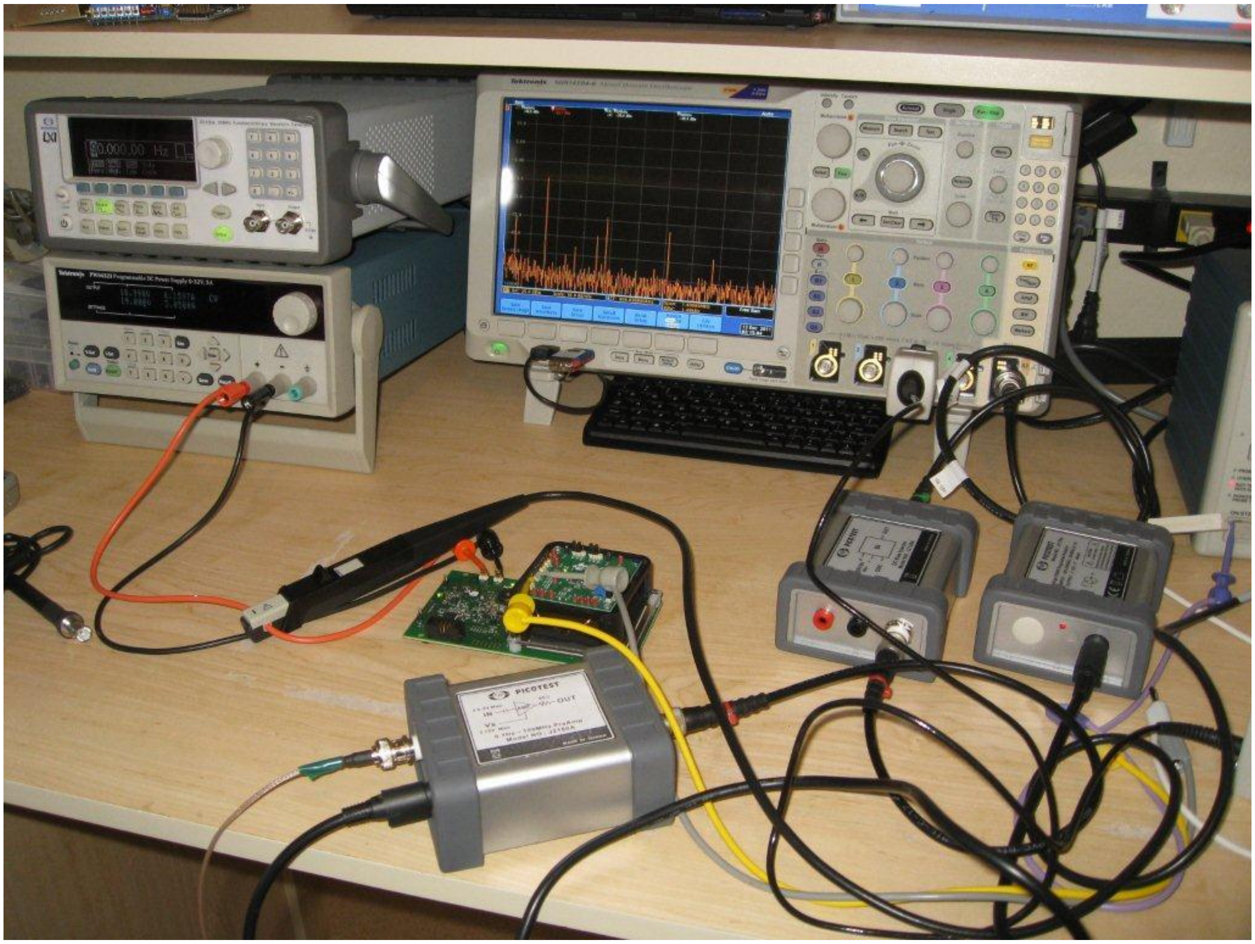


Nearly every electronic product is required to conform to Electromagnetic Compatibility, or EMC (also commonly referred to as EMI for Electromagnetic Interference and RFI for Radio Frequency Interference) requirements. While there are many different standards, such as MIL-STD-461 for military products, DO-160 for Aircraft, EN 61000 and CISPR standards for European approval as well as CE, VDE and FCC standards to name just a few. Each of these standards contains sub-requirements defining the limits for conducted and radiated emissions from the product as well as the products susceptibility to radiated and conducted signals.

Most engineers do not have convenient access to the equipment necessary for EMC testing and certified test labs, while readily available, and necessary for conformance testing, are a very expensive solution for troubleshooting EMC issues. Complicating the EMC issues a bit further, all of the standards require that the certification testing be performed on a production unit, built in accordance with the production drawings. Any changes to the design after the certification testing is completed can require retesting of the product. The cost of testing and retesting can become quite expensive.

The environment in which the EMC testing is performance is very well controlled, with testing taking place inside a screen room, eliminating all signals other than those produced by the product being tested or the signals that are introduced into the screen room for the purpose of susceptibility testing. Additionally, the antennas are calibrated, located in a particular position (generally reflecting far-field performance) and measured using an EMI receiver. The EMI receiver looks and acts very much like a Spectrum Analyzer; however an EMI receiver has many specific characteristics specific to EMI testing.

Despite these details and complications there are tools and methods available that can help to ensure a successful design, while minimizing program cost. The tools required may cost less than a trip or two to a certified lab and will fit on the average lab bench, making the testing very convenient as well.

A few disclaimers are necessary before we actually start testing. First, we will be using near-field hand held probes to identify the EMC sources in our product being tested. The result of near field test may not correlate with far field measurements made in a test lab. This is not an issue at this stage as we have several simple goals:

1) Locate the significant conducted and radiated signal sources
2) Identify key characteristic that we can use as markers in the final certification testing
3) Consider possible EMC reduction techniques for each signal source, so that you will be prepared to implement fixes as necessary
4) Wherever possible, provide implementation schemes for the predefined fixes

The equipment we will use for our EMI testing include the Tektronix MDO4104-6 multi domain Oscilloscope, which includes a 4 channel oscilloscope, a 16 channel logic analyzer and a 50kHz to 6GHz Spectrum analyzer. We will also use a Tektronix xxx current probe , a Picotest J2180A 0.1Hz-100MHz low noise 20dB preamp (with J2170A power supply), a J2130A DC Bias injector for DC blocking and an Electro-Metrics near field probe kit.

The near field probe kit includes both E field probes for measuring voltage induced signal and and H field probes for measuring current induced signals. At these close distances, the signals will generally show up with either E or H field probes. The kit also includes different sizes of probes. A larger probe offers greater sensitivity and lower selectivity. A smaller probe allows more precise location of the noise source, but often requires additional gain to recover sensitivity. The J2180A preamplifier is used for this purpose.

