insight into questions regarding frequency reuse, channel spacing, satellite antenna design, and ultimately, user loading levels on ACSSB/FDMA mobile satellite systems.

TEST SET UP AND SUBJECTIVE TESTING METHODOLOGY

The purpose of the experimental set up shown in Figure 1 was to model the return link of a mobile satellite system. The set up was intended to simulate a link where two terminals transmit over independently varying propagation paths and interfere with one another at a common base station on a co- and adjacent channel basis. Desired and interfering signals were controlled in both amplitude (+/-1dB) and frequency (+/-1Hz), and transmitted over separate propagation paths prior to their summation, demodulation, and taping for subjective evaluation. Propagation path conditions for both the desired and interfering signals were controlled by two independent simulators which could statistically emulate Rician propagation (Fig.2) and noise characteristic of mobile satellite environments. System linearity was such that the worst case two tone third order intermodulation products were -31 dBc or better for any test condition.

Speech samples for subjective evaluation were created by recording Harvard sentence pairs that had been passed through the experimental set up and corrupted with known amounts of thermal noise and co- and adjacent channel interference. The recorded samples were randomized and played to a total of 68 subjects who listened to the samples over standard telephone handsets. Subjects were asked to rate individual samples of speech as bad, poor, fair, good, or excellent. The five opinion categories were assigned numerical values from 1 (bad) to 5 (excellent). Responses to a particular sample of speech (and test interference test condition) were averaged over the population of subjects, thereby generating a Mean Opinion Score (MOS) for that condition. This subjective test procedure was based on the Absolute Category Rating (ACR) method defined in Annex A of Ref. 2.

SIGNAL CALIBRATION

The ACSSB modems used for this study were developed in-house at CRC. The DSP modulation algorithms for these modems have been optimized for satellite propagation conditions. The modems use the general concepts of transparent tone-in-band and feed forward signal regeneration for SSB speech modulation (Refs. 3,4). Figure 4 shows the baseband ACSSB spectrum.

The NBFM modems used for these tests came as part of two Motorola DynaTac™ 2000 cellular telephones. These are commercially available radio transceivers with performance optimized for 800 MHz terrestrial cellular operation. It was decided to use these transceivers because they represent an acceptable standard of performance by virtue of their widespread use . A test-tone to noise test was conducted on these radios and performance, as a function of C/No, is shown in Figure 3.The audio frequency responses of the ACSSB and NBFM terminals were approximately equal. The -6 dB bandwidth of the NBFM was 300 to 3100 Hz. The ACSSB -6 dB bandwidth was approximately 300 to 3000 Hz.

Throughout the experiment there was an effort to ensure that signal modulation levels were kept constant and within realistic limits. With the NBFM modulator the amplitude of the input speech was set so that peak deviation would not exceed 12 kHz. Nominally, the average deviation was 4-6 kHz. The power of the NBFM signal was easy to monitor and control because of its constant envelope characteristic.

The ACSSB spectrum has an envelope that varies in proportion to the input speech. Measurement of average carrier power requires a technique which samples and averages the carrier envelope power over a period of time during which speech is continuous. To do this, a sampling system was devised which used a spectrum analyzer to view the ACSSB spectrum through a 10 kHz resolution bandwidth filter. The detected spectrum was rectified and passed through a video filter having a width of 30 to 300 Hz. The resultant output was the ACSSB envelope which varied at the syllabic rate (this output is called the short term mean power of the speech signal, Ref. 5). The envelope was sampled at 1000 Hz by a digital voltmeter and the resultant samples were stored on disk for analysis.

The sampled data was analyzed by a computer program which calculated the difference in mean power between an ACSSB signal containing speech and pilot tones and an ACSSB signal containing only pilot tones. The pilot tone ACSSB signal had a constant envelope, and its absolute power was easily measured using conventional power measurement techniques. With the absolute measurement and the relative difference in the mean power of the two ACSSB signals, it was possible to calculate the absolute, short term mean power of the ACSSB speech signal.

