System-Level Design and Verification of Wireless Embedded System to Meet Global Demands Using a Mixed Domain Oscilloscope

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Designing and implementing wireless systems to be used in different geographic regions around the world represents a significant challenge. Wouldn't it be nice if everyone all agreed on the use of frequency, modulation type, power levels, and bandwidth? Unfortunately, that's not the world we live in and radio regulations vary from region to region, especially for some of the frequencies used in unlicensed radio control and telemetry applications.

For some applications, standardized radios operating at 2.4 GHz (for example Bluetooth, ZigBee, or Wi-Fi) can be used almost anywhere in the world. However, for other applications, improved building penetration, less interference, and lower power consumption of lower frequency radios may be a better option. The task in this case is to optimize and verify radio integrated circuits (ICs) for the same application, but for use in different geographic regions.

These radio ICs and modules typically have dozens of set-up registers to allow flexibility. In order to meet the requirements of different markets including power, frequency, and occupied bandwidth, the engineer must be able to verify the RF operation of the radio, as well as to confirm that the commands and data sent to the radio are correct.

In the past, this was a difficult task due to the need to correlate the RF output of the radio transmitter while simultaneously reading control signals including the ability to trigger on and decode SPI and other buses, as well as measuring current draw, power supply voltages, and other analog and digital signals. Typically this involved the use of an oscilloscope together with a spectrum analyzer to make measurements and then to manually correlate the captured signals. Recently, Tektronix introduced the mixed domain oscilloscope (MDO) that combines an oscilloscope and spectrum analyzer in a single instrument.

Understanding the Regulations

When it comes to propagating signals throughout a building, radio ICs in the range of 900 MHz are more effective than those in the 2.4 GHz band. These ICs can be used in most parts of the world and offer the flexibility to be configured differently to comply with local regulations. It helps to start with a clear understanding of what's allowed in the different regions you're targeting.

In much of Europe, unlicensed radio systems are permitted in the range of 868 MHz with enough power to cover up to hundreds of feet in buildings with transmitter power of 25 mW or even higher in some countries and band segments. These systems are also required to have limited occupied bandwidth because of the relatively narrow spectrum segments provided in the regulations.

By contrast, in North America, there is a relatively large allocation of unlicensed spectrum around 915 MHz (902 to 928 MHz). However, to transmit with more than a small fraction of a milliwatt, the signal must be spread over at least 500 kHz of spectrum with further limitations on peak power. The North American market allows the choice of either a narrowband low power application, or wideband higher power application in the 900 MHz spectrum. Frequency hopping can also be used, but this typically requires much more complex software than wideband (digital) modulation. While there is some disadvantage to using the wider bandwidth signal, it can provide higher data throughput. The wider bandwidth with greater transmitter power will be useable at longer range than the much lower power level of a narrow band signal allowed in North America.

A Microchip Technologies MRF89XA IC on a MRF89XAM8A module was selected to illustrate some of the integration issues and tests that are needed to confirm correct operation. In addition to having a lot of flexibility in operating modes, this IC has low receiver power consumption making it attractive for battery powered applications. For convenience, the same module optimized for the 868 MHz band is used, though slightly different components would typically be needed for North America.

On the instrument side, a Tektronix MDO4104-6 mixed domain oscilloscope was used, because it has the ability to simultaneously display analog signals to 1 GHz bandwidth, 16 digital waveforms including decode of digital data, and RF signals to 6 GHz. All of these signals can be time correlated to show the effects of control signals and analog signals on the RF time and frequency domains.

To illustrate the signals that need to be measured to assure correct operation of the two transmitter modes, a Microchip Explorer 16 demonstration board was used to control the radio module and allow connection of the oscilloscope. **Figure 1** shows the setup used.

