



# Troubleshooting Common EMI Problems

## A Digital Designer's Handbook

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Learn best practices for troubleshooting common EMI problems in today's digital designs. Industry expert William Kimmel of Kimmel Gerke Associates shares the techniques he's learned through years of experience, and shares examples of common causes of EMI and how to discover root cause. The MDO4000 Series Mixed Domain Oscilloscope is featured as the tool of choice in this insightful Digital Designer's Handbook.

EMI compliance testing can induce fear in even the most experienced digital designer. When you receive your EMI Test Report back and problems have been identified, you are now facing a potentially frustrating and lengthy troubleshooting exercise.

In this article, recommended test practices and measurements for identifying common EMI problems in digital designs will be discussed.

### STEP 1: Choosing Your Test Tool

Spectrum analyzers are key elements in EMI emission testing. However, the data collected during testing is not well suited for diagnosing the causes of emission problems. In fact, modern spectrum analyzers can be used to gather much more useful information than what is presented in the typical EMI Test Report. In particular, three factors that are very useful for diagnosing problems are precise frequency measurements, bandwidth control and span control.

A relatively new test option is the Mixed Domain Oscilloscope, like the Tektronix MDO4000 Series. A Mixed Domain Oscilloscope (MDO) combines the functionality of an oscilloscope (time domain) and a spectrum analyzer (frequency domain) in one instrument. This dual capability is particularly helpful when troubleshooting EMI problems, which are often specified in the frequency domain.

A potentially useful feature for EMI troubleshooting is the time-correlated display. With the MDO, a trigger is set up on one channel (analog, digital or RF) and when the trigger event occurs, data from all channels is acquired, ensuring the displayed signals are time-correlated. This allows us to look at cause and effect relationships between EMI problems in both the frequency domain and the time domain.

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Figure 1 shows a combined frequency and time plot of a periodic signal on the Tektronix MDO4104-6, which we'll be using for this article. The time display is gathered by a voltage probe at the signal output. The frequency display is gathered by a small loop antenna.

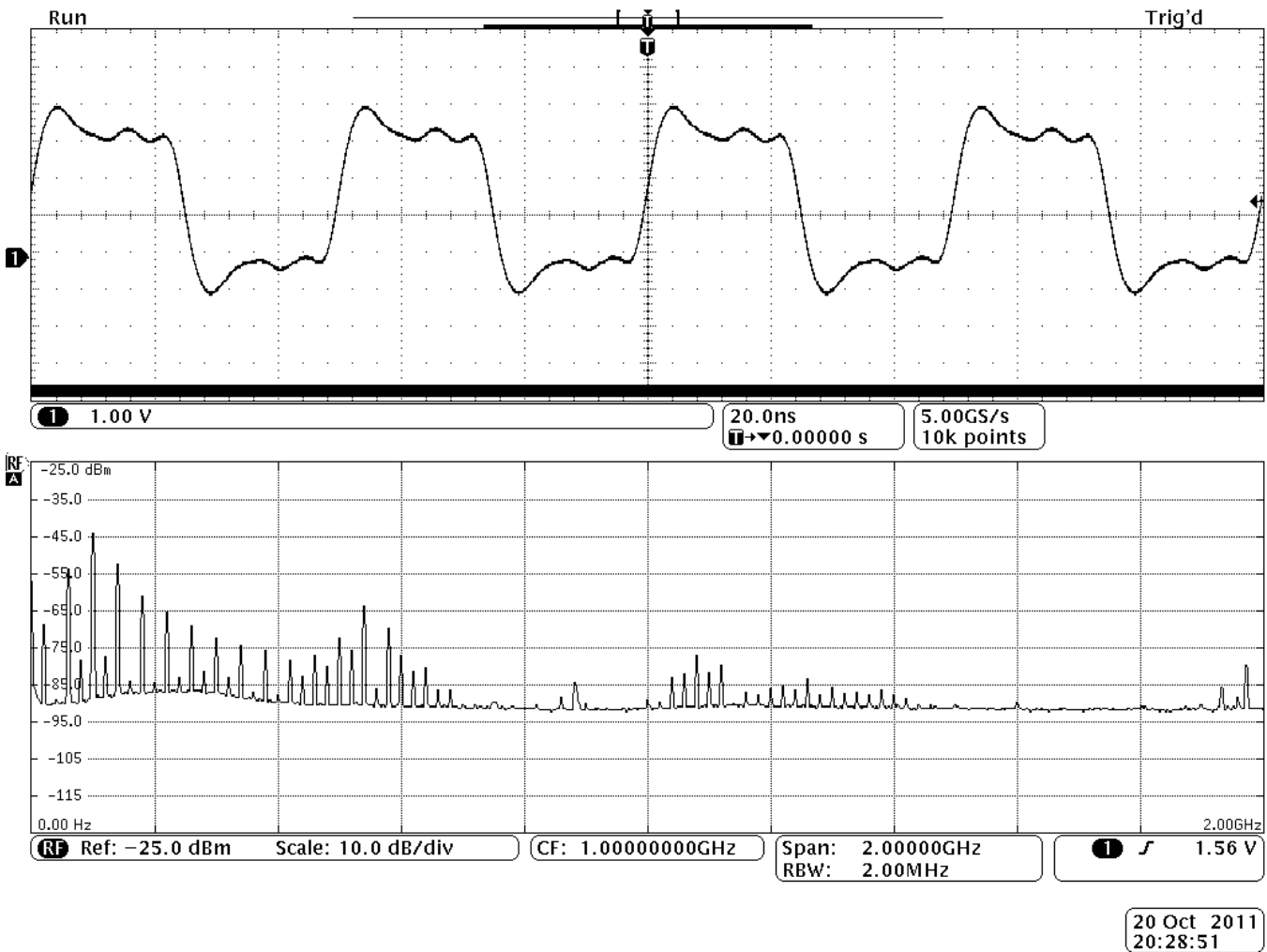


Figure 1. Time Frequency Plot from Tektronix MDO 4104-6. Clock 20 MHz, Span 0 - 2 GHz.

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### STEP 2: Identify Offending Frequency Sources

Although readily available during testing, and generally logged as part of the test process, the EMI test report does not always show the exact frequency contributions. The graphical data shows the spectral lines, but does not show the exact frequencies involved. Tabular data is needed, and more than just the readings that are near or over the specified limits.

Crystal oscillators and clocks are very accurate frequency sources. The possible problem frequencies on an EMI report will be the actual clock frequency or a harmonic (integral multiple) of the clock frequency. Clock frequencies are often divided into submultiples of the clock frequency, and harmonics of those will show up from data and address buses.

When troubleshooting emissions, the first order of business is to identify the specific frequency source. If there is only one clock in the equipment, then the source is self-evident, but if there are multiple clocks, the answer is not always obvious – you will have to dig a little.

With a spreadsheet, you can quickly generate a list of possible harmonic frequencies, given the actual clock frequencies in use. Combined with the test data, you can quickly hone in on the offending source.

Periodic waves in power switching devices are also detectable, even though they are not as stable as a crystal source. In addition, some switching techniques deliberately vary the oscillator frequency. Even so, we can still glean useful information from the spectrum of our signal – particularly the frequency spacing between spectral lines.

### STEP 3: Looking for Resonance

Radiated emissions are the result of two factors: "hidden transmitters" and "hidden antennas." The former are usually harmonics of clocks or other highly repetitive signals, and the latter are usually cables, circuit board traces, etc.

Like real antennas, exciting a resonance with a harmonic can cause the emissions to peak, just like hitting the right key on a piano can cause a tuning fork to ring. This is often why emissions fail at higher frequencies, when lower frequencies are in compliance.

Furthermore, most systems have multiple hidden antennas that are resonant at multiple frequencies. Thus, fixing one problem frequency may result in problems at other frequencies. When troubleshooting, it is often helpful to look at the bigger picture, rather than focusing on one or two offending frequencies. This is done by choosing a wider frequency span.

Spectrum analyzers can be set to display a start frequency and a stop frequency – this is called the frequency span, or just the span. The MDO, and most quality spectrum analyzers allow any frequencies (within the range of the instrument) to be used. Some lower cost analyzers have limited range selection. Also note that some analyzers specify the span as the full scale frequency range, while others call the span per major division – not a problem, as long as you know which is which.

Usually, the horizontal frequency scale is linear, making it good for viewing – over a wide range, a logarithmic scale is used, particularly on printed graphs, but it is hard for us humans to interpolate log scales.

For test purposes, especially automated testing, the span setting is not critical. For manual use, the span can be set so that the amplitude and frequency are easily readable. But this approach misses a lot of useful diagnostic information – setting a very wide span or a very narrow span can uncover more information. Feel free to experiment.

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A wide span is good for identifying resonant conditions. Figure 2 shows a 20 MHz frequency source displayed over a 2 GHz span. In this example, there are significant harmonics up to about 1.5 GHz, and a probable resonance at 1.2 GHz. With the Tektronix MDO4104-6, we can capture up to 3 GHz of span with a single acquisition, allowing us to easily see these higher order frequency components.

