Signal Leakage Patrolling in the 700 MHz Frequency Band

Welcome to the 1st Quarter 2013 CSEI Technical Report. My last technical report, in the 2nd Qtr of 2012 (the 3rd & 4th quarters of 2012 were extremely busy, and time simply did not allow for this leakage testing to be accomplished), dealt with the advantages of a real-time spectrum analyzer (RTA), to demonstrate why these instruments have become so important for accurate analysis in today's crowded electromagnetic spectrum. Since considerable time was spent in the 1st and 2nd Qtr reports of last year on the subject of spectrum analysis, you may wish to refer back to those before reading on. This report makes use of a real-time analyzer in a real world situation; signal leakage patrolling at higher frequencies than the 108 to 137 MHz aeronautical spectrum normally used. I sought to verify and perhaps expand on valid issues that have been raised by at least several industry authors the past several years.

The basic issues are:

- Does leakage found in higher frequencies in HFC plant correlate, to any degree, with leakage in the 108 to 137 MHz range?
- Does leakage appear to be prevalent at higher frequencies, even in a plant that is 'squeaky clean' in the aeronautical range?
- What are the implications for the cable operator or the cellular company?

And, sure enough, issues were discovered during testing and are expanded on in this report, especially when patrolling in areas where cellular LTE field strength levels are quite strong.

Test Conditions

The equipment employed in this testing was:

- A calibrated Tektronix SA2600/EP1 'real time' spectrum analyzer, with an operational range of 10 KHz to 6.2 GHz.
- Omni-directional, unity gain antennas, tuned for two frequency bands: 118 to 136 MHz & 700 to 900 MHz.

The SA2600 analyzer is GPS enabled, and also has a calibrated 'field strength' mode where internal tables are employed to track & correct for antenna factor and connecting cable loss, and thus calculate calibrated field strength readings in µvolts/meter for leaks located in both ranges.

I deliberately chose a small, rural HFC cable system that I knew to be well maintained and thought would contain very few leaks in the 108 to 137 MHz aeronautical band. Cellular coverage in this area was unknown before I arrived on site; however I quickly determined that there was a Verizon tower located on the east-central edge of the community utilizing LTE Band 13, with a downlink frequency allocation of 746 to 756 MHz. This band overlaps CEA/EIA channels 116 and 117 in the cable plant, with the cable system utilizing CH116 for a 256-QAM carrier & CH117 for an un-modulated analog carrier (for level/tilt setting). After preliminary measurements in several locations, I determined that measurement using the analog luminance and aural carriers at CH117 would provide for more detailed, accurate, and very low-level measurements. *The LTE Band 13 uplink frequency allocation of 777 to 787 MHz (CH121 & CH122) was not used in the cable system, so interference in this spectrum was not checked.*

With that decided, I patrolled an estimated 50 to 60% of the plant (total plant size is 18 to 19 miles and approx. 1,200 homes passed), which is mostly aerial (I did include one underground subdivision). I also made the decision to patrol as much of the physical plant as was possible that day, but to not take time to determine the *source* of any leakage found.