The DC input power for our device being tested is provided by a Tektronix PWS4323 programmable power supply. The device we are demonstrating our testing with is a Texas Instrument Wireless Power set, including a Bq500210EVM-689 transmitter and Bq51013EVM-725 receiver.

The test setup is shown in Figure 1 while Figure 2 shows a close-up image of the smallest near field H probe, current probe, preamp and the device under test.

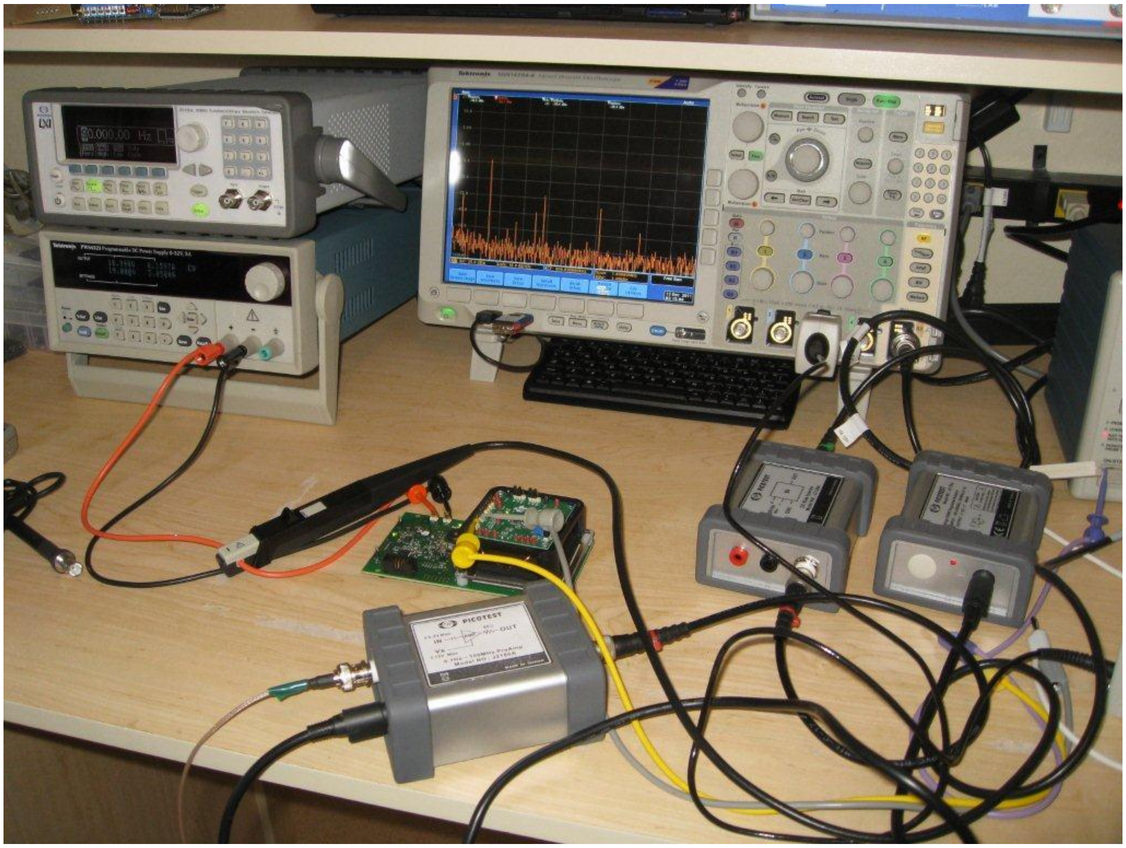


Figure 1 shows our compact EMC test bench

Figure 2 showing the current probe, J2180A preamp and near-field probe with the wireless transmitter/receiver set.

Figure 3 shows the spectrum results with and without the use of the Picotest J2180A preamplifier. With the preamplifier connected we can see that there are several signals that are related and one that is unrelated. No significant signals were evident above 1.5MHz.

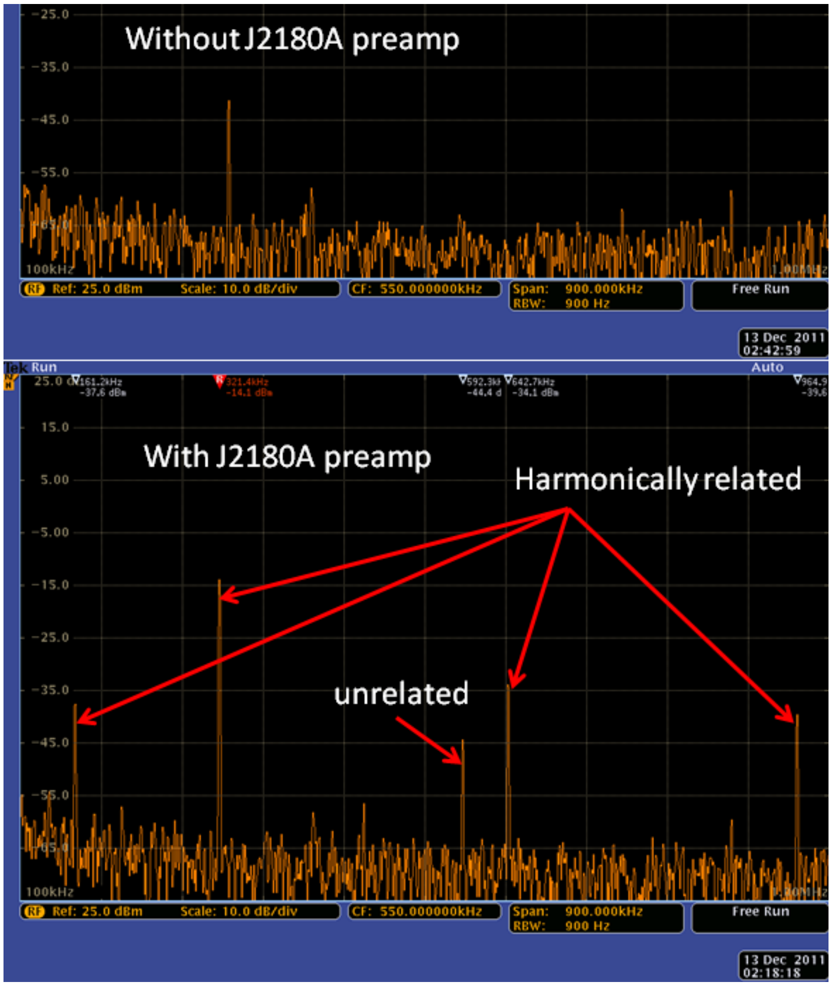


Figure 3 show the current measured on the DC input wire. There are harmonically related and unrelated signals evident.