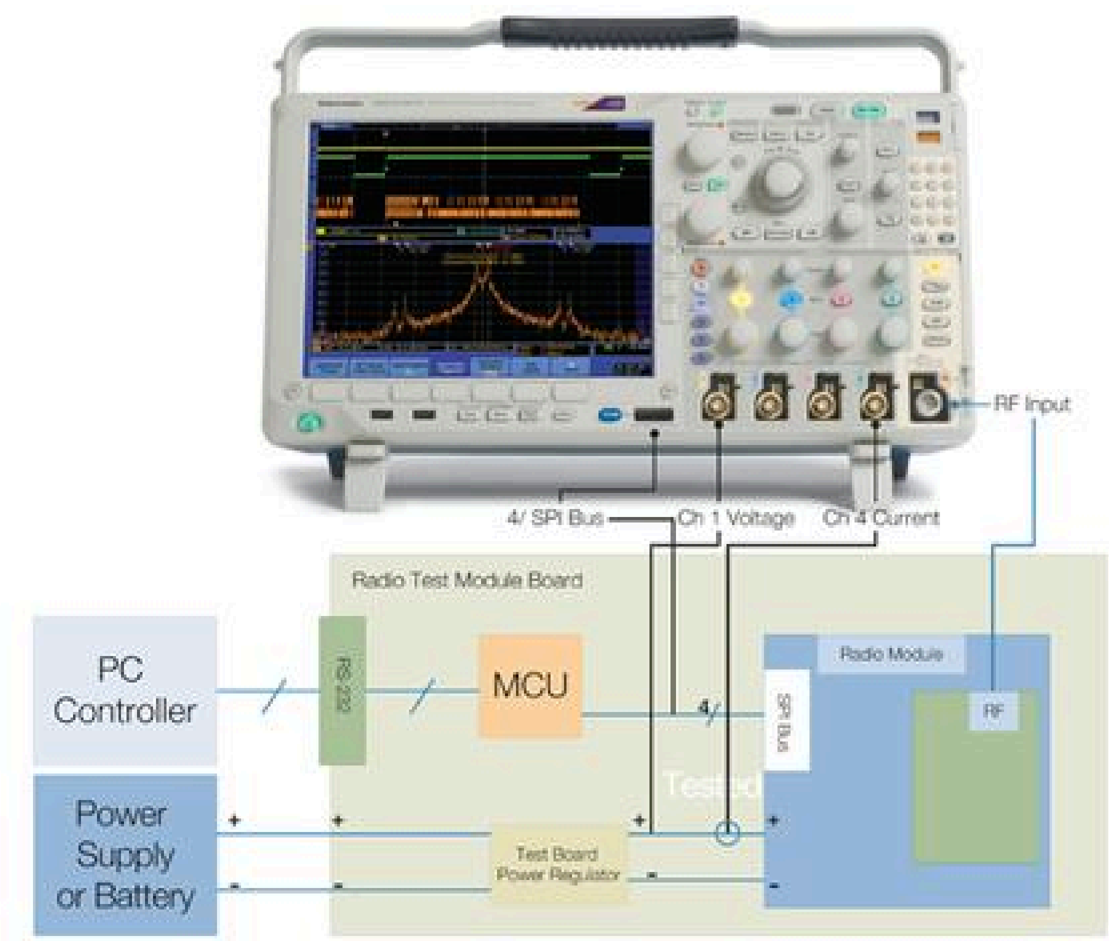

Figure 1 *–Test connection between the device under test (Microchip MRF89XA module) and the Mixed Domain Oscilloscope.*

Performance Settings and Measurements

For most of Europe in the 868 MHz band, up to 25 mW with a bandwidth typically of 100 kHz is allowed (depending on the particular sub-band). For this system, set it up to transmit FSK (frequency shift keyed) at 5 kbits per second with a nominal deviation of 33 kHz. The orange bar in **Figure 2** shows the spectrum of this signal captured during the preamble portion of the transmission to be about 4ms, as well as several time domain traces on the same time scale. The Spectrum Time is determined by the Window Shaping Factor divided by the resolutions bandwidth (RBW). For this example, a Kaiser Window function with a shaping factor of 2.23 and a 550 Hz RBW requires an acquisition of about 4 ms. The Total Power and Occupied Bandwidth measurements are also displayed in the Frequency Domain Display.

