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Peak Radiated Power Measurement of the DOE Mark II Container Tag with Integrated ST-676 Sensor Radio Frequency Identification Device

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Abstract

The total peak radiated power of the Department of Energy Mark II container tag was measured in the electromagnetic reverberation chamber facility at Sandia National Laboratories. The tag's radio frequency content was also evaluated for possible emissions outside the intentional transmit frequency band. No spurious emissions of any significance were found, and the radiated power conformed to the manufacturer's specifications.

Acknowledgement

This work was sponsored by Dr. James M. Shuler, manager of the Department of Energy (DOE) Packaging Certification Program, within the DOE's Environmental Management, Office of Packaging and Transportation. The author is indebted to Dr. Shuler for his overall support, guidance, and vision in pursing advanced technologies that enhance the safety and security of nuclear materials.

The author also wishes to recognize Dr. Yung Liu, Argonne National Laboratory (ANL), for his assistance and technical interchanges related to the design and operation of the DOE/ANL Mark II tag. This effort could not have been accomplished without Dr. Liu's support.

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Nomenclature

ACF	antenna calibration factor
DOE	Department of Energy
EM	Environmental Management
HERO	Hazards of Electromagnetic Radiation to Ordnance
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
Mk	Mark
mW	milliwatt
MHz	Mega Hertz
RF	radio frequency
RFID	radio frequency identification
RTCA	Radio Technical Commission for Aeronautics
Savi	Savi Technology, Inc. [Lockheed Martin Company]
SMR	Savi Mobile Reader
SNL	Sandia National Laboratories
SR	Savi Fixed Tag
ST	Sensor Tag

Peak Radiated Power Measurement of the DOE Mark II Container Tag with Integrated ST-676 Sensor Radio Frequency Identification Device

1 Introduction

The Department of Energy (DOE) Packaging Certification Program, within the DOE Office of Packaging and Transportation (EM-45), has developed the Mark II (Mk-II) radio frequency identification (RFID) tag for the tracking and monitoring of nuclear materials during storage and transportation [1]. The Mk-II tag design has integrated the sensor tag (ST) -676 sensor RFID tag, which provides all RF communications in conjunction with other functions. The ST-676 is a commercial off-the-shelf product developed by Savi Technology, Inc. for use with International Organization for Standardization (ISO) shipping containers [2]. A Savi ISO container tag system is comprised of ST-676 RFID sensor tags, tag interrogators (Savi Mobile Reader [SMR]-650) handheld units [3] and/or Savi Fixed Reader [SR]-650 units [4]), and a host computer. The potential uses of the Mk-II tag in venues where explosives and ordnance could reside require the tag's RF emanations to be thoroughly characterized for safety.

2 Goal

The goal of this effort was to characterize the total radiated power and RF spectrum content for the Mk-II RFID tag. The data are required for the completion of safety studies related to the Hazards of Electromagnetic Radiation to Ordnance (HERO). The Mk-II tag and the SMR-650 Savi handheld interrogator unit used for the characterization testing are shown in Figure 2.1.

Figure 2.1. Mk-II ST-676 RFID tag (left) and handheld interrogator unit.

3 Measurement Techniques

3.1 Overview

Two standards exist for the measurement of radiated emissions within a reverberation chamber: 1) DO-160F, published by the Radio Technical Commission for Aeronautics (RTCA) [5], and 2) draft 61000-4-21 Ed. 2.0, published by the International Electrotechnical Commission (IEC) [6]. Use of the draft 61000-4-21 Ed. 2.0 was desirable because of its inclusion of mode stirring techniques for radiated power measurement. Both standards were used for chamber calibration and qualification to minimize potential concerns associated with the draft IEC standard.

One Mk-II measurement challenge was associated with the stand-alone operation mode of the ST-676 that produces intermittent bursts of RF at intervals of approximately every 10 seconds versus an ideal continuous transmission. This issue was addressed by using the spectrum analyzer's peak hold mode that enables the instrument to continuously scan over a long period of time until the acquired spectrum stabilizes. For the Mk-II tag, this would typically take about 20 minutes.

