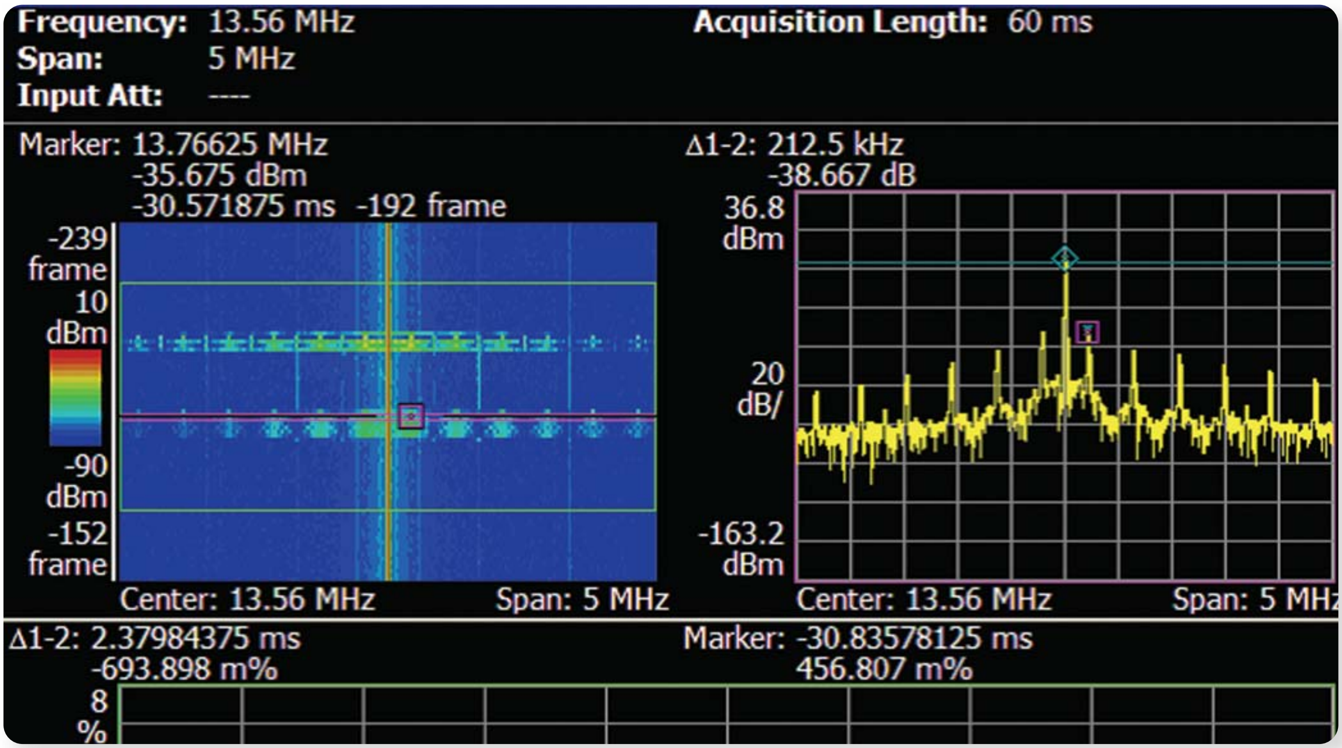
Evaluating and Optimizing Radio Frequency Identification (RFID) Systems Using Real-Time Spectrum Analysis



Key technical issues in the deployment of RFID systems are global interoperability and radiated emissions conformance. The main purpose of this application note is to demonstrate using a Real-Time Spectrum Analyzer to evaluate an RFID system's compliance to ISO/IEC standards as well as government regulations regarding intentional transmitters (i.e. FCC 47 part 15, ARIB STD-T82, and EN 300 330). ISO/IEC 18000-3 (Parameters for RFID Air Interface Communications at 13.56 MHz) will be specifically referenced as many regulations governing other RFID frequency bands are very similar in their requirements.

