The Advantages of a “Spectrogram Display” in Spectrum Analysis

Welcome to the 1st Quarter 2012 CSEI Technical Report. The 1st Qtr was very busy for CSEI, so I’m late in issuing this report. This time around, I’m going to address the issue of varying, intermittent, or just plain ‘hard to capture’ signals on a spectrum analyzer, and illustrate how a *spectrogram display* can help in these instances. I’m also going to outline the general differences between modern ‘swept’ vs ‘real-time’ spectrum analyzers.

Spectrum Analyzer Basics *(Footnote 1)*

Analyzer Types

Spectrum analyzer types are dictated by the methods used to obtain the spectrum of a signal. The two basic types are swept-tuned and FFT based spectrum analyzers:

- A swept-tuned spectrum analyzer uses a super heterodyne receiver to down-convert a portion of the input signal spectrum (using a voltage-controlled oscillator and a mixer) to the center frequency of a band-pass filter. With a super heterodyne architecture, the voltage-controlled oscillator is swept through a range of frequencies, enabling the display of frequency vs RF amplitude (typically signal power).
- A FFT spectrum analyzer computes the discrete Fourier transform (DFT) of the input signal, a mathematical process that transforms a time domain waveform into it’s frequency spectral components, thus allowing creation of the same frequency vs amplitude display.

Some modern spectrum analyzers use a hybrid technique where the incoming signal is first down-converted to a lower frequency using super heterodyne techniques, and is then analyzed using Fast Fourier Transformation (FFT) techniques.

Most lower cost modern spectrum analyzers are moving towards this *hybrid* super heterodyne-FFT based, which often provides a significant improvement in sweep time. However, even in this approach there is still processing time required to sample the spectrum and calculate the FFT. For this reason, both the swept-tuned and FFT based analyzer produce ‘blind times’, meaning that while calculation of the spectrum is being performed, the instrument has processing gaps & may miss information in the RF spectrum.

A true real-time spectrum analyzer does not have any ‘blind times’. The analyzer is able to sample the incoming RF spectrum in the time domain and convert the information to the frequency domain using the FFT process. Successive FFT's are processed in parallel, but are gapless and overlapped, so there are no ‘blind areas’ in the calculated RF spectrum *and no information is missed*.

FFT Overlapping

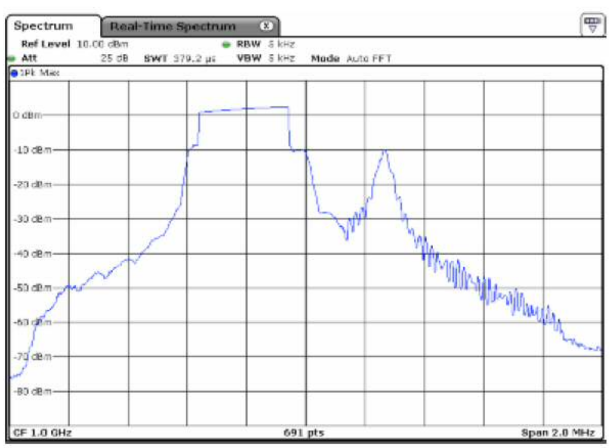
In all spectrum analyzers we want to have information with the least distortion possible. The FFT process applies windowing techniques to improve the output spectrum due to producing less side lobes. The effect of windowing (the ‘stitching together of successive FFT’s) may also reduce the level of a signal where it is captured ‘on the boundary’ between one FFT and the next. For this reason FFT's in a real-time spectrum analyzer are overlapped, and the overlapping rate can be as high as 80%! An analyzer that utilizes a 1024 point FFT process may re-use approximately 819 samples from the previous FFT process.

Minimum Signal Detection Time (100% Probability of Intercept)
This is related to the sampling rate of the analyzer and the FFT rate. It is also important for the real-time spectrum analyzer to provide good level accuracy.

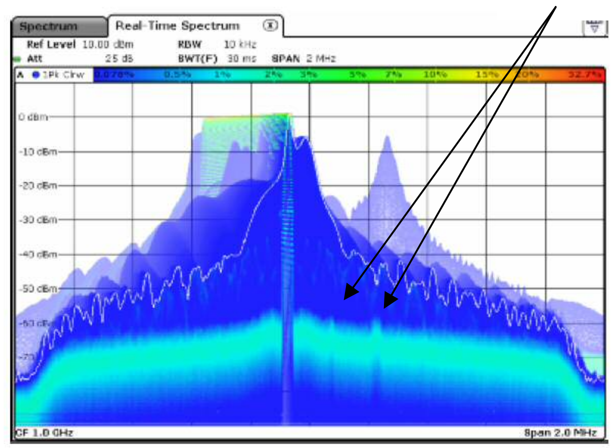
Example: For an analyzer with 40 MHz of real-time bandwidth (the maximum RF span that can be processed as a real-time FFT; 40 MHz BW would only be found in a lab grade real-time analyzer) approximately 50Msample/second (complex) are needed. If the spectrum analyzer produces 250,000 FFT/sec, a FFT calculation is produced every 4us. For a 1024 point FFT a full spectrum is produced 1024 x (1/50x10^6), approximately every 20us. This also gives us our overlap rate of 80% (20us − 4us)/20us = 80%.

Real-time Display Examples

Digital Persistence
Real-time spectrum analyzers are able to display much more information, and in greater detail, for users to examine in the frequency spectrum under analysis. A normal swept spectrum analyzer would produce max-peak & min-peak displays for example, but a real-time spectrum analyzer is able to show all calculated FFT's over a given period of time by use of color coding which represents how often a signal appears. For example, the following images show the difference between how spectrum is displayed in a normal swept spectrum view versus using a "digital persistence" view (sometimes termed DPX) on a real-time spectrum analyzer.