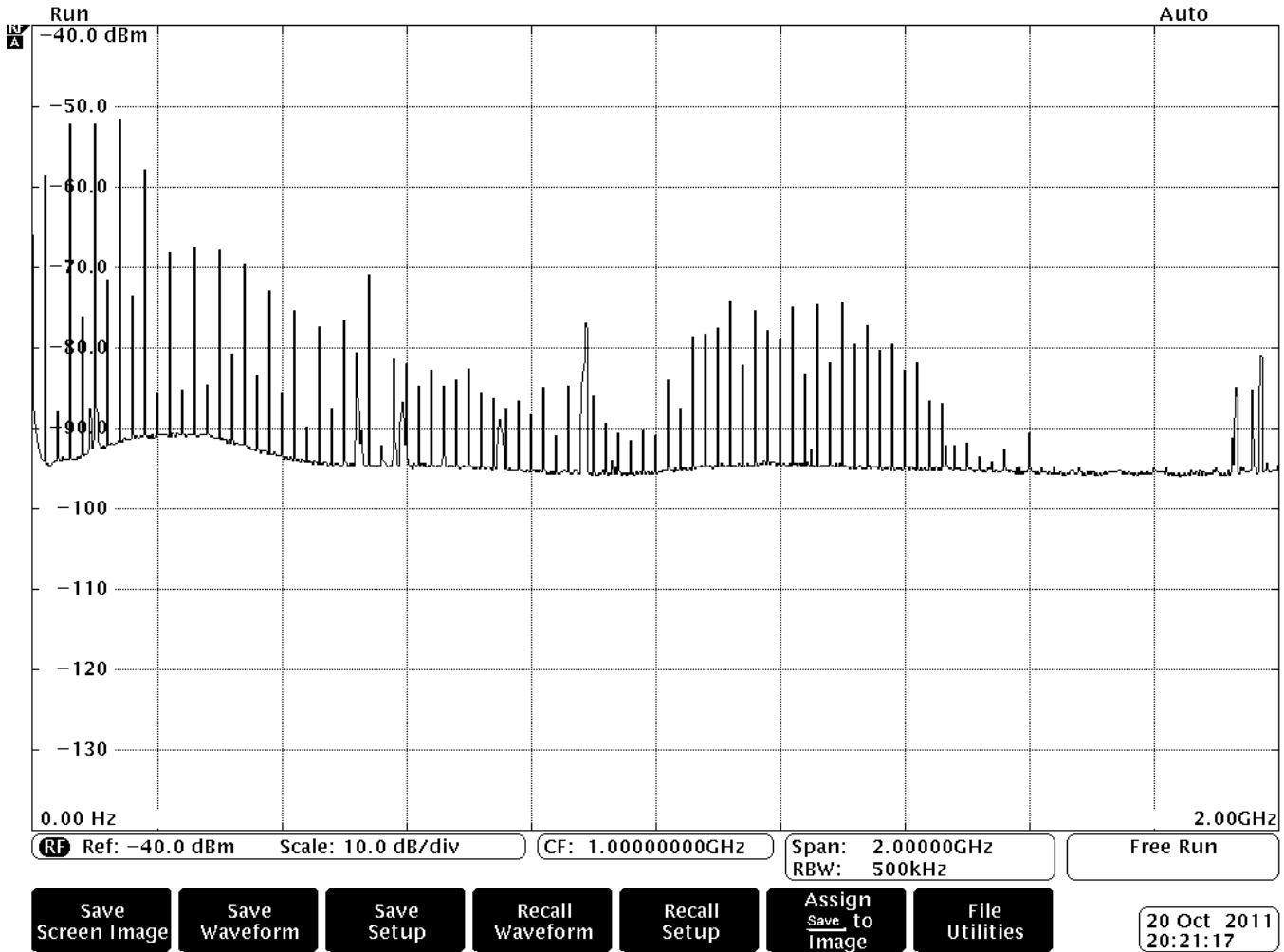


Figure 2. 20 MHz clock over a wide span (0 – 2 GHz, RBW 500 kHz).

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Depending on what causes the resonance, it may or may not show up on the noise floor, as in Figure 3. If it shows up on the noise floor, the resonance is likely a dimensional resonance, like circuit board dimensions, slot opening, etc.

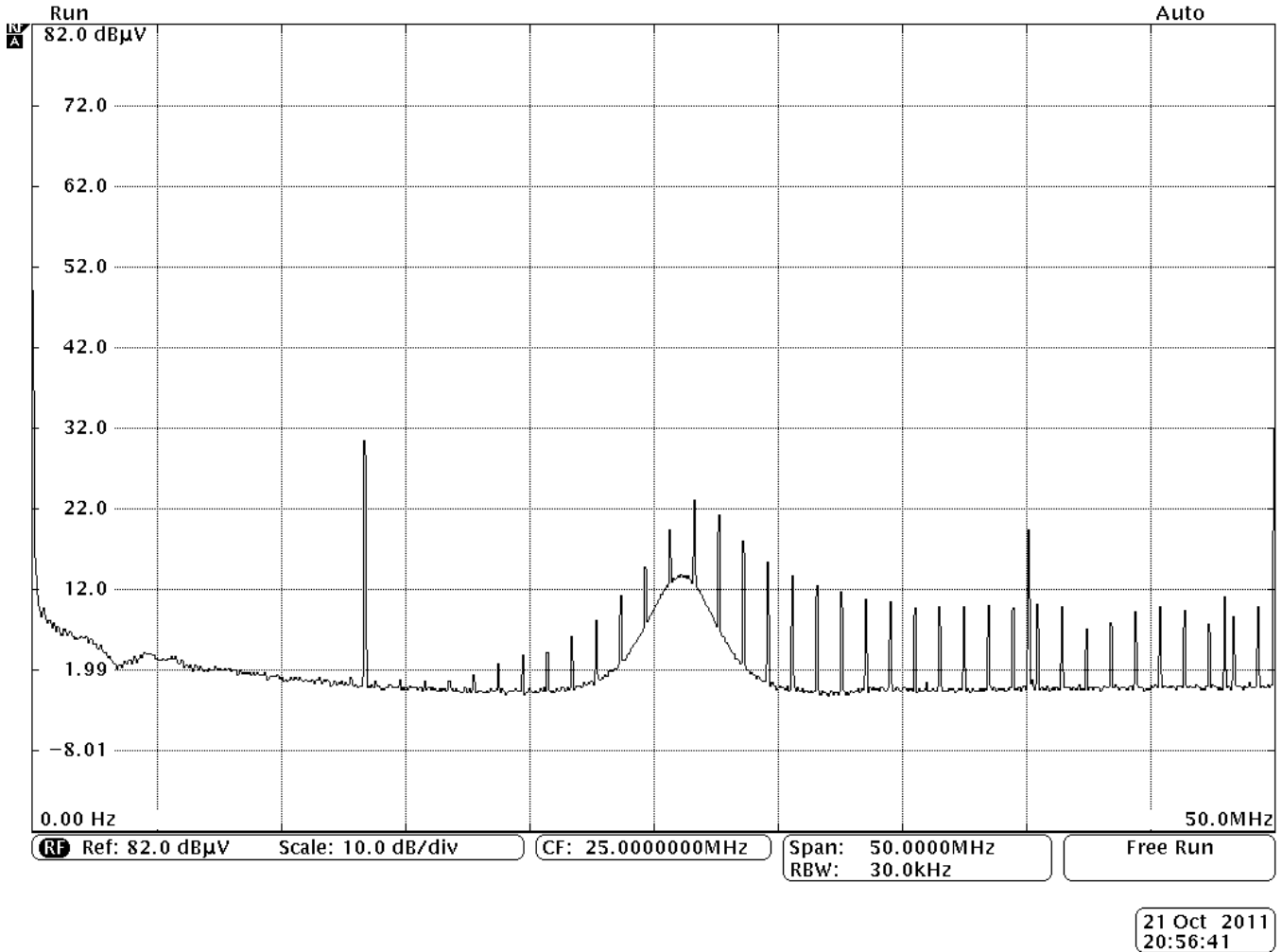


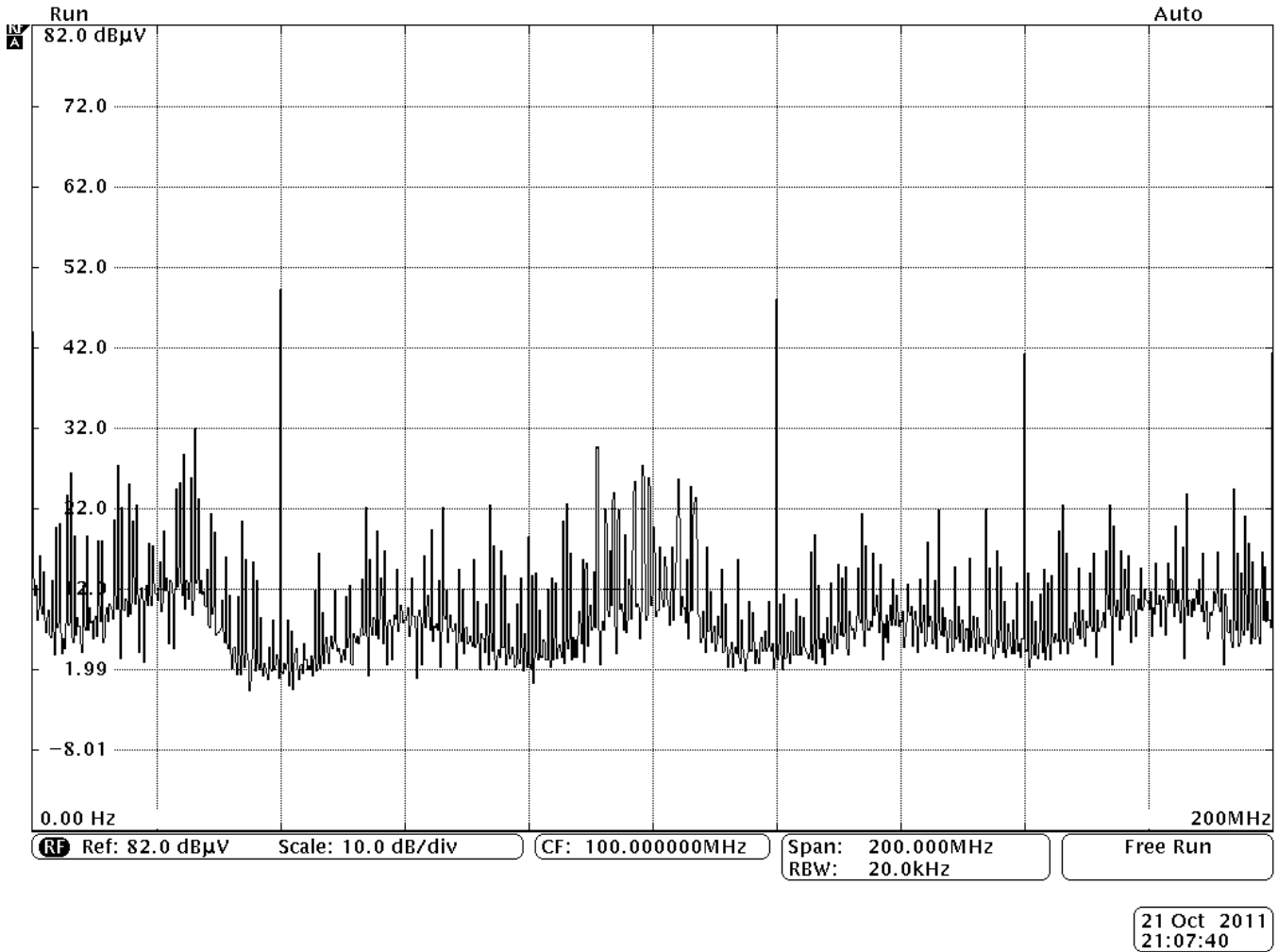
Figure 3. Noise Floor Resonance. Span 0 - 50 MHz, RBW 30 kHz.