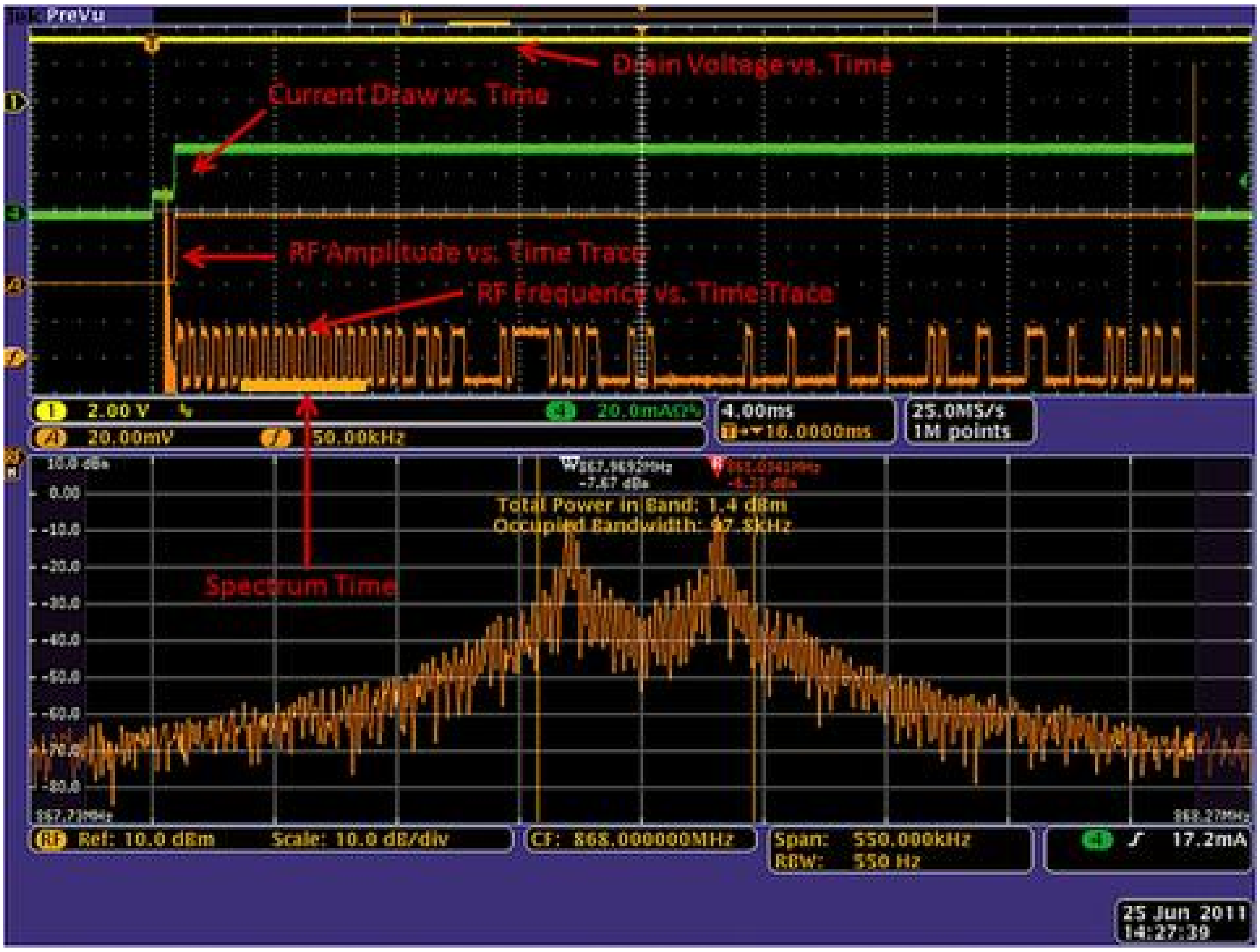

Figure 2 *– Time and Frequency domain views and measurements (note annotations).*

The measured occupied bandwidth during the preamble is 98 kHz which fits the specification for this FSK signal. The output power of 1.4 dBm (just greater than 1 mW) is lower than the target, but can easily be increased to 25 mW or more when country regulations permit with better matching high gain antenna or a simple power amplifier.

In the upper part of the screen, the Green Trace (trace 4) is the current drawn by the module. The Yellow Trace (Trace 1) shows the voltage provided to the module. Trace A is the amplitude of the RF signal. Note that the current initially rises by a few mA as the IC is turned on. Only when the current is at the full 40 mA do we see the RF signal.

The Frequency vs. Time trace, represented by the Orange Trace “f” shows the frequency deviation of the FSK modulation of the signal at 50 kHz per division. This confirms the expected +/-33 kHz deviation in both the spectrum (frequency domain) and in the time domain.