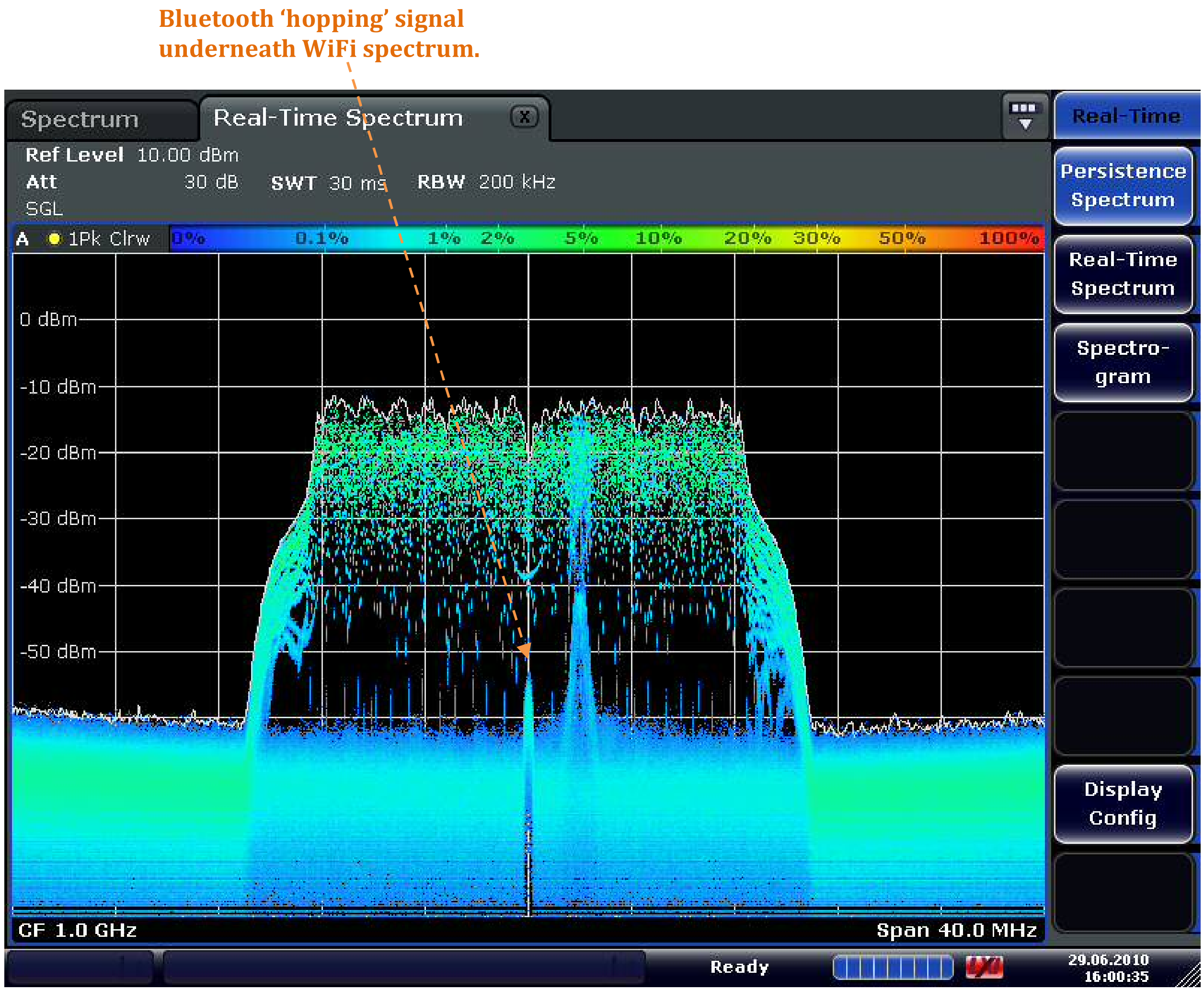
Normal Peak-Hold View



Digital Persistence View

Real-time spectrum analyzers using digital persistence are able to see signals hidden behind other signals. This is possible because no information is missed and the display to the user is the direct output of thousands of FFT calculations per second.

The following is another example; a Bluetooth signal behind a WiFi signal.



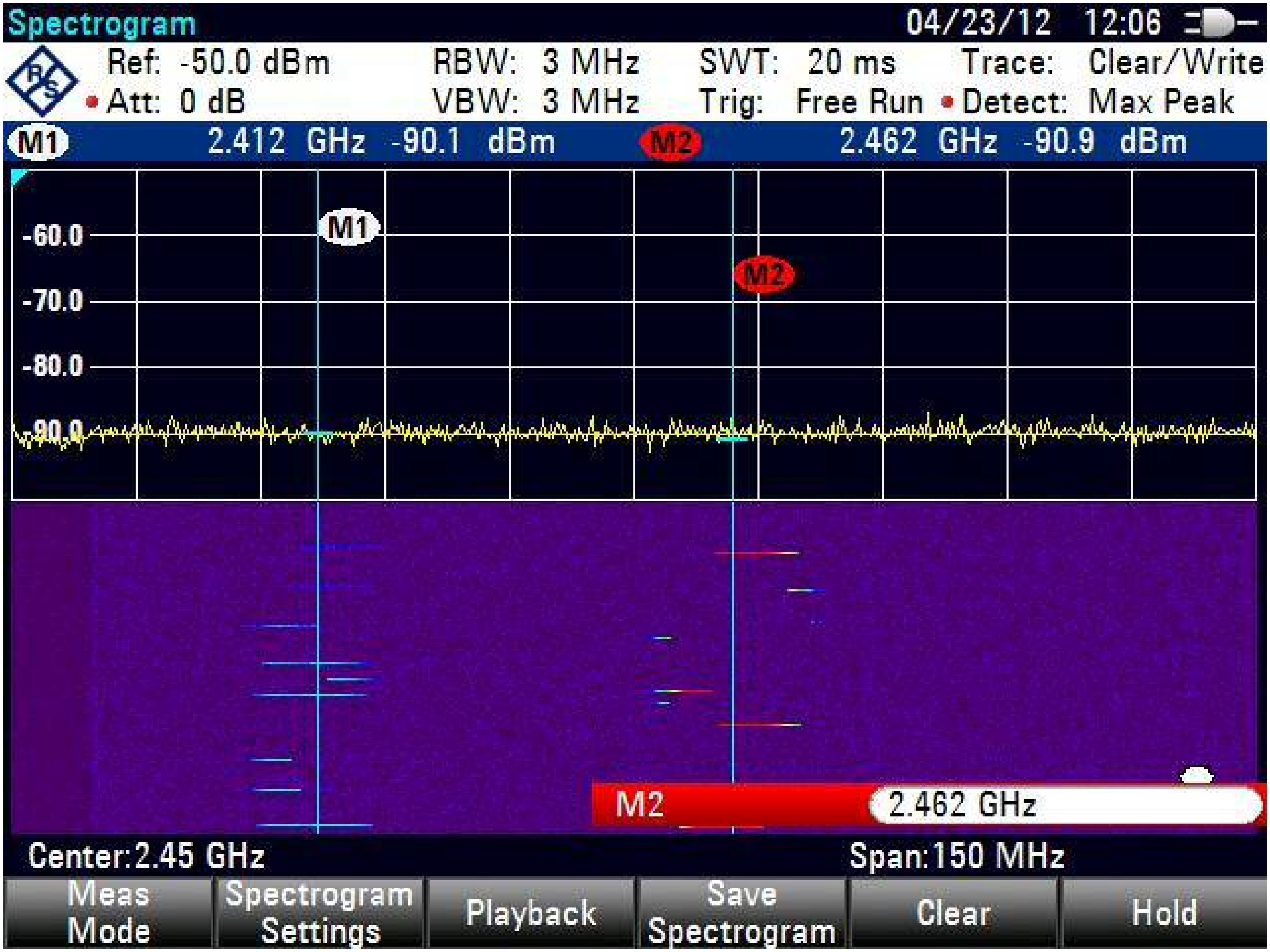
Spectrogram Display
A spectrogram is a time-varying spectral representation that shows how the spectral density of a signal varies with time, and may also be called a waterfall display.

