FCC Regulatory Requirements For Design and Sale of SDARS In-Home Repeater

Frank M. Hirschenberger
Frank.m.hirschenberger@delphi.com
Delphi Corporation
Product and Service Solutions Division
Consumer Electronics
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1 Scope

This paper has five purposes:

1) Operational description of Delphi SDARS in-home repeater
2) Review F.C.C. regulations for device
3) Design considerations based on F.C.C. requirements
4) Provide recommendation for certification test stimulus
5) Present requests for F.C.C. rules interpretation

The intended audience is specifically the F.C.C. Office of Engineering and Technology.

2 Product Overview and Operational Description

Currently, Delphi is the leading maker and distributor of satellite radios in the United States, with a growing aftermarket customer base in excess of 1 million customers. One current limitation of satellite radio installations is that, generally, the SDARS antenna that is connected to the satellite radio needs to be placed at a point where the service signal is present (typically outside the house or in a window exposed to the service signal). The Delphi SDARS In-Home Repeater product is intended to overcome the limitation mentioned above such that current Delphi satellite radio customers would be able to receive the satellite radio signal (as broadcast by the service providers) at any place in their home without having to connect to the SDARS antenna.

Note that the primary intention of this product is to rebroadcast the XM signal in an effort to increase sales of current Delphi aftermarket satellite radios (all of which utilize XM as service provider).

Though termed as an in-home product here for identification purposes, the product is intended to also be applicable to other environments, including offices, health clubs, and malls.

In this system, the S-band antenna module which feeds the transmitter has an in-band passive gain of +7 dBiC and an effective active gain of + 20 dB (low noise amplifier gain minus cable loss).

The product concept involves receiving the XM SDARS signal at S-Band (centered at 2338.75 MHz), frequency-converting it to the 915 MHz ISM band, broadcasting it into the desired coverage space by radiating the SDARS signal in the 915 MHz ISM band, receiving the SDARS signal in the 915 MHz ISM band near the SDARS receiver, reconverting the signal back to S-Band, and conducting the signal into the target satellite radio via its existing antenna input.

The product inherently is comprised of two units:

1) Downconverter/Transmitter

2) Upconverter

The usage of these two elements in the system is illustrated below in Figure 1.

