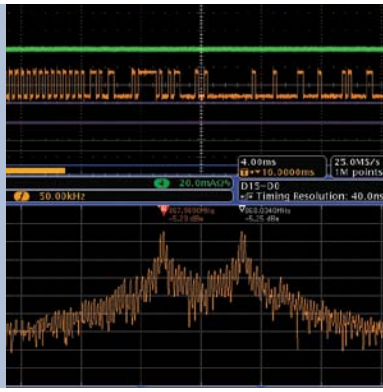

System Level Design and Verification of Wireless Embedded Systems

Application Note

When designing embedded wireless technologies for worldwide deployment, it is important to consider the different regional regulatory requirements. Radio regulations vary around the world for some of the frequencies most attractive for unlicensed radio control and telemetry. 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, the greater building penetration, less interference, and lower power consumption of lower frequency radios may be more attractive. This application note will demonstrate the use of the Tektronix MDO4000 Series Mixed Domain Oscilloscope in the design, verification and optimization of radio IC's (integrated circuits) for the same application, but two different geographic regions - Europe and North America.

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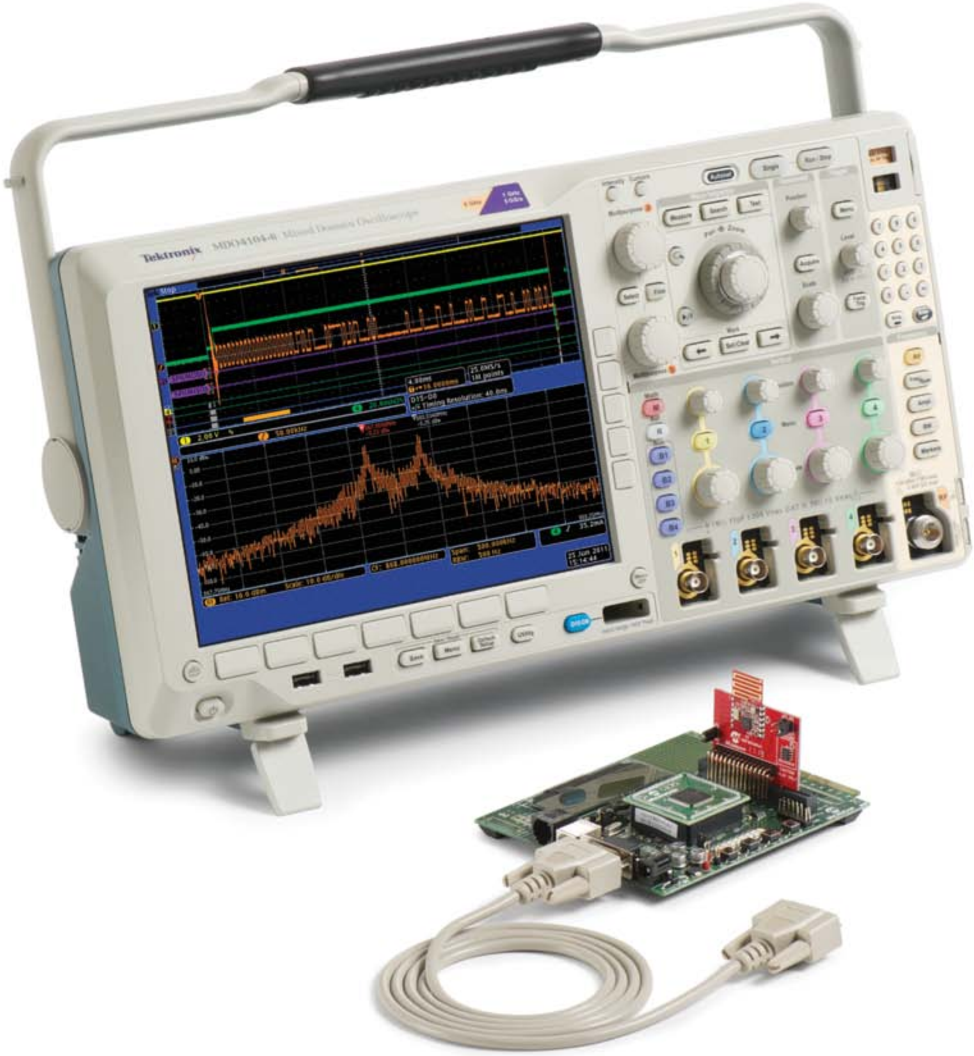

Figure 1. Tektronix MDO4000 Series Mixed Domain Oscilloscope and Microchip Radio Test Board Module.

Selecting the Frequency, Power, and Operational Bandwidth for 900 MHz Band Radios

There are several very flexible radio integrated circuits and modules available today for the unlicensed frequency bands in the range of 900 MHz. Due to the propagation properties at lower frequency, the 900 MHz band has much better in-building penetration than the 2.4 GHz band. These unlicensed radio technologies can be used in most parts of the world, but must be configured differently to comply with local regulations.

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 best set up 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 wide band (digital) modulation. While there is some disadvantage to using the wider signal, it can provide higher data throughput. The wider bandwidth with greater transmitter power will be usable at longer range than the much lower power level of a narrow band signal allowed in North America.

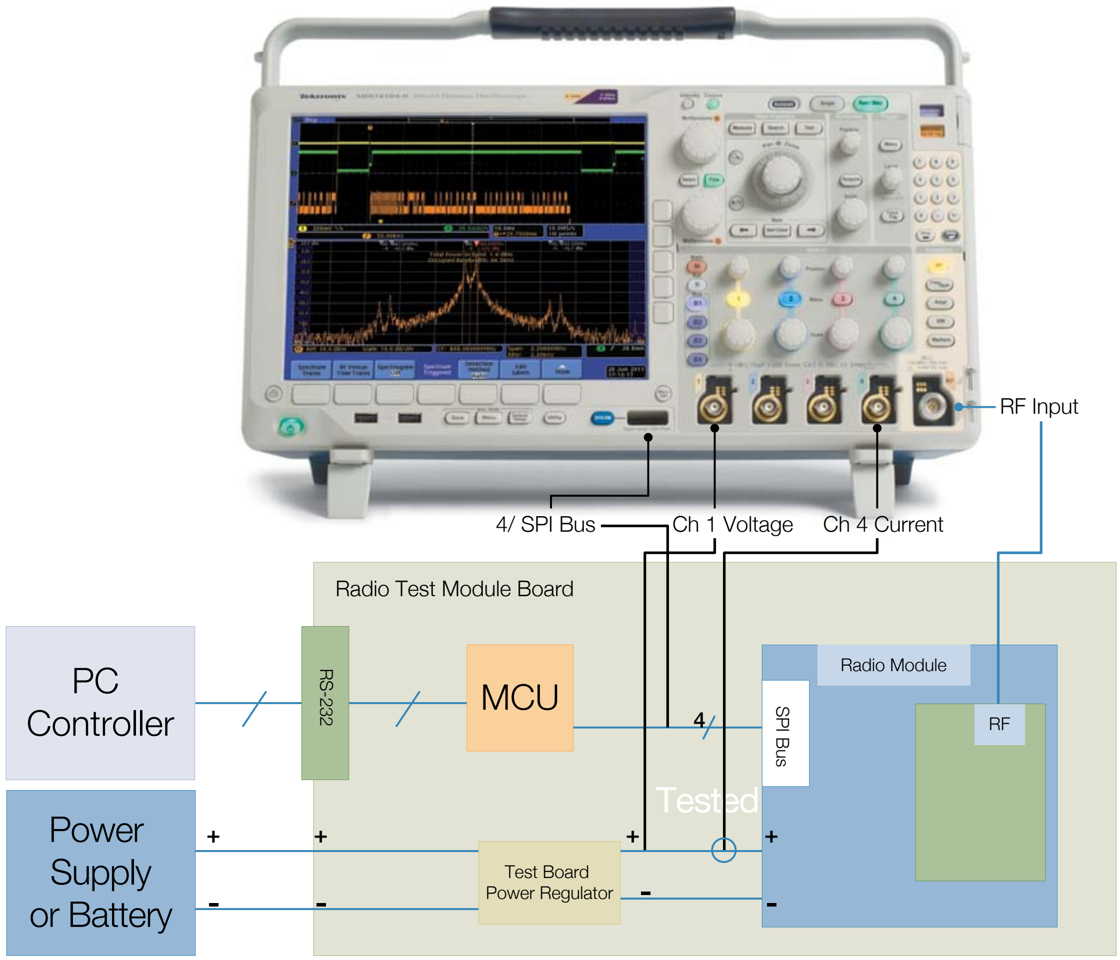

Figure 2. Test connection between the device under test (Microchip MRF89XA module) and the MDO4000 Series Mixed Domain Oscilloscope.