The spectrogram is a graph with two geometric dimensions; however a 3rd dimension is added by use of color as in the 'digital persistence' display above. In the most common spectrogram view, the horizontal axis represents frequency, the vertical axis is *time*; and a third dimension representing the RF amplitude of a particular frequency at a certain time is represented by the color of each point in the image, with the colors and their range set by the user during the setup procedure.

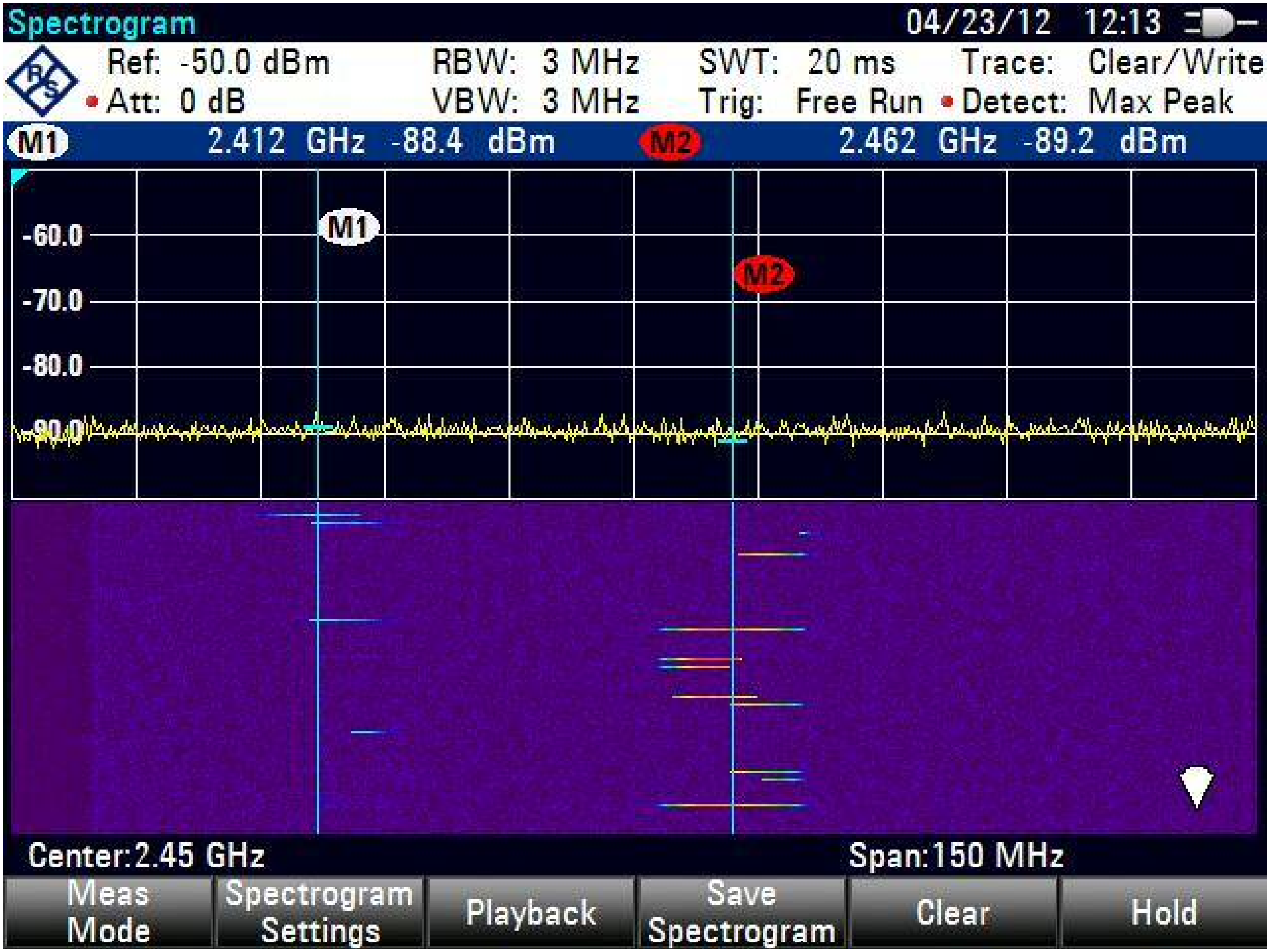
The Rohde Schwarz FSH 8.18 analyzer has a K14 spectrogram option. While the FSH 8.18 is not a 'real time analyzer', in that the front end is still swept and processed in 'analog mode', the spectrogram view can still be very helpful in the capturing and analyzing of intermittent or hard to characterize signals, as the following sample waveform sections will now illustrate.

Sample Waveforms
The following waveforms are intended to provide illustration of how the spectrogram display offers a more complete picture of spectral activity (frequency, amplitude and *time*) as compared to the conventional spectrum analyzer view.