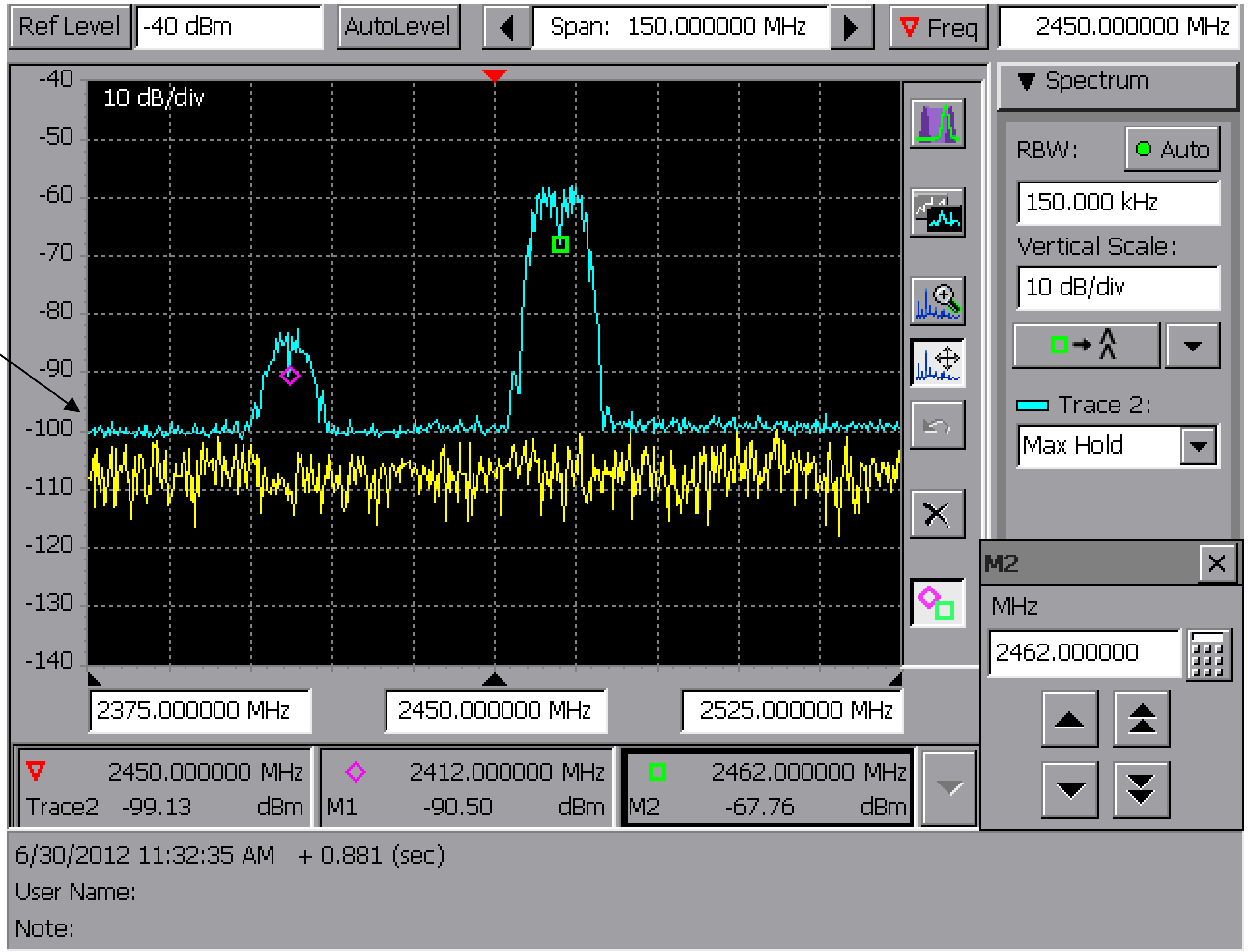
Summary of Findings

- In the estimated 9 to 10 miles of plant patrolled, I only found one significant leak, and it was still within FCC specifications in both the aeronautical band and at CH117. In this particular location, I could indeed measure leakage in both bands; however field strength level correlation was non-existent, with leak field strength levels fairly high at CH117 but just barely visible at CH14. And even in this worst case leak, the predominance of the measured field strength energy at CH117 came from the LTE signal - not from the analog carriers (more on this below). Plant leakage in this system was very low in the aeronautical band.
- I would estimate that in aerial plant sections, approx. 20 to 25% of all utility poles showed some evidence of very low-level leakage at CH117. In some plant areas there was a low-level leak at almost every pole; while in other plant sections they were intermittent in location. I made no attempt to determine the source of the leaks, as I did not have a ‘‘near-field’ probe’ with me, and even if I had I would not have been able to gain access to the aerial plant. Possible sources of these very low-level leaks are (a)loose mainline connectors, (b)leaking tap faceplates, (c) loose F-connectors or craft related issues in F-connector installation, (d)other issues such as physical damage from squirrels, etc. I want to again note that these leakage levels were very low and most that I found would not present a problem for the cellular company, nor was any leakage evident at these same locations in the 108 to 137 MHz band except for a few. The waveform section of this report will further depict this issue.
- Given the strong field strength from the local Verizon tower and tight nature of the cable plant, my conclusion is that in this particular system, *minor* breaks in system integrity are far more likely to create ingress problems, where the LTE Band 13 spectral energy would interfere with QAM channel 116, although if the leak were large enough it is certainly possible that QAM carrier energy from CH116 could affect cellular reception. Remember, however, that (Verizon) LTE traffic utilizes OFDM with either QPSK, 16-QAM or 64-QAM modulation; so in instances where discrete carriers egress, such as with un-modulated analog carriers, the OFDM system will simply avoid those areas with interfering energy and use the remaining spectrum. Therefore and in my opinion, only a high-level QAM leak would likely disrupt cell service in this particular system.
- If I were to perform this exercise a 2nd time, I would seek out a cable system where I knew cellular coverage was poor and suspected that the cable plant was not as well maintained. Under those conditions, my findings would likely be different and I might indeed find areas where cellular coverage and reception could be affected by plant leakage at higher frequencies. In this first test system, that was not the case.
- My findings do bear out those found in other papers published the past several years, in that I generally found little to no correlation between leakage levels (when found) in the 108 to 137 MHz spectrum as compared to plant leakage from carriers in the 700 to 800 MHz range. Stated differently, there appears to be almost zero correlation between the field strength levels of low and high frequency leaks found in the plant I patrolled. A ‘clean plant’ in the VHF aeronautical band gives no indication as to what may be happening at higher frequencies.