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

Measurements will be made utilizing the Tektronix MDO4000 Series Mixed Domain Oscilloscope. The MDO4000 has the unique ability to simultaneously display four analog signals with up to 1 GHz bandwidth, 16 digital waveforms, up to 4 decoded serial and/or parallel buses, and one RF signal to 6 GHz. All of these signals are time correlated to show the effects of control and analog signals on the RF time and frequency domains.

To illustrate the signals that must be measured to assure correct operation of the two transmitter modes, a Microchip Explorer 16 demonstration board will control the radio module and allow easy connection of the oscilloscope. Figure 2 shows the setup for the following tests.

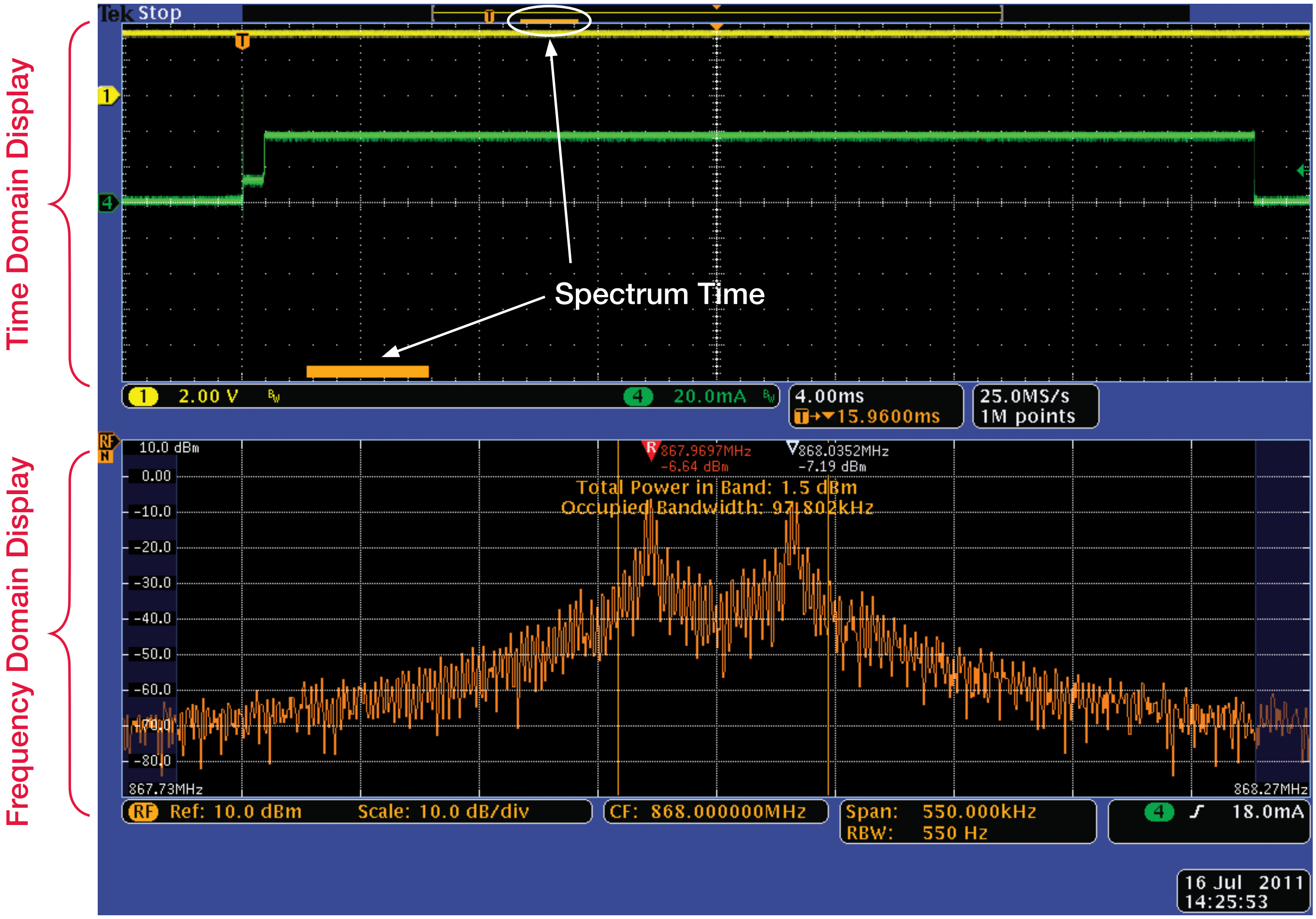

Figure 3. Time Domain and Frequency Domain views of low powered radio triggered on current probe (Channel 4).

Performance Settings and Measurements:

Europe setup under ETSI EN300 220 rules – 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, the radio IC is set up to transmit FSK (frequency shift keyed) at 5 kbits per second with a nominal deviation of 33 kHz.

Figure 3 shows the MDO4000 Series displays of both the time and frequency domains views. The upper half of the display shows a traditional time domain view of the power supply voltage (Channel 1, Yellow Trace) and current (Channel 4, Green Trace). The lower half of the display shows the time correlated view of the RF output. In this case, the radio transmitter output is shown sometime after the transmitter is turned on. The spectrum is calculated by performing a Fourier Transform (FFT) on the input of the RF acquisition in the frequency span of interest. This is a common technique for Vector Signal Analysis based spectrum analyzers, and has the benefit of being able to provide frequency information on very short sets of acquired data compared to a traditional swept spectrum analyzer.

The Orange Bar in Figure 3 shows the spectrum of this signal captured to be about 4 ms, as well as the 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 default 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. As a comparison, a typical swept spectrum analyzer might take several seconds to sweep across the spectrum for similar RBW and Span settings. This RF burst event lasting less than 40 ms occurs far too fast to be able to use a traditional spectrum analyzer for spectrum behavior analysis.