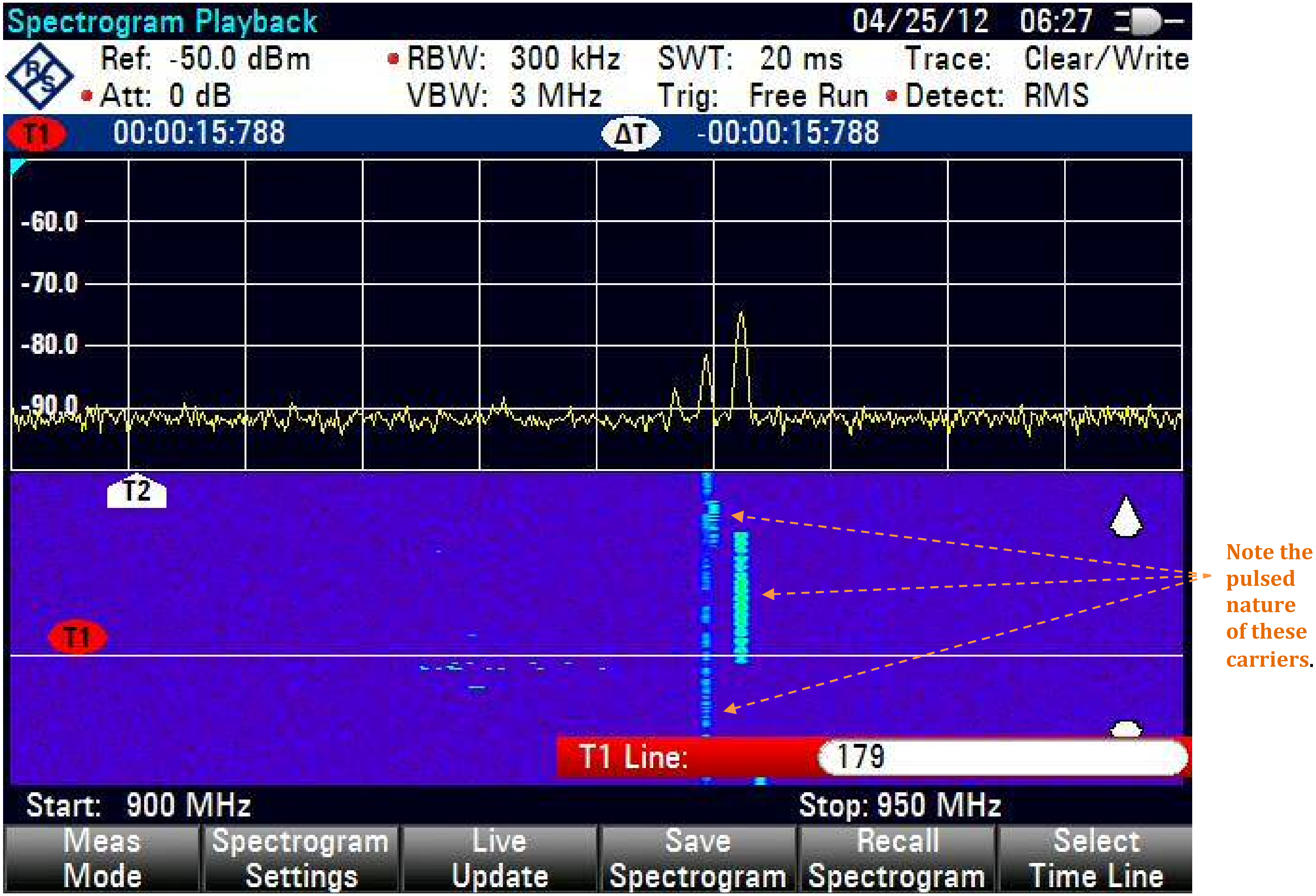
An 'omni-directional' test antenna positioned within the transmit area of two WiFi routers, with the closest router using WiFi Channel 11, and the more distant router using CH1. A second trace (green) captures the two very intermittent WiFi signals in peak-hold; however it provides no indication of how often transmissions occur. One can readily see that the peak-hold signal for the router using CH1 at 2.412 GHz is lower (more distant) than the closer router using CH11 at 2.462 GHz.



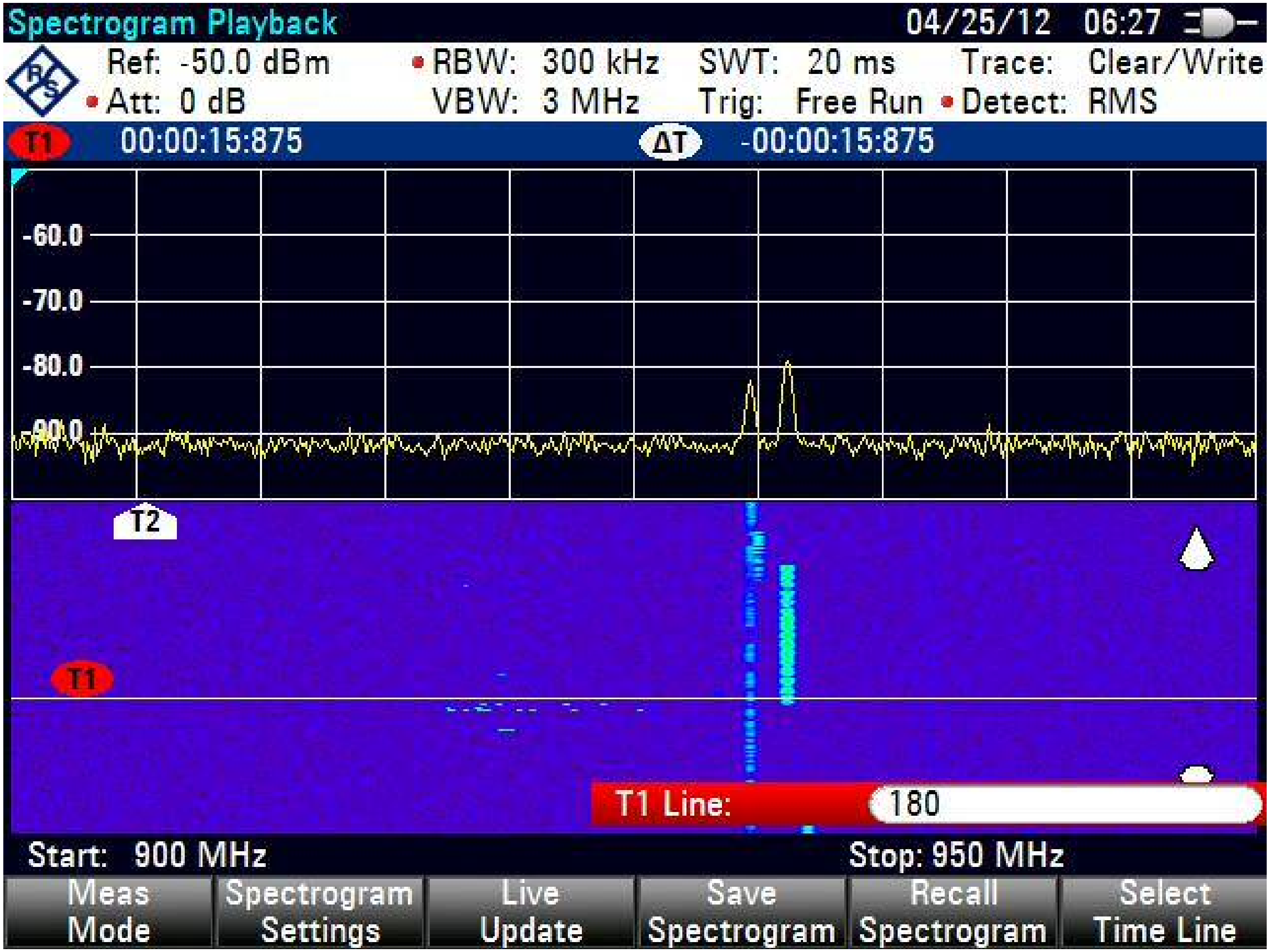
The top of the split view (above) still shows 'real time spectrum activity'; however, neither router was transmitting when the waveform was captured. The bottom spectrogram display shows frequency on the X axis, time on the Y axis (real time is the top pixel line), and signal amplitude is shown as varying colors, with dark blue representing the noise floor - all the way to red as close to peak amplitude (the user maps colors to levels during spectrogram setup). This view now depicts WiFi activity over time, and one can more easily see the transmissions of both routers. The near-by router, using CH11 at 2.462 GHz, shows the higher amplitude signal with the yellow through red colors. Transmission activity appears to be roughly the same on both routers (the number of horizontal lines where transmissions occur).