The harmonically related signals were noted to vary with receiver output loading, input voltage and transmitter receiver alignment. This makes sense, since the wireless transmitter is an LLC resonant converter, regulated with variable frequency. It is also noted that the fundamental frequency is approximately 140 kHz and the largest signal is the 2nd harmonic of this frequency.

Using the smallest size near field probe, again with the preamplifier, the radiated signal sources can be located and identified. Figure 4 shows the layout of the wireless transmitter with the 3 significant circuit locations identified.

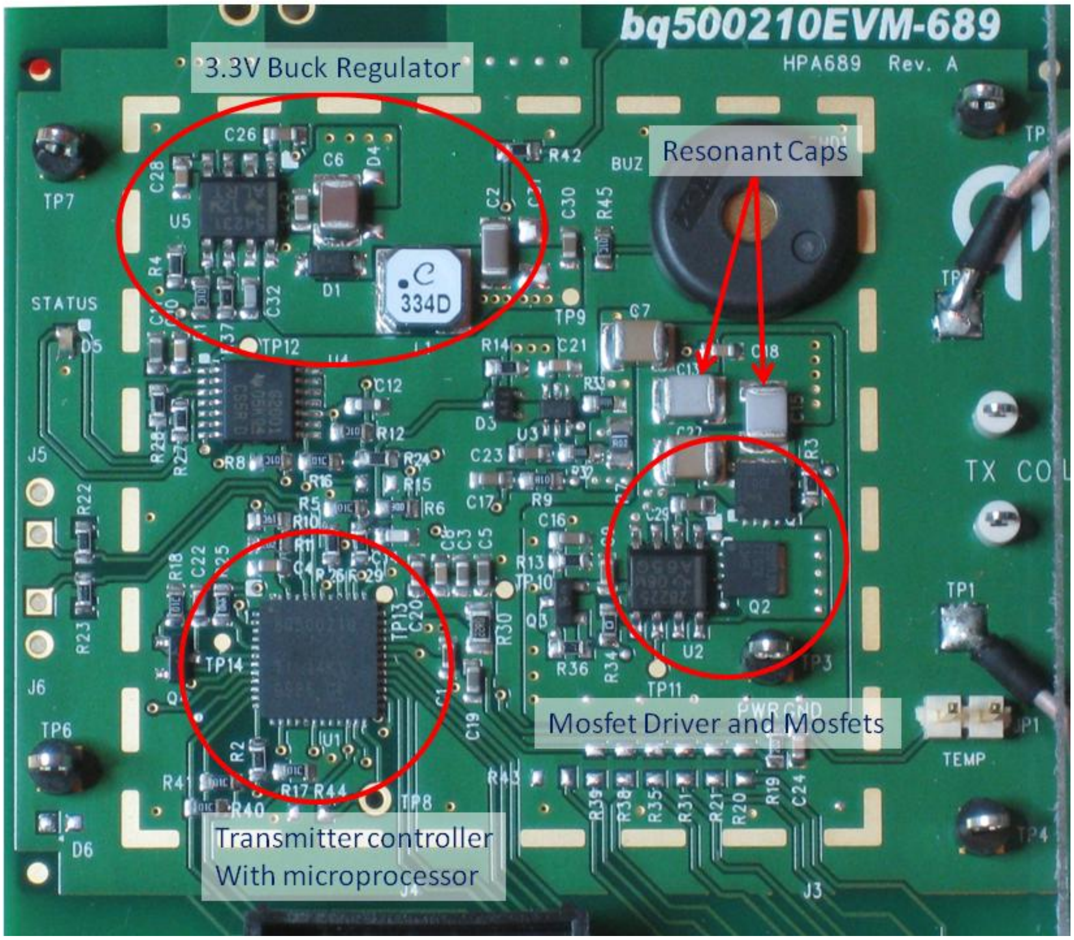
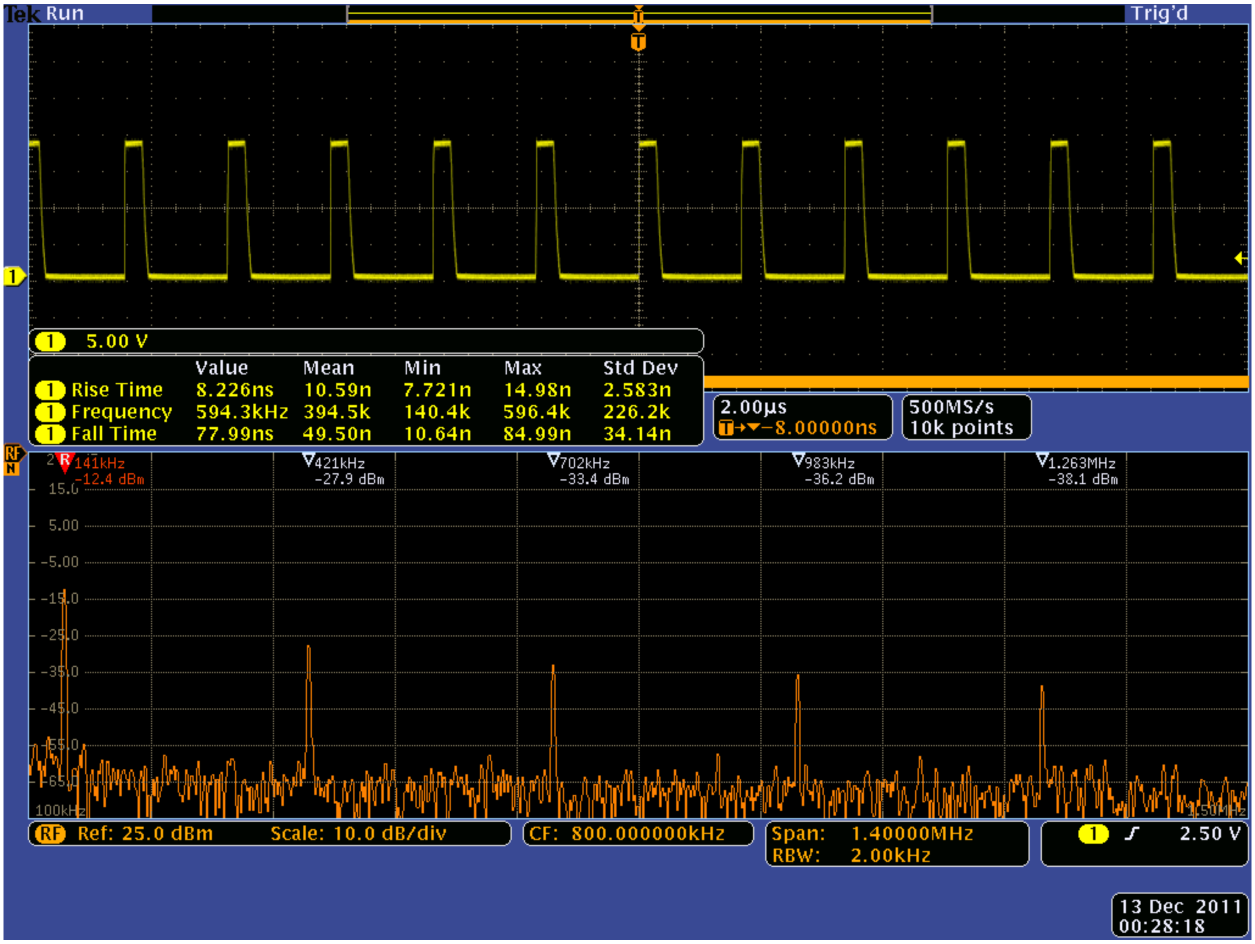