A second measurement challenge arose because of the unavailability of antenna radiation pattern data for the ST-676. Without antenna pattern data, anechoic chamber measurements over the entire 4π solid angle would be required to establish the total radiated power. Such a measurement process would be both extremely time consuming and expensive. Therefore, the reverberation chamber measurement methods were used given in the draft IEC 61000-4-21 Ed. 2.0 standard.

3.2 Sandia Reverberation Chamber Facility

A reverberation chamber is an enclosure that has highly conducting walls, floor, and ceiling. RF energy transmitted from a device is continuously reflected from each of these surfaces with very little absorption. As a result, peaks and nulls of the device's radiation pattern are smoothed, giving the appearance of transmitting isotropically. Nearly all reverberation chambers also have a mode-stirring mechanism that enhances this effect. By properly calibrating a reverberation chamber, the total radiated power can be captured in a single measurement. This was the technique used to measure the total radiated power of the Mk-II tag.

The interior of the Sandia National Laboratories (SNL) reverberation chamber used for characterization of the MK-II tag is shown in Figure 3.1. The chamber is a welded aluminum enclosure that is 37 feet deep, 23 feet wide, and 13 feet high. The rotating paddle mechanism, with its intersecting red axle used to mode stir the chamber, can be seen in the upper half of Figure 3.1.

Figure 3.1. Sandia reverberation chamber.

3.3 Radio Technical Commission for Aeronautics Standard

The RTCA is a private, non-profit corporation that develops recommendations regarding communications, navigation, surveillance, and air traffic management system issues. Its recommendations are used by the private sector and the Federal Aviation Administration as the basis for policy, program, and regulatory decisions. The RTCA has published a test standard [5] that addresses, in part, the qualification and calibration of reverberation chambers for radiated emission measurements.

The qualification procedure is summarized as follows:

1. A transmitting antenna is placed inside the chamber but outside the working volume of the chamber. A receive antenna is placed inside the working volume of the chamber.
2. A calibrated electric field (E-field) probe is placed at one of the eight corners defining the working volume of the chamber.
3. An RF source is set to the lowest test frequency and is adjusted to inject an appropriate input power into the transmit antenna.
4. The stirrer/tuner is rotated through 360 degrees in discrete steps.
5. Various measurements taken by the E-field probe are recorded: the value of the input power averaged over a complete rotation of the stirrer, average and maximum of the received power, and the maximum vector field strength.
6. Steps 3–6 are repeated in log-spaced frequency steps to the maximum test frequency of at least 10 times the starting frequency.
7. Steps 2–6 are repeated with the E-field probe at each of the eight corners of the test volume and at the exact center of the test volume. The receive antenna is

moved to a new random location and orientation for each of the nine E-field probe positions.

8. All E-field data are normalized to the square root of the measured input power.
9. The standard deviation of each of the three E-field components, as well as the standard deviation for all individual components taken together (27 measurements), must fall within the specification.

The calibration procedure is summarized as follows:

1. An antenna calibration factor is calculated for an empty chamber by averaging the ratio of the received power to the input power over the nine locations described above for each test frequency.
2. A chamber calibration factor is determined for the actual device under test by placing the unpowered device in the chamber and measuring the ratio of received to input power for at least one location of the receive antenna.
3. A chamber loading factor is calculated as the ratio of the chamber calibration factor to the antenna calibration factor determined in step 1 above. In this case, the Savi RFID tag did not measurably load the reverberation chamber, and an intermediate step of determining a maximum allowable loading was skipped.
4. The radiated emission power is determined by:
5. Measuring the ratio of the input power to the received power and multiplying by the antenna efficiency. This process will determine the chamber insertion loss. An antenna efficiency of 0.75 is typical for the log periodic antenna
6. Setting the spectrum analyzer to peak detect mode and the display to peak hold mode.
7. Terminating the transmit antenna in a 50 Ω load. The transmit antenna remains in the chamber for the test, even though it is not used directly.
8. Setting the device under test to operational mode.
9. Measuring the received power.
10. Calculating the transmitted power; it is the numerical product of the received power and the insertion loss.