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## STEP 4: Checking Emissions from Clock and Data Buses

While computer clocks are the principle concern in high frequency emissions, subdivisions also appear – usually, these are simple subdivisions, like  $1/4$ ,  $1/8$ , etc. All other factors being equal, each time you divide the frequency to half, the emission level goes down 6 dB. So subdivision reduces the emission levels quite quickly, which is why the fundamental clock is often the biggest contributor. Figure 4 shows a wide span with the fundamental clock being the highest contributor, and data or clock harmonics, being lower frequency, showing up at lower amplitudes.



**Figure 4** Clock and Bus Harmonics. Span 0 - 200 MHz, RBW 20 kHz.

But if your clock harmonics are well confined, the data and address buses may be the primary contributors, especially if the buses go off board.

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## STEP 5: Checking for Broadband Noise

By definition, a signal is broadband if the fundamental frequency is lower than the bandwidth of the receiver. Thus, a switching power source of, say, 80 kHz looks broadband if the receiver or spectrum analyzer is set at 100 kHz to 120 kHz (the two common bandwidths cited for radiated emissions). Random noise, such as might come from a brush type motor, will look like broadband noise, no matter what the receiver bandwidth is set to.

Figure 5 shows a broadband plot of a computer power supply, shown with the supply turned on and with it turned off. In this case, there is no evidence of any harmonic activity – it looks purely broadband.

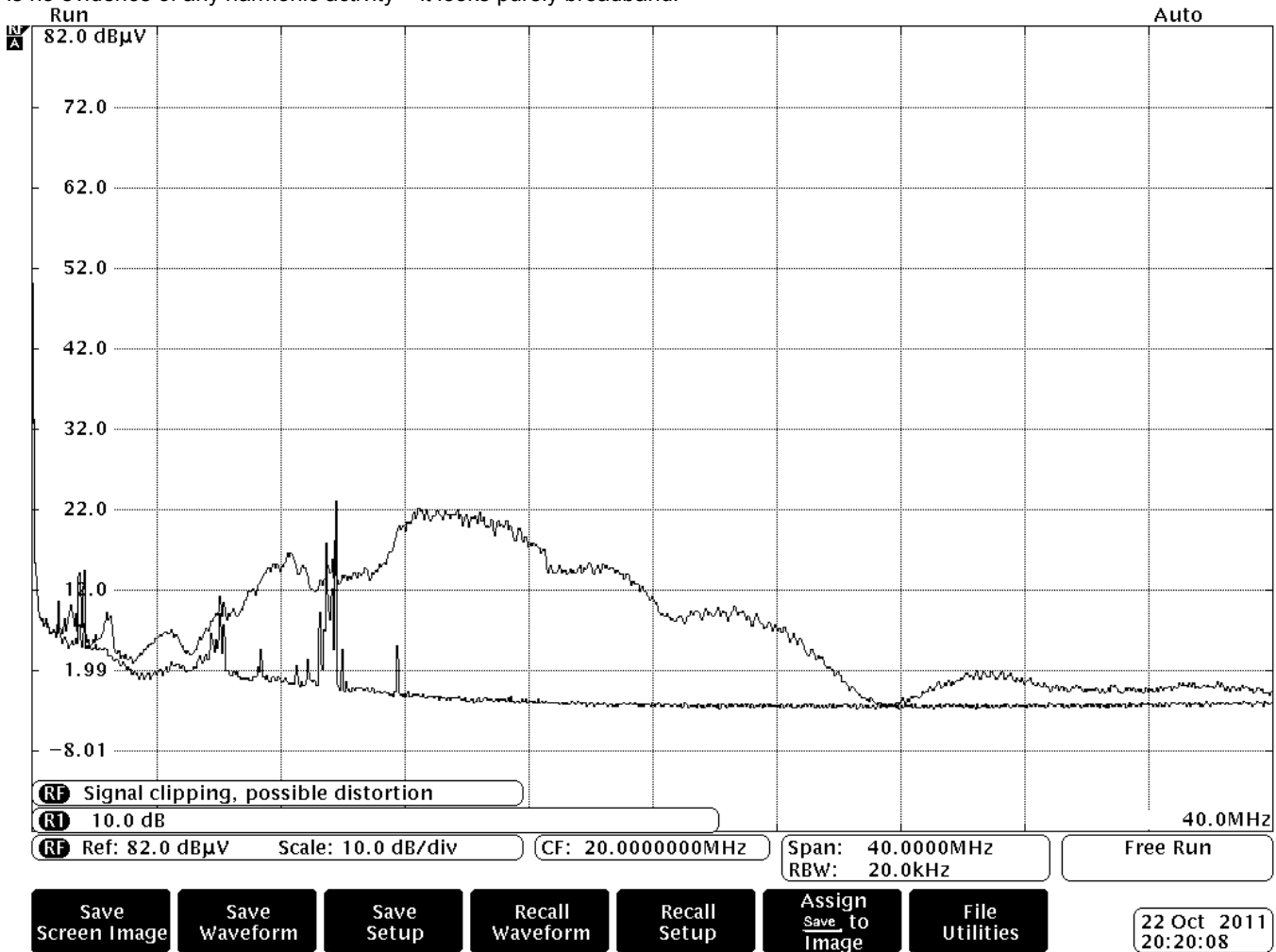


Figure 5. Broadband noise from a power supply. Span 0 - 20 MHz, RBW 20 kHz.

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Left untouched, broadband noise can completely hide narrowband signals. Figure 6 shows a plot of broadband noise that masks the narrowband signal (also shown in the plot with the broadband noise suppressed.)

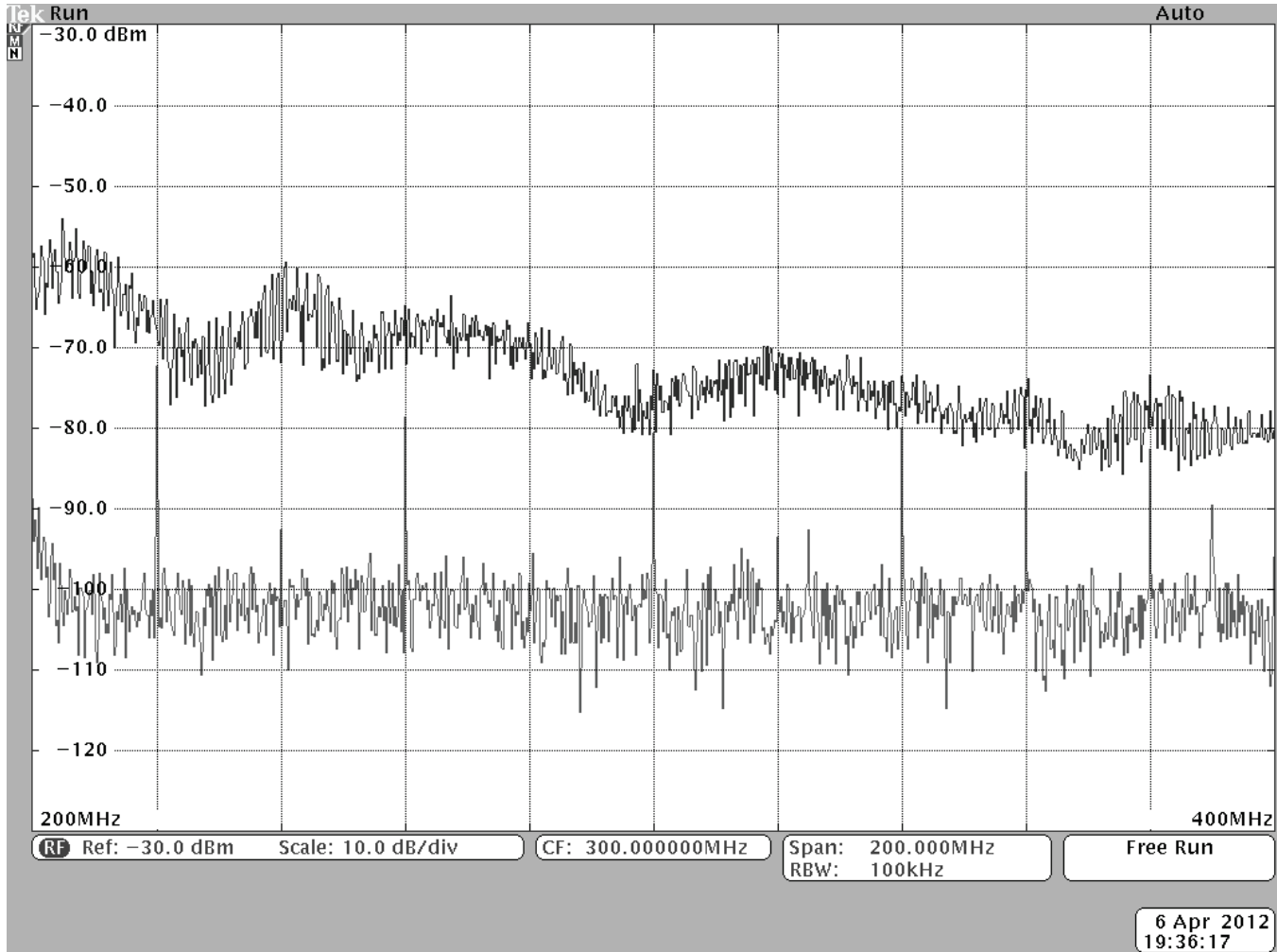


Figure 6. Broadband noise masks narrowband signal. Span 200 - 400 MHz, RBW 100 kHz.