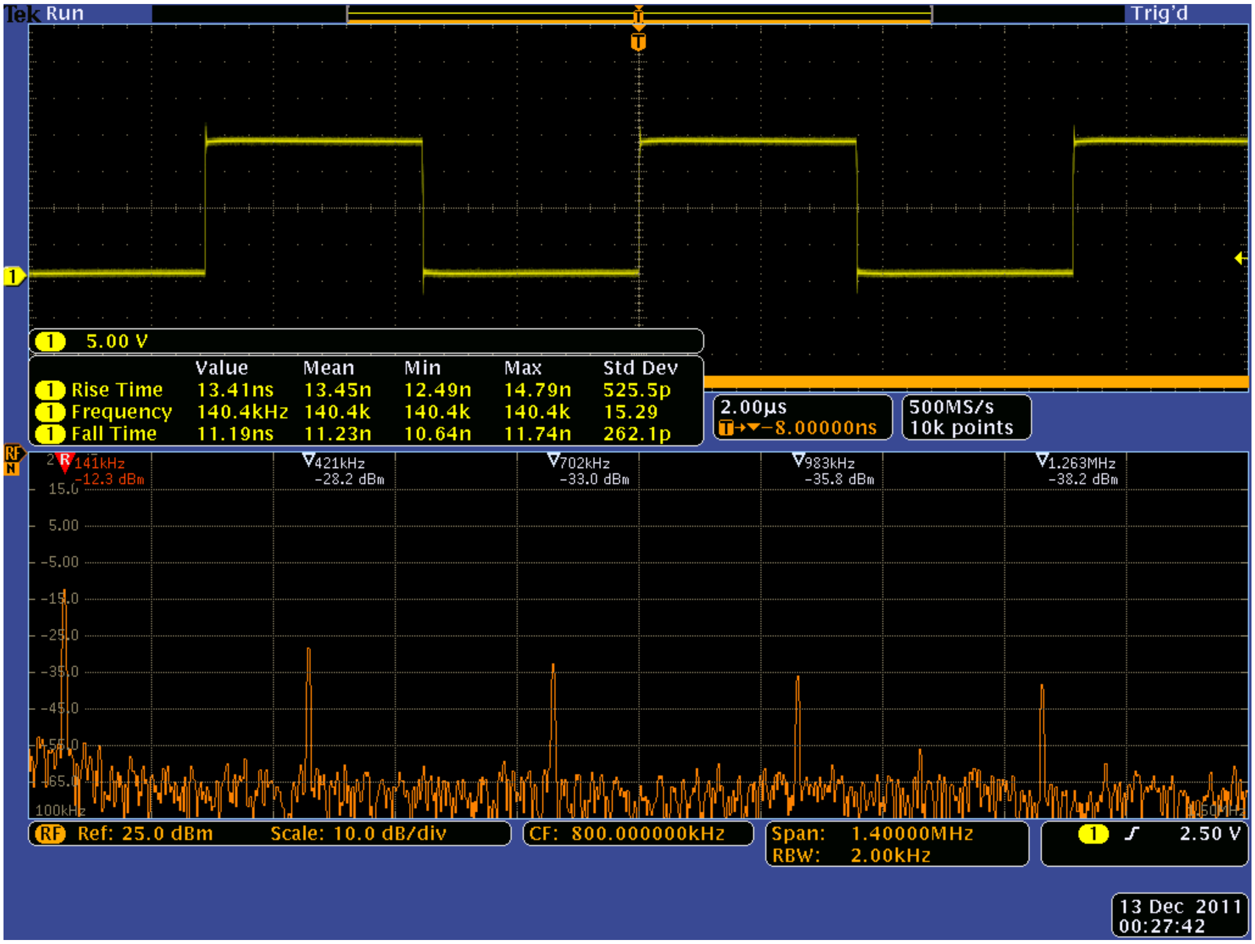
Figure 4 showing the significant circuits on the wireless transmitter PC Board

The near field antenna located a large spectrally rich signal directly above the Mosfet driver and Mosfets. A 3.9pF scope probe was used to monitor the switching voltage at the switch node of the buck regulator. The buck switch is operating at 593 kHz, which corresponds with the unrelated signal in the conducted emissions. This is unrelated to the half bridge signal at the Mosfet Driver and Mosfets, which was the dominant signal in the conducted emissions, shown in figure 3.



|  | Value | Mean | Min | Max | Std Dev |
|---|---|---|---|---|---|
| 1 Rise Time | 8.226ns | 10.59n | 7.721n | 14.98n | 2.583n |
| 1 Frequency | 594.3kHz | 394.5k | 140.4k | 596.4k | 226.2k |
| 1 Fall Time | 77.99ns | 49.50n | 10.64n | 84.99n | 34.14n |

Figure 5 The scope portion of the MDO4104-6 is displaying the Buck switch voltage while the RF section is displaying the spectrum of the Mosfet Driver and Mosfets.