With the CRC ACSSB modems the mean power of an ACSSB signal containing speech and pilot tones was approximately 3 dB above the power of an ACSSB signal containing only pilot tones. It should be noted that within this study, ACSSB carrier power is defined as the mean power of the signal containing continuous speech. For the propagation environments, all carrier powers are specified at unfaded levels.

TEST RESULTS AND ANALYSIS

Figure 5 compares the performance of ACSSB and NBFM in a static environment. As can be seen, the best ACSSB performance is achieved at a C/No between 50 and 55 dB-Hz. Above 55 dB-Hz the ACSSB performance will not improve because digital signal processing noise of the modem dominates the thermal noise of the channel. This limitation is a constraint due to equipment. More recent implementations of ACSSB have exceeded this limit. Below 50 dB-Hz, ACSSB static performance degrades slowly to a MOS of 3 at 45 dB-Hz.

NBFM deteriorates only slightly under Rician propagation providing the C/No is high (compare Figs. 5 and 7). However, if the signal level is lowered from 65 to 58 or 51 dB-Hz, the effects of propagation become quickly apparent. The rapid deterioration of NBFM is attributed to the threshold effect common to this modulation. NBFM signals undergoing Rician propagation are driven below threshold, causing a rapid drop in the baseband S/N. For the cellular transceivers, a 2 dB variation of the C/No at approximately 60 dB-Hz will result in a 2-3 dB degradation of output S/N. At 53 dB-Hz, such a variation will result in a 6 dB degradation (see Fig.3).

ACSSB deteriorates in a slower, more linear fashion and does not exhibit a threshold like NBFM. As C/No is reduced, the subjective acceptability of ACSSB in a Rician environment drops slowly and shows less of a dependence on signal strength than NBFM.This is seen in the variation in MOS of Rician ACSSB between 51 and 45 dB-Hz.

With ACSSB the most significant source of deterioration is due to the propagation channel. Comparing static ACSSB to Rician ACSSB at 51 dB-Hz, there is almost a one opinion category drop (i.e. from "good" MOS of 4.0 to "fair" of 3.0). This drop can be attributed to several factors, one of these being the decrease in mean signal power which drops by 2.5 dB in the Rician environment from its static unfaded value. A second source of degradation that is evident in a Rician environment (and is non-existent in the static case) are the instances where the received signal has deep fading (Fig.2). Deep fades are compensated by the ACSSB demodulator but their duration is such that there is a noticeable effect on perceived quality.

With both ACSSB and NBFM, the effects of co-channel interference become noticeable at a C/I of approximately 15 dB (see Figs. 6 and 7). The general mechanism of deterioration is due to the energy of the interference adding to the thermal noise of the channel. With ACSSB this is more pronounced if the interfering signal falls directly on top of the desired signal, corrupting the pilot tones carrying the companding information. Even at the relatively low C/I levels of 20 dB one can see a difference in MOS when the interfering signal falls directly on top of the desired signal and when it is offset by several hundred Hertz (see Fig.9 with $\Delta F=0$ Hz).

Figures 8 and 9 show the effect adjacent channel interference has on the NBFM and ACSSB demodulators. Both figures show that the desired signals' performance deteriorates as a function of interferer power and frequency.

It is interesting to note that the response of ACSSB to adjacent channel interference is non-symmetric. This is due to the power of an ACSSB signal being unevenly distributed around the pilot tones (see Fig. 4). An ACSSB interferer overlapping the desired signal on the positive frequency side will result in the relatively high power low frequency components of the interfering signal overlapping the low power high frequency components of the desired signal. Conversely, when the interferer approaches from the negative frequency side, the low power high frequency components interfere with the desired signals' high power low frequency components. The result of this is that the perceived S/N will be lower in the former case. This is borne out by the results shown in Figure 9: for the same magnitude of frequency offset, mean opinion scores are slightly better on the negative frequency offset side.