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By setting a narrower resolution bandwidth (RBW), the broadband contribution is reduced, while leaving the narrowband contribution untouched. Figure 7 shows the bandwidth reduced to 1/10, reducing the broadband noise contribution by 20 dB.

Lower bandwidth means you capture less broadband energy, while the narrowband signal energy remains the same. This has the effect of improving the signal-to-noise ratio for a narrowband signal. The result is that the "noise floor" appears to drop in amplitude, while the narrowband signal remains at the same level. If the broadband energy is high enough, it may actually mask the narrowband signals unless the bandwidth is narrowed.

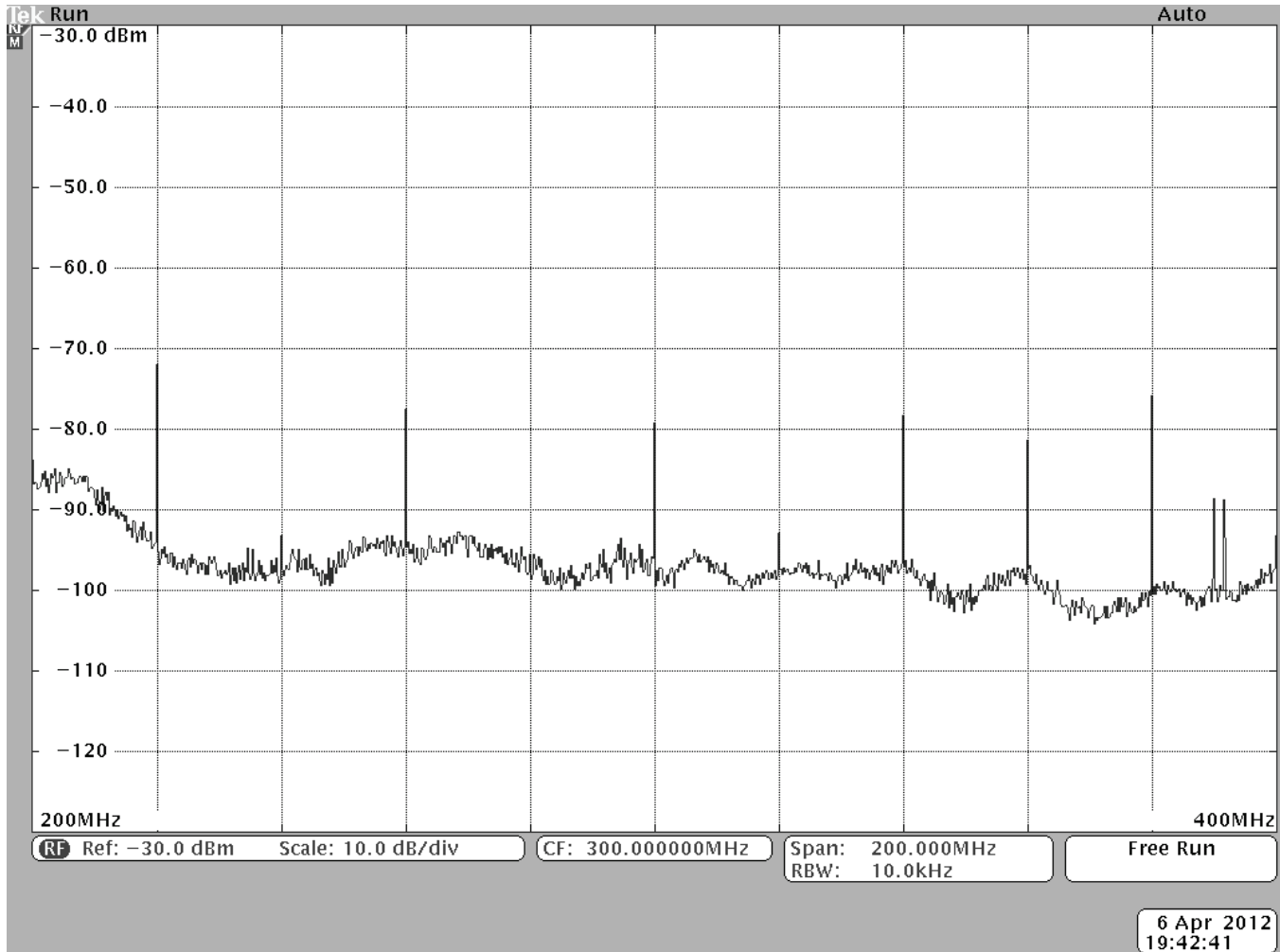
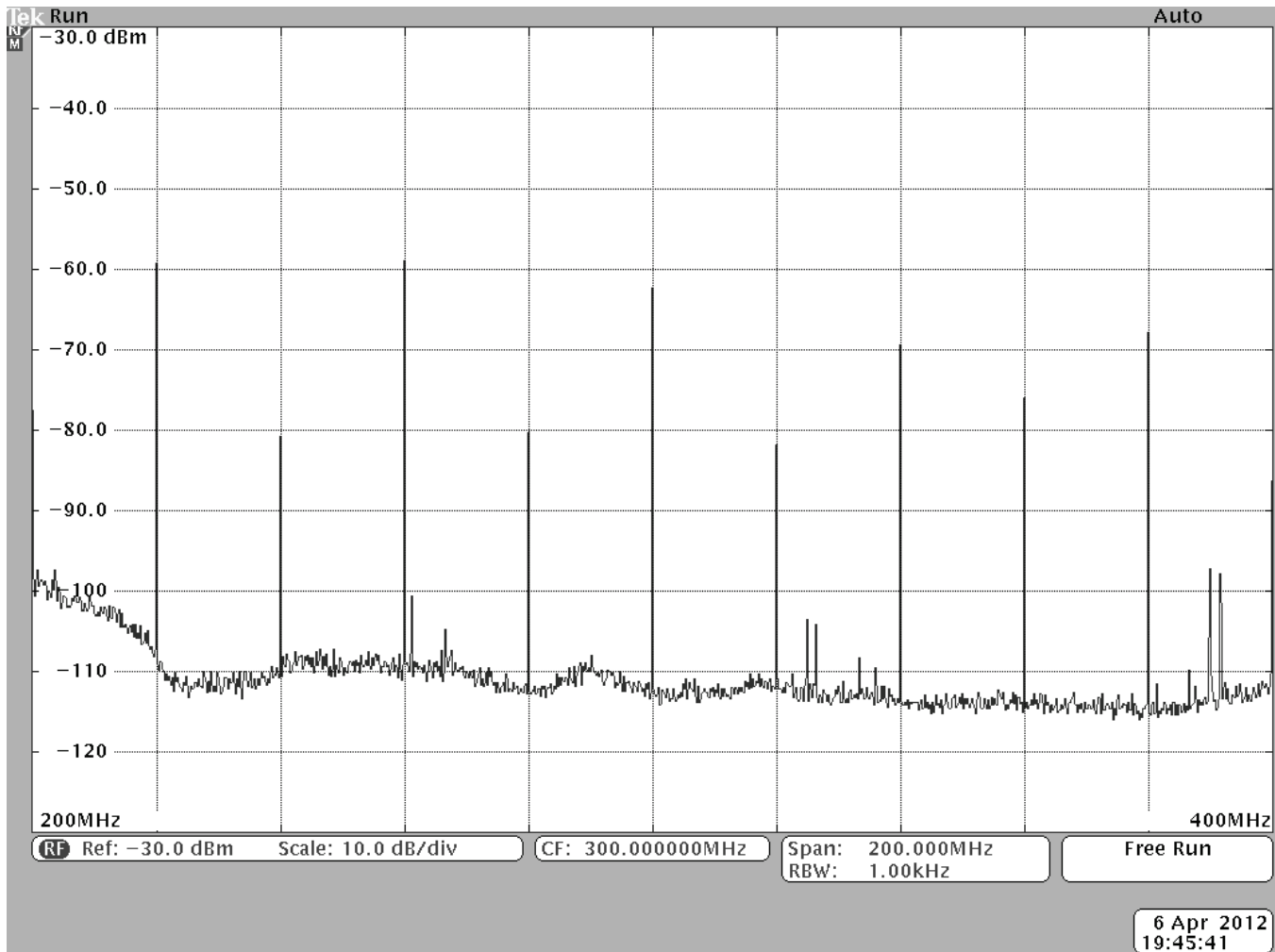


Figure 7. Narrower bandwidth setting allows narrowband signal to be observed. Span 200 - 400 MHz, RBW 10 kHz.

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Setting the bandwidth even narrower, shows the broadband noise reduced substantially. A very narrow bandwidth does slow the processing rate of the test equipment considerably since more data must be processed, so don't set the bandwidth unnecessarily low. Generally, it is adequate to have the signal 6 dB or more above the noise level.