In **Figure 3** the spectrum is taken later in the packet as shown by the new location of the orange bar. The output power is the same, but more of the energy is at the lower of the modulating frequencies which is consistent with the symbol packet representation of the data in the frequency vs. time trace. This capability can be used to find any aberration in the RF output or modulation. The ability of the MDO to provide time correlation of the power supplies, the modulation and the RF spectrum is very difficult to replicate with a separate oscilloscope and standard spectrum analyzer. One option would be to print out and overlay the screens together. This would assume that the two instruments can be triggered together, which is difficult if not impossible.

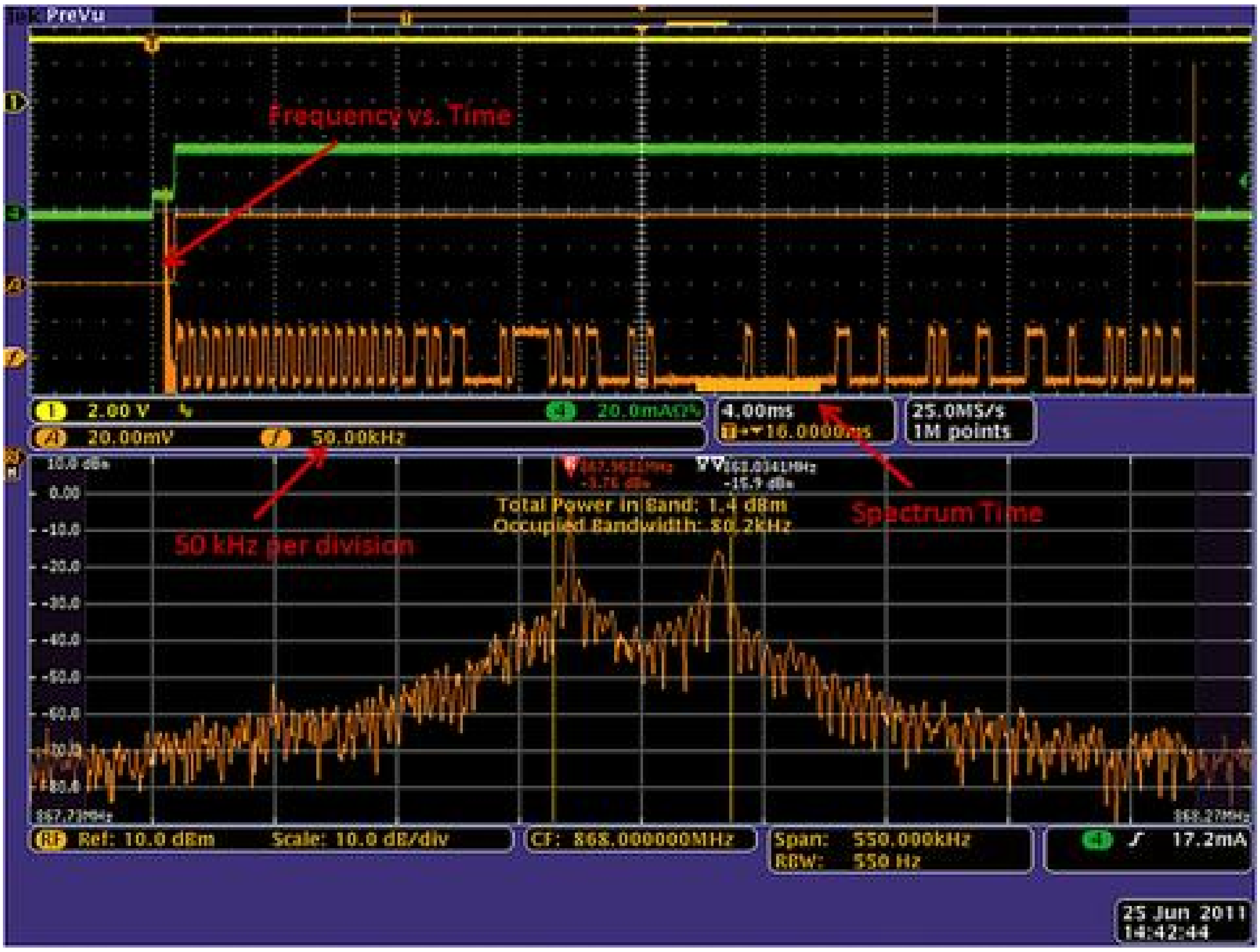

Figure 3 *– Spectrum later in the packet when symbol energy primarily from lower frequency of FSK modulated signal.*

It is also helpful to see the commands being sent to the radio from the microcontroller. With the digital probes connected to the SPI bus going to the radio module, it is possible to then turn on decode of the SPI bus and see the spectrum aligned with the digital data.