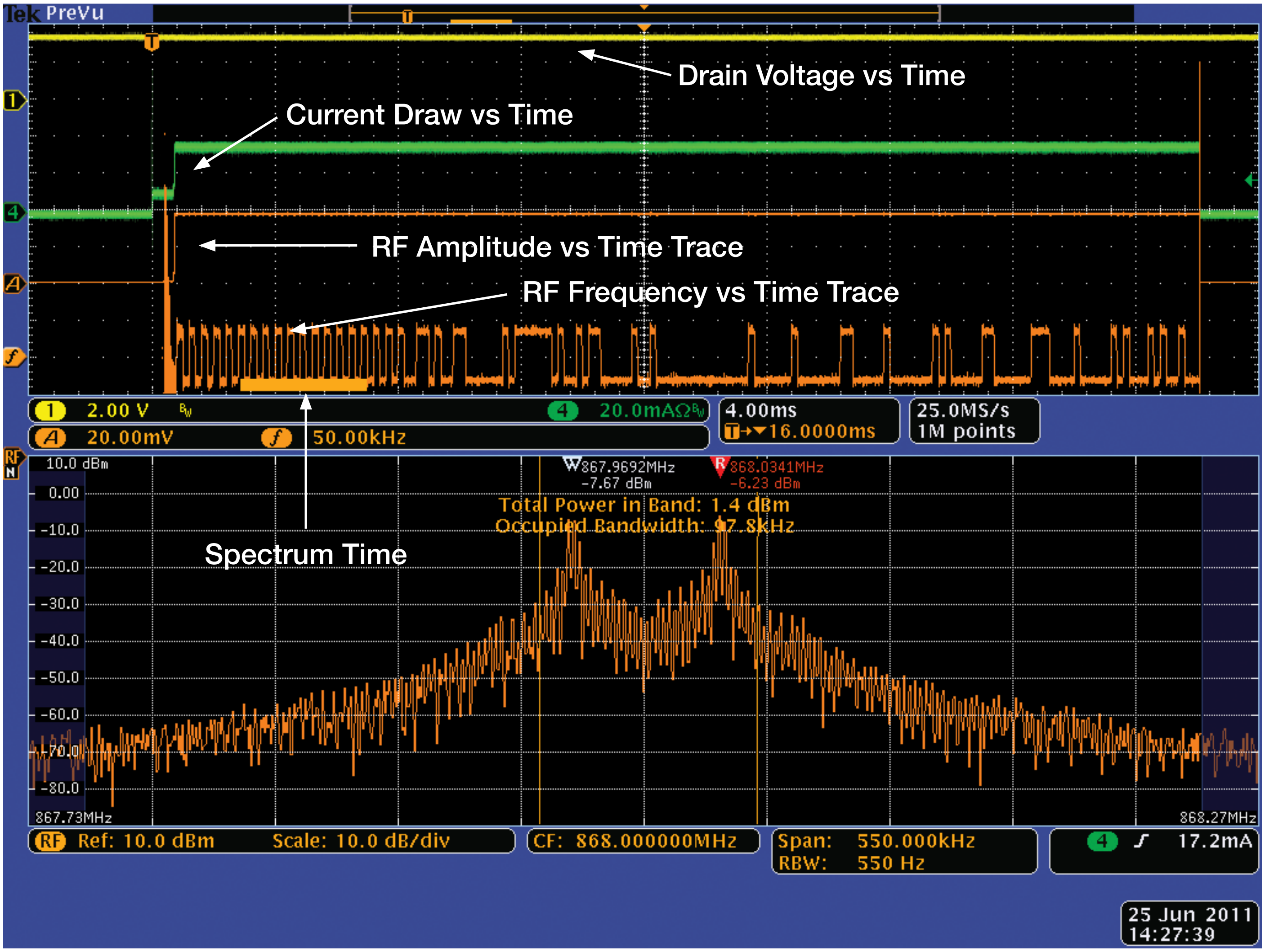

Figure 4. Correlated RF Amplitude and Frequency versus Time Traces are now added to show this event correlates to the transmitter turn-on and preamble portion of an FSK radio.

In Figure 4, the RF Amplitude and Frequency versus time displays are added in the Time Domain Display. Since the MDO4000 Series Oscilloscope RF acquisition acquires a time record of the RF acquisition, a digital down conversion process can be used to produce the I (Real) and Q (Imaginary) data. Each I & Q sample represents the instantaneous deviation of the RF input from the current Center Frequency. With this analysis, the RF Amplitude and Frequency versus Time can be computed on the same set of data and displayed in a time-correlated view to the other analog and digital channels.

Figure 4 demonstrates that this signal is an FSK modulated signal, and the spectrum time is acquired on the preamble portion of this FSK radio. The Resolution Bandwidth (RBW) has been set to a long enough acquisition to capture of both frequencies of the FSK radio to enable Occupied Bandwidth and Power in Band measurements to be made with the RF peak detector.

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 or a simple power amplifier. Again, just as in the previous Figure 3, 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. The RF signal turns on only when the current is at the full 40 mA.

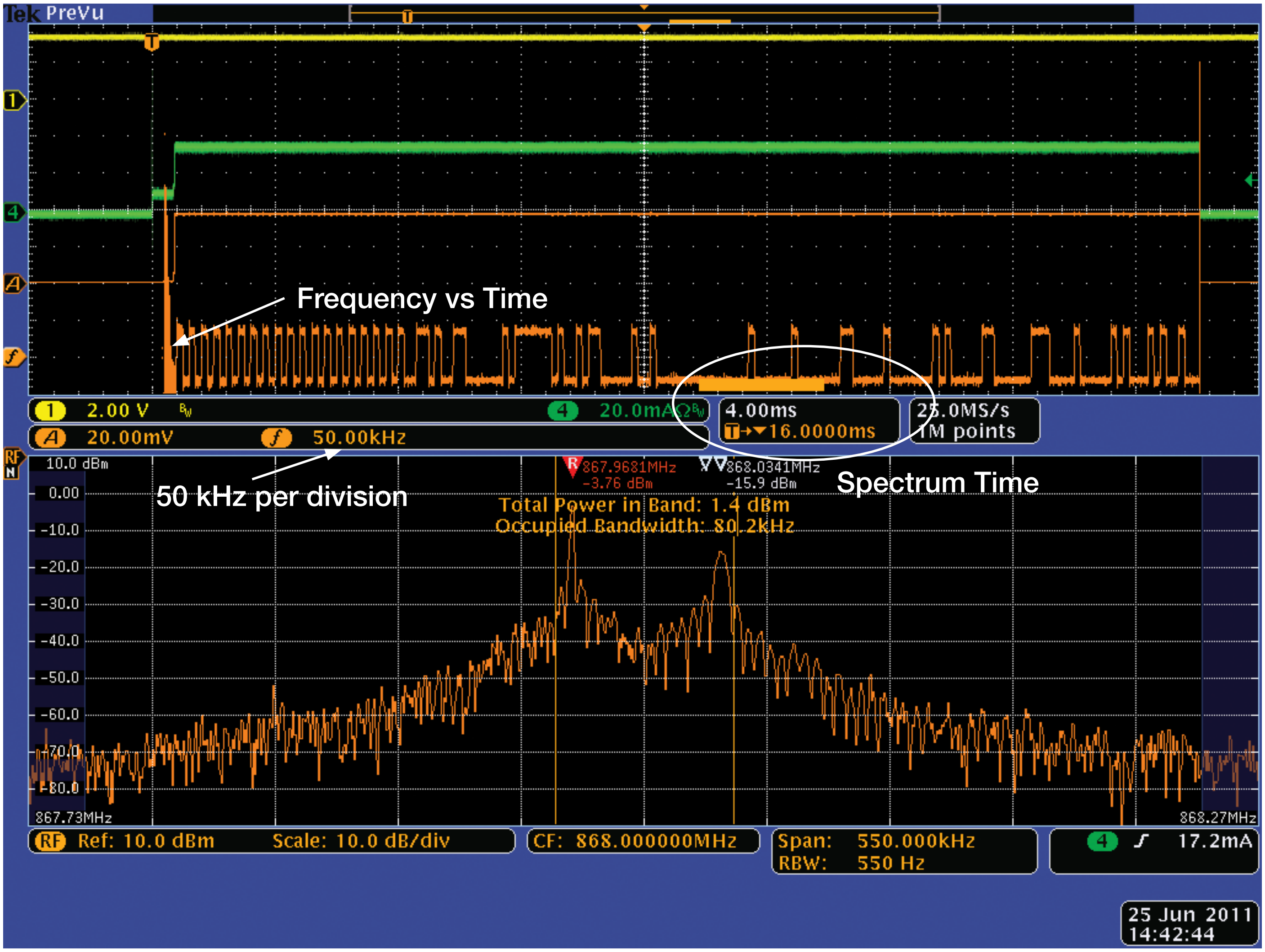

Figure 5. Spectrum time moved later in the packet transmission when most of the energy is at the lower of the two frequencies.

The Frequency versus Time Trace, represented by the Orange Trace "*f*" shows the frequency deviation of the FSK modulation of the signal at 50 kHz per division. Thus the expected +/-33 kHz deviation is confirmed in both the spectrum (frequency domain) and in the time domain. This shows the power and convenience of the MDO4000 oscilloscope.

In Figure 5 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 two FSK modulated frequencies which is consistent with the symbol period 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. At best with a separate oscilloscope and spectrum analyzer, the two screens could be printed and overlaid. This assumes that the two instruments can be triggered together and the timing latencies removed, which is often difficult if not impossible.