Additional emission power measurement details are provided in Ref. 4.

3.4 International Electrotechnical Commission Standard

The International Electrotechnical Commission (IEC) is an organization that prepares and publishes international standards for all electrical, electronic, and related technologies. The IEC also manages conformity assessment systems that certify that equipment, systems, or components conform to its international standards. The IEC has published the standard *Electromagnetic compatibility (EMC) - Part 4-21: Testing and measurement techniques - Reverberation chamber test methods* [6]. This standard presents a second competing calibration standard option for reverberation chambers. The first edition of this standard was published in 2003 and is currently being revised. The revised version is

scheduled for release in a 2010 as edition 2.0 [6]. The methodology of the draft edition 2.0 was used in this work.

The methodology specified in the IEC standard is similar to the RTCA standard, but has the following differences as related to this work:

- Only eight locations of the E-field probe at the corners of the working volume are required versus the additional ninth center measurement location required by RTCA.
- The electric field standard deviation requirements to qualify the chamber are more stringent.
- Mode-stirring using continuous motion of the tuner is allowed. (Mode-stirring techniques are generally preferred. The calibration factors determined in this manner have been used to establish the peak radiated power for the Savi RFID tag.)

3.5 Description of Peak Radiated Power Measurement

To measure RF radiated power, a spectrum analyzer[1]was connected to a log periodic antenna[2] located inside the chamber using low-loss coax cable to connect both units. The antenna was positioned in accordance with RTCA DO-16F guidance, and the spectrum analyzer was set to peak detect mode as also described in DO-16F. The analyzer was then allowed to scan continuously until the spectrum stabilized and peaks ceased to increase.

Two separate spectrum measurements were taken. The first acquired data for approximately 30 minutes to provide some margin above the 20 minutes typically required for the captured spectrum to stabilize. To ensure that no emissions were missed, a second measurement taken over a two-hour period. Both measurements produced the identical result of 0.14 mW peak radiated power as discussed in the following chapter.

4 Results

4.1 Chamber Qualification and Calibration

4.1.1 RTCA DO-160F Qualification

The SNL chamber qualification was performed in accordance with DO-16F; results shown in Figure 4.1. These data show that the chamber has adequate uniformity for all frequencies above 100 MHz. The MK-II tag with ST-676 operates at approximately ±434 MHz, with a chamber variation at this frequency of less than 2 dB.

[1] Agilent Spectrum Analyzer Model 4446A, 3 Hz to 4 GHz
[2] Amplifier Research Log Periodic Antenna, Model AT1000