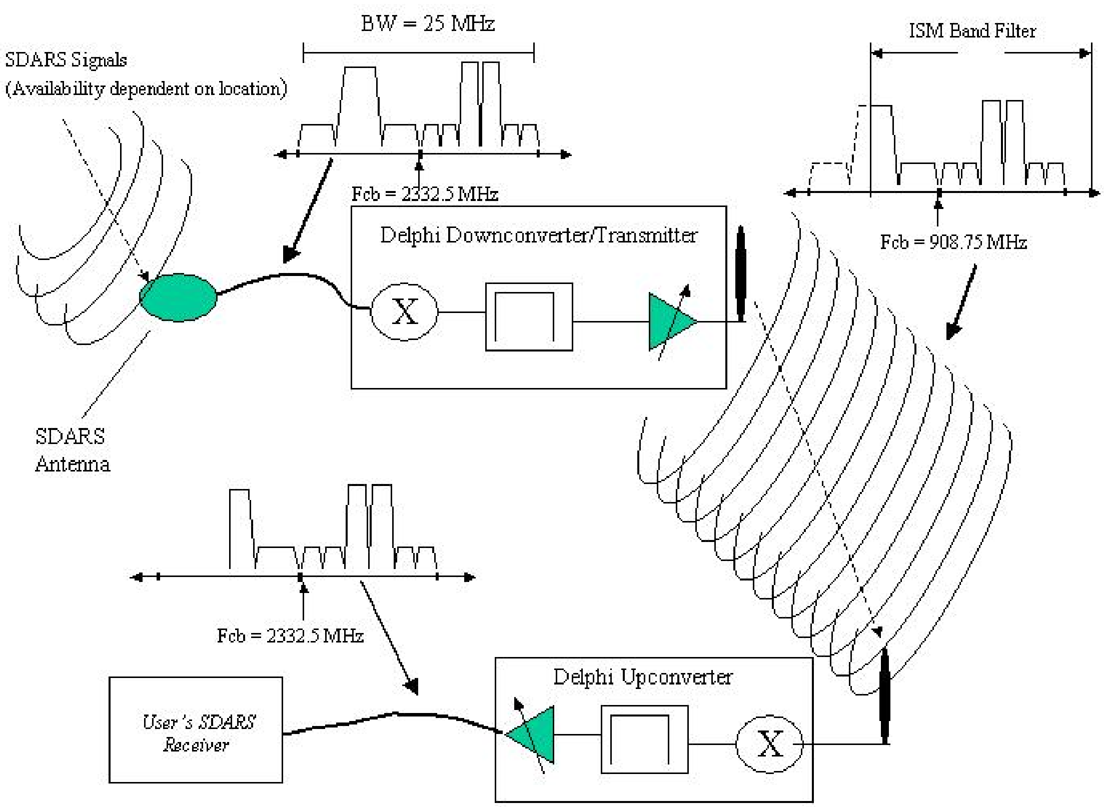

Figure 1: Delphi Repeater System

Note that the SDARS spectrum consists of signals from both XM and Sirius. Both systems use QPSK digital modulation for satellites and OFDM digital modulation for terrestrial repeaters.

As indicated from the system diagram, the basic tenet of the system from a bandwidth usage perspective is to take the 12.5 MHz XM SDARS spectrum and place in the 915 MHz ISM band, which has an available bandwidth of 26 MHz. The entire SDARS spectrum consisting of Sirius and XM has a bandwidth of 25 MHz. In order to meet the FCC out-of-band emission requirements, an ISM-band bandpass filter will be utilized. Spectrum shifting is performed such that the overall XM band center frequency is shifted to 915 MHz; this minimizes the XM in-band roll-off and minimizes overall transmit power requirements for functionality and range. The center frequency of the overall SDARS signal is shifted from 2332.5 MHz to 908.75 MHz with adequate accuracy such that filtering requirements are straightforward.

The downconverter is equipped with active gain control to keep the transmit power constant (within a predetermined range) in order to maximize the range while meeting the FCC maximum transmitted power limits. The signal is intentionally radiated within the 915 MHz band. The radiated signal is received by the upconverter, which is placed in front of the pre-existent receiver.

To provide a further understanding of the frequency conversion being utilized, the figures below show the received SDARS spectrum and the appearance of the spectrum when translated to the ISM band for rebroadcast.