The MDO was set to acquire 1 million samples across the screen. Even though the digital signals are quite fast, it is possible to see the data using pan and zoom. **Figure 4** shows the decoded data just before the packet is transmitted. The data that was sent was 0x01, 0x02, …0x08. This data can be seen decoded in the figure. The digital version of the data can also now be read at the bottom of the time domain section of the screen.

Figure 4 *– Decoded data and digital waveforms.*

The Spectrum Time in this display now includes sampled data from the pre-trigger and turn-on behavior as it include samples from when the RF signals are “ON” and “OFF” and is displayed at a reduced power level. By selecting the decode line for commands instead of data, commands can similarly be decoded and checked.

Using a pan and zoom function, **Figure 5** shows the decoded command to read and write the general configuration register. The first pair of bytes in the SPI(MOSI) line reads the general configuration register which returns the value of 30 in the SPI(MISO) line. The second pair of bytes 00 30 sets the general configuration register at address 0 to standby mode in the 868 MHz band.

***Figure 5** – Decoded commands and digital waveforms.*

This approach is useful for confirming that the radio IC is correctly set up. Another technique is to trigger on SPI commands. For example, the instrument could be used to trigger on command 040B which sets the frequency deviation of the transmitter output. The SPI trigger would be set to trigger on a two byte word with the first byte being the command. The remaining commands can be decoded with the assistance of the MRF89XA radio IC data sheet.

Turn-on latency between and SPI command and an RF event can also be evaluated in one display as shown in **Figure 6**. This was done using the SPI(MOSI) trigger condition and setting the frequency deviation, changing the Horizontal Timebase (200 µs/div) and using Zoom out to measure the impact of the SPI command. A current draw was measured on Channel 4 (Green Trace), and the Frequency vs. Time (Orange Trace) now demonstrates an RF signal present almost 700 µs later.

Figure 6 *– Triggering on the SPI(MOSI) command and viewing the Frequency vs. Time trace.*

North American setup under FCC rule 15.247

As mentioned above, FCC rules require wider bandwidth to transmit data with enough power for significant in-building range. While this allows faster data transmission, the effective receiver sensitivity is reduced. To achieve this wider bandwidth, one strategy is to increase the data rate to 200 kbps and the deviation to +/- 200 kHz.

In **Figure 7** the spectrum is shown during the preamble of the packet. The occupied bandwidth is now over 500 kHz so this meets the regulations. The time domain frequency versus time, Trace “f,” shows the deviation of +/- 200 kHz as desired. Also, note that current (Green Trace 4) and the RF amplitude (Trace A) signals track each other.