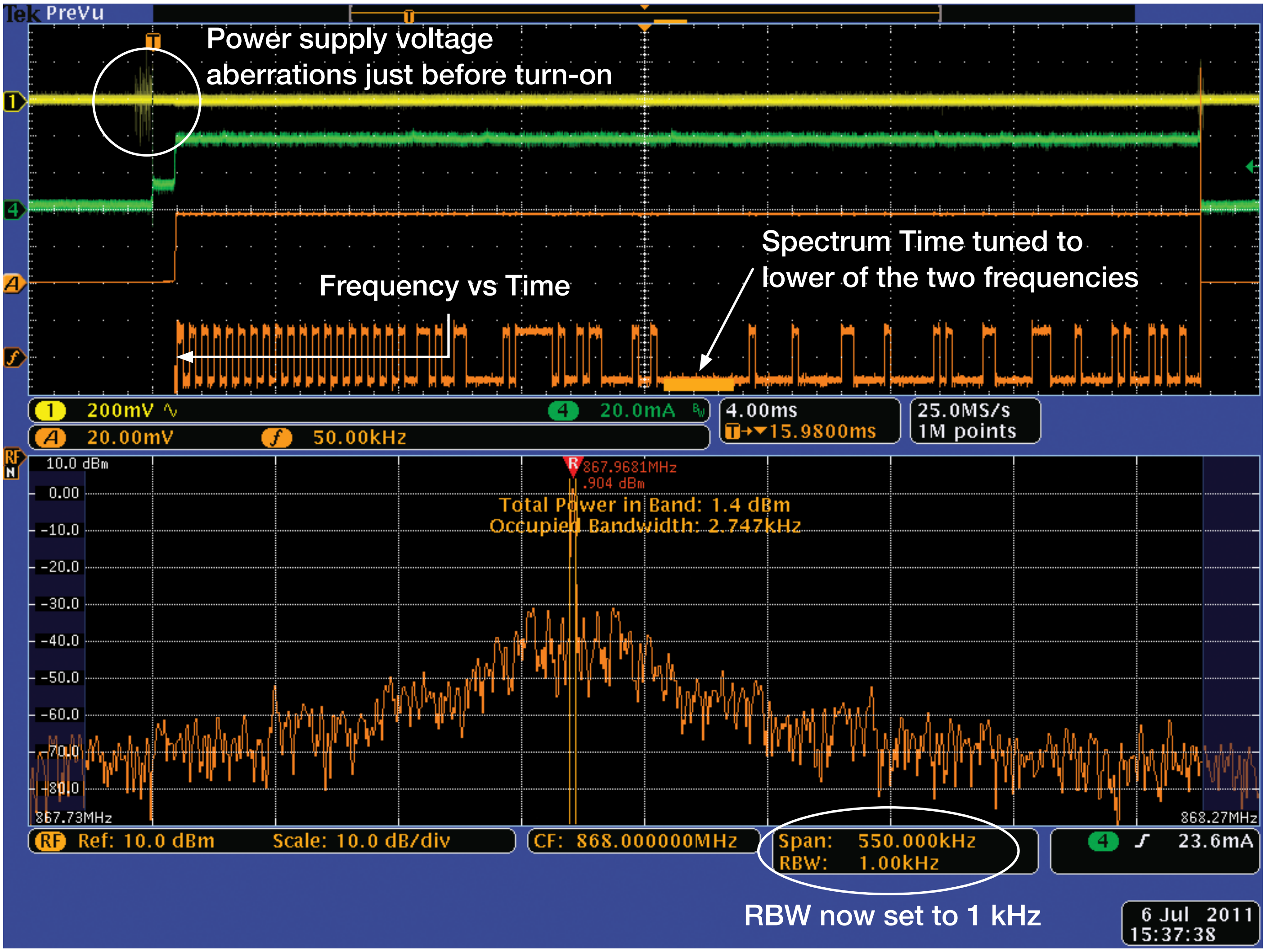

Figure 6. Spectrum during an interval of only one frequency in the FSK signal.

By changing the resolution bandwidth setting, the RF display will show the spectrum during a period when only one frequency value is displayed as shown in Figure 6. The total power measurement is the same as in Figure 5. The RF display can be scaled with the RBW setting and can be moved to any part of the spectrum. Here the resolution bandwidth is increased from 550 Hz to 1 kHz to display the spectrum over a shorter period (~ 2 ms) than in Figure 5 so that only one frequency is shown. Also notice the scale on the Voltage measurement on Channel 1 has been changed (200 mV/div) to show some aberrations just as the current begins to rise.

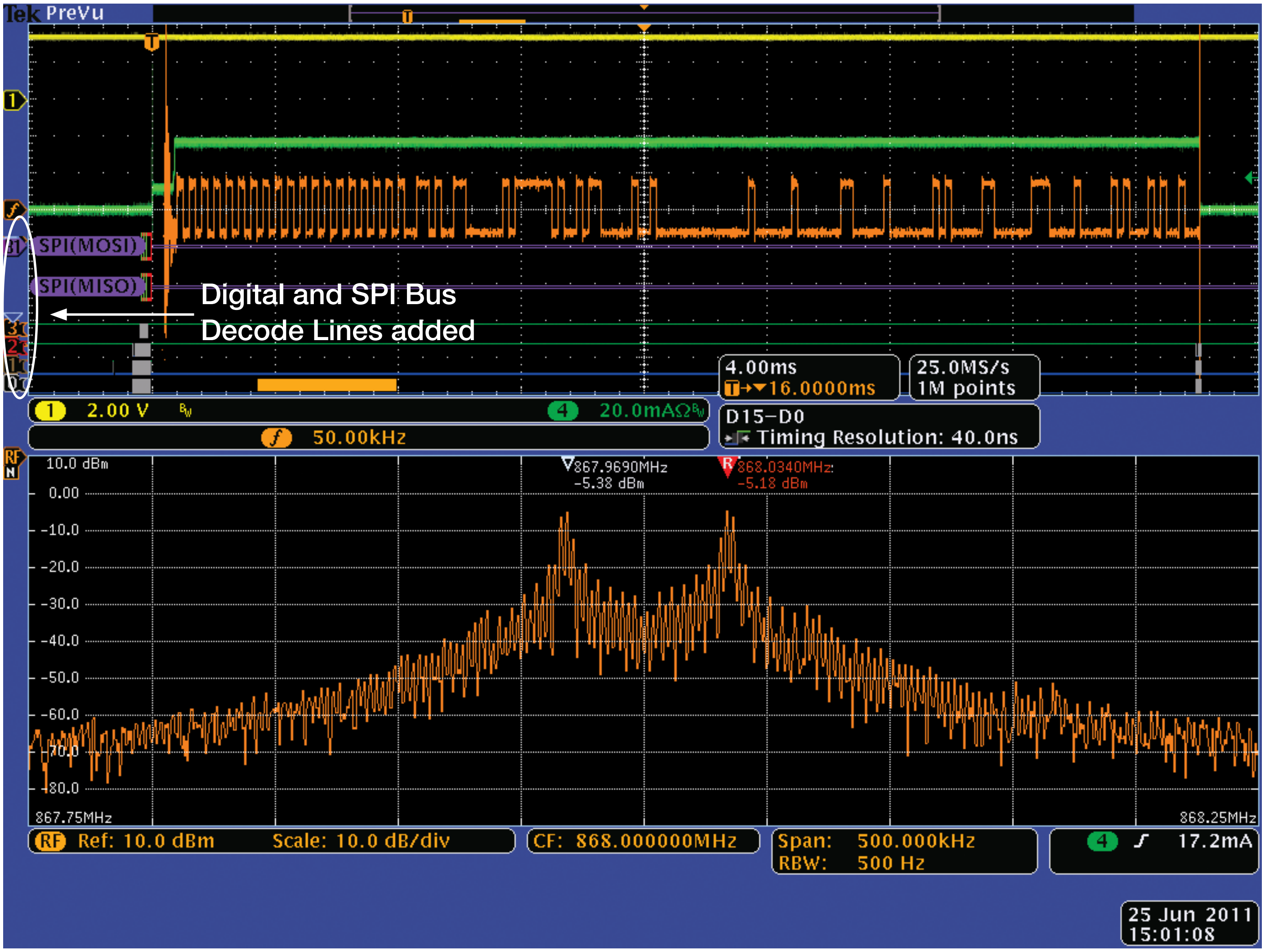

Figure 7. SPI digital decoded data is displayed (MOSI and MISO) during the same event acquisition.