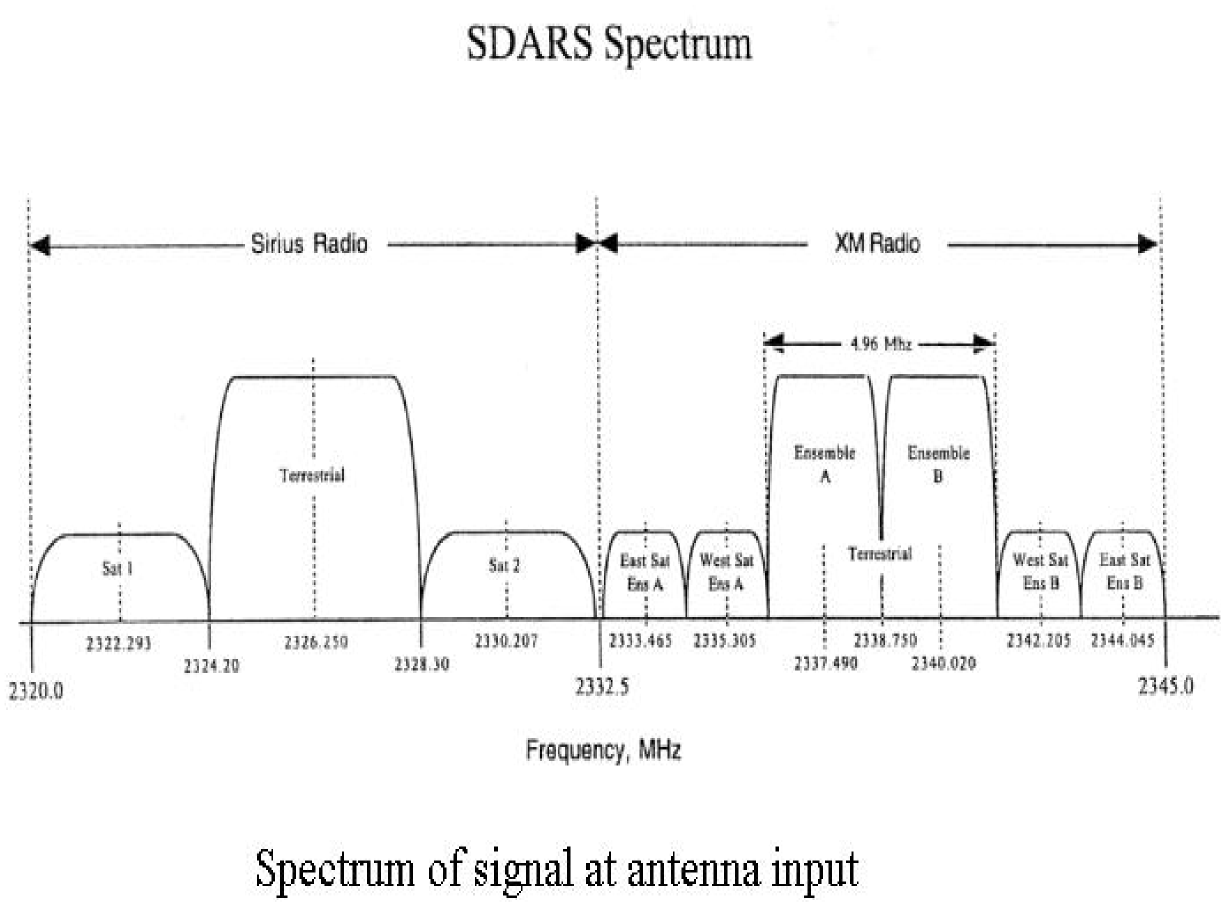

Figure 2: SDARS Spectrum

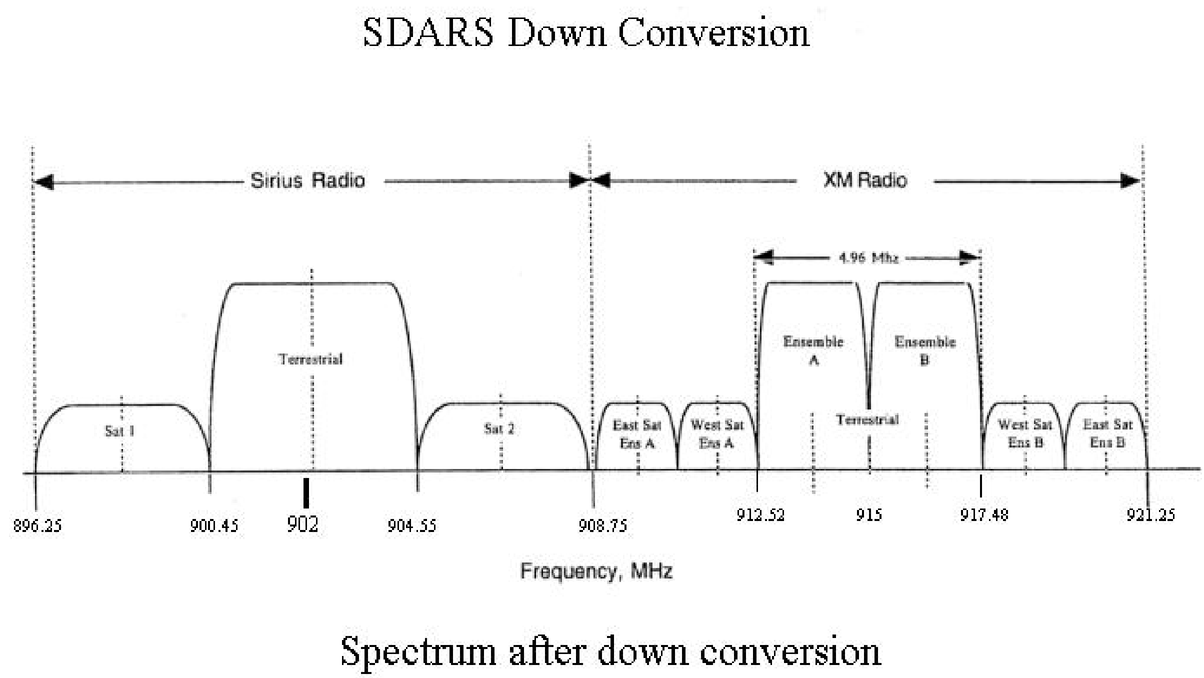

Figure 3: SDARS Spectrum translated to ISM Band

3 F.C.C. Requirements

FCC-published requirements for intentional radiators that may apply to this product as determined from Delphi research are addressed in this section.