**Figure 8.** Still narrower bandwidth reduces broadband noise to a very low level. Span 200 - 400 MHz, RBW 1 kHz.

You may find a setting for both Resolution and Video Bandwidth. Resolution bandwidth is the bandwidth of the receiver – for regulatory testing, this setting is specified.

Video bandwidth is a filter applied to the video display. Usually, it is set equal to the resolution bandwidth, but may be set lower to reduce screen clutter. Averaging, as included in the Tektronix MDO Series, works well for reducing clutter, while leaving the resolution bandwidth unaffected.

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## Making the Measurements – An Example Circuit

A wide span setting on the spectrum analyzer or mixed domain oscilloscope usually makes it easy to identify harmonic sources. Figure 9 shows that harmonics from a 20 MHz clock are easily identifiable. This is a good place to start. In this case, we've used a span of 200 MHz. With the MDO4104-6, we could choose up to a 3 GHz span, if needed.

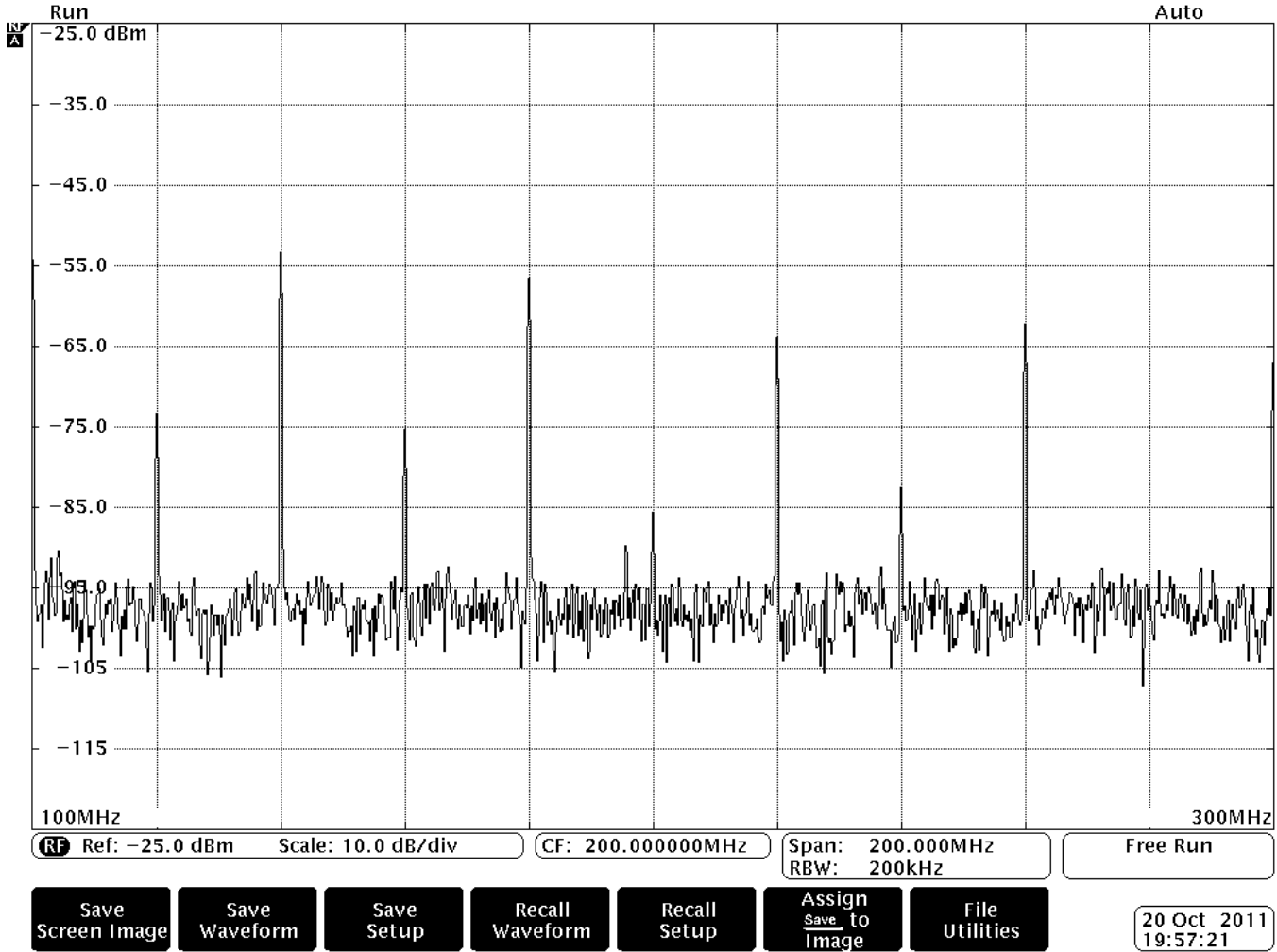
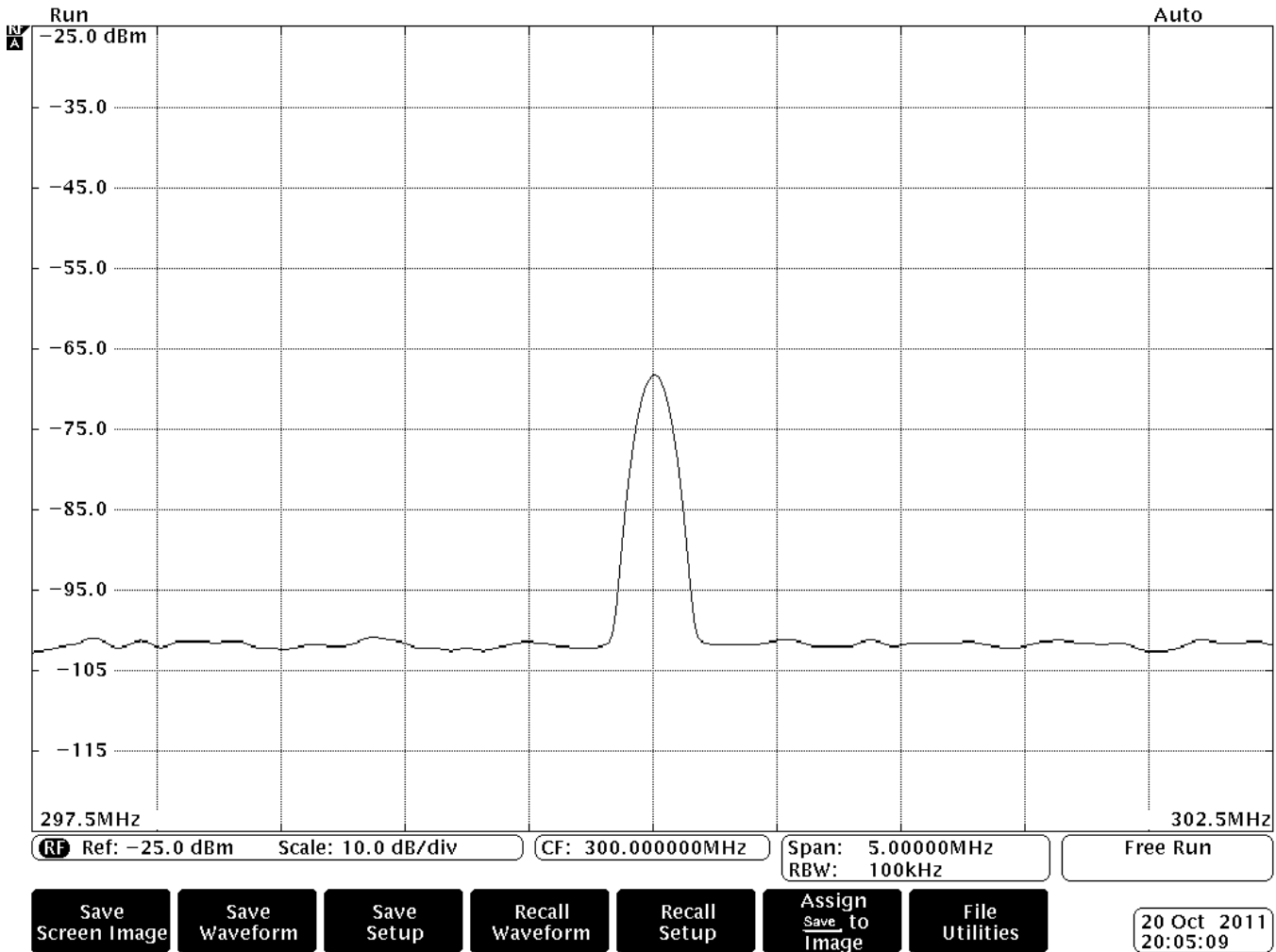


Figure 9. Wide span shows an array of harmonic frequencies. Span 100 - 300 MHz, RBW 200 kHz.

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Setting to a narrower span makes it easy to read an individual contributor. Figure 10 shows a span and resolution bandwidth setting that would be easy with which to take an accurate amplitude and frequency reading.



**Figure 10.** Narrower span makes for accurate data readings. Center Frequency 300 MHz, Span 5 MHz, RBW 100 kHz.

Note in this case, we have started specifying center frequency.

There appears to be nothing abnormal about this setting, however, if the trace seems to bob up and down, it may mean that there are two or more harmonics at nearly the same frequency, drifting in and out of phase.

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To take a closer look, we go to a narrower span and resolution bandwidth. Figure 11 indicates that there may be two frequencies very close together.