It is also helpful to see the commands being sent to the radio from the microcontroller. In Figure 7, the digital probes have been connected to the SPI bus going to the radio module and the SPI bus decode is turned. The MDO is capable of displaying decoded data from a wide range of buses including I²C, CAN, RS232, USB, Ethernet and others, so most control buses can be monitored and even used to trigger the oscilloscope.

Figure 8. Decoded data and digital waveforms using the Zoom function of the MDO4000 Series Oscilloscope.

The MDO is set to acquire 1 million samples across the screen, so that even though the digital signals are quite fast, it will be possible to see the data using the MDO's Wave Inspector pan and zoom capability. Figure 8 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 8 when the time domain display is zoomed to 20 us per division. The digital version of the data can also now be read at the bottom of the time domain section of the screen. A careful look at the frequency domain Trace "*f*" in Figure 8 as well as at the top of this Figure shows the same data after the header.

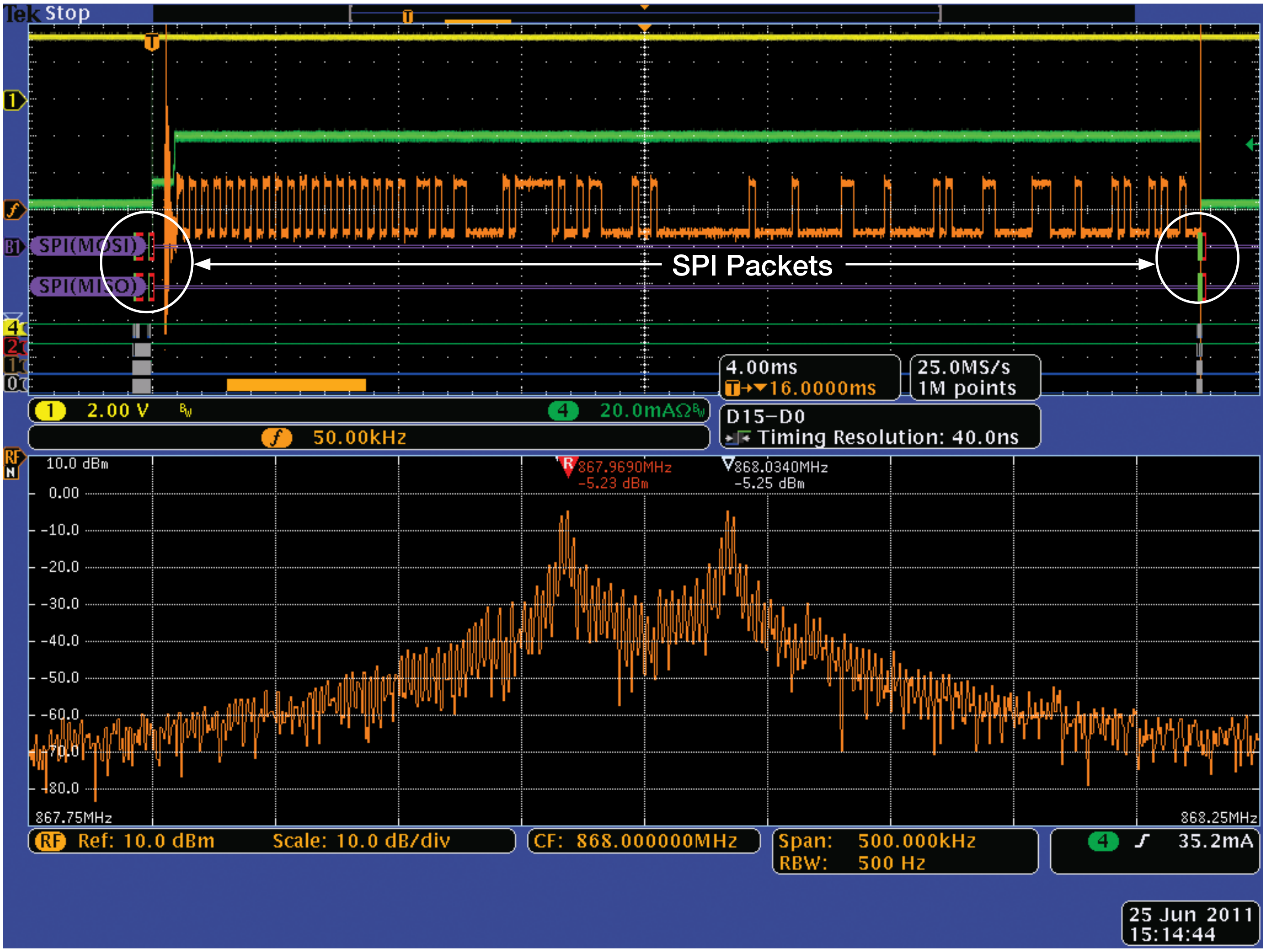

Figure 9. Spectrum with SPI digital commands.

In Figure 8, 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 the resultant spectrum displayed level is reduced.

By selecting the decode line for commands instead of data, commands can similarly be decoded and checked. Figure 9 shows the full packet with digital decode of commands at the beginning and end of the packet.