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RFID Polling and Timing Measurements

The Real-time Spectrum Analyzer (RSA) allows a user to see a complete time record of reader and tag interaction using over-the-air trigger, memory capture, and de-modulation of analog and digital signals. Should polling time be delayed, it is possible to analyze the cause.

▶ **Figure 1.** *Example of a setup to test interaction between RFID reader and tag using the RSA3303A and Near Field Probe Set, Tektronix Product number: 119-4146-00*

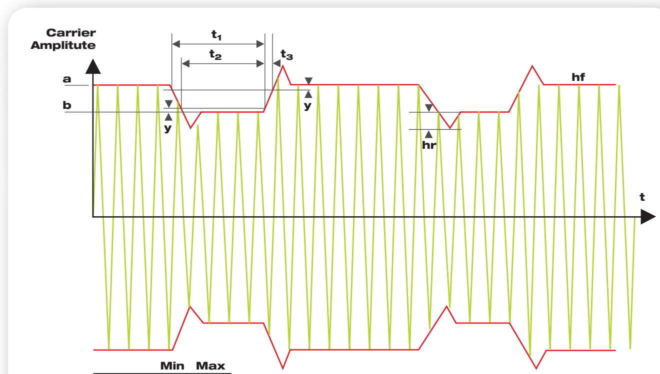
When the RFID reader/interrogator searches for a tag it is referred to as “polling”. Associated with polling is a number of timing measurements called out in various RFID standards. One key timing measurement is “turn around time”, both for transmit to receive and receive to transmit modes. Using the RSA to capture the interaction, a simple delta marker function is used to measure the time gap between the end of transmit from the reader and response from the tag, and vice versa.

Other timing measurements are “dwell time” or “interrogator transmit power on ramp”, “decay time” or “interrogator transmit power down ramp” and “pulse pause” timing. These specifications are usually given in the form of a mask as seen in Figures 2 and 3.

Dynamic Range (Vertical Resolution)

While an oscilloscope is certainly a useful bench tool in RFID applications, the RSA is optimized for the types of RF measurements required for conformance testing and optimizing of RFID systems.

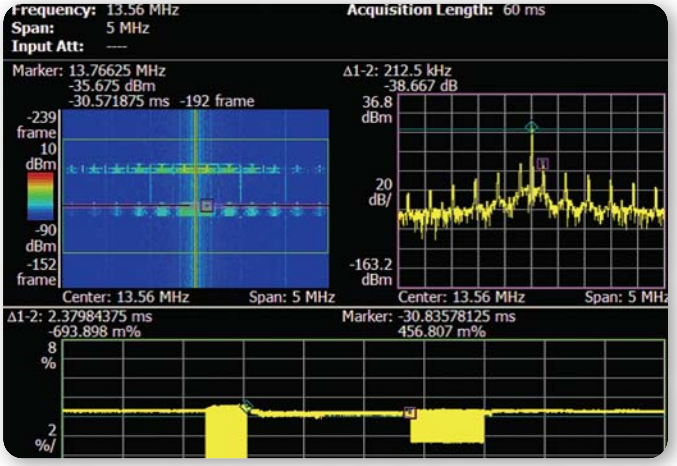
For example, the RSA offers the advantage of a significant increase in dynamic range over use of an oscilloscope. This is important in RFID testing because the response from the tag is often at the same frequency as the reader but at a significantly lower power level (on the order of -80 dB).



	Min	Max
t_1	6,0 µs	9,44 µs
t_2	3,0 µs	t_1
t_3	0	9,44 µs
modulation index	10%	30%

y	0,005 (a-b)
hf, hr	0,1 (a-b) max

▶ **Figure 2.** *Example Timing mask from reader to tag (ref: ISO/IEC 18000-3 and MIT-AUTOID-TR-011)*



▶ **Figure 3.** *Example of polling measurement with the Tektronix RSA 3308A*

Figure 3 shows the multi-domain view of an RFID system interaction. In the upper left we see the spectrogram display, upper right is the frequency domain, and at the bottom of the screen we see the AM demodulation. Previously, in order to see the signal in all these domains (Spectrogram, Frequency, and Demodulation) required the use of an oscilloscope, swept spectrum analyzer, and Vector Signal Analyzer (VSA).