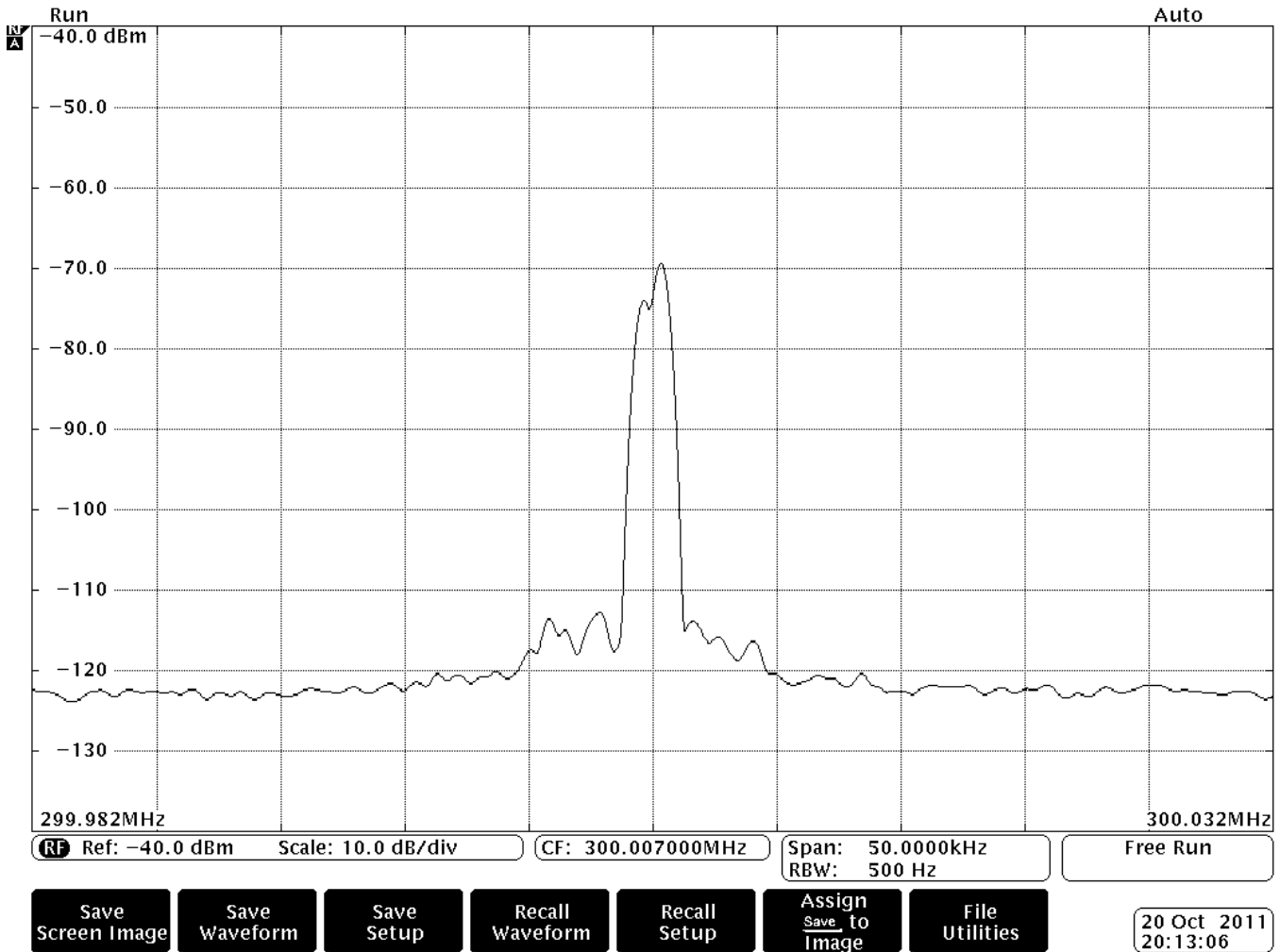


Figure 11. Setting to a narrower bandwidth and span. Center Frequency 300 MHz, Span 50 kHz, RBW 500 Hz.

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Setting to a still narrower bandwidth, we see the two contributors separating into two distinct frequencies, as in Figure 12.

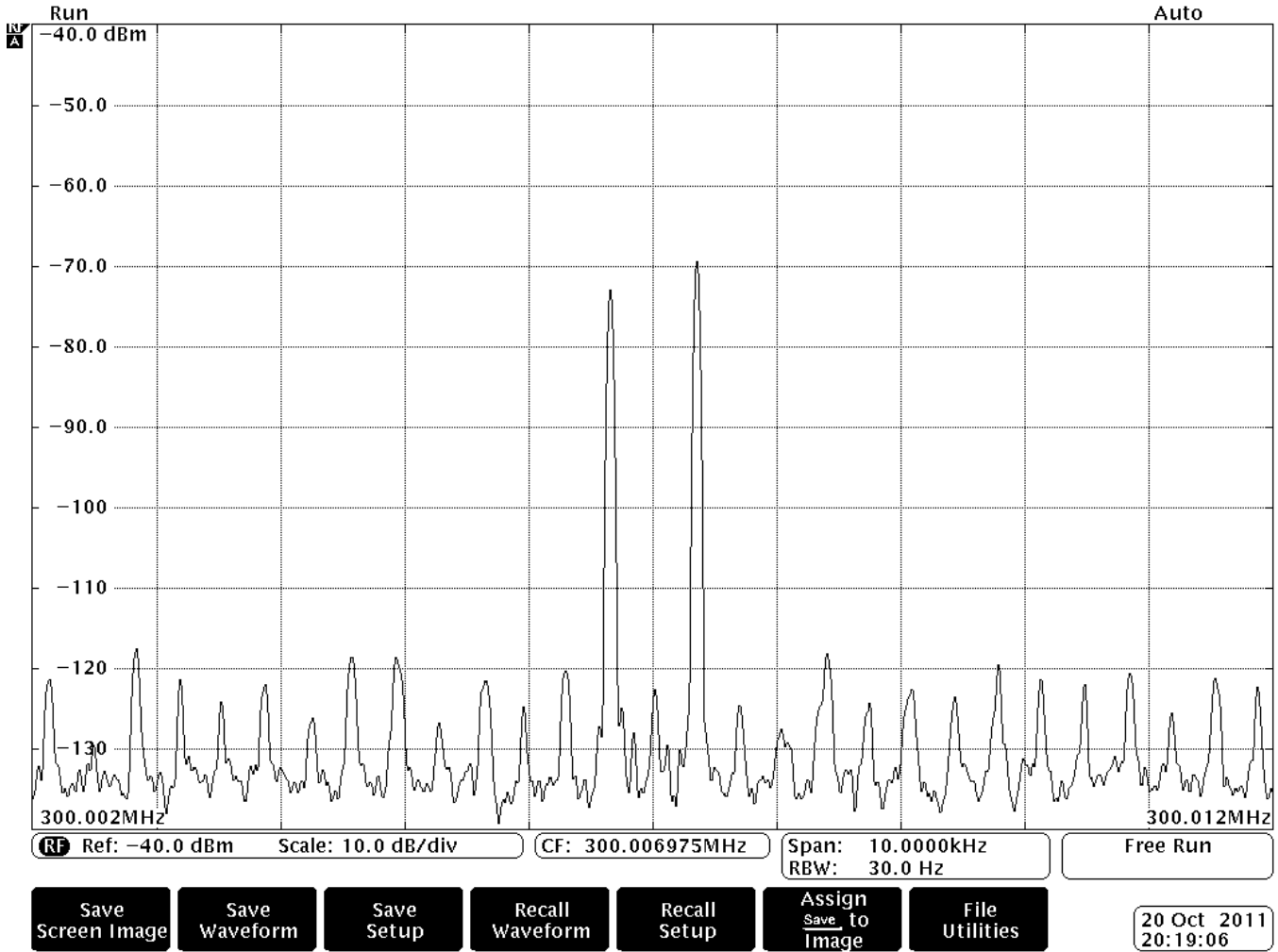


Figure 12. Setting to a very narrow bandwidth and span. Center Frequency 300 MHz, Span 10 kHz, RBW 30 Hz.

Usually, one contributor will be greater amplitude. If there is significant difference, you will want to chase the stronger one first. Using a sniffer probe on the circuit board with these settings, you can identify and attack the dominant contributor.

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### Switching Power Supply Harmonics

With switching power supplies, we are usually dealing with lower frequencies, typically below 30 MHz. Figure 13 shows a plot that appears to be broadband noise.