CONCLUSIONS

The purpose of this study was to determine protection ratios for ACSSB modulation operating under co- and adjacent interference conditions in a Rician propagation environment. For the purpose of this study, protection ratio is defined as the C/I at which the quality of the desired signal deteriorates by 0.5 MOS units from the condition where no interferer is present. Using this definition, the protection ratio for co-channel interference in a Rician environment for ACSSB is approximately 11 to 13 dB. Cellular NBFM requirements under identical conditions is about the same. The estimated adjacent channel protection ratio for ACSSB in a Rician environment is -12 to -15 dB for interferers one channel spacing higher in frequency than the desired signal and -15 dB for interferers one spacing lower. For cellular NBFM the ratio is -12 to -15 dB.

ACKNOWLEDGEMENTS

I would like to thank my colleagues at CRC for their help in undertaking this experiment and the participants from the Department of Communications and Telesat Canada who volunteered their services as evaluators. Special thanks to Barbara-Anne Chalmers at DOC/CRC for helping pull this work together.

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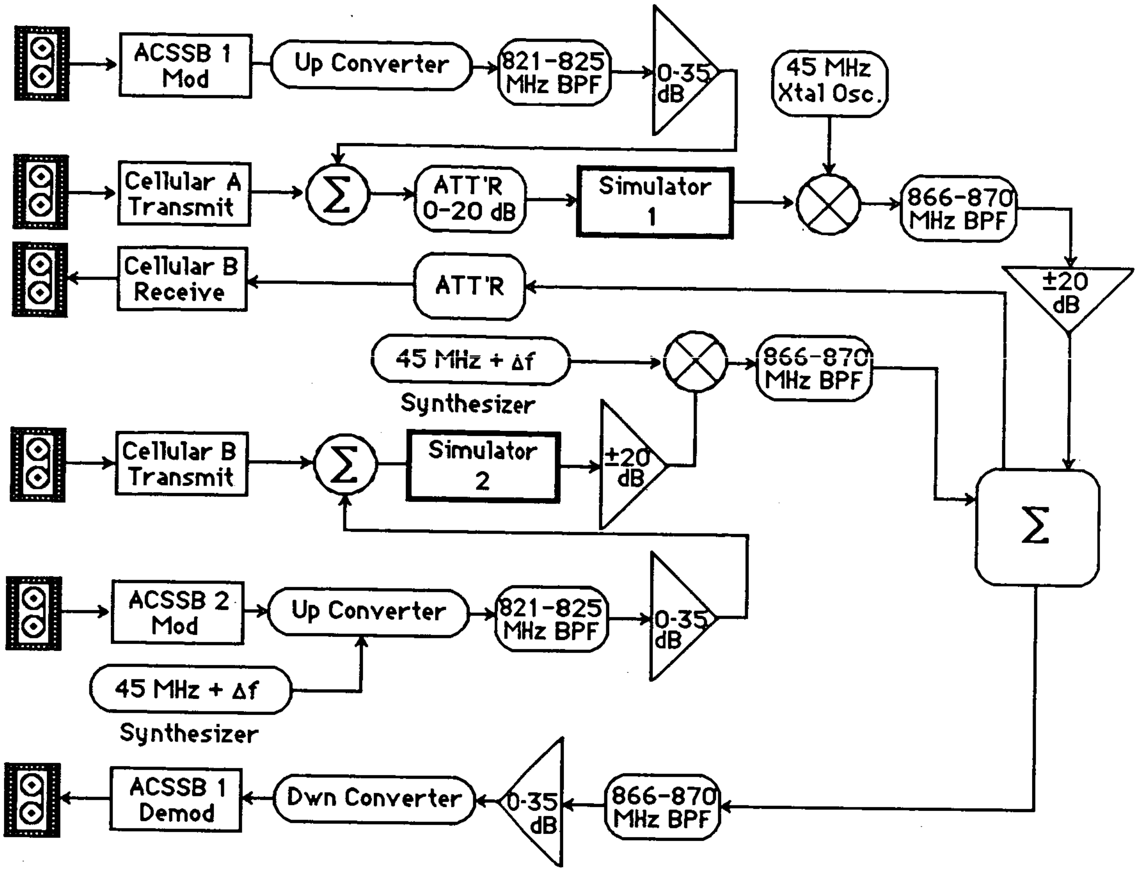

Fig 1. Test set up.