1 5.00 V

| | Value | Mean | Min | Max | Std Dev |
|---|---|---|---|---|---|
| 1 Rise Time | 13.41ns | 13.45n | 12.49n | 14.79n | 525.5p |
| 1 Frequency | 140.4kHz | 140.4k | 140.4k | 140.4k | 15.29 |
| 1 Fall Time | 11.19ns | 11.23n | 10.64n | 11.74n | 262.1p |

2.00µs
T→▼−8.00000ns

500MS/s
10k points

RF Ref: 25.0 dBm Scale: 10.0 dB/div

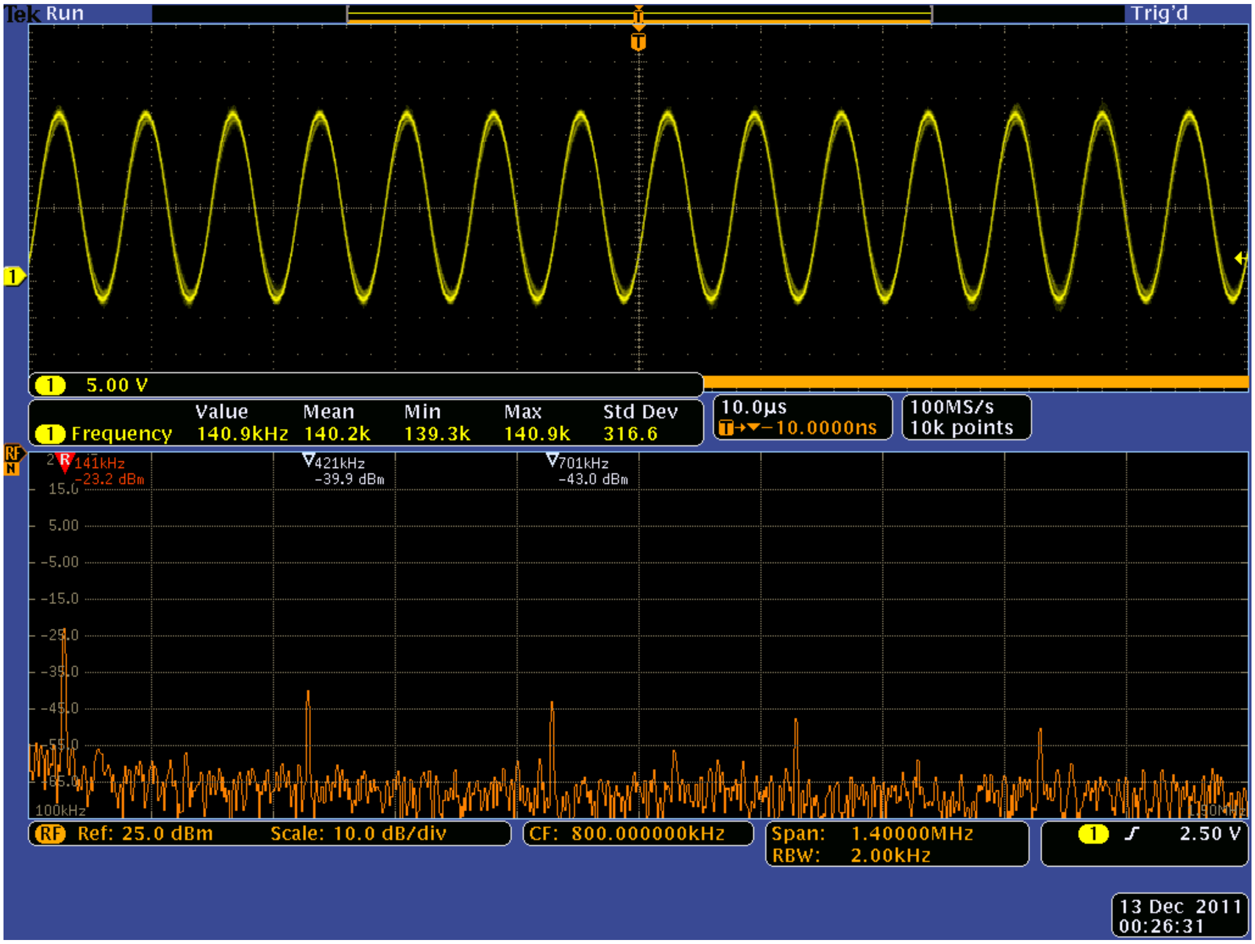
CF: 800.000000kHz

Span: 1.40000MHz
RBW: 2.00kHz

1 2.50 V

13 Dec 2011
00:27:42

Figure 6 The scope portion of the MDO4104-6 is displaying the Mosfet switching voltage while the RF section is displaying the spectrum of the Mosfet Driver and Mosfets.



1 5.00 V

| | Value | Mean | Min | Max | Std Dev |
|---|---|---|---|---|---|
| 1 Frequency | 140.9kHz | 140.2k | 139.3k | 140.9k | 316.6 |

10.0µs
T→▾−10.0000ns

100MS/s
10k points

R 141kHz
-23.2 dBm

▽421kHz
-39.9 dBm

▽701kHz
-43.0 dBm

RF Ref: 25.0 dBm Scale: 10.0 dB/div

CF: 800.000000kHz

Span: 1.40000MHz
RBW: 2.00kHz

1 ⎍ 2.50 V

13 Dec 2011
00:26:31

Figure 7 The scope portion of the MDO4104-6 is displaying the half bridge capacitor voltage (resonator) while the RF section is displaying the spectrum of the Mosfet Driver and Mosfets.

One additional signal source was located directly above the Bq500210 transmitter controller, which includes a microcontroller. While there is little information in the datasheet about the uController, it apparently operates at 31.3 MHz as seen in figure 8.