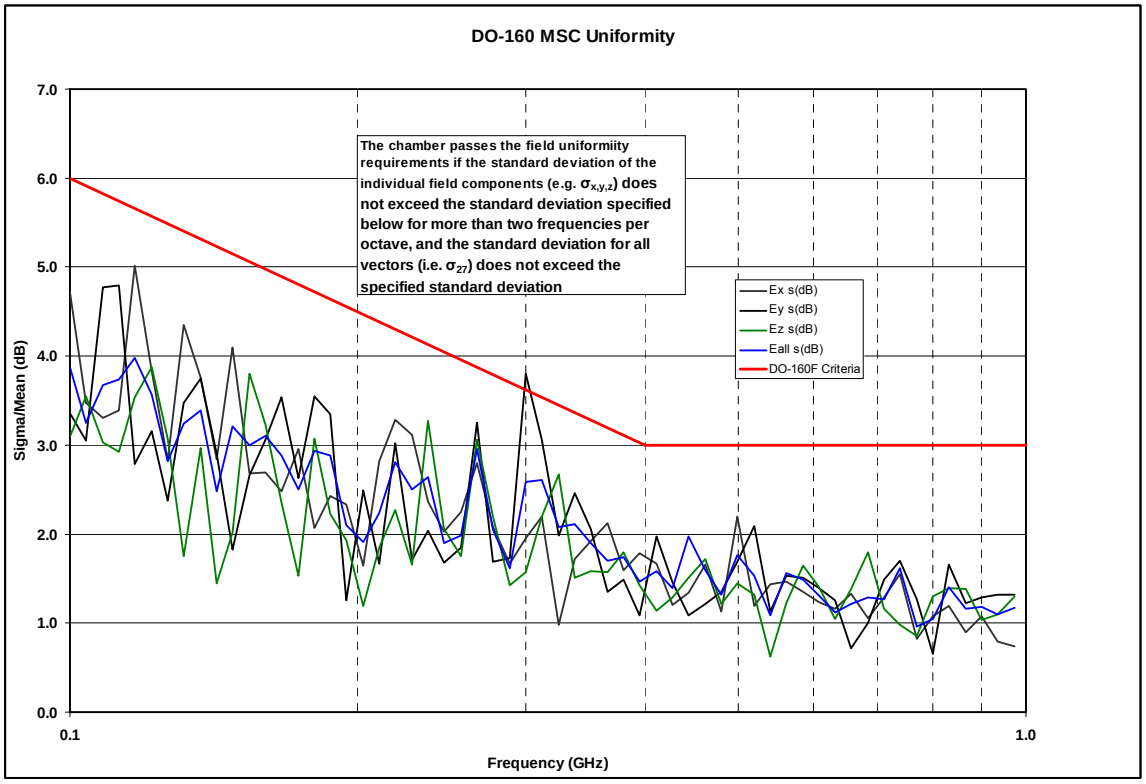

Figure 4.1. SNL reverberation chamber qualification in accordance with RTCA standard DO-160F.

4.1.2 IEC 61000-4-32 Calibration

A second independent chamber qualification was performed in accordance with 61000-4-21; results are shown in Figure 4.2. These data show that the chamber has adequate uniformity for all frequencies above 125 MHz and are consistent with the DO-167F qualification results. This result is acceptable for the measurements on the Mk-II tag with ST-676 since there were no emissions at these low frequencies.

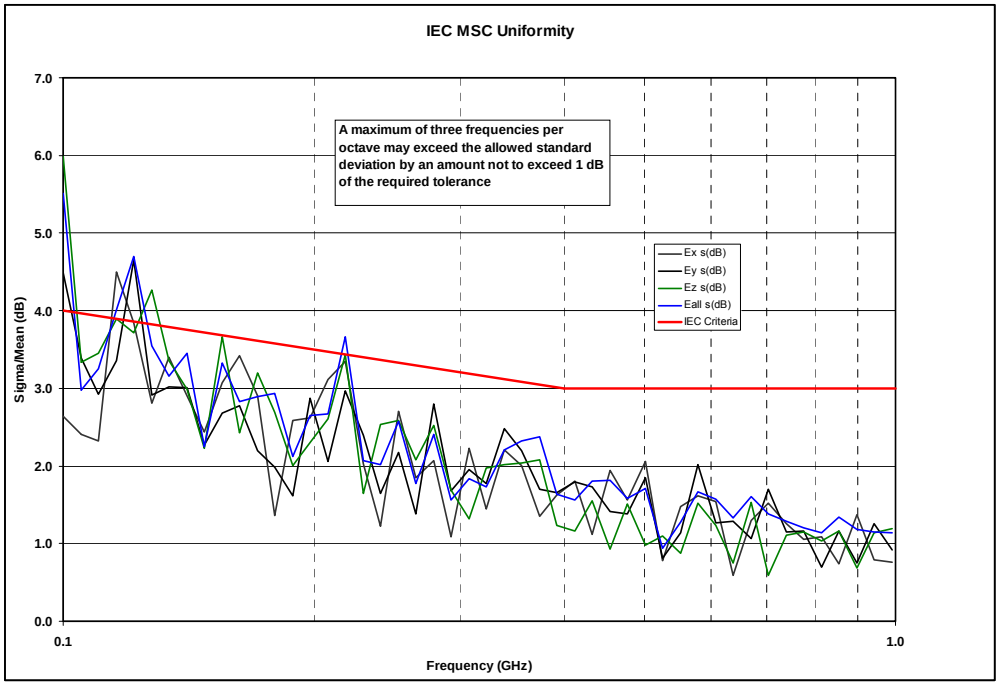

Figure 4.2. SNL chamber uniformity in accordance with the IEC 61000-4-21 Ed. 2.0 draft standard.