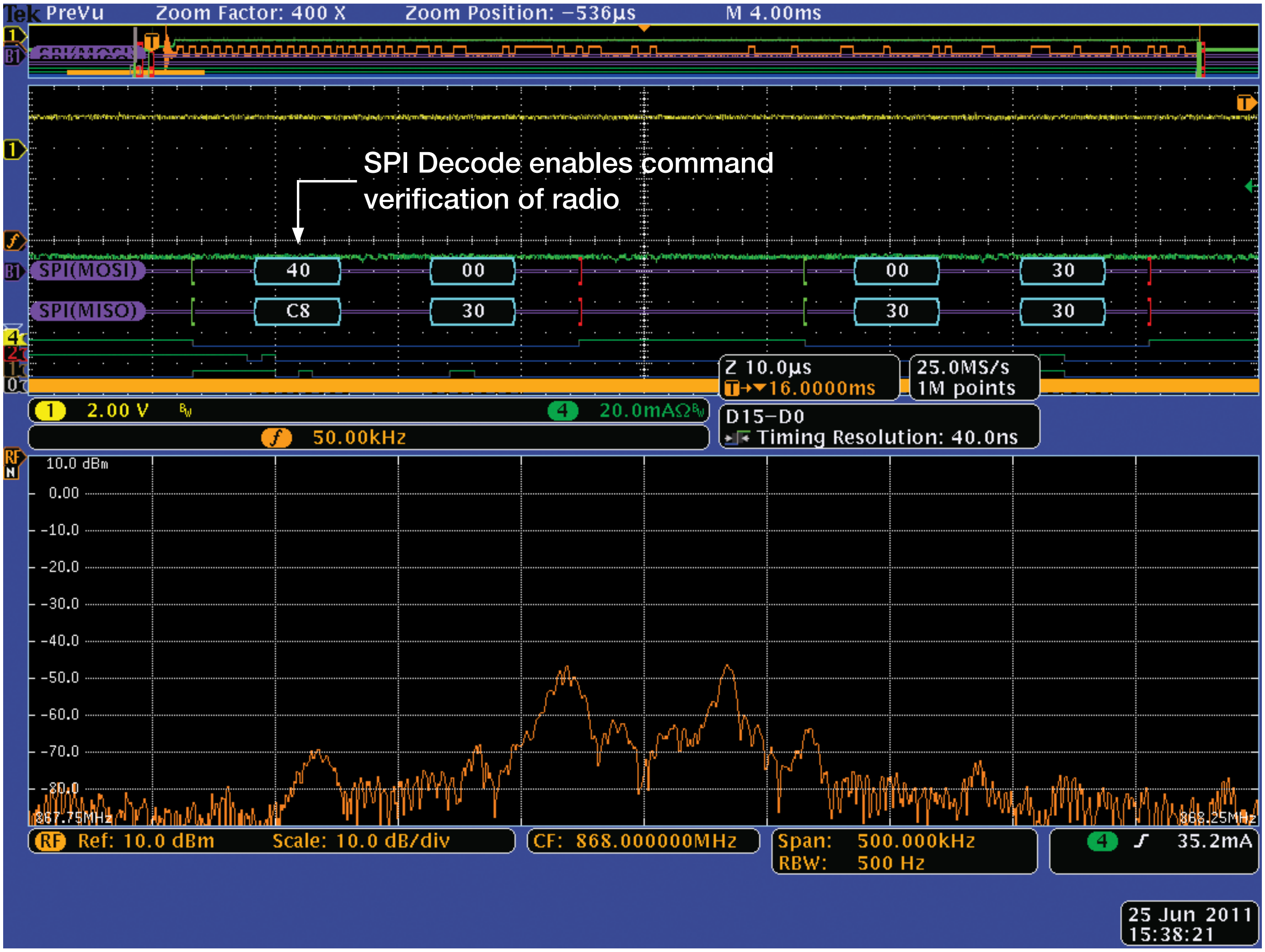

Figure 10. Decoded commands and digital waveforms.

Using the Wave Inspector Pan and Zoom function, Figure 10 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}. The second pair of bytes {00 30} sets the General Configuration register at address 0 to standby mode in the 868 MHz band.

This capability is very powerful for confirming that the radio IC is correctly set up.

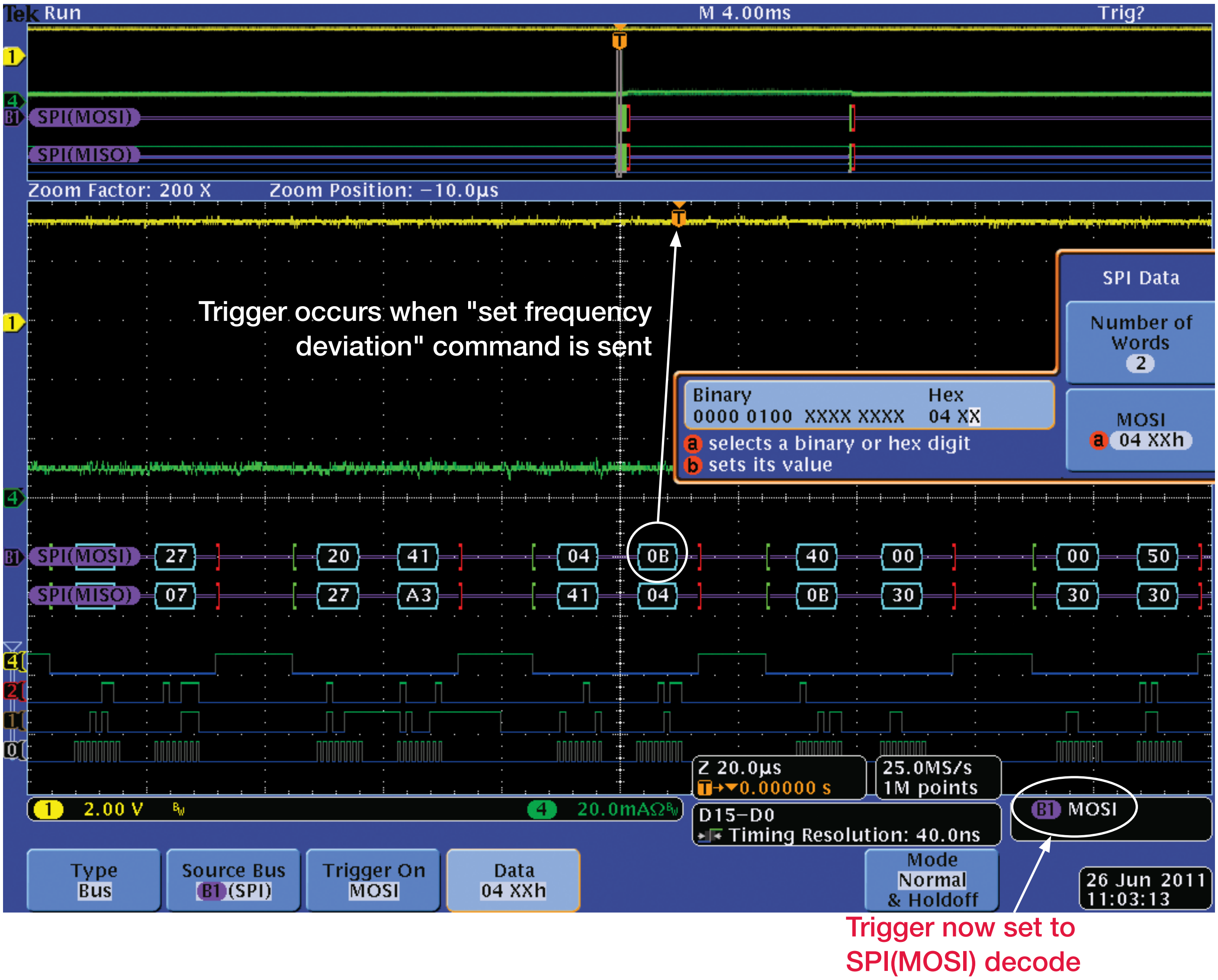

Figure 11. Triggering on a set frequency command {04 XX} on MOSI(B1).

The MDO4000 Oscilloscope also allows triggering on SPI commands. In Figure 11, at the center of the screen the command {04 0B} is shown. Command {04} sets the frequency deviation of the transmitter output. The SPI trigger was set to trigger on a two byte word with the first byte being the command. The value shown is the value for +/- 33 kHz deviation in the FSK transmitted signal. The other commands can be decoded with the assistance of the MRF89XA radio IC data sheet.