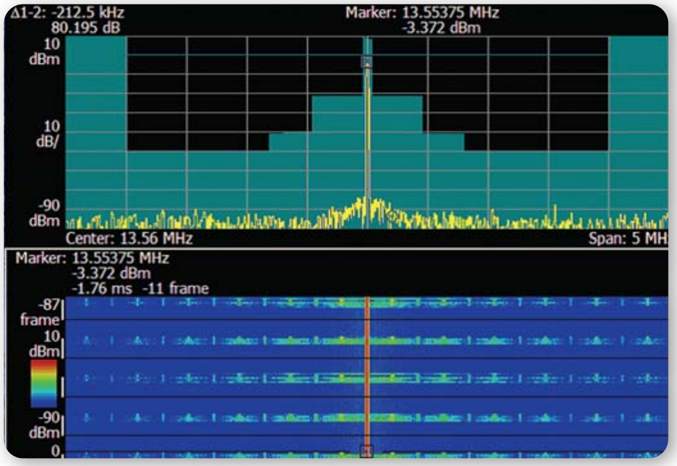
After triggering on the over the air signal and storing it into memory, we analyze the signal. A reference cursor is placed at the end of the 100% ASK modulated signal from the reader and a second marker at the 10% load-modulated ASK response from the tag. When using a 5 MHz span, the RSA offers 156.25 ns of time domain resolution, easily enough to determine compliance and optimize the system for response time.

Collision Management

The RSA offers the ability to store signals to internal memory for post-capture analysis. This can be very useful for measuring interaction with multiple tags in order to verify collision management. ISO/IEC 18000-3 section 6.2.7.9 calls for reading 500 tags within 390 ms. It also calls for reading 50 words of data within 930 ms from static tags, and 944 ms from active tags. If only using a PC to time stamp the interactions and test for compliance, there is no way to know why the interaction takes so long, at which point a is collision occurring, or where there is a particular tag that is being problematic. However, by using the RSA and monitoring the over-the-air interface during polling, it is possible to troubleshoot when a collision occurs and determine the cause (i.e. interference, faulty tag, hopping pattern error, etc.)

The Tektronix RSA3300A Series Real-Time Spectrum Analyzer allows a user to set up a record length of seconds, minutes, or even hours, depending on the frequency span. In instances where Frequency Hopping is utilized, the RSA can seamlessly capture and record signals in a 15 MHz bandwidth, often allowing all RFID uplink and downlink channels to be viewed and analyzed.

Figure 4 shows the RSA display of numerous tag/reader interactions. If desired, no trigger event need occur; the RSA will simply gather data without any time gaps in a “free-run” mode for the length of the time record set by the user, then either re-acquire and overwrite or stop acquiring and wait for further input from user (store current data, reacquire, etc.).



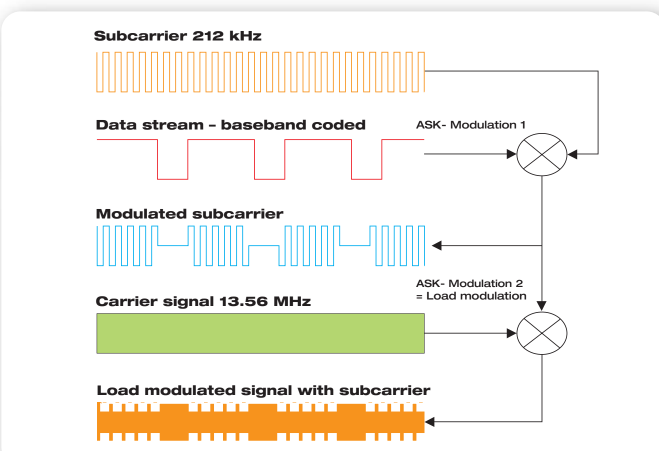
▶ **Figure 4.** *RSA capture of multiple tag interactions. Spectrogram (bottom of display) shows a time record which can be scrolled through allowing a user to view all signals present in the entire frequency span. All signals at the corresponding instant in time are also displayed in the frequency domain window (top of display).*