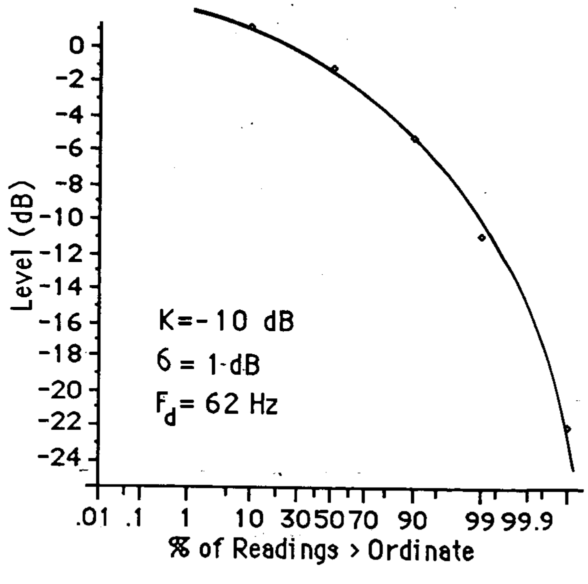

Fig.2 Cumulative Distribution Function for Rician Fading

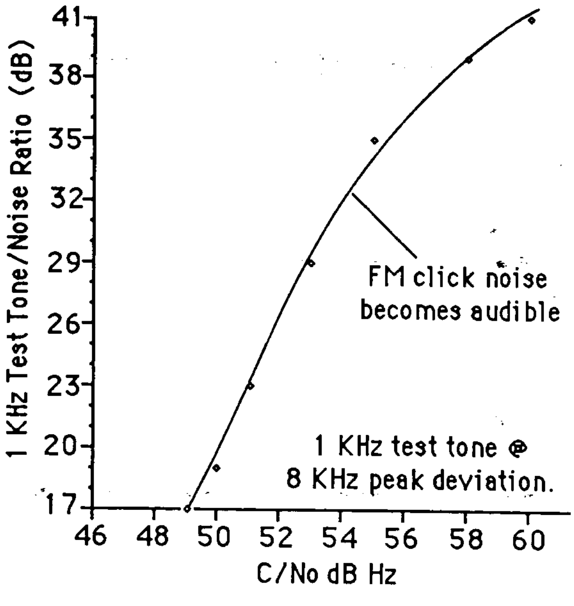

Fig. 3 Test Tone to Noise Ratio vs. C/No Performance for the Cellular FM Transceivers