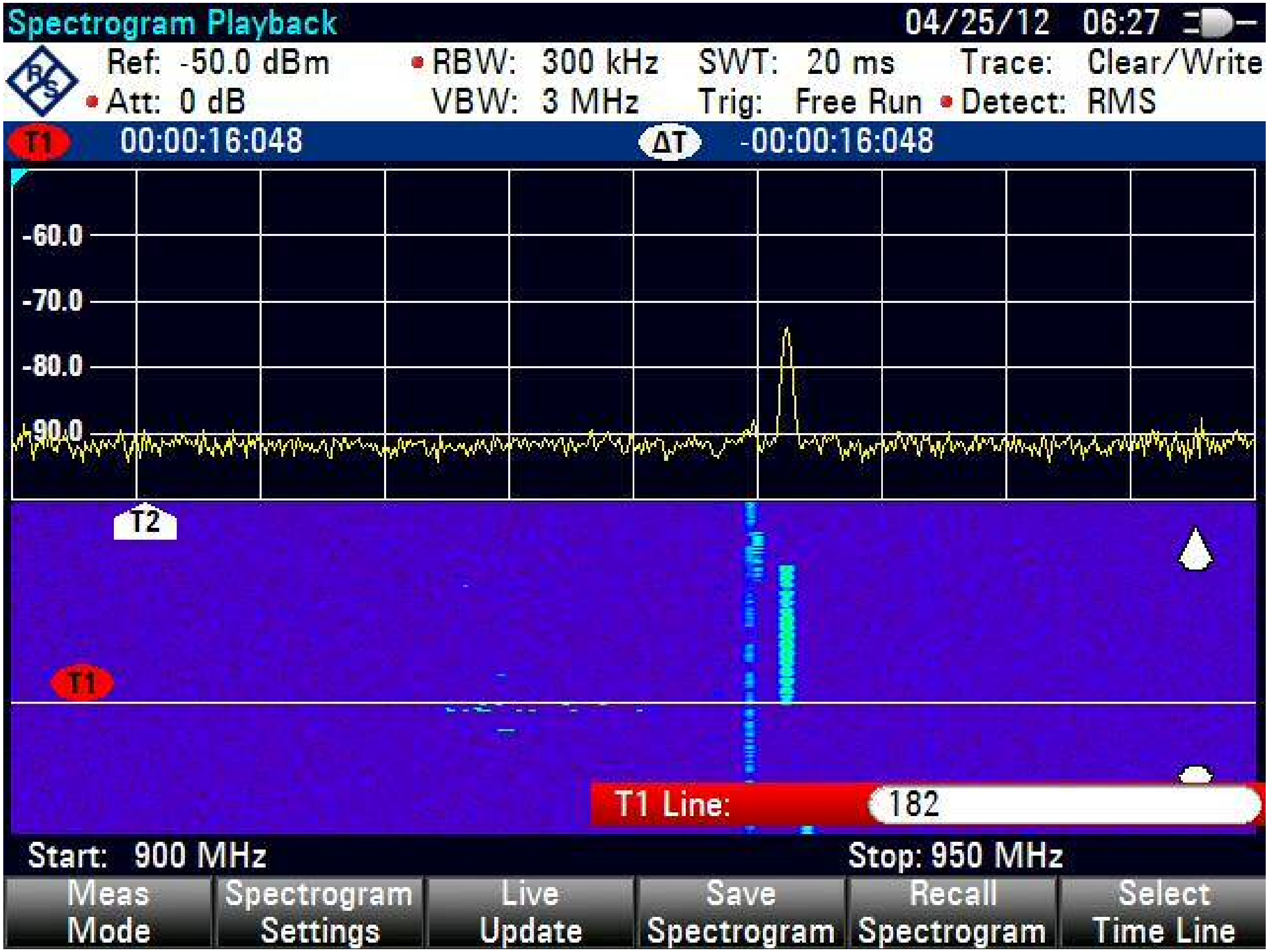
This spectrogram capture is similar to the previous one, except that we now note that transmission activity is higher (more horizontal lines) on the stronger CH11 WiFi router.



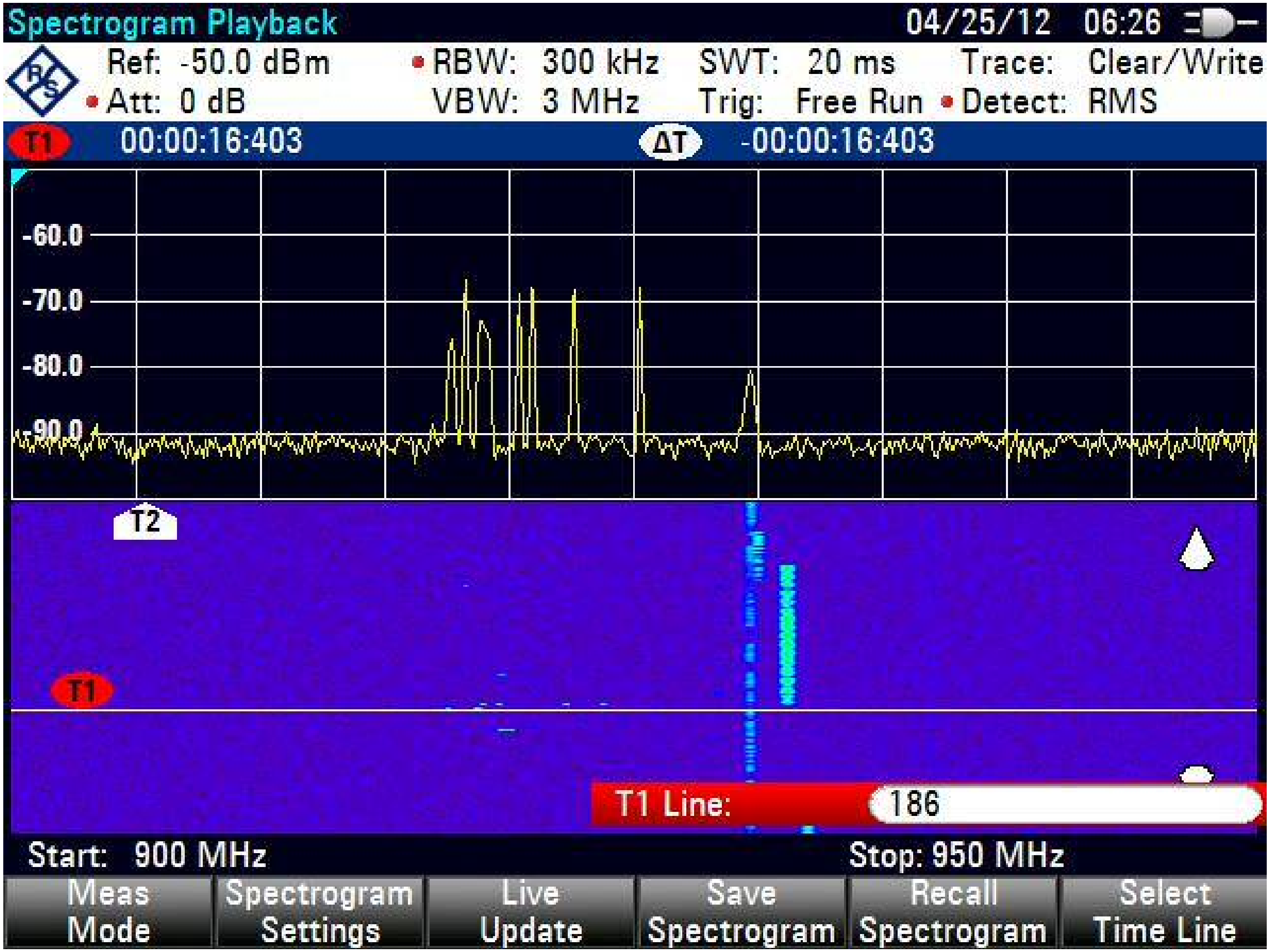
I've now captured some signals at approx. 930 MHz, with all three varying in transmission over time. The spectrogram has been paused, and we are viewing 3 carriers (see top spectrum analyzer view) as we look at scan line 179, which is 15.79 seconds into our spectrogram capture. Note the distinct on/off pulsed nature of all three carriers under analysis.