Modulation Rate and Quality

The RSA permits measurement and analysis of both interrogator and transponder modulation rate and quality. The modulation used in RFID (as defined by ISO/IEC 18000-3) is typically ASK (either 10% or 100%) for the downlink (reader to tag) and load modulation for the uplink with a rate defined as a division of the carrier.

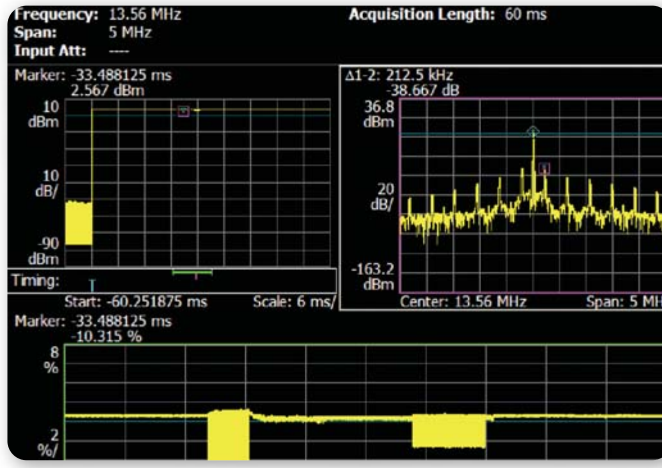
The load modulation produces Sub-carriers, which utilize Binary Phase Shift Keying (BPSK) modulation.

Figure 5 diagrams this approach.



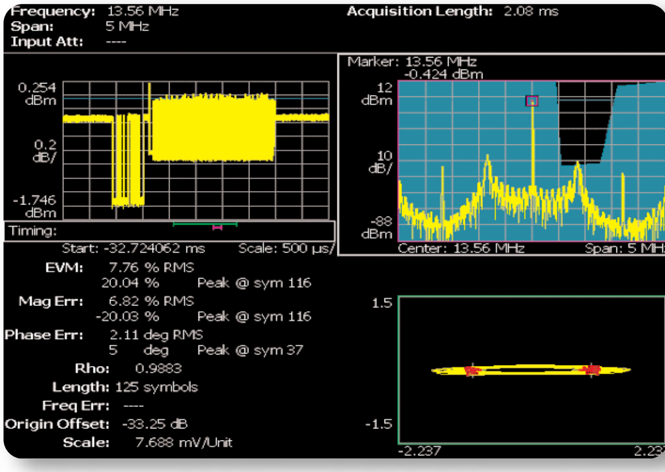
▶ **Figure 5.** *Load modulation diagram*

Load modulation appears in the frequency domain as sidebands offset by the subcarrier frequency from the transmission frequency. Figure 6 shows a load modulated 10% ASK with a 212 kHz (13.56 MHz ÷ 64) subcarrier. In the upper right, we see that a simple delta marker function shows the load modulation frequency. The bottom display reads out the 10% ASK. The upper left shows power versus time and can be used to measure the constant power of the transmission signal.

