IEEE 802.11
Wireless Access Methods and Physical Layer Specifications

Discussion of 0.39 GMSK Modulation for Frequency Hop Spread Spectrum

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Introduction

In a previous IEEE 802.11 submission, P802.11-93/11, Motorola proposed a physical layer specification. One of the important elements of that specification is the modulation format 0.39 GMSK at 1 Mbit/sec. The data rate of 1 Mbit/s is selected because it meets the minimum requirements for IEEE 802.11 yet meets the FCC bandwidth requirements without undue implementation complexity or cost. The specific objective of this submission is to address the compatibility of the proposed 0.39 GMSK modulation format with the FCC bandwidth requirement.

FCC Bandwidth Requirement

Part 15 and in particular section 15.247 set the FCC regulations for operation of intentional radiators in the ISM bands. The particular ISM band of interest to this committee is the 2.4 to 2.4835 GHz band. Motorola proposes frequency hop spread spectrum which is addressed in paragraph a-1-ii of section 15.247 of the FCC regulation. Here, the regulation states that "the maximum 20 dB bandwidth of the hopping channel is 1 MHz". The FCC provides definition of terms in Part 2, paragraph 2.202. There, the FCC defines occupied bandwidth as "the frequency bandwidth such that below its lower and above its upper frequency limits the mean powers radiated are each equal to 0.5 percent of the total mean power radiated by a given emission". Thus, the 20 dB bandwidth is the bandwidth that occupies 99% of the power of the spectrum. Appendix A of this submission discusses an alternative interpretation.

Modulation Method

The modulation method is Gaussian Minimum Shift Keying (GMSK). The frequency deviation shall be 25% of the bit rate (250 kHz), and the Gaussian pre-modulation filter shall have a 3 dB cutoff frequency equal to 39% of the bit rate (BT=0.39).

A block diagram of a 0.39 GMSK modulator is illustrated in Figure 1. A 7-pole Bessel lowpass filter is used to closely approximate the Gaussian pre-modulation filter.

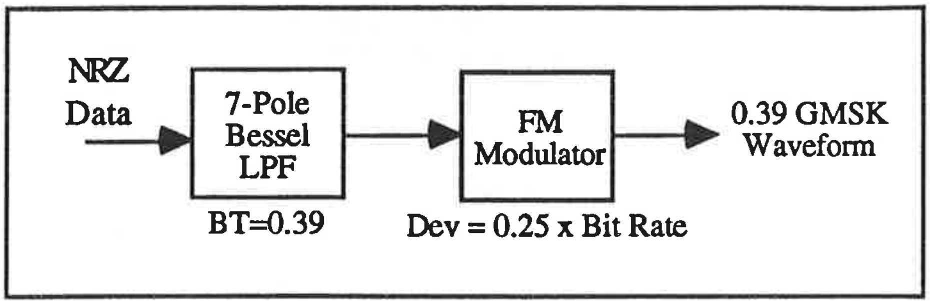

Figure 1. 0.39 GMSK Modulator Block Diagram

As discussed below, computer simulations and hardware measurements have verified that the 0.39 GMSK waveform meets the proposed 99% power bandwidth specification.

Performance Verification

Computer Simulations

Detailed simulations of the modulator shown in Figure 1 were used to evaluate the 0.39 GMSK waveform. The resulting signal spectrum, which is illustrated in Figure 2, was obtained by performing an 8192-point FFT over a 512-bit PN sequence (at 16 samples per bit). The corresponding frequency resolution is equal to 0.195% of the bit rate.