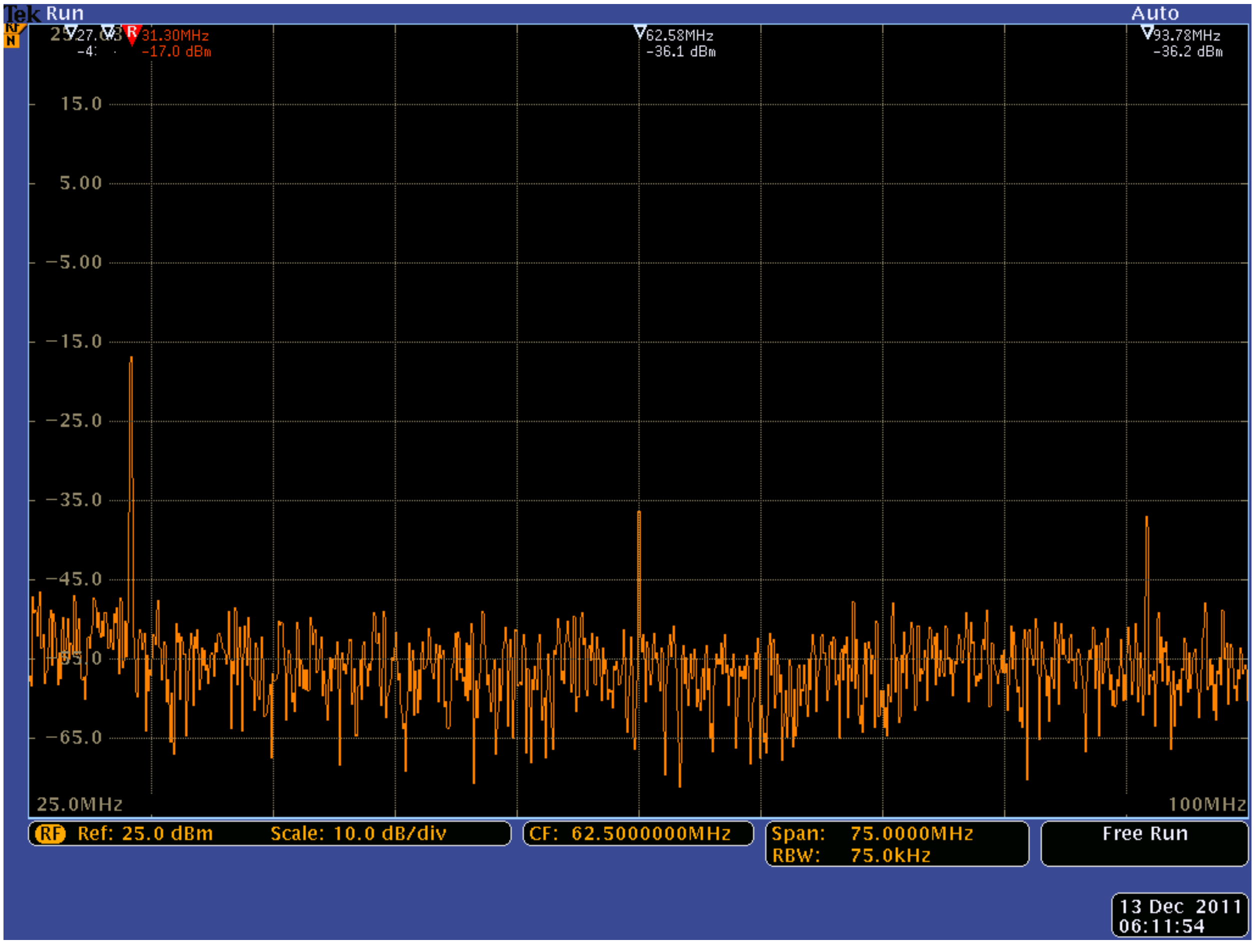


Figure 8 Radiated signal directly above the Bq500210 transmitter controller. We can be certain that the 31.3 MHz frequency is the fundamental frequency, since no signals were detected at 10.43MHz or 15.65MHz.

Figure 9 shows the uController signal along with the Mosfet switching signals. We know that the EMI from the Mosfets is due to the dV/dT and not due to the dI/dT, since the current signal, as