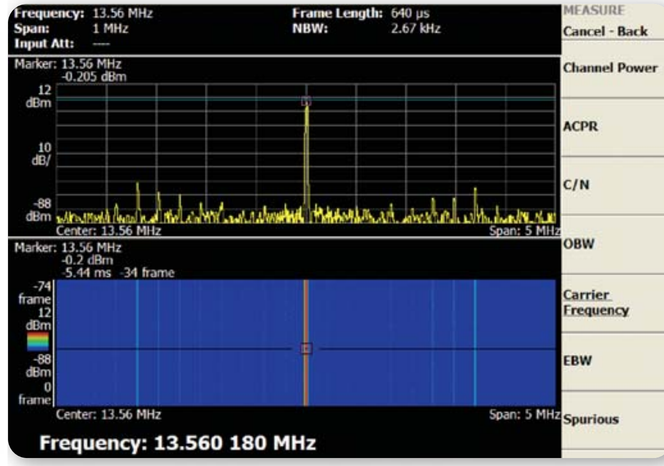


▶ **Figure 6.** *Example of transponder modulation quality measurement with the Tektronix RSA 3308A*

Future development of RFID devices will include more complex modulation. As technologies such as Software Defined Radio (SDR) are implemented in Dedicated Short-Range Communications (DSRC) and other applications, the RSA's benefits will be even more pronounced. The RSA offers the ability to demodulate complex digital signals such as QPSK, GMSK, QAM, etc. Also available are baseband (I, Q) inputs, both balanced and differential, so that an SDR modem output can be directly input to the RSA. It is possible to simultaneously view three domains (constellation, frequency, time, or spectogram), as well as display signal quality measurements (EVM, Frequency Error, etc.). This is illustrated in Figure 7.



▶ **Figure 7.** *Demodulation of BPSK Sub-carrier signal showing: power vs. time, frequency domain (with frequency mask trigger enabled), constellation diagram, and modulation quality measurements.*



▶ **Figure 8.** *Example of frequency deviation measurement with the Tektronix RSA 3308A*

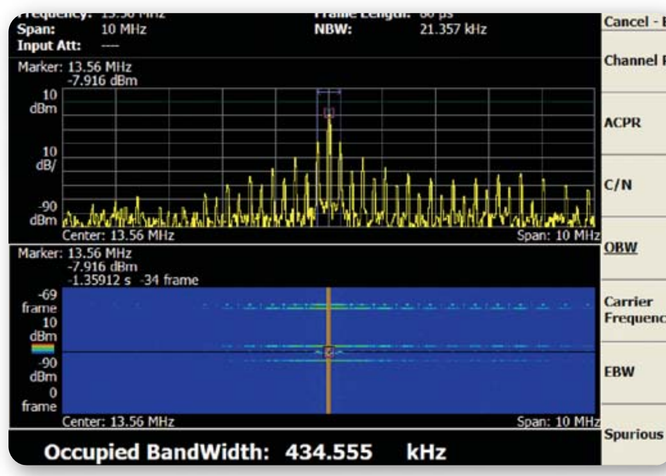
Frequency Deviation

Bending tags or placing them in close proximity to conductive objects and other tags can detune the tag antenna, preventing them from going into resonance and thus either becoming inoperative or significantly reducing the operating range. Consequently, frequency deviation measurements are critical to ensuring compliance with various RFID and transmitter standards.

The Tektronix RSA can make frequency measurements with a resolution of 1 Hz and excellent accuracy. For example, frequency accuracy for a 13.56 MHz RFID interrogator is typically specified at +/- 7 kHz. By simply enabling the "carrier frequency" feature on the RSA, a user can scroll through the captured reader/tag interaction and measure to an accuracy of +/- 4 Hz.

Occupied Bandwidth

Like frequency deviation measurements, occupied bandwidth measurements ensure compliance with standards designed to prevent interference with other signals. Figure 9 shows a reader signal being measured for compliance with ISO/IEC 18000-6, which allows 423.75 kHz +/- 40 kHz for a single subcarrier modulated signal.