The following section contains test equipment waveforms along with field strength measurements and other comments as appropriate.

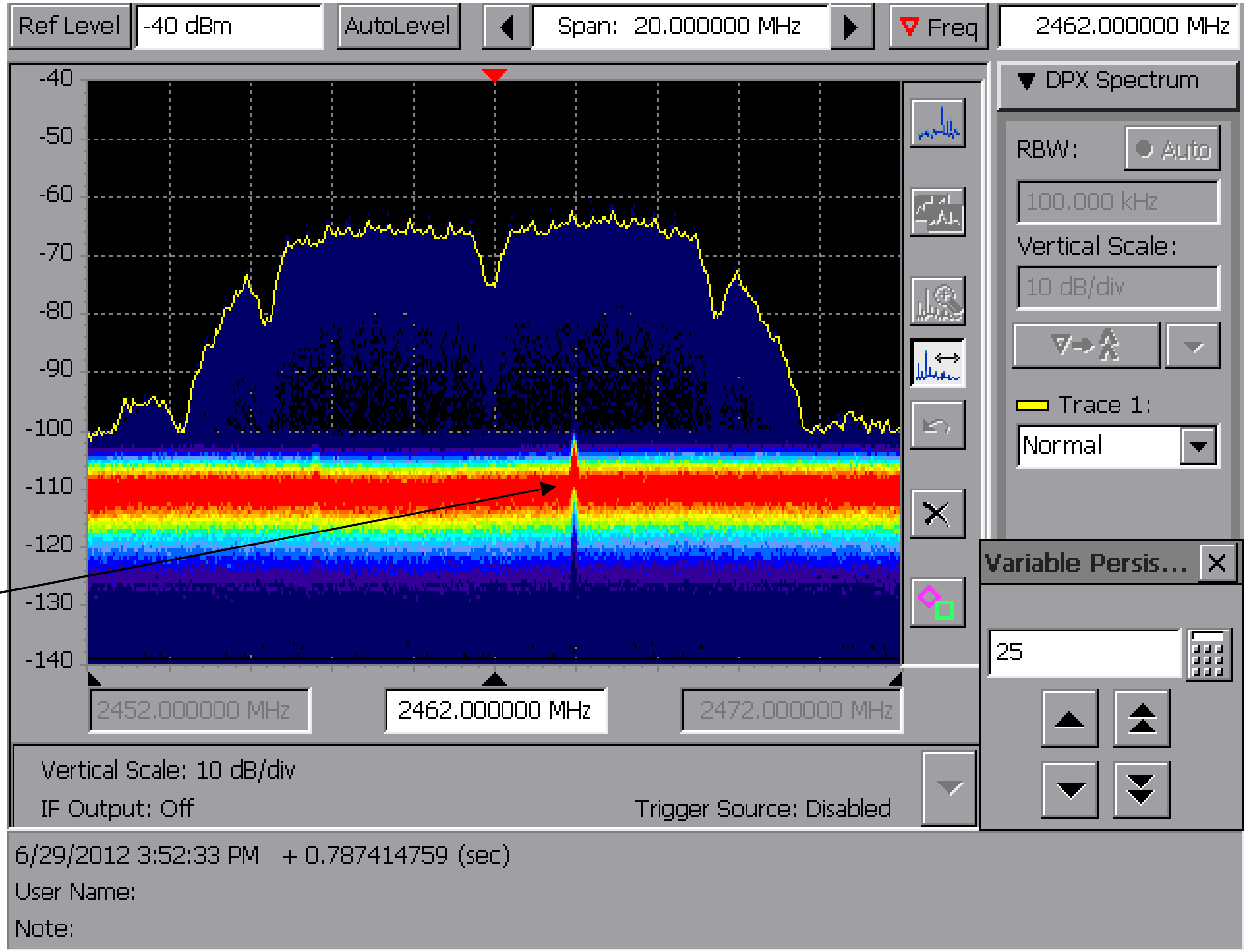
Waveforms With Notations

Before proceeding with leakage waveforms, a quick review of DPX measurements with a Tektronix SA2600 analyzer may be helpful. The following waveform shows spectral energy from two Wifi routers in ‘normal’ spectrum analyzer mode.