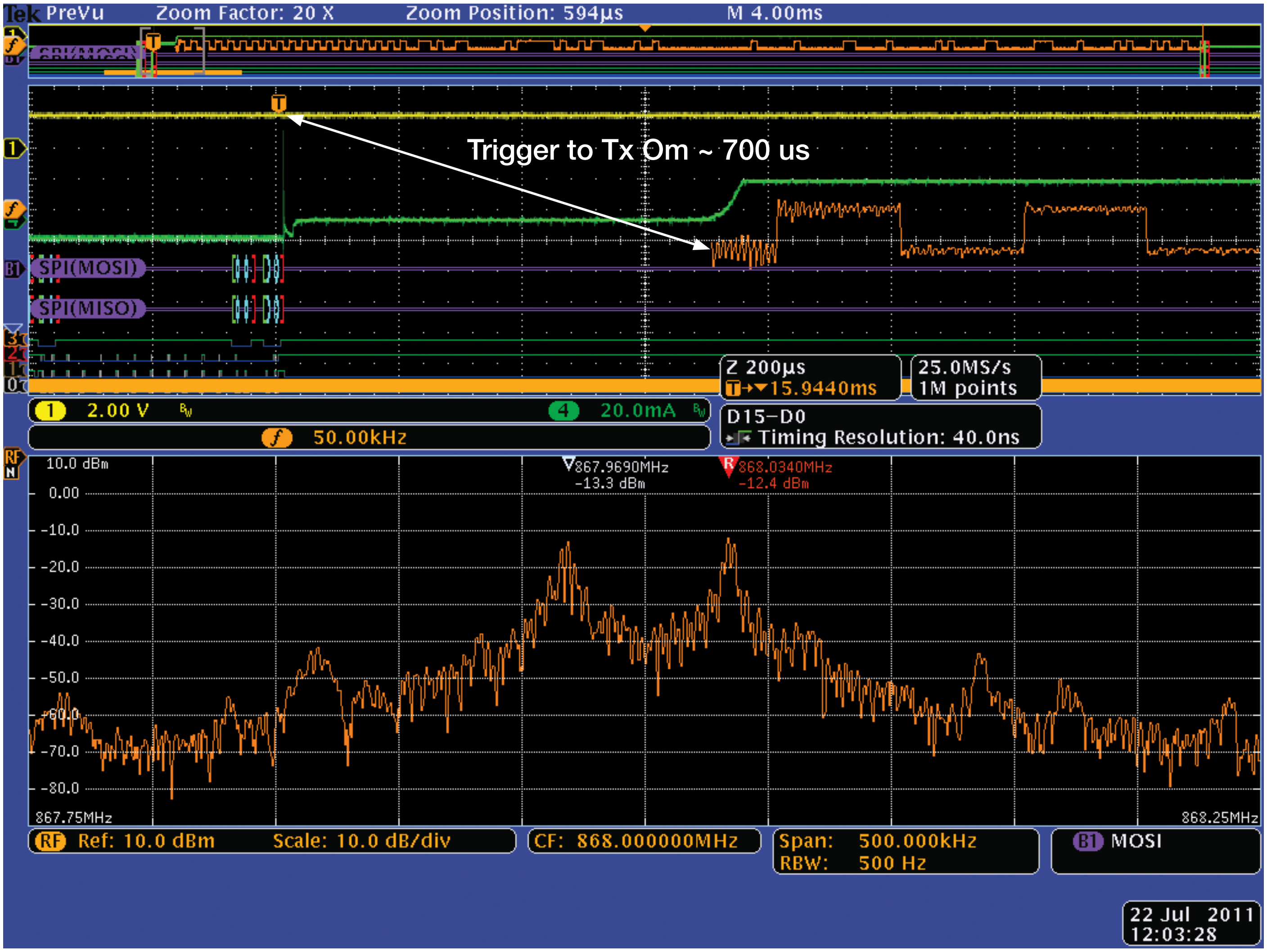

Figure 12. Triggering on the MOSI command and viewing the Frequency vs Time Trace

One of the unique benefits of the MDO4000 Oscilloscope architecture is demonstrated in Figure 12 screen shot. Using the SPI (MOSI) trigger condition defined in Figure 11 setting the frequency deviation, we now change the Horizontal Time base (200 us/div) and Zoom out to measures the impact of the SPI command. A current draw is immediately measured on Channel 4 (Green Trace), and the Frequency vs Time (Orange Trace) now demonstrates an RF signal present almost 700 us later. This demonstrates the turn-on latency between the SPI command and RF event in one simple display.

North American setup under FCC rule 15.247 – As mentioned previously, the FCC rules require wider bandwidth to transmit data with enough power for significant in-building range. Note that while this allows faster data transmission, the effective receiver sensitivity is reduced. To achieve this wider bandwidth, the data rate is increased to 200 kbps and the deviation to +/- 200 kHz.

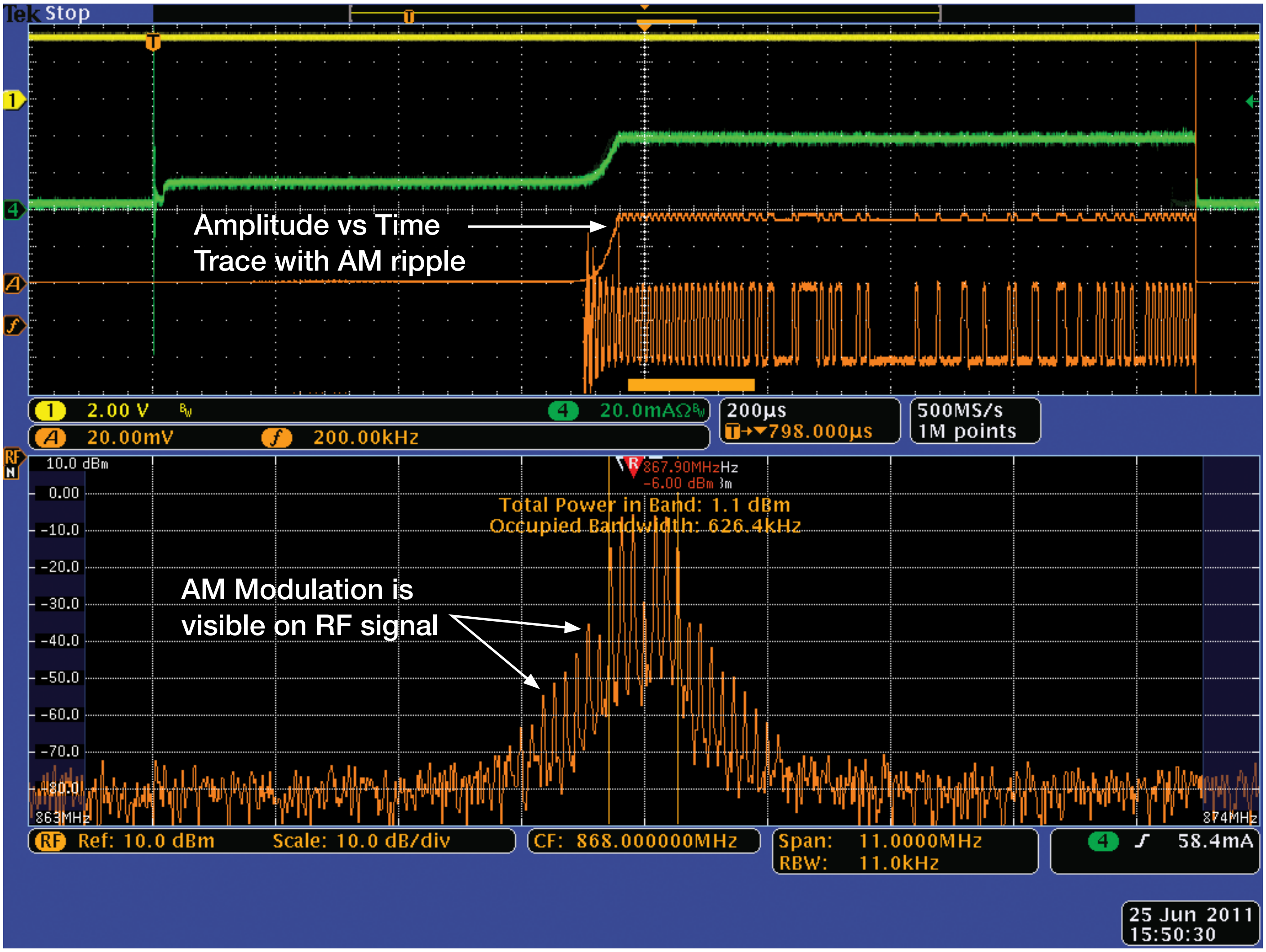

Figure 13. Wide band spectrum and measurements for North American unlicensed band during preamble transmission.

In Figure 13 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. Note that the amplitude versus time, Trace "*A*", shows some amplitude modulation at this wide deviation (which was not present in the lower frequency deviation setting for Europe as shown in Figures 4-6). The AM modulation can easily be seen in the spectrum results. While amplitude modulation of an FSK signal is not desirable, this amount will probably not cause any difficulties for the receiver in decoding this signal. Also, note that current (Green Trace 4) and the RF amplitude (Trace *A*) signals track each other.