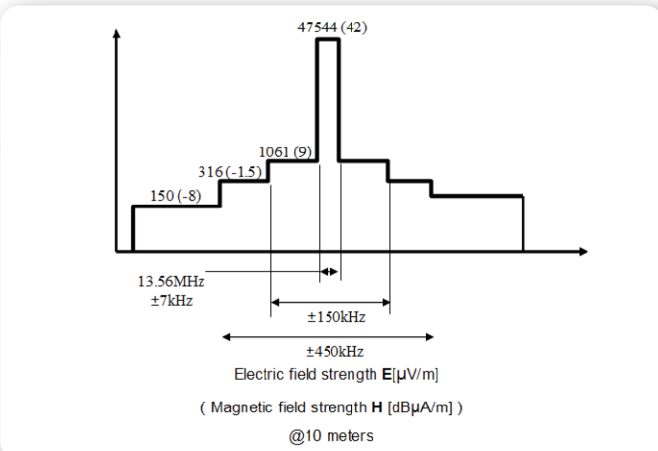


▶ **Figure 9.** *Example of occupied bandwidth measurement with the Tektronix RSA 3308A*

Interrogator Transmission Spurious Emissions and EIRP (Field Strength)

RFID readers and tags are "intentional transmitters" that fall under regional regulations such as: FCC 47 part 15 in the United States, EN 300 330 in Europe, and ARIB STD-T60/T-82 in Japan. As RFID heads towards global acceptance, the most stringent of these regulations will apply.

Also under close scrutiny is the effect of human exposure to RFID electromagnetic fields as spelled out in documents such as IEEE C.95-1 and EN50364.

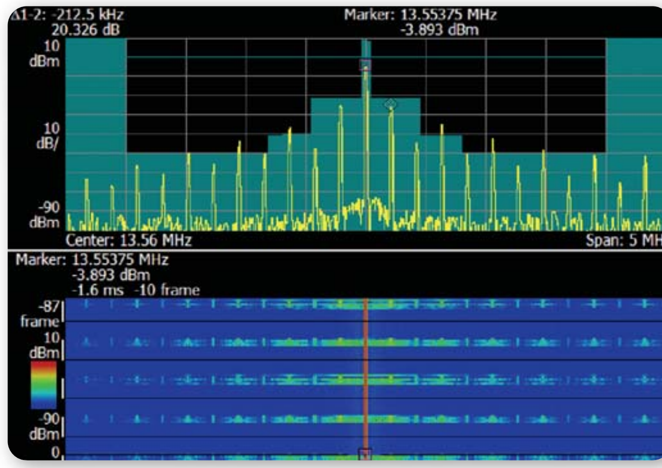


▶ **Figure 10.** *Example of a radiated emissions mask*

Various regulations will spell out limits in different units. The power flux density **S** [mW/cm^2], electric field strength **E** [V/m], and magnetic field strength **H** [A/m] are interchangeable according to the equation below.

$$S=E^2/3700=37.7H^2 \qquad (1\text{-}1)$$

By use of a directional antenna (and, in some cases, a pre-amplifier), Effective Isotropic Radiated Power (EIRP) and field strength measurements can be made. Frequency Mask Trigger allows a user to create a pass/fail mask by using the mouse to literally draw the allowable EIRP parameters, as shown in Figure 11.



▶ **Figure 11.** *A Frequency Mask is drawn which, when violated (as shown here), triggers the RSA to capture and store the spectral data. A TTL signal is also sent from the trigger output of the RSA, this can be used to trigger an alarm or recording device. The white bars to the left of the spectrogram display represent trigger points, the top of the white bar being the instant in time that the mask was violated. Both pre and post trigger data is available for analysis.*

Conclusion

The Tektronix Real-Time Spectrum Analyzer (RSA) delivers unique solutions and advantages for designers working with RFID signals of all kinds. Only the RSA offers the over-the-air triggering, memory storage, and analysis features to help designers understand the full range of RFID interrogator and transponder behavior. The RSA is the solution that can go forward with emerging trends in RFID design.

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Last Update August 13, 2004

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09/04 AD/WOW 37W-17155-1

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