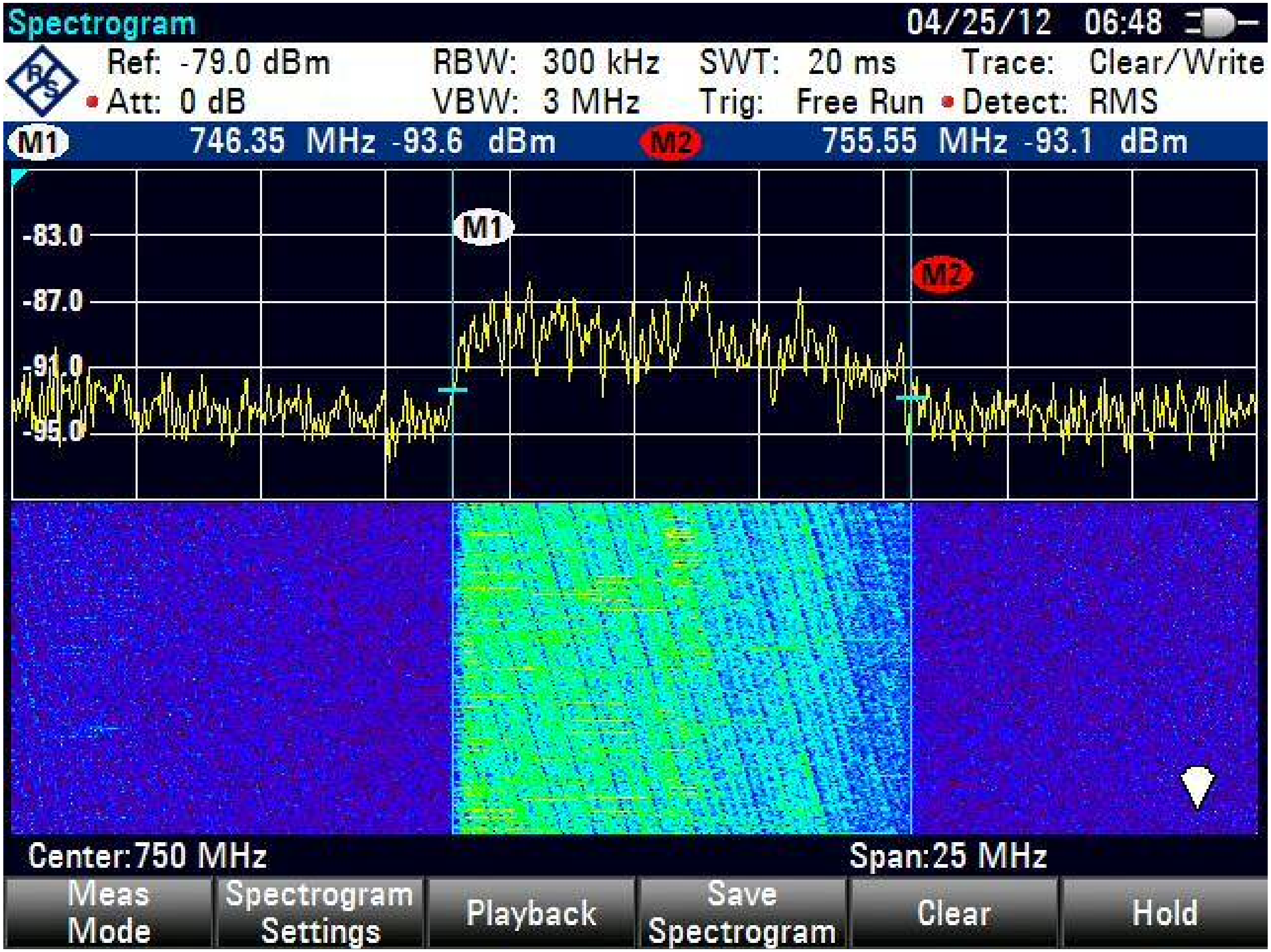
Compared with the previous waveform, we've now advanced to scan line 180 (87 msecs later) and we now note that the lowest frequency carrier is absent (see upper spectrum analyzer view with only two carriers).