Note that unintentional radiator requirements also apply, but are not addressed in this paper.

The primary source of FCC requirements at this time:

Title 47 – Telecommunications, Chapter I (FCC)

Applicable sections of Title 47 are referenced below.

Based on negotiations between Delphi and F.C.C. Office of Engineering and Technology, it has been agreed in principle that Delphi is allowed to pursue certification of SDARS repeater product under F.C.C. Part 15, Section 15.249.

3.1 In-band and harmonic limits

For the 902-928 MHz band, 15.249 indicates the following limits:
Field strength of fundamental: 50 mV/m @ 3 m
Field strength of harmonics: 500 uV/m @ 3 m

These limits are based upon a quasi-peak measurement with a 120 kHz bandwidth.

3.2 Out-Of-Band Limits

Per Section 15.249, the emissions limits outside the ISM band are restricted as follows:

50 dB below peak in ISM band
OR
Absolute limits per 15.209,
(whichever is less severe)

Per 15.209, the emissions limits in the 216-960 MHz are 200uV/m @ 3m.

3.3 Special Concerns for Repeaters

3.3.1 Signal Identification Requirements

Per the FCC interpretation in Section 3.3.1.1 below, there is some concern that, for a repeater to be qualified under Part 15, that it must be able to determine if a signal is valid prior to repeating. In verbal discussions with the F.C.C. OET, it has been agreed by OET personnel that this requirement may be bypassed in this case based on the fact that the input spectrum being repeated is a restricted (SDARS) band.

This subject will later be addressed in this document in the form of and interpretation request.

3.3.1.1 FCC Interpretation 20000308-009

(FCC Interpretation 20000308-009, Spread Spectrum, Part 15 DSS
Repeater:
This interpretation, available through the FCC interpretations
database, states that:
“An application for a repeater that consisted of a RX front-end, downconverter,
up-converter, amp and antenna (port), retransmitting at
spread spectrum power levels was denied. While such devices may be
authorized under licensed Rules Parts (formerly Type Acceptance), they

cannot be authorized under Part 15. As a part of a licensed system, they would only receive signals licensed to operate on certain specific frequencies. A Part 15 repeated such as this one, however, could receive, amplify and retransmit ANY incoming signal (the Adtran device, operated in the 2.45 GHz band, so it could, in theory, have received and retransmitted emissions from a microwave oven). We have authorized repeated under Part 15 where they demodulated the incoming signal in order to determine if it was "valid", I.e., it came from a specific device with which the repeater was designed to operate. In these cases, we list the FCC ID of the transmitter with which he repeater operates on the Grant. In the Adran case, the difference is that it does not demodulate the incoming signal in order to identify its source. This cannot be allowed under Part 15. If the device had been designed to operate with a hopper, Section 15.247(a)(1) would have been cited, which requires that a frequency hopping receiver have an input bandwidth matching the transmitter bandwidth, and have the ability to hop in sequence with the transmitted signal. We will only grant a spread spectrum repeater (or any Part 15 repeater) if it has the ability to determine the source and validity of the incoming signal, and only retransmits signals from a specific transmitter, which is listed on its grant."

3.3.2 Single-Tone Interferer Magnitudes

Since this device is a true repeater, the design must consider limiting the output level when energy other than the desired signal exists at the input. It is necessary to determine the maximum level for a single-tone spur which the receiver may be exposed to in normal and operation and, in that case, verify that the radiated emissions will not exceed the set limits.