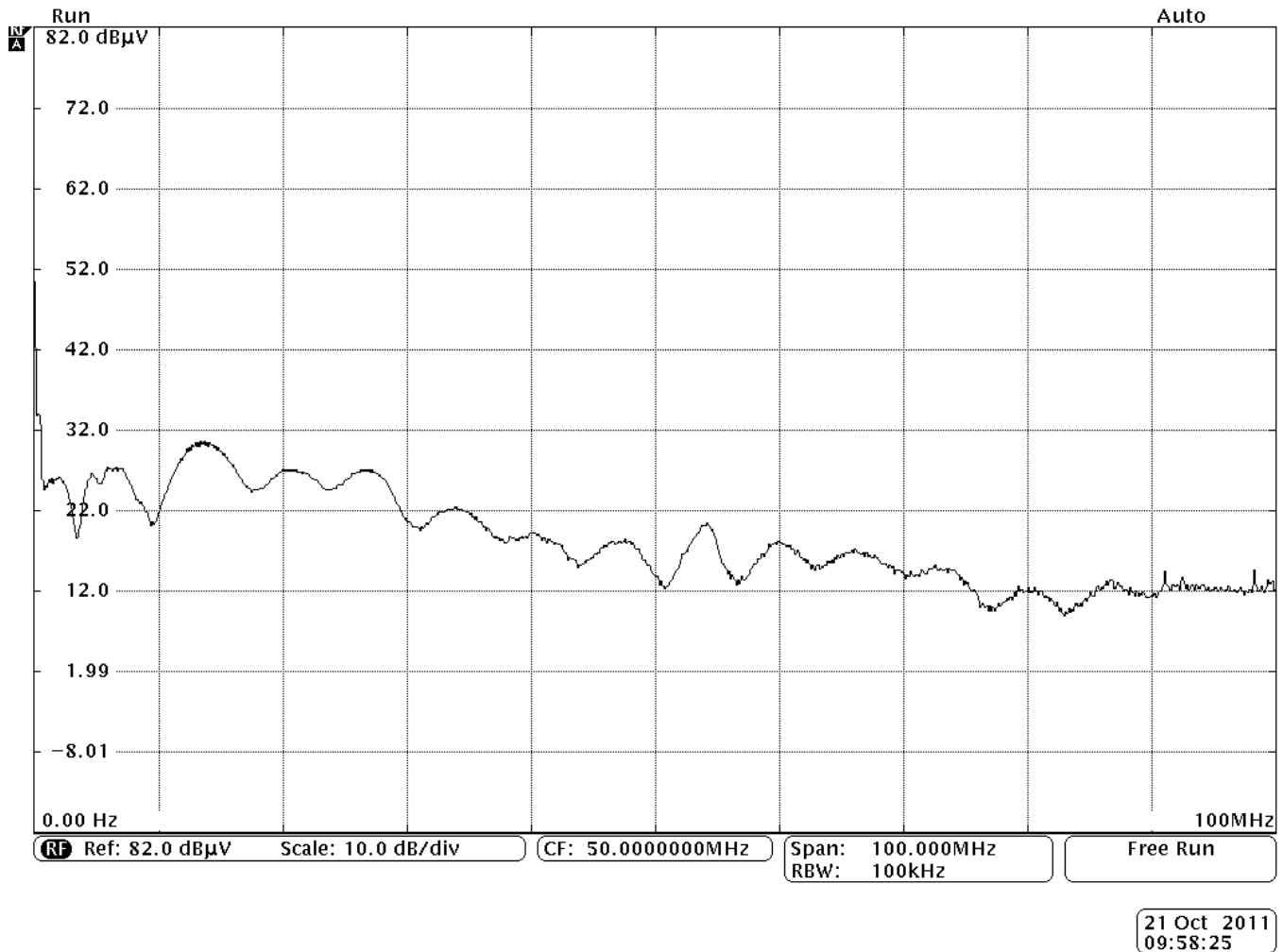


Figure 13. Switching Power Supply Harmonics. Span 0 - 100 MHz, RBW 100 kHz.

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By reducing the span and resolution bandwidth, we see key information start to emerge. We can see that there is some closely spaced harmonics, but details cannot be discerned at this setting.

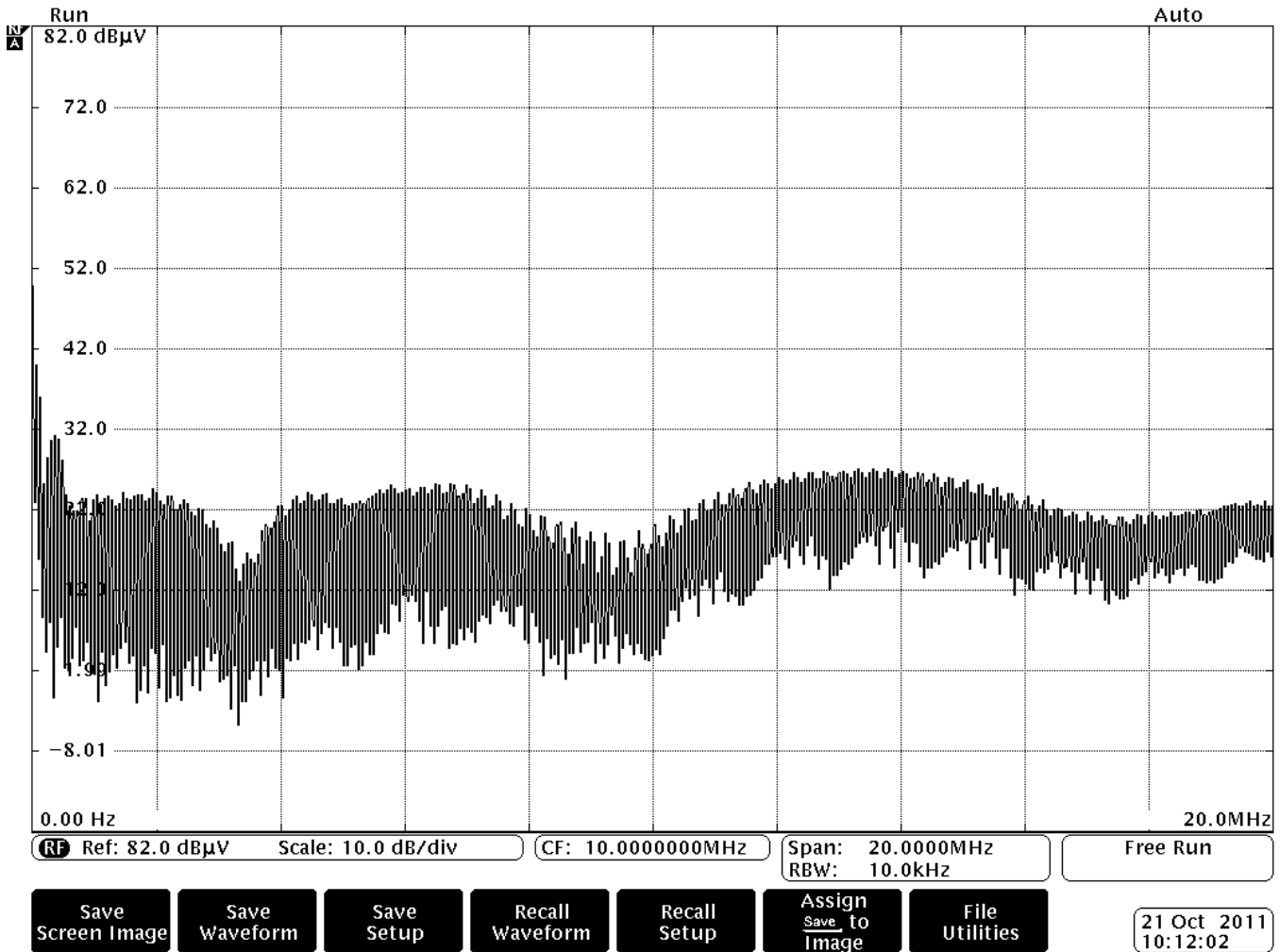


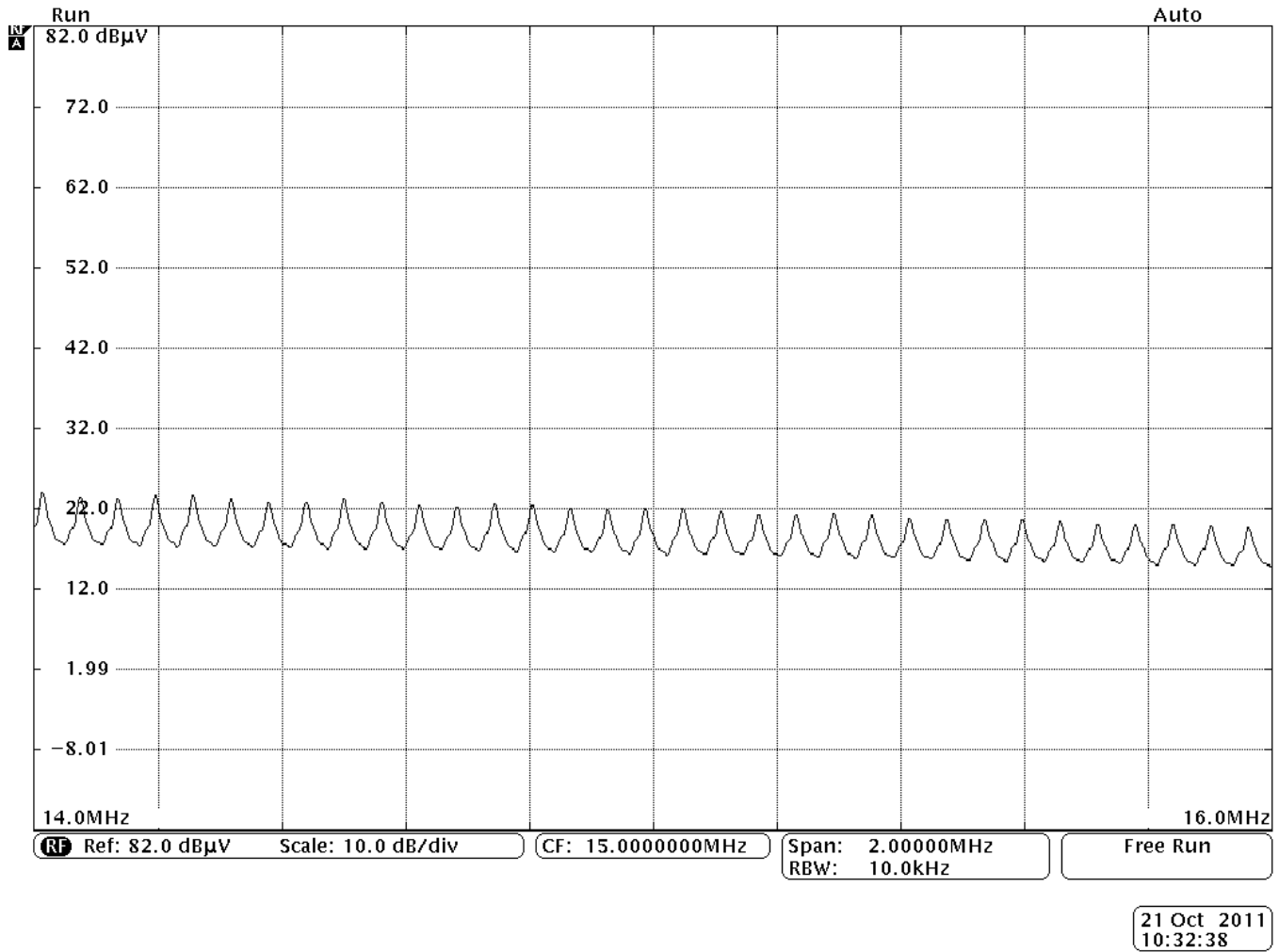
Figure 14. Power supply harmonics start to emerge. Span 0 - 20 MHz, RBW 10 kHz.