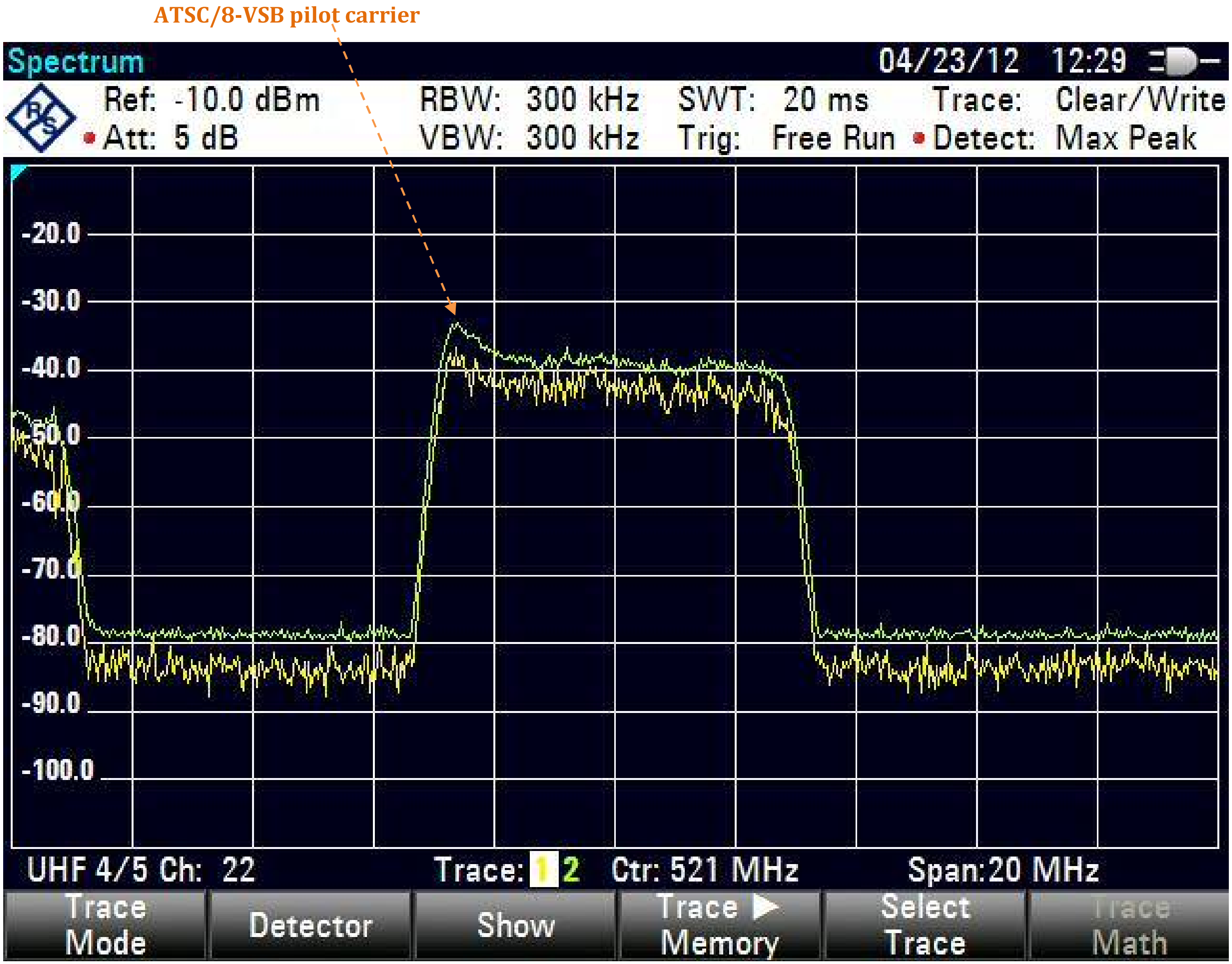
In this waveform, as compared to the previous, we've now advanced to scan line 182 (173 msecs later) and note that only one of the three carriers is transmitting (again, see top spectrum analyzer view).



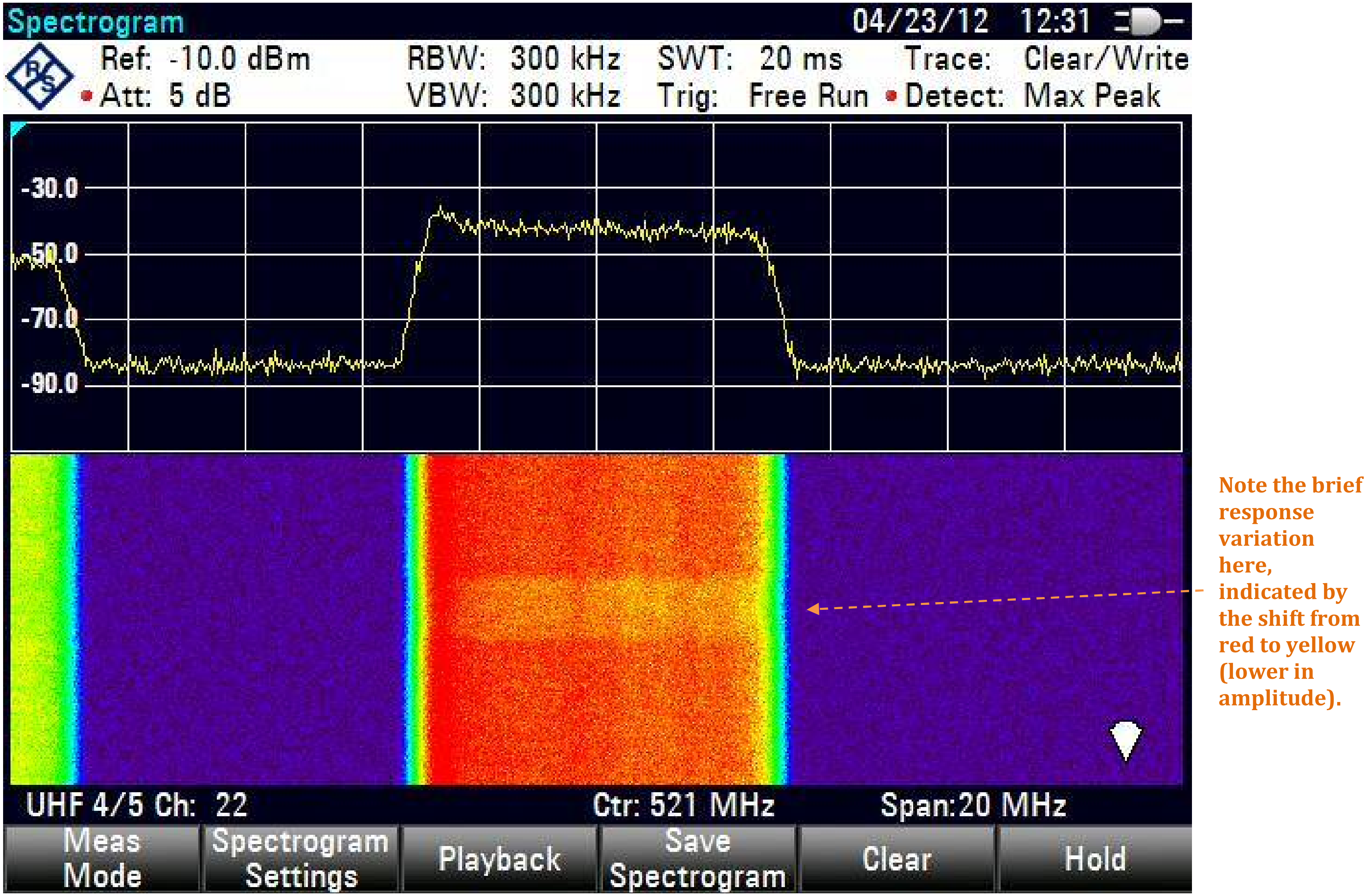
I've now advanced to scan line 186, 355 msecs from the previous waveform. Note a 'burst of multiple carriers' from approx. 917 to 926 MHz that are much higher in amplitude than the three carriers we've been examining. See top spectrum view plus the previous waveforms for this carrier burst.