Per a meeting between F.C.C. OET and Delphi on November 8, 2004, it was indicated that the following assumptions could be made to determine the maximum spur level, which must be handled:

a) Spur magnitude = 500uV/m (assumed to be from a borderline-compliant device at a distance of 3 meters from the SDARS receive antenna)
b) Spur will enter the SDARS antenna from the back side (azimuth angle 90-270 degrees using 0 degrees as a boresight). Thus, the front-to-back ratio of the antenna can be considered in the calculation.

Utilizing the 2 assumptions listed above, a received spur level for the Delphi transmitter can be ascertained as shown below.

The average back-side passive gain of the XM home antenna utilized in this system is –11 dBi for a linearly-polarized E field (verifiable with separate data set).

If a 500 uV/m spur is received on the back-side of the XM home antenna, using the average gain of –11 dBi, the power output of the passive antenna can be calculated as follows:

Pr = (|E|^2/377)*(λ^2 * G) /(4*pi),

Where:
Pr: output power from passive antenna element
|E| = 500uV/m
λ = wavelength = c/f = 3E8 m/s / 2332 MHz = .128 m
G = -11 dBi (.0794)

Using this, Pr = 6.8E-11 mW (Pr = -101.6 dBm).

The XM home antenna has an effective gain of 20 dB; thus, the spur level presented at the input to the transmit module would be –81.6 dBm.

Delphi wishes to design the SDARS repeater transmitter such that the output of a –81.6 dBm in-band spur would not exceed emissions limits stated previously (within ISM band and outside ISM band). This will be addressed later in this document.

3.3.3 Test Stimulus Methodologies

Since the emissions from a repeater are dependent upon the input signal presented, the actual procedures for testing the product for emissions need to have the appropriate stimulus conditions identified. In order to enable this testing (and empower third-party test and TCB certification route), the appropriate test stimuli must be identified. Later in this document, a recommendation will be established for test stimuli to be used in emissions testing of this repeater.

4 Specific Design Information

4.1 Automatic Gain Control (AGC) and Output Power

Through the use of wide-band AGC control (detector bandwidth > 50 MHz), the repeater design can be made to set the transmit power at a level which will comply with FCC requirements in any SDARS source signal condition. The AGC function will respond equally to any input energy in the SDARS band.

The AGC has been set up to limit the output power to +12.75 dBm under all conditions. This will effectively limit the power of the transmitted E field to be within F.C.C. requirements. This is based upon the analysis below.

The relationship between power and |E| is known to be as follows (in linear terms):

Pt * Gt = ((|E|^2/377) * 4 * pi * R^2))

Where:

Pt = transmitter power
Gt = transmitter antenna gain
|E| = magnitude of transmitted electric field at a distance R from transmitter
R = distance from transmitter

From a bandwidth perspective, the worst-case valid signal (in terms of minimum bandwidth) expected at the input to the repeater will be the case where only one XM satellite is received. The overall transmit bandwidth of an XM satellite is 3.77 MHz. For the equation above, it is desirable to work in a 120 kHz bandwidth. This effectively factors down the power by 3.77M / 120 k = 31.4167 (note that SDARS spectra is essentially flat and uniform for calculation purposes).

Pt' = +12.75 dBm (18.83 mW)

Pt = 18.83 mW / 31.4167 = .599 mW (worst-case power in a 120 kHz bandwidth).

Gt = 1 (maximum linear gain of transmit antenna)

R = 3 m (distance from D.U.T. used for F.C.C. electric field measurements)

Solving for |E|: |E| = 44.68 mV/m

The F.C.C. limit per 15.249 is 50 mV/m in a 120 kHz bandwidth. Thus, the unit is designed to limit power appropriately under worst-case conditions.

4.2 Out-Of-Band Filtering

The design strategy to be utilized for this product will be to limit emissions outside the ISM band to be below the 15.209 limit (200uV/m) under all valid input conditions. In order to accommodate this, substantial filtering has been designed into the transmitter to limit emissions to only be in the ISM band.