The receive antenna calibration factor (ACF) for the chamber empty was calculated in accordance with draft 61000-4-21 Ed. 2.0 Section B.1.2 and plotted in Figure 4.3. The chamber's insertion loss when empty was calculated in accordance with draft 61000-4-21 Ed. 2.0 Section B.1.3 and also plotted in Figure 4.3. The ACF and IF are used in the radiated power calculations.

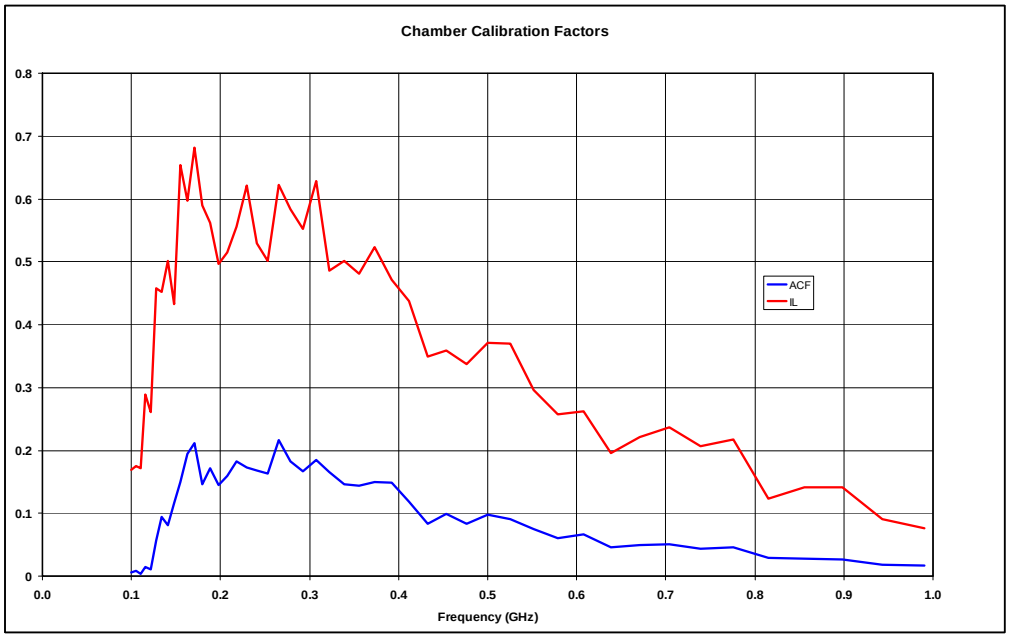

Figure 4.3. Calibration factors for the SNL reverberation chamber.

4.1.3 Chamber Loading Results

To establish the chamber loading factor, an unpowered Mk-II tag was positioned within the chamber. Three measurements were then performed to determine the chamber loading factor as a function of frequency. No measurable loading of the chamber could be detected and therefore the chamber loading factor was established as unity. This loading factor was used in calculations to convert power levels to electric field levels.

4.2 Mk-II Tag with ST-676 Device Results

4.2.1 Spurious Emissions

The spectrum content of radiated emissions over the range of 100 MHz to 900 MHz is shown in Figure 4.4. Two very small spurs were noted at 423 MHz and 868 MHz. The 868 MHz peak is the second harmonic of 434MHz and is 56 dB down. It is unclear if the 423 MHz peak is intentional. Because this emission is 52 dB down from the 434 MHz peak, there is effectively no energy in this peak or the one at 868 MHz. Overall, this is a very clean spectrum. This spectrum peak is in agreement with the manufacturer's stated value of 433.92 MHz.