seen in the figure 7 resonator voltage, is sinusoidal, and so would not be spectrally rich. The sinusoidal response can also be seen in the resonant voltage waveform shown in figure 7. Probing the switch voltage and displaying it in the RF display confirms the very high spectral content due to the dV/dT.

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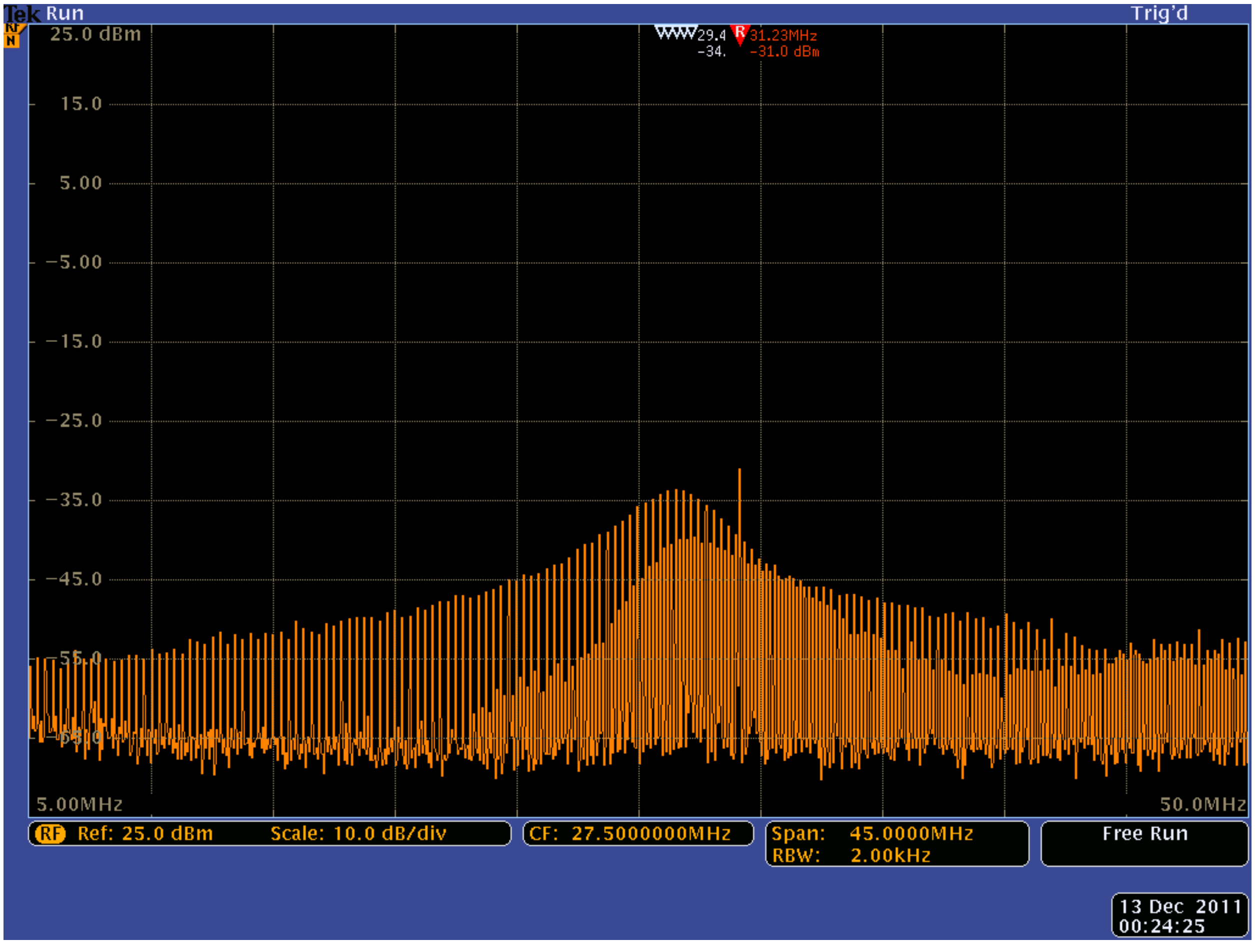
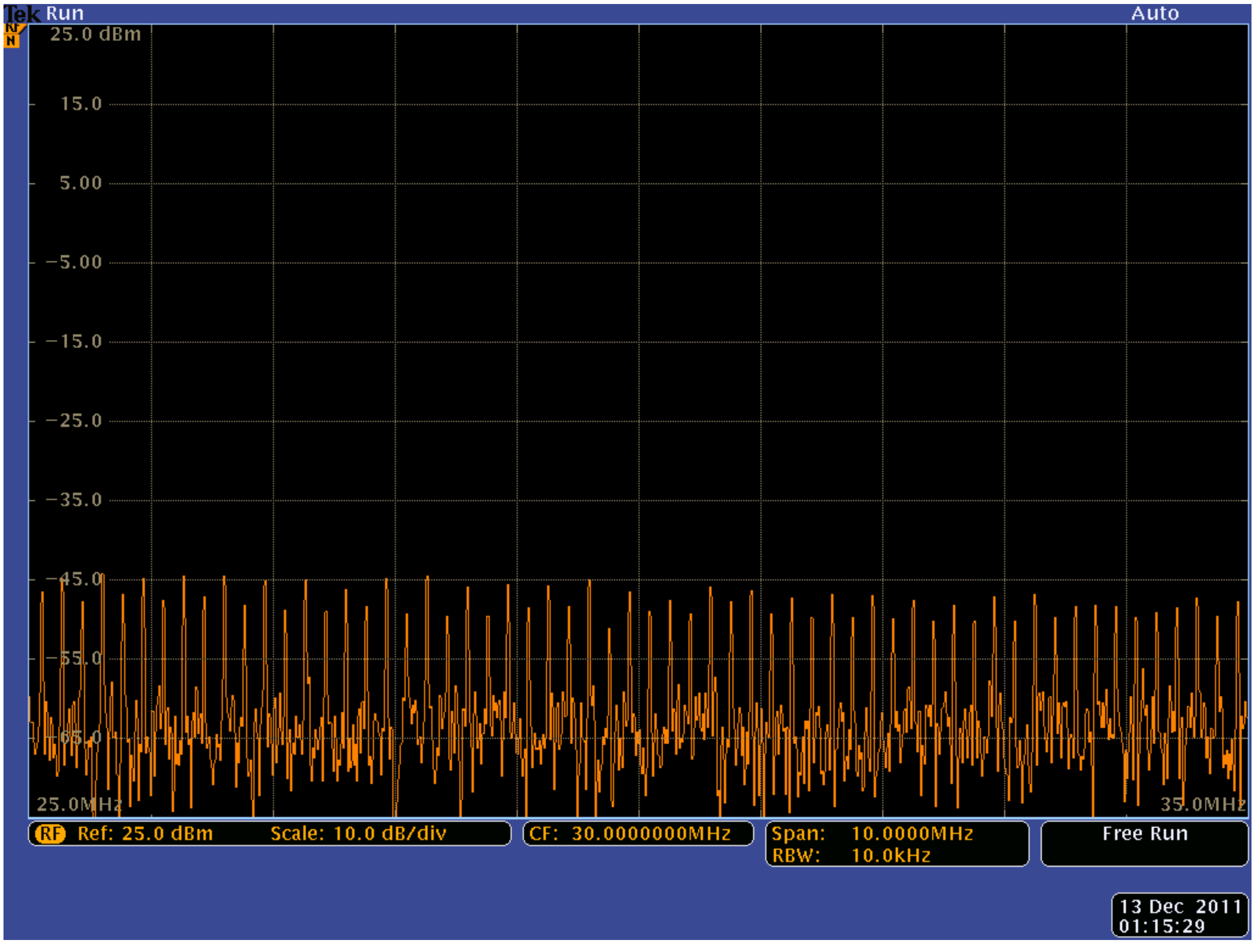