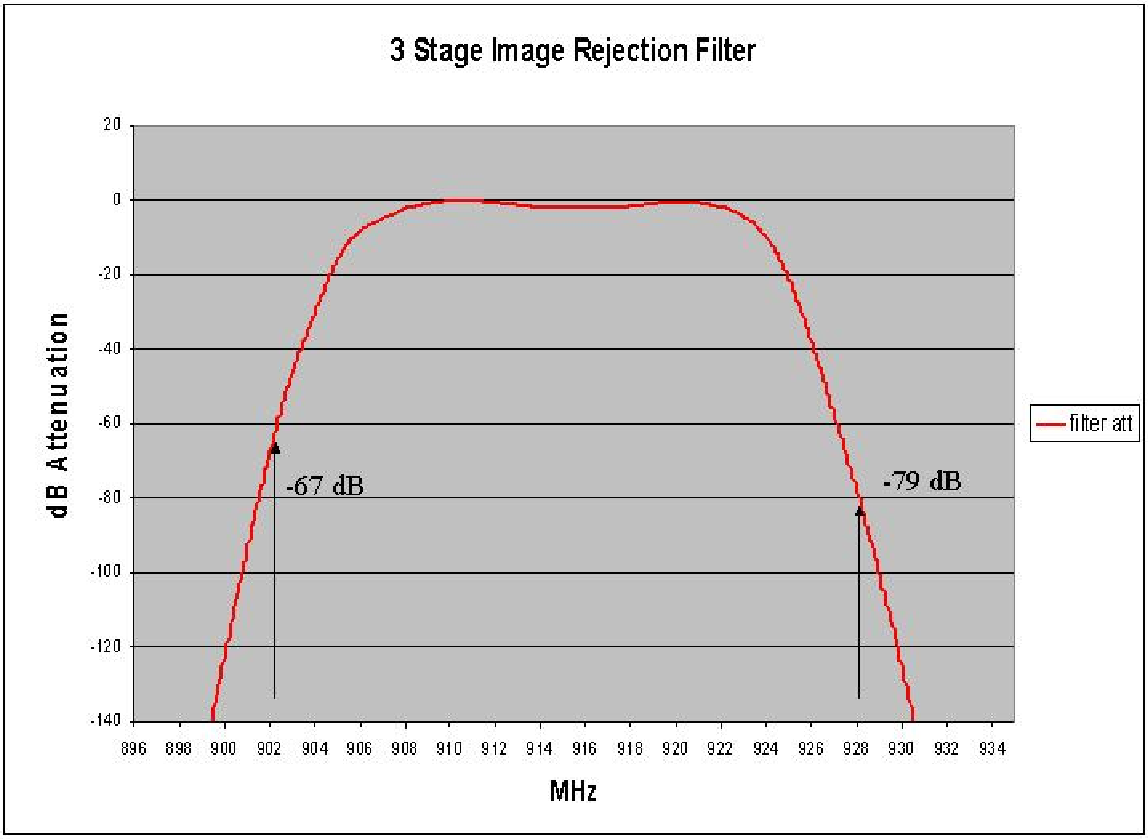

Figure 4: Transmitter Filter Response

Per Figure 4, the rejection at 902 MHz is 67 dB and rejection at 928 MHz is 79 dB. This will provide excellent ability of the device to only transmit signals that are in the SDARS band as well as limiting emissions to be specifically in the ISM band.