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Honing in on a frequency range where there are significant contributions, individual harmonic contributions can be resolved.



**Figure 15.** Narrow span and bandwidth, harmonics are resolvable. Center Frequency 15 MHz, Span 2 MHz, RBW 10 kHz.

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At still narrower span and resolution bandwidth, the harmonics are clearly separate so that accurate frequency measurements can be made.

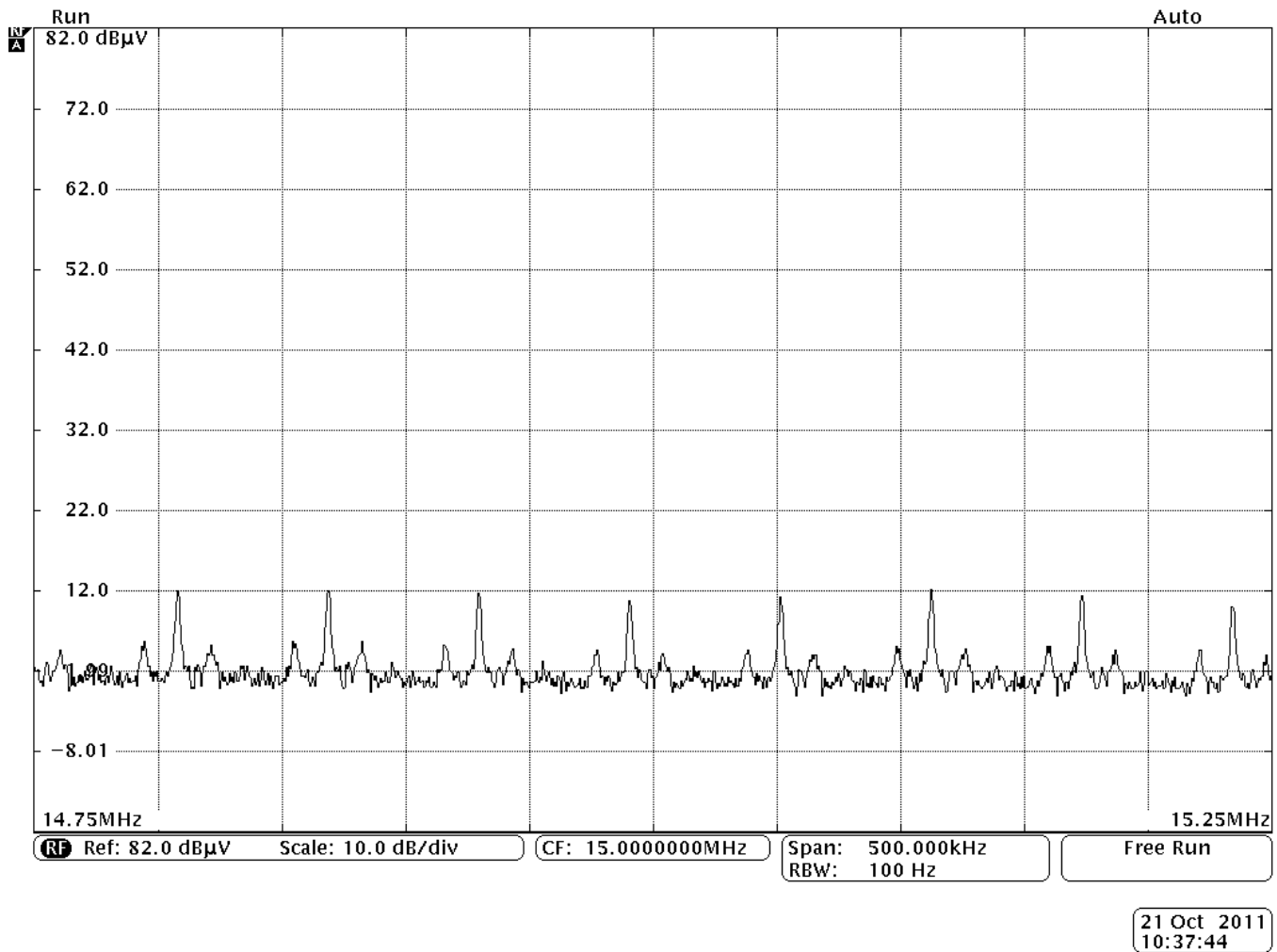


Figure 16. Narrowest span and bandwidth. Center Frequency 15 MHz, Span 500 kHz, RBW 100 Hz.

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This is the time to activate the frequency markers to take an accurate reading. The spacing between two contributors will almost always be the frequency of the switcher. Even if odd or even harmonics dominate, both will almost always be visible.

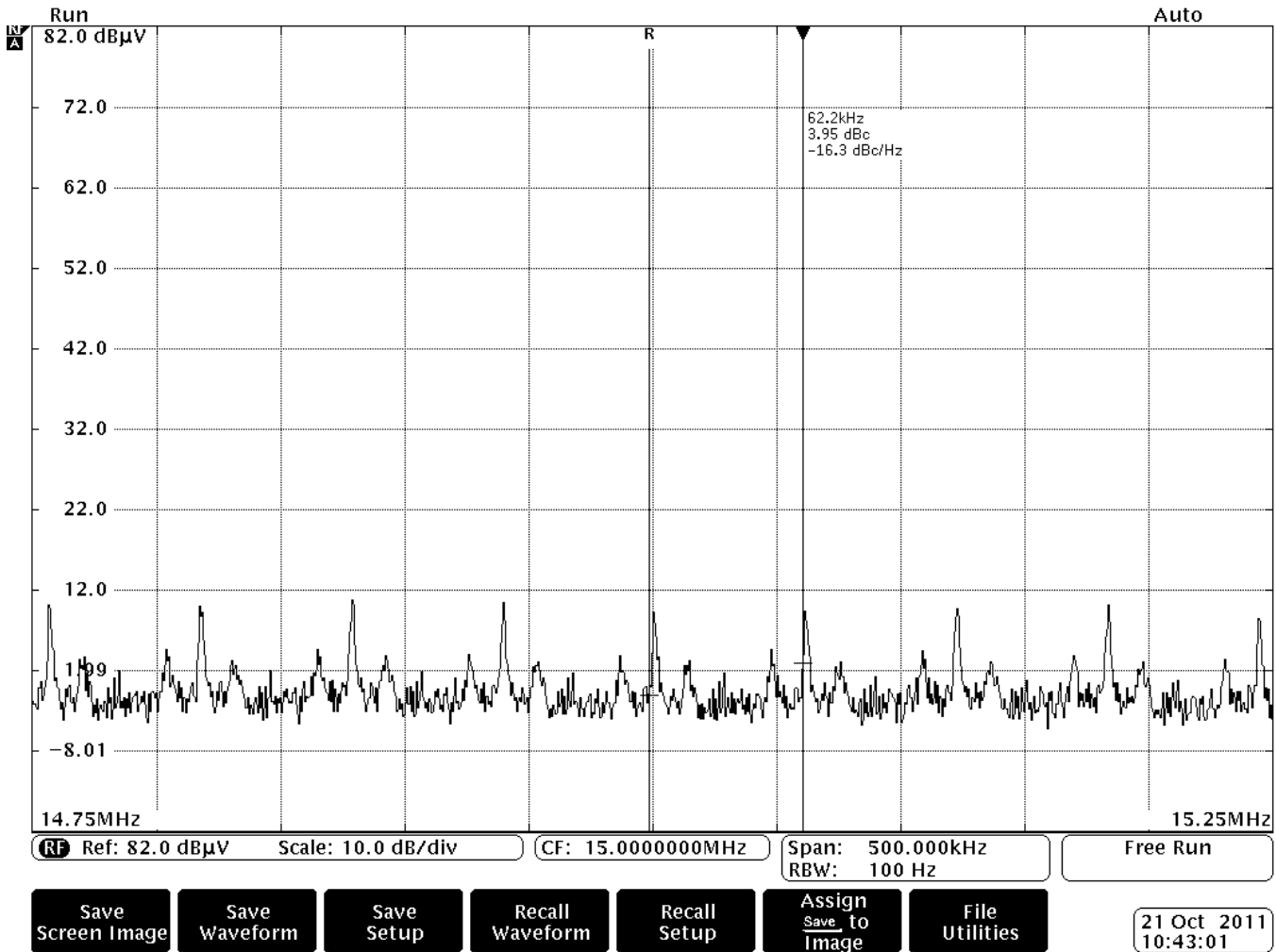


Figure 17. Use frequency markers to measure switcher frequency. Center Frequency 15 MHz, Span 500 kHz, RBW 100 Hz.

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## Summary

Spectrum analyzers and Mixed Domain Oscilloscopes can be more useful for EMI diagnostics by manipulating frequency span and bandwidth. Wide frequency span shows a good overall picture of harmonic generation. This is particularly useful for identifying resonances, which may be LC or wavelength related. Narrow span and receiver bandwidth helps identify problem frequencies. Broadband noise on screen is proportional to receiver bandwidth, and can be lowered by reducing bandwidth – narrowband amplitudes are nearly independent of receiver bandwidth. If the receiver bandwidth is then set narrower, the separate harmonic frequencies will become visible.

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