Figure 9 A spectrally rich radiated signal from the Mosfet switching and also evident is the 31.2MHz uController signal.



Ref: 25.0 dBm
Scale: 10.0 dB/div
CF: 30.0000000MHz
Span: 10.0000MHz
RBW: 10.0kHz

Figure 10 Displaying the Mosfet switch voltage in the RF display shows how rich the harmonic content is from the dV/dT of the switching.

Figures 11 and 12 show an overview of the radiated signature including the buck regulator spectral content and the half bridge dV/dT content. These figures show that the buck regulator harmonics do not varies with operating conditions, such as the DC input voltage and load current, while the half bridge frequency does vary with load current, DC input voltage and alignment of the transmitter and the receiver. The uController signal does not show up in these figures, since the fundamental frequency is at 31MHz, well above the range of this measurement.

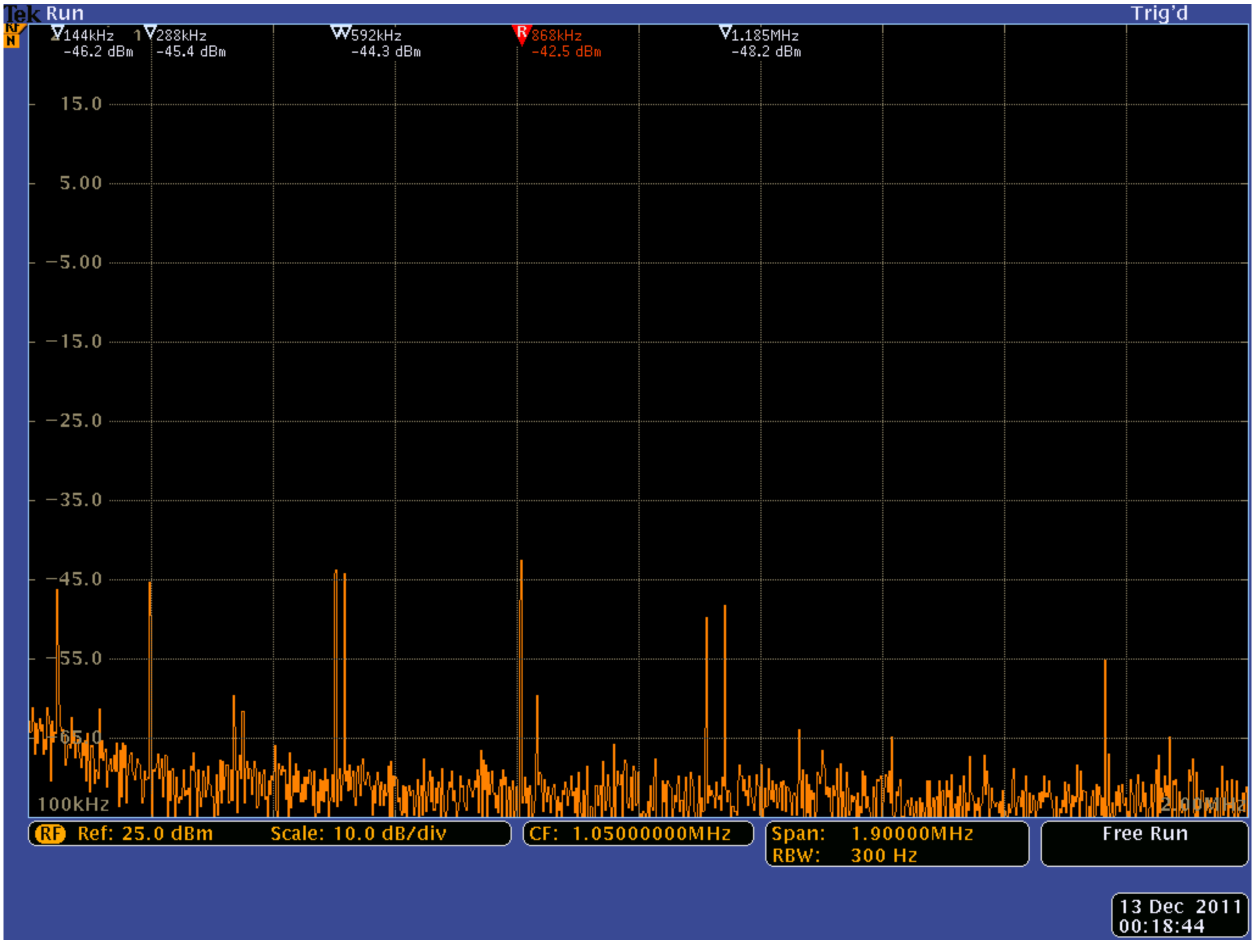
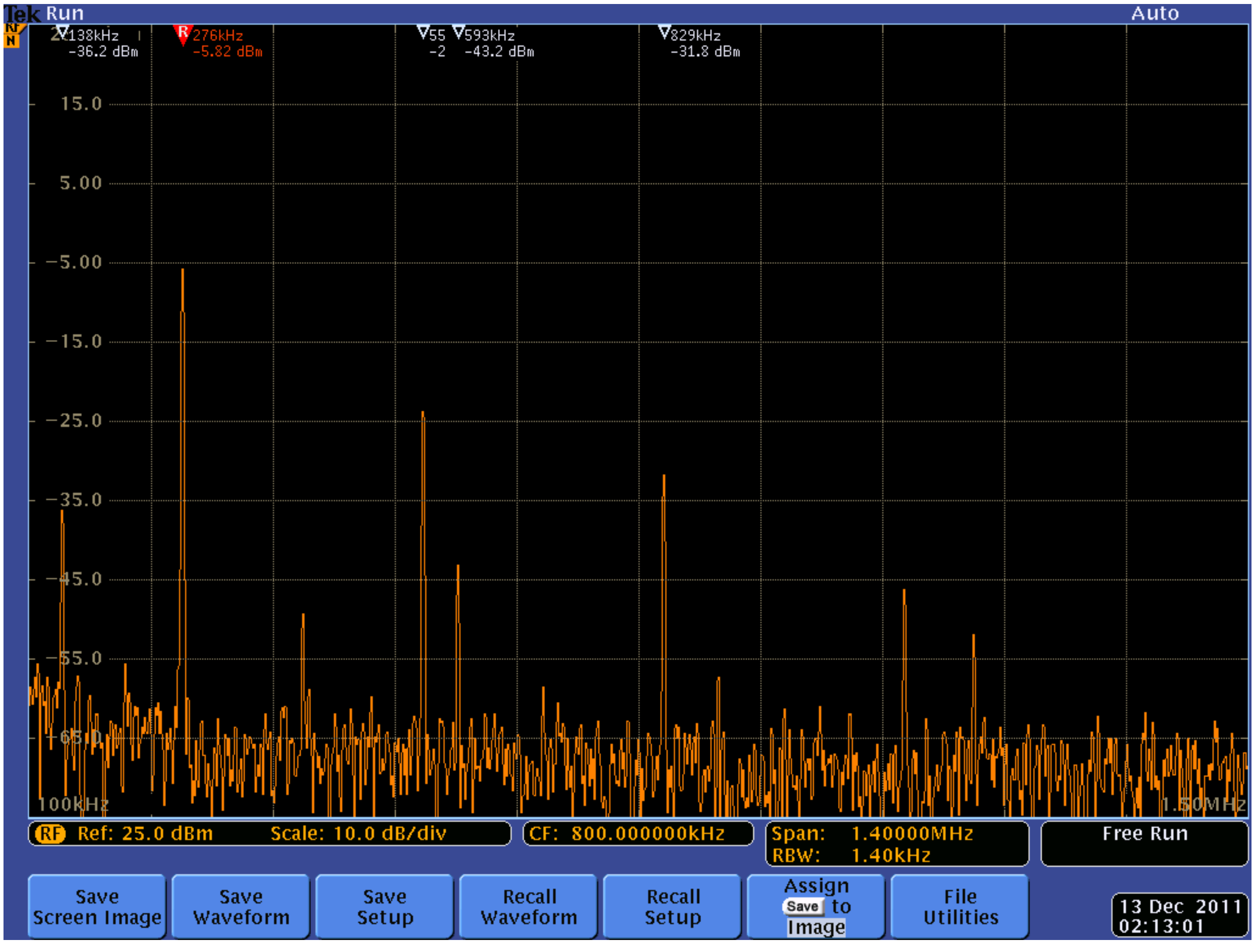


Figure 11 Displaying the Mosfet switch voltage in the RF display shows how rich the harmonic content is from the dV/dT of the switching.



Interestingly, a significant portion of the EMI is due to the high dV/dT of the switching Mosfets. The resonant converter uses zero current resonant switching and so one way to reduce the noise from the Mosfets is just to slow them down.

The buck regulator is only used to provide power to the low power circuits and it may be worth considering the impact of using a linear regulator or a lower noise topology

Reviewing our original goals, we have accomplished each task. We have located the significant conducted and radiated signal sources.

We have identified characteristics that define each of these sources. For example, we identified the sensitivity of the Mosfet signal to operating load current, alignment of the transmitter and receiver and to the DC input voltage. We identified the buck regulator as a fixed frequency device with a fundamental frequency of 593kHz and we also identified a uController signal that is a fixed frequency of 31.3MHz. These characteristics can be used to identify any troublesome sources in the final testing. We identified a possible mitigation for the high dV/dT of the Mosfets, which is to slow them down. Testing of this mitigation prior to the final certification testing might eliminate the issue before it even becomes an issue.