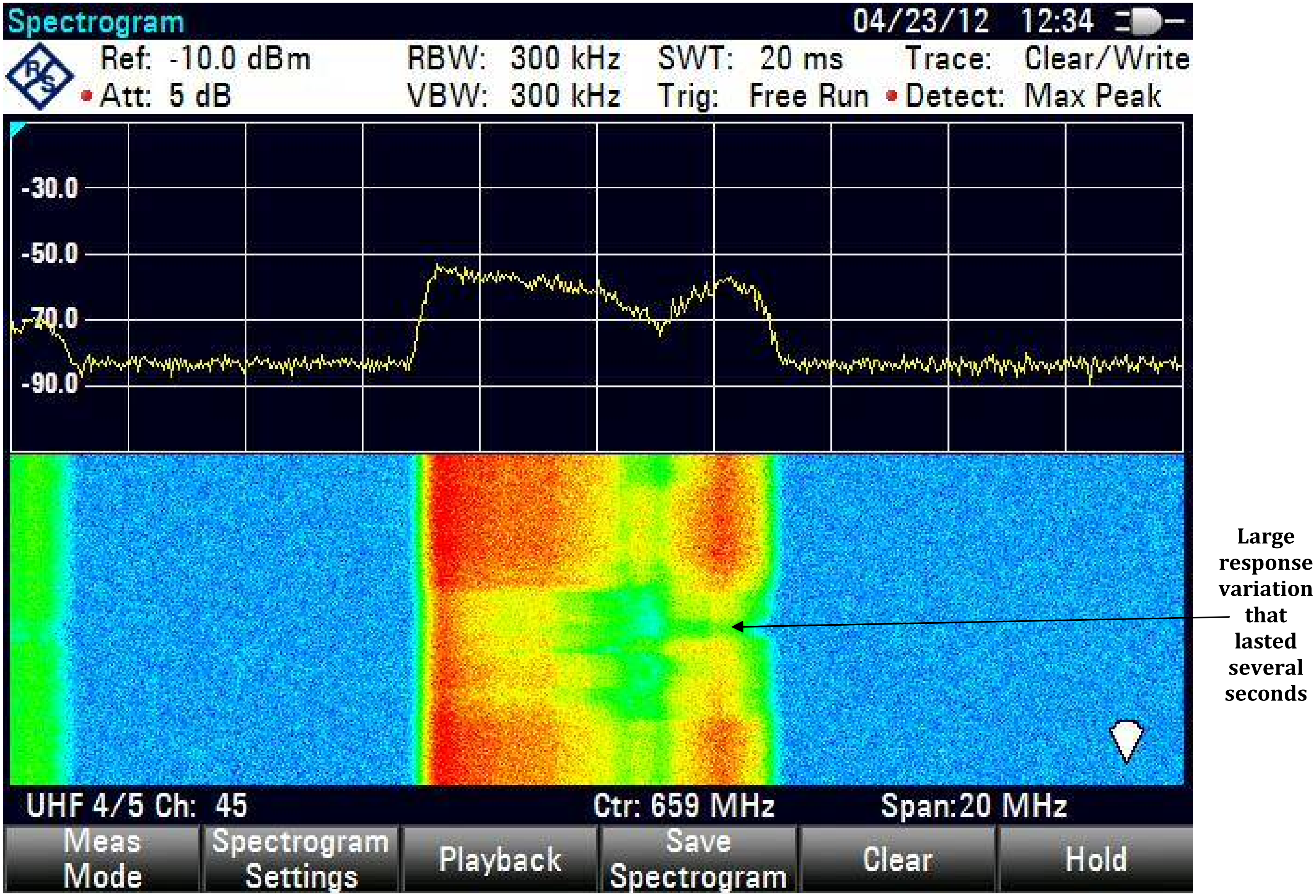
Finally, this spectrogram captures the spectral activity from a nearby cell tower that has been upgraded to carry LTE (Verizon) traffic. One can see from the spectrogram that spectral usage is fairly dense, and that a hypothetical leak from a nearby cable system utilizing EIA channels 116 or 117 could definitely impact the cell carriers ability to properly utilize this spectrum.



I've now shifted back to a standard spectrum analyzer view, using a handheld dipole to tune a local 8-VSB (off-air high def) signal (UHF CH22).The above trace shows a reasonably flat (could be better) 8-VSB 'haystack', with the green trace in peak-hold. As in the earlier WiFi analysis, what this display mode does not show is variations in signal level or frequency response over time, except for what can be viewed by watching the yellow 'active' trace. Now let's switch to spectrogram view while examining this same carrier.



The same signal in a split screen spectrogram mode, with the top in spectrum analyzer view and the bottom section set as a spectrogram, shows a slightly different story. The 'yellow shaded' section in the middle section of CH22 shows that average power levels dropped for several seconds (top to bottom is approx. 8 seconds in this view). I can 'pause' the spectrogram and examine the signal one scan/sweep at a time, with the top spectrum analyzer view updated to examine what was missed.



This final 8-VSB haystack shows a less than desirable 'haystack response', and the yellow spectrum analyzer trace indeed shows that there is a 'response suckout'; however, the spectrogram view also indicates the response varies over time, with the middle section showing a much larger and varying response suckout as evidenced by the green to yellow color (amplitude) changes.

Conclusions
The spectrogram view is invaluable in capturing, analyzing and storing (for later analysis) intermittent changes in both amplitude and frequency, even if the spectrum analyzer is still of the swept front-end type. Spectrogram runs can be captured and stored for later examination, and several runs can be compared against each other. While a 'real-time' (FFT) analyzer is still highly desirable as compared to swept analog (example: the basic Tektronix SA2600 hand-held real-time analyzer (without any options) will capture all signals lasting longer than 500 µseconds within a selected 20 MHz BW with 100% probability of intercept), they are much more costly, with lab grade 'real-time' analyzers in the $50K to $100K range or even higher. Adding the K14 option to the Rohde Schwarz 'swept' analyzer costs a mere (by comparison) $1,300, and the capabilities that the spectrogram option adds to the unit are invaluable in my opinion.

Present plans for the 2nd Qtr Technical Report are to go through many of these same measurements; however this time we will us a true FFT real-time analyzer, to see by comparison what we missed with the traditional swept front-end approach due to the 'blind times' created during sweep retrace and signal processing.

Take care and best regards.

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Cablesoft Engineering, Inc.

<u>Footnotes</u>

1. Due credit is given to Wikipedia as a source for some of the information provided on basic spectrum analysis and 'swept' versus 'real time' analyzers.