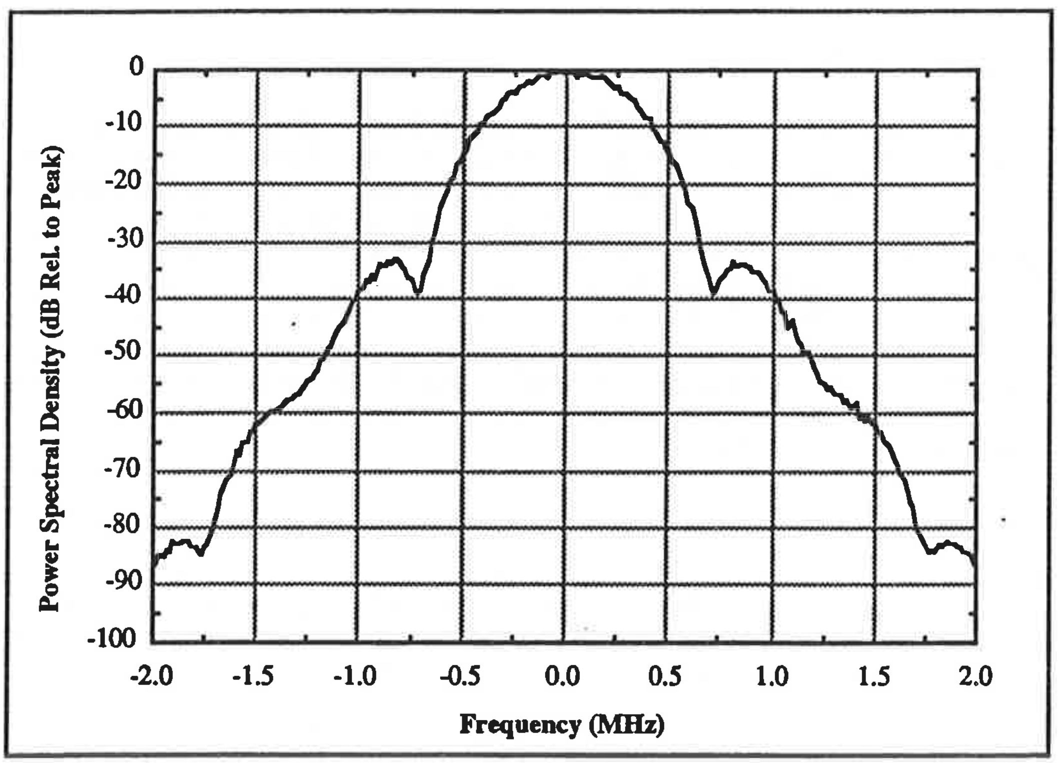

Figure 2. Simulated 0.39 GMSK Power Spectrum

These simulations indicate that 99.20% of the transmitted signal power falls within ±500 kHz of the carrier frequency, which is in compliance with the proposed 99% power bandwidth requirement.

Hardware Measurements

The test setup used to measure the total power within the channel is the same as that shown in Figure 1 with the output of the FM modulator viewed with a spectrum analyzer. Pseudo-random NRZ data was input to the system. The 7-pole Bessel filter was designed with a 3 dB cut-off at 39% of the data rate. The deviation was set to 25% of the data rate and was calibrated using a Bessel null technique. With the modulation amplitude for the proper deviation known, the pseudo-random data was applied and the normalized output spectrum of Figure 3 was generated. The one-sided spectrum of Figure 4 was taken for enhanced accuracy of a numerical integration. The results of this integration show that with a 1 Mbps data rate, 99.18% of the transmitted power is within ±500 kHz of the carrier frequency.