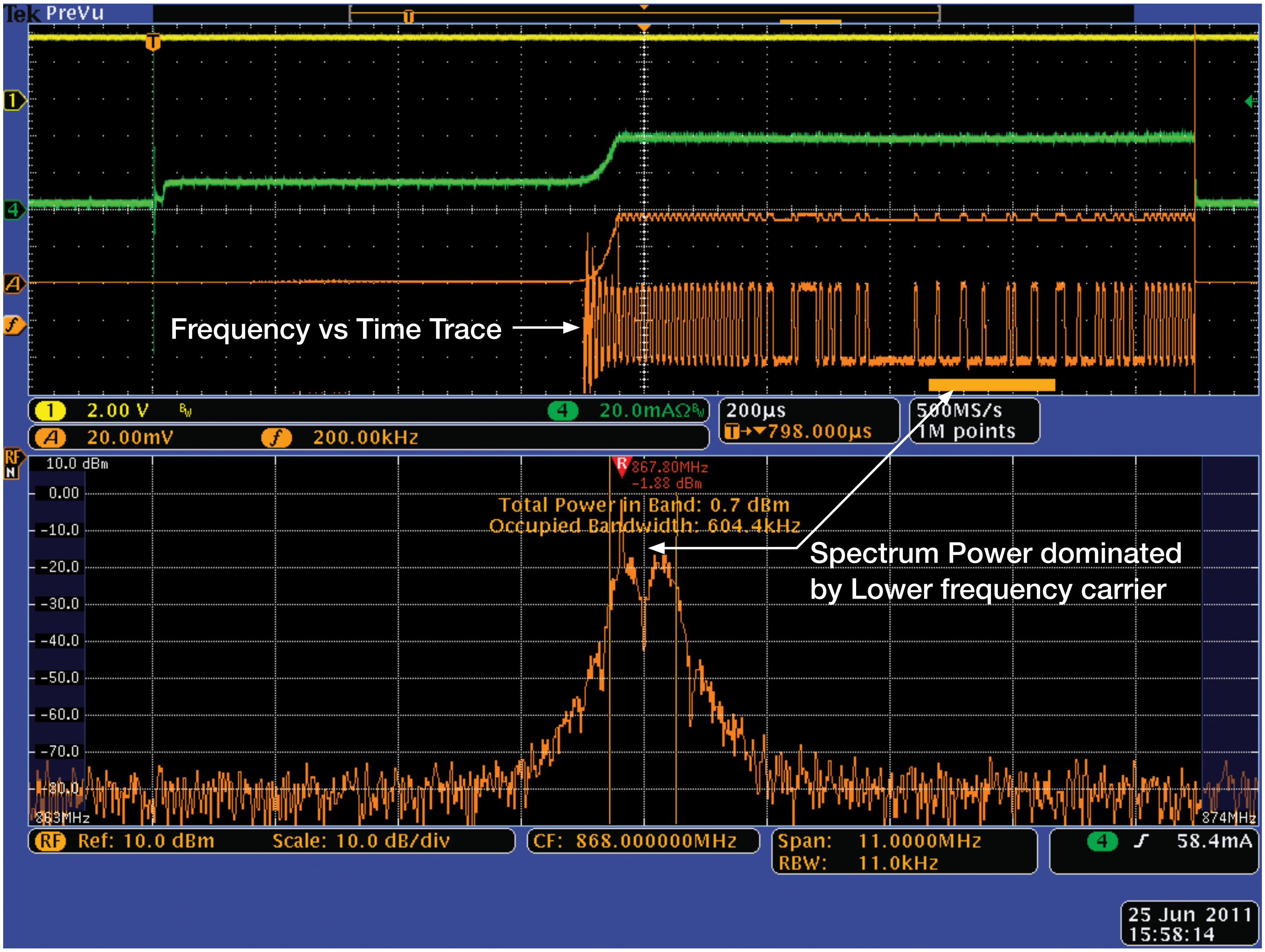

Figure 14. Wide band spectrum and measurements during data transmission.

Figure 14 shows the same signal, but with the spectrum taken during the data portion. Note that the occupied bandwidth is smaller than during the preamble, but it still meets the regulations. The lower frequency dominates with this particular data as seen on the spectrum display The spectrum time is determined by the acquisition time to support the 11 kHz RBW in this case.

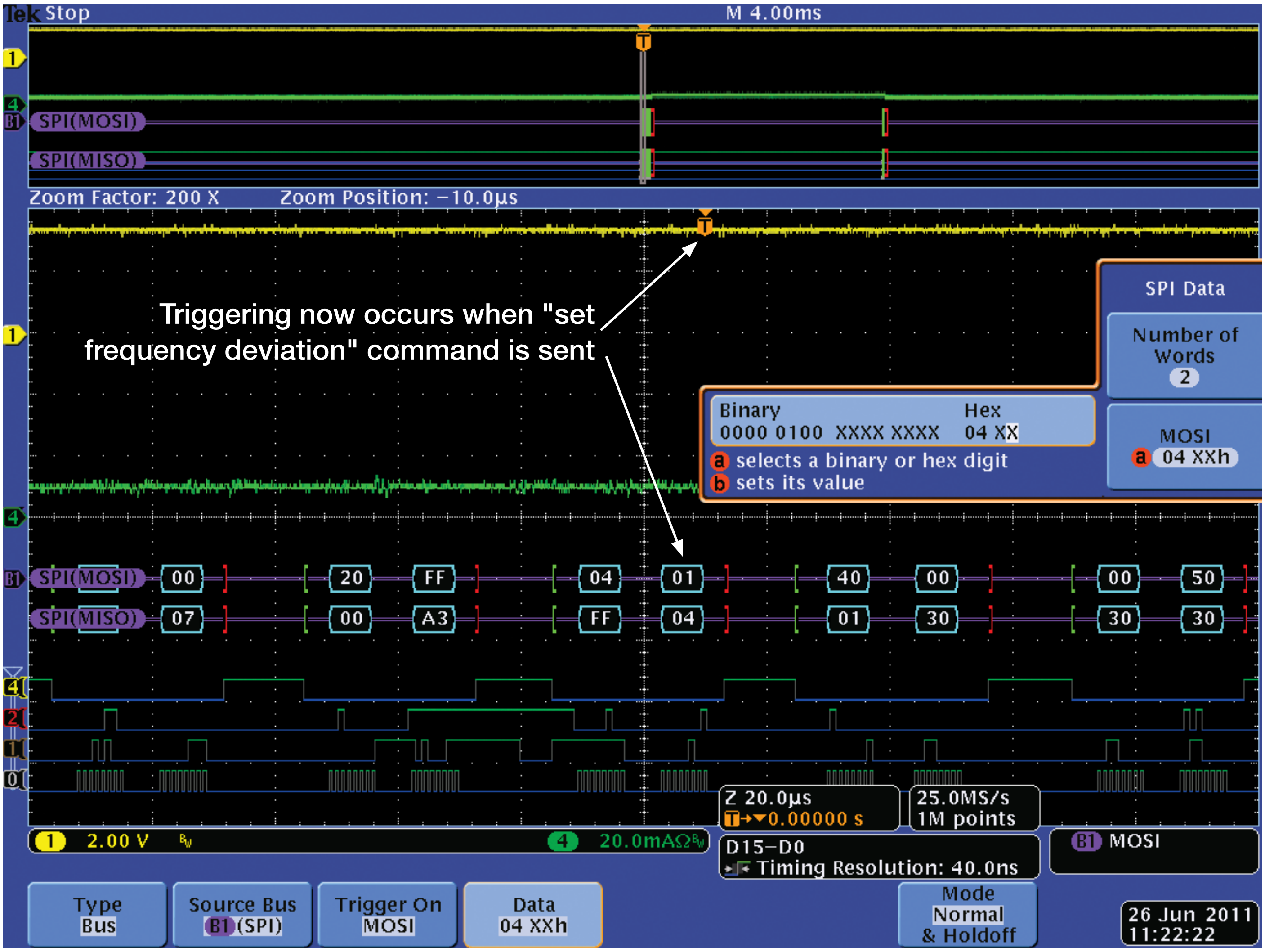

Figure 15. Triggering on a set frequency command {04 XX} on MOSI(B1).

Figure 15 shows the same SPI(MOSI) deviation command triggered in the same way as in Figure 11. Note that the value of deviation is now {01} which corresponds to 200 kHz; the widest setting allowed by this radio IC.

Summary

Embedded radio ICs and modules that 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.

The Tektronix MDO4000 Series Mixed Domain Oscilloscope provides a powerful tool to observe and measure 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. All of these measurements are time correlated. The MDO also provides time domain versions of the RF signal (Frequency, Amplitude, and Phase versus time) to observe the output power and, for simple modulation schemes, allow confirmation of the data being transmitted.

The Tektronix MDO4000 Series provides a very cost effective way to develop, debug, and confirm regulatory compliance of radio systems like the one discussed above.

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