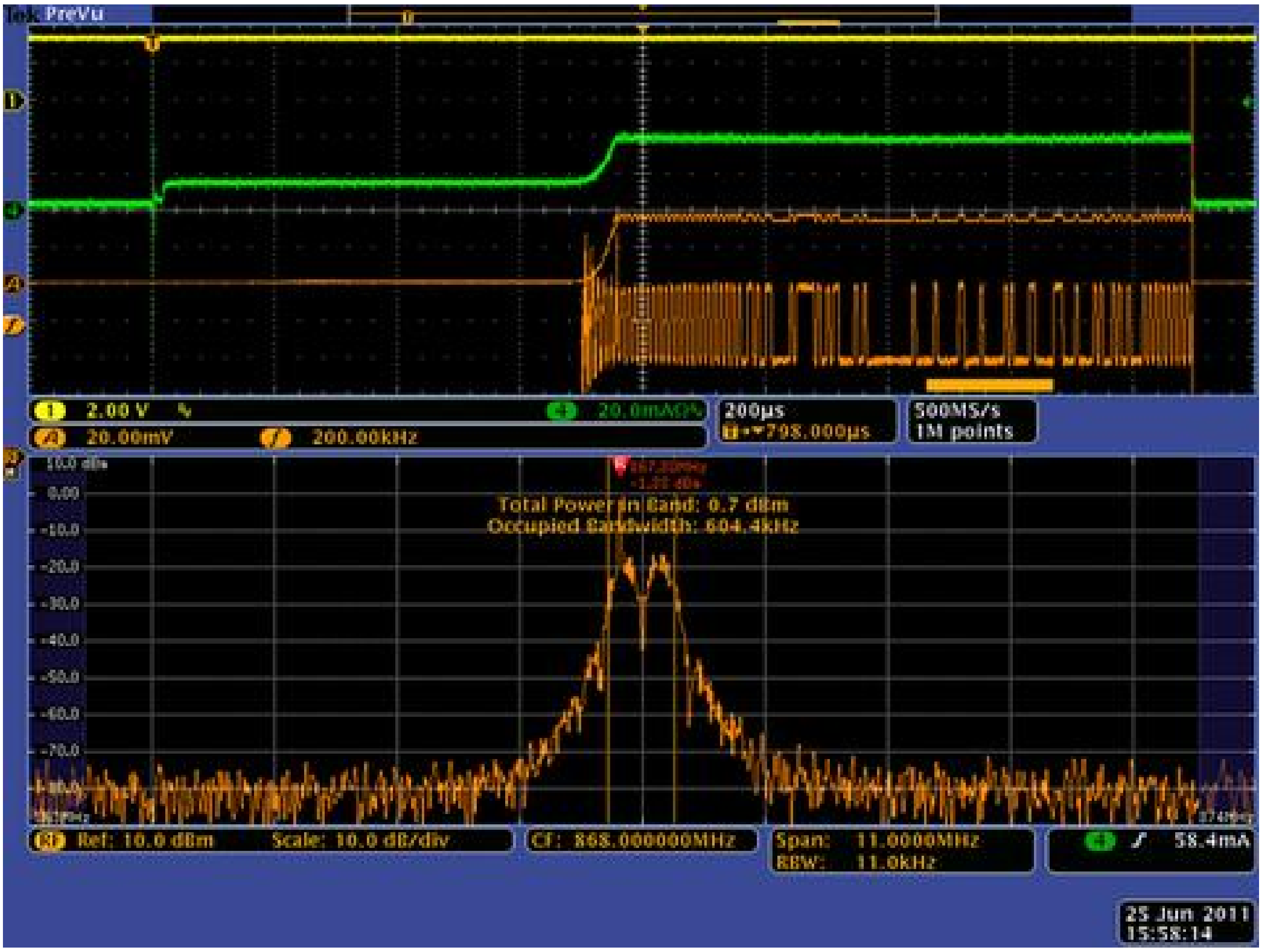

Figure 7 *– Wide band spectrum and measurements.*

The next step would be to look at the same signal, but with the spectrum compared to the data portion. In this case, the occupied bandwidth was smaller than during the preamble. This measurement is important to determine if it still meets the regulations. Then, by triggering on the deviation command, the value of deviation can be determined. In the example, the deviation was 01 which corresponds to 200 kHz, the widest setting allowed by this radio IC.

Summary

Embedded radio ICs and modules offer a lot of flexibility in configuring radio systems to meet different sets of regional regulations as well as any specialized requirements of the application such as Frequency, Power Levels, and Occupied Bandwidths. These radio ICs and modules typically have dozens of set up registers to allow this flexibility.

It is important for the engineer to be able to verify the RF operation of the radio as well as to confirm that the commands and data sent to the radio are correct.

Mixed domain oscilloscopes make it possible to observe and correlate the RF output of the radio transmitter while simultaneously reading control signals or measuring current draw, power supply voltages and other analog and digital signals. For confirmation of the data being transmitted, the MDO can provide time domain versions of the RF signal including frequency, amplitude, and phase versus time. The MDO represents an improved way to develop, debug, and confirm regulatory compliance of radio systems like the one discussed above.

About the Author

Faride Akretch is a technical marketing manager for Tektronix. In nearly 20 years in the industry he has held a variety of positions in Germany, Japan and the US, including application engineer, product marketing, and business and market development. He holds a masters in electrical engineering /electronics from the Technical University in Berlin/Germany.