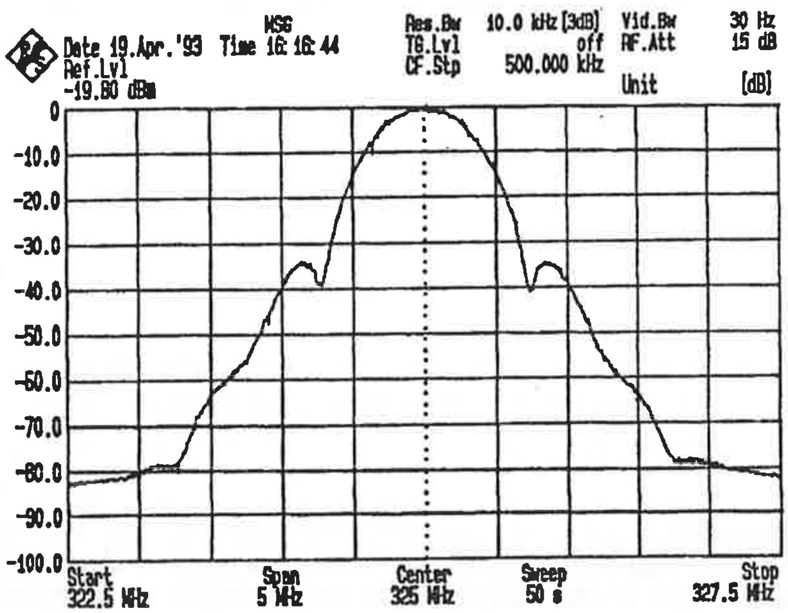

Figure 3. Measured 0.39 GMSK Power Spectrum

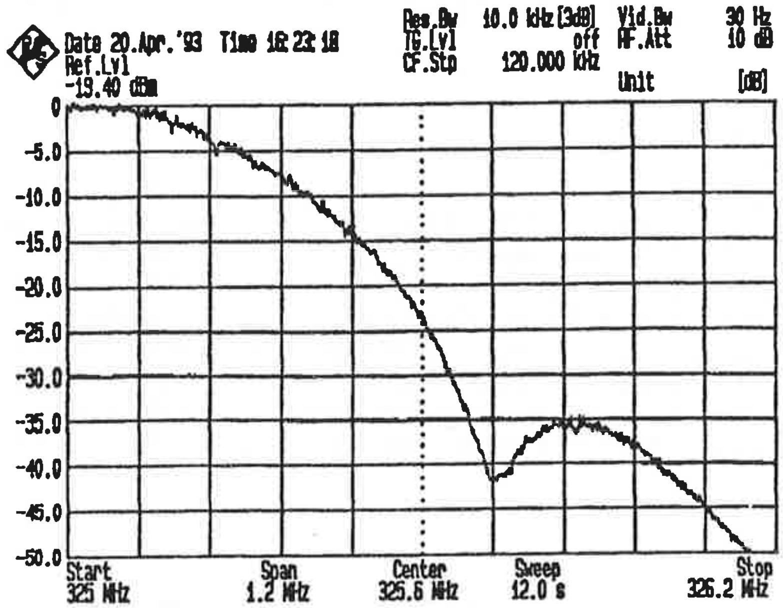

Figure 4. Measured 0.39 GMSK One-Sided Power Spectrum

Appendix A

Overview

An alternate interpretation of the FCC rule regarding the 20 dB bandwidth in Part 15.247 has been discussed. This interpretation, called *Filter Method* here, tends to follow the traditional methods of filter bandwidth measurement, suggesting that the bandwidth is defined by the + and - deltas in frequency associated with reduction of the signal spectral power density to a level 20 dB below the midband level. One would test for compliance by using a spectrum analyzer where the resolution bandwidth has been reduced to a small enough bandwidth that further reduction would not cause a change in the shape of the spectrum as displayed on the analyzer or in the bandwidth measurement. This appendix will show that this method of measurement allows the primary intent of the FCC in specifying bandwidth and in establishing the spread spectrum criteria to be usurped. In addition, it will be shown that this definition cannot be applied to some perfectly legitimate forms of modulation. Thus, this alternate definition is clearly inappropriate for this application. Conversely, direct acceptance of the FCC definition tends to discourage methods to usurp FCC intent and is applicable on a general purpose basis.

Limiting Interference

The FCC's intent in establishing the spread spectrum rules for unlicensed operation in the ISM bands was to provide low interference profiles thus achieving sharing of the spectrum among uncoordinated users. The bandwidth limit imposed by the 20 dB bandwidth specification of part 15.247 is a component of the low interference profile requirement of the FCC ISM band rules.

With this in mind, let us consider a system using a very basic form of digital modulation, PSK. The spectrum of such a signal is shown in Figure A1. According to the *Filter Method*, the second and third lobes on either side of the main lobe exceed the requirement for 20 dB attenuation. This, however, may be remedied by filtering to produce, for example, the spectrum shown in Figure A2, where the second and third lobes on either side of center are attenuated 7 and 3 dB, respectively, to meet the 20 dB criteria. Notice, however, the interference profile of this spectrum. The signal continues at a level less than 30 dB down from the main lobe for 5 MHz on either side of center frequency. Integration of this spectrum indicates that only 95.5% of the transmitted signal power falls within ±500 kHz of the carrier frequency. Clearly, this spectrum is not consistent with the low interference profile intent of the FCC rules.

General Purpose Applicability

While the *Filter Method* may be applied to many transmitted spectral shapes, there are some to which it may not be applied without producing ambiguous results. One such spectrum is that of a transmitter using continuous phase shift keying where the carrier represents 10% of the signal power since it is not nulled. Some may consider this to be a highly effective form of modulation since for a very small penalty in efficiency, the benefits of coherent demodulation may be easily implemented because of the constant envelope nature of the signal and the presence of carrier to aid in acquisition. A similar spectrum would result from BPSK where the data does not consist of 50% 1's and 50% 0's.

These spectra contain significant power in the carrier. The *Filter Method* of measuring bandwidth, however, would fail to provide a measurement since as the resolution bandwidth is reduced from a high starting value, a bandwidth would never be found where the shape of the spectrum does not change with further reduction in resolution bandwidth. Thus, the *Filter Method* is inappropriate for spectral bandwidth measurement.