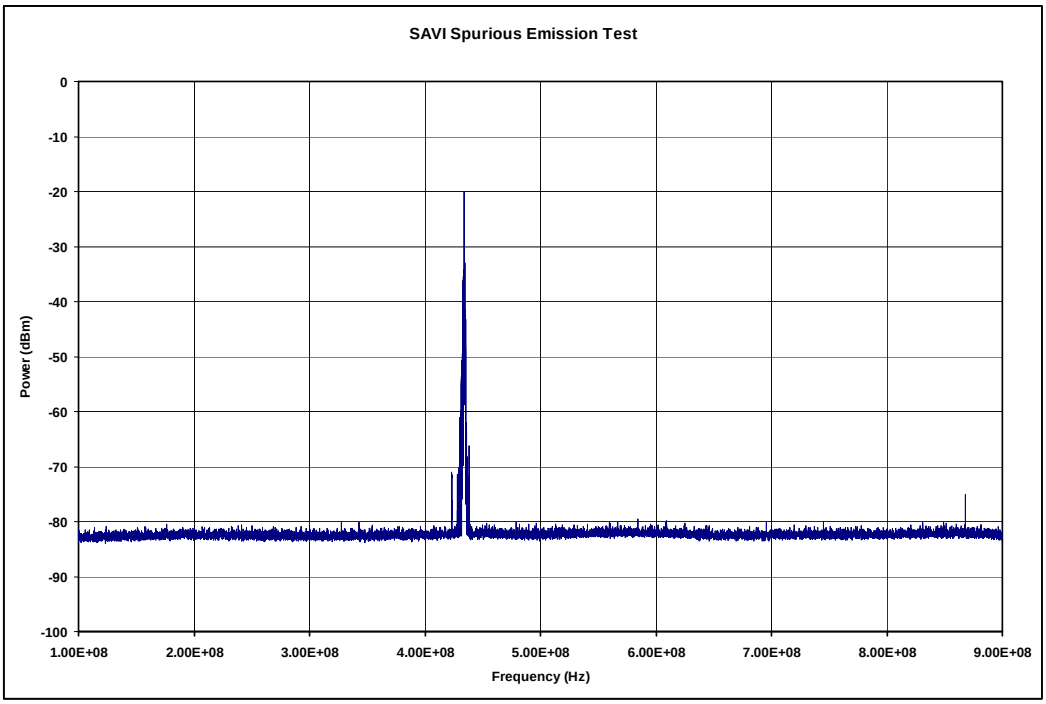

Figure 4.4. Mk-II ST-676 RFID tag spurious emission.

4.2.2 Measurement of Peak Radiated Power

Two measurements of the peak radiated power were made following the procedure described in Section 3.5. Shown in Figure 4.5 and Figure 4.6 are plots for the 30-minute and 2-hour scan respectively. The total power was determined by integrating the spectra over all frequencies. In both cases the total radiated power was determined to be 0.14 mW. These results are in agreement with the manufacturer's stated value of 0.15 mW.