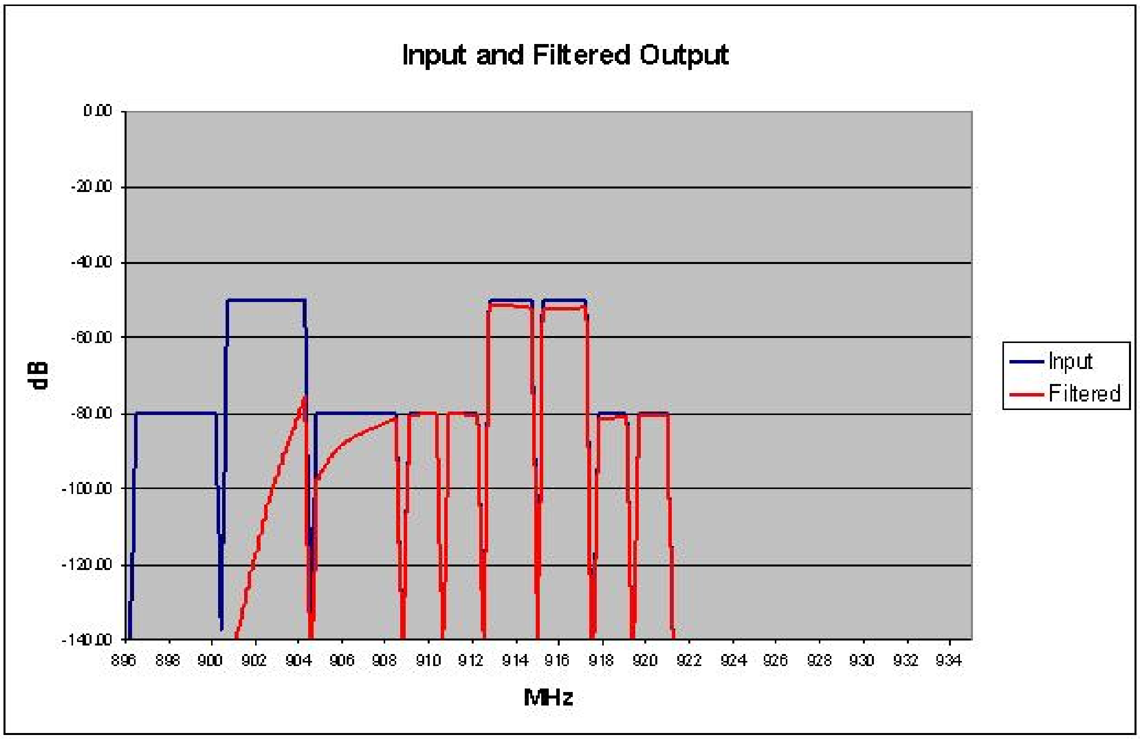

Figure 5: Signal Filtering Example

As a further clarification of the signal filtering characteristics, Figure 5 shows an example relative received SDARS spectrum and the effective filtering operation that is imposed upon the input signal. As can be seen from the figure, the following occurs:

a) The low-frequency satellite of Sirius (TDM1) is filtered out almost completely.
b) The Sirius OFDM signal is partially filtered.
c) Any spurious tones that land outside the ISM band will be heavily filtered.

5 Test Stimuli for Emissions Testing Recommendations

This section comprises the recommendation from Delphi for test stimuli to use during F.C.C. radiated emissions testing.

5.1 Base Stimulus

In cases where the response of the transmitter to undesired signals is being tested (Sirius satellite signal [Section 5.3], Sirius terrestrial signal [Section 5.5], and single-tone spur [Section 5.6]), it has been established verbally with F.C.C. OET on 11/8/04 that the presence of at least one valid XM signal of minimum bandwidth can be assumed such that the device is actually operational.

Delphi proposes that the following base stimulus exist in these cases:

Base Satellite signal: Input power @ transmitter input: -66 dBm.
Modulation: QPSK
Bandwidth: 3.77 MHz
Frequency: 2334.385 MHz

NOTE: In cases where presence of base signal is specified, it is considered to be a more severe case (from a radiated emissions spectral density perspective) if the base signal is not present. As a result, verified compliance to radiated emissions limits without base signal present will also be considered as valid certification data.

5.2 XM Satellite Stimulus

From a bandwidth perspective, the maximum spectral density involves receiving only a single XM satellite signal. The overall bandwidth of an XM satellite transmission is 3.77 MHz. The usable signal levels received from XM home antenna output vary from –55 dBm to –75 dBm.

As a result, Delphi recommends the satellite test stimuli is as follows for emissions testing:

Satellite signal: Input power @ transmitter input: -55 to –75 dBm in 5 dB increments.
Modulation: QPSK
Bandwidth: 3.77 MHz
Frequencies: Test @ 2334.385 MHz and 2343.125 MHz

Note that these signals do not exactly represent the XM signal (because XM transmits two ensembles of 1.84 MHz, not one at 3.77 MHz) but are adequate for testing of this product.

5.3 Sirius Satellite Stimulus

Since Sirius satellite #1 will result in transmitter output power outside the ISM band, it is required to test for emissions with this stimulus.
The overall bandwidth of an Sirius satellite transmission is 4.2 MHz. The expected signal levels received from XM home antenna output vary from –60 dBm to –80 dBm.