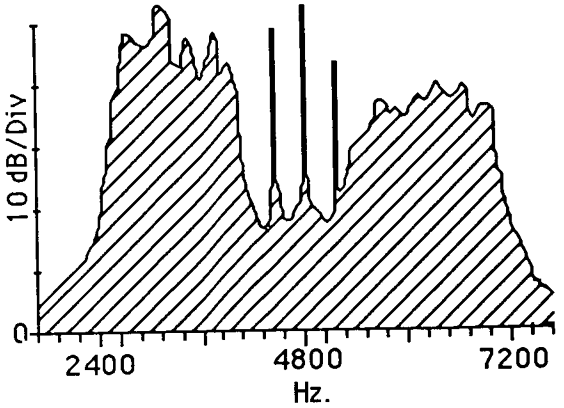

Fig. 4 Base Band ACSSB Spectrum

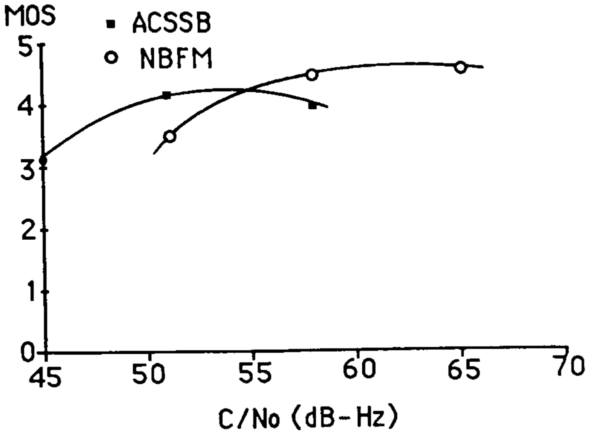

Fig.5 ACSSB and NBFM Performance
Static Environment
No Interference C/I=∞

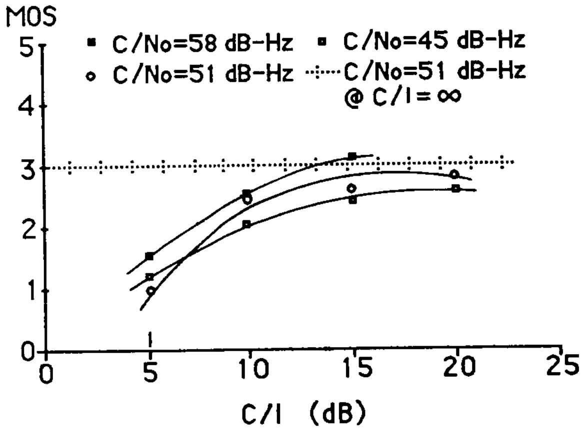

Fig. 6 ACSSB Co-Channel Performance
Rician Propagation Environment

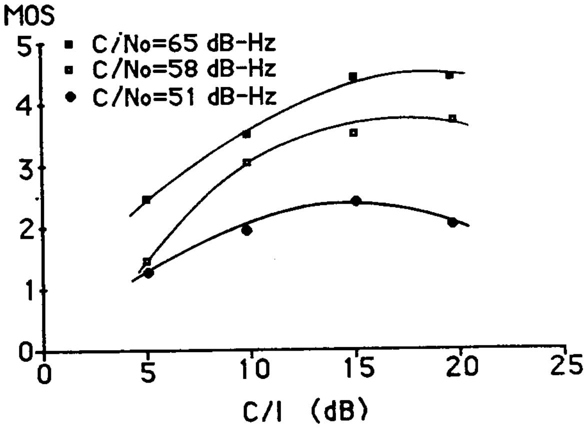

Fig.7 NBFM Co-Channel Performance
Rician Propagation Environment

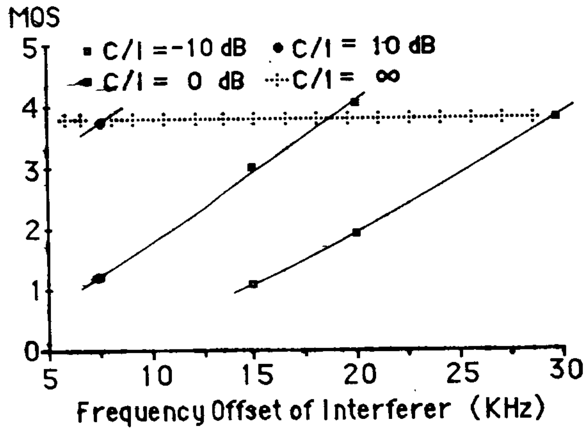

Fig.8 NBFM Adjacent Channel Performance
Rician Propagation Environment with
C/No=58 dB-Hz

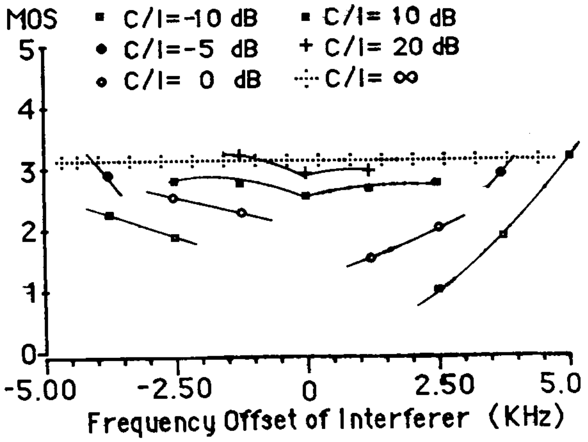

Fig.9 ACSSB Adjacent Channel Performance
Rician Propagation Environment with
C/No=51 dB-Hz