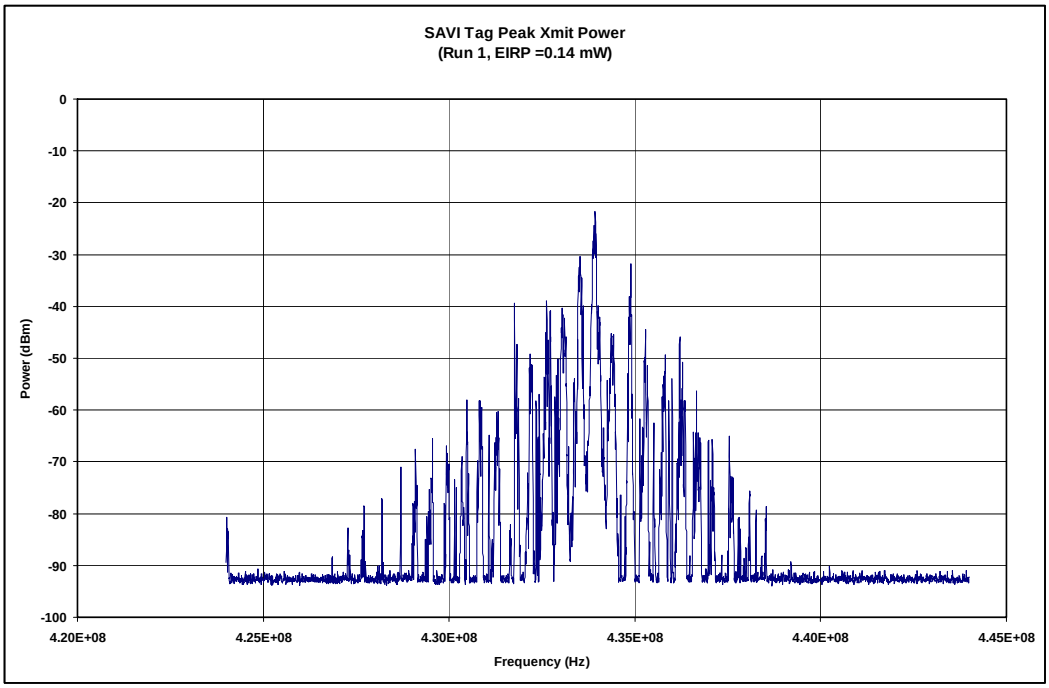

Figure 4.5. Detailed spectrum for Mk-II ST-676 RFID tag (scan time: 30 minutes).

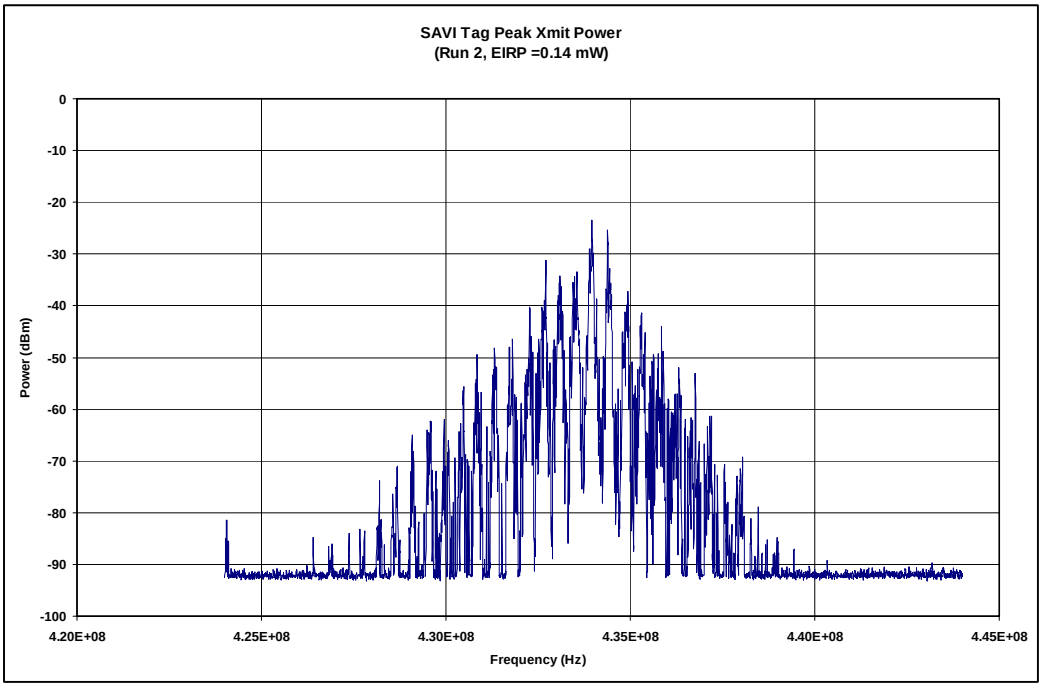

Figure 4.6. Detail spectrum for Mk-II ST-676 RFID tag (scan time: 2 hours).

5 Conclusion

The Mk-II ST-676 RFID tag was evaluated for both spurious emissions and total peak radiated power. No significant unintentional emissions were found. In addition, the measured value for peak radiated power was 0.14 mW, which is in excellent agreement with the manufacturer's stated value of 0.15 mW.

6 References

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