As a result, Delphi recommends the satellite test stimuli is as follows for emissions testing:

Satellite signal: Input power @ transmitter input: -60 to –80 dBm in 5 dB increments.
Modulation: QPSK
Bandwidth: 4.2 MHz
Frequency: Test @ 2322.293 MHz
(NOTE: Base stimulus also present)

5.4 XM Terrestrial Stimulus

Testing to validate that XM terrestrial signals are handled appropriately from an ISM in-band output power perspective and a harmonic levels perspective is required.
The overall bandwidth of an XM terrestrial transmission is 4.96 MHz. The expected levels received from XM home antenna output vary from –20 to –70 dBm.

As a result, Delphi recommends the XM terrestrial test stimuli is as follows for emissions testing:

Terrestrial signal: Input @ transmitter input: -20 to –70 dBm in 20 dB increments.
Modulation: OFDM (DQPSK carriers)
Bandwidth: 4.96 MHz
Frequency: Test @ 2338.75 MHz

5.5 Sirius Terrestrial Stimulus

Testing to validate that Sirius terrestrial signals are handled appropriately from an ISM in-band output power perspective and a harmonic levels perspective is required. In addition, Sirius will cause energy to exist outside ISM band.
The overall bandwidth of a Sirius terrestrial transmission is 4.096 MHz. The expected maximum level received from XM home antenna is –20 dBm.

As a result, Delphi recommends the Sirius terrestrial test stimuli is as follows for emissions testing:

Terrestrial signal: Input @ transmitter input: -20 dBm.
Modulation: OFDM (DQPSK carriers)
Bandwidth: 4.096 MHz
Frequency: Test @ 2326.25 MHz
(NOTE: Base stimulus also present)

5.6 Single-Tone Spur Test

Per Section 3.3.2, the received single-tone spur amplitude to be handled by the design is –81.6 dBm at transmitter input. The presence of this tone should be tested across a large bandwidth of the input.

As a result, Delphi recommends the following conditions for single-tone spur test:

Single-Tone Sweep: -81.6 dBm, swept from 2312 to 2352 MHz in 1 MHz increments.
(Note: Base stimulus also present).

6 Request for Interpretations

The interpretations listed below are requested by Delphi of F.C.C. OET staff.

6.1 Requirement for determining signal validity

Per FCC Interpretation #20000308-009, no repeater can be certified under part 15 rules unless signal validity (in the implied form of demodulation and decoding) is determined prior to re-transmission of the signal. Given that the device proposed here only intends to repeat signals received in a restricted band (SDARS signals), can the requirement for signal validity determination be waived? Specifically, can the device then be qualified under Part 15, Section 15.249?

6.2 Test Stimuli

Given that the proposed device is a true signal repeater, is the following proposed set of test stimuli (each tested independently) adequate for testing of the device for radiated emissions under Part 15?

XM Satellite signal: Input power @ transmitter input: -55 to –75 dBm in 5 dB increments.
Modulation: QPSK
Bandwidth: 3.77 MHz
Frequencies: Test @ 2334.385 MHz and 2343.125 MHz

Sirius Satellite signal: Input power @ transmitter input: -60 to –80 dBm in 5 dB increments.
Modulation: QPSK
Bandwidth: 4.2 MHz
Frequency: Test @ 2322.293 MHz
(Base stimulus present)

XM Terrestrial signal: Input @ transmitter input: -20 to –70 dBm in 20 dB increments.
Modulation: OFDM (DQPSK carriers)
Bandwidth: 4.96 MHz
Frequency: Test @ 2338.75 MHz

Sirius Terrestrial signal: Input @ transmitter input: -20 dBm.
Modulation: OFDM (DQPSK carriers)
Bandwidth: 4.096 MHz
Frequency: Test @ 2326.25 MHz
(Base stimulus present)

Single-Tone Sweep: -81.6 dBm, swept from 2312 to 2352 MHz in 1 MHz increments
(Base stimulus present)

WHERE:
Base stimulus is defined as follows:
Base Satellite signal: Input power @ transmitter input: -66 dBm.
Modulation: QPSK
Bandwidth: 3.77 MHz
Frequency: 2334.385 MHz

Testing with base stimulus is considered to be only an advantage to attaining certification; test data without use of base stimulus shall also be considered a basis for certification.