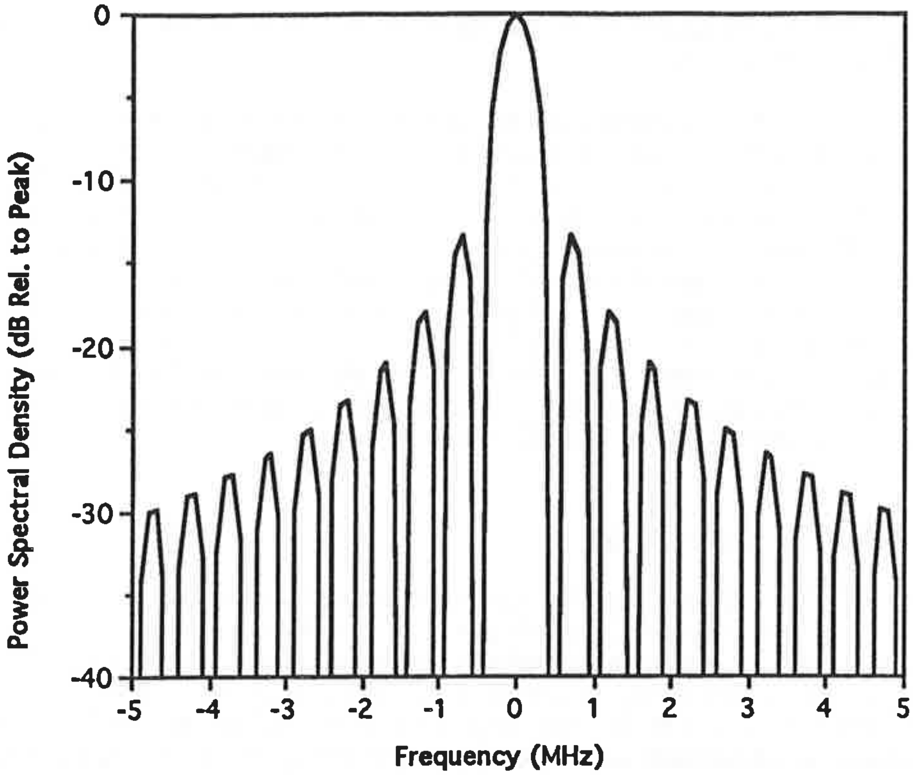

Figure A1. 500 kbit BPSK Power Spectrum

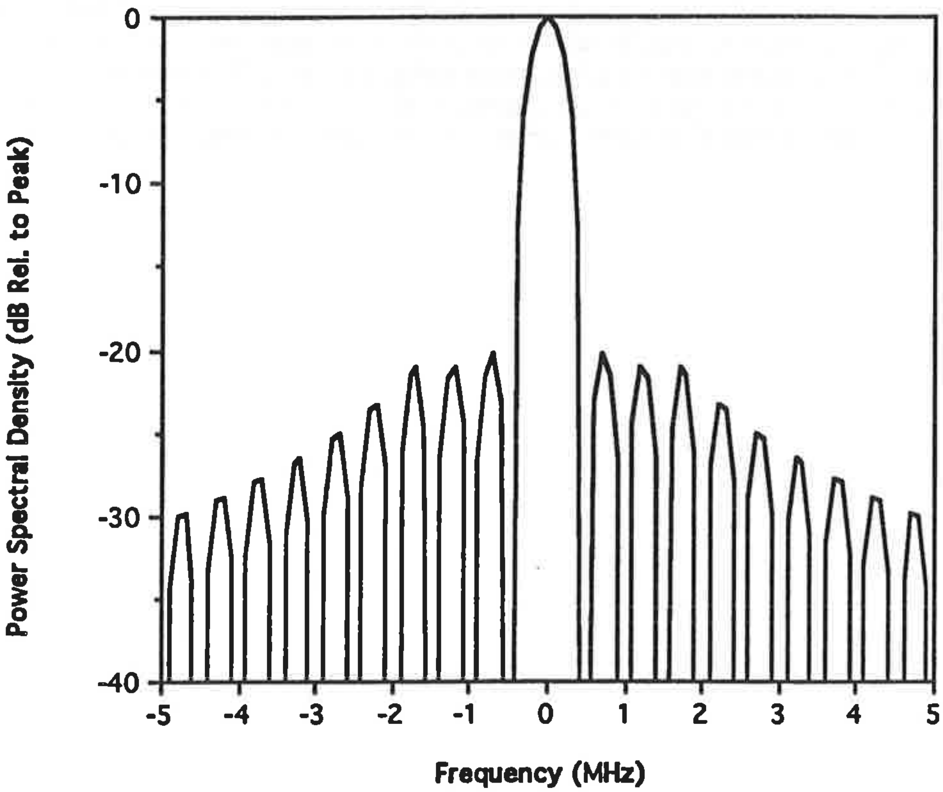

Figure A2. 500 kbit BPSK Power Spectrum with Filtering