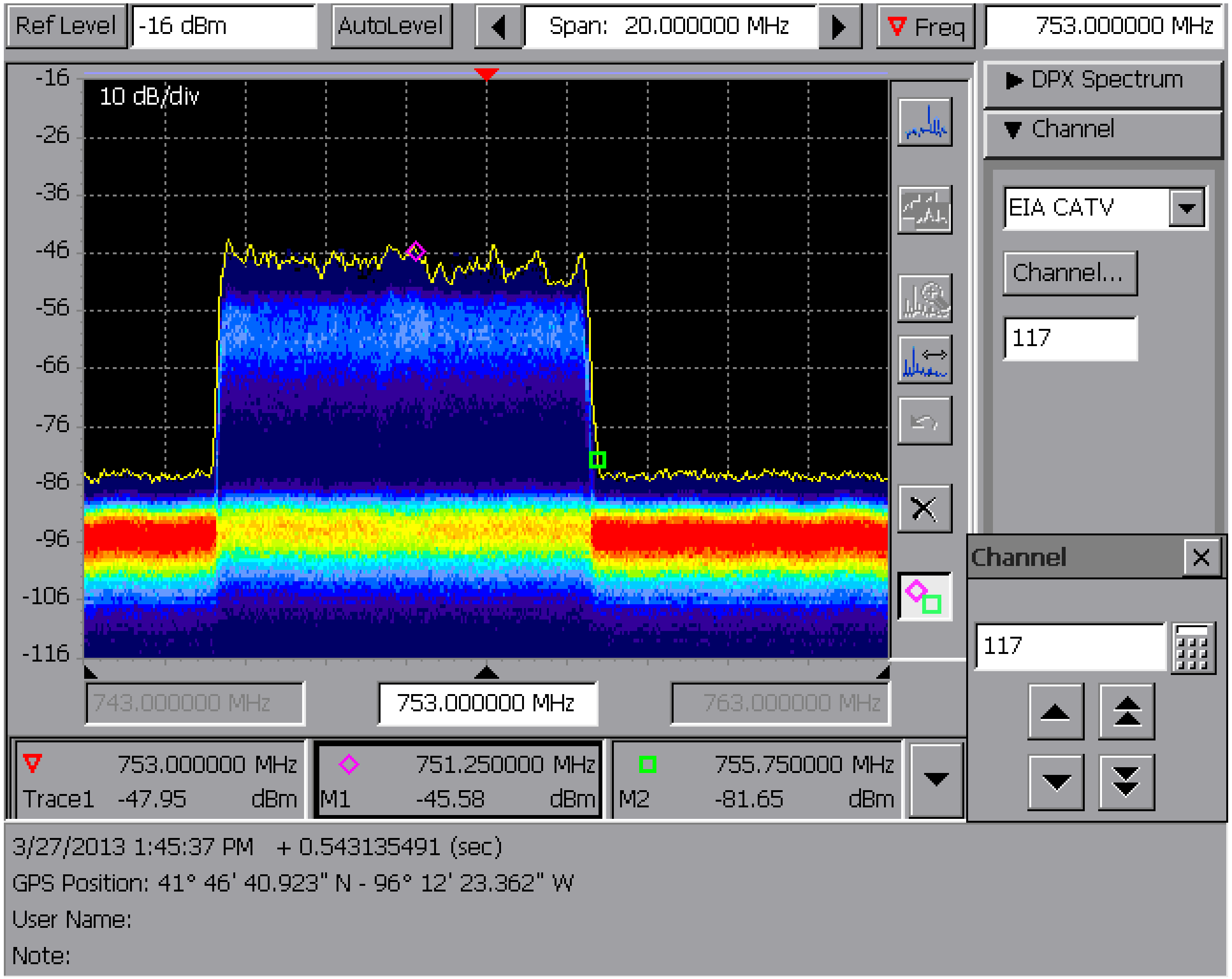
An ‘omni-directional sniffer’ test antenna was positioned within the coverage area of two Wifi routers, with the closest router using Wifi Channel 11 and the more distant router using CH1. The blue trace captures the two very intermittent (OFDM) Wifi signals in peak-hold; however it provides no indication of how often transmissions occur or the presence of other interfering signals. CH1 is centered at 2.412 GHz & CH11 is centered at 2.462 GHz. Levels are in dBm (the antenna and analyzer are 50Ω devices), & total frequency span is 150 MHz.

Low-level beat within Wifi CH11 spectrum is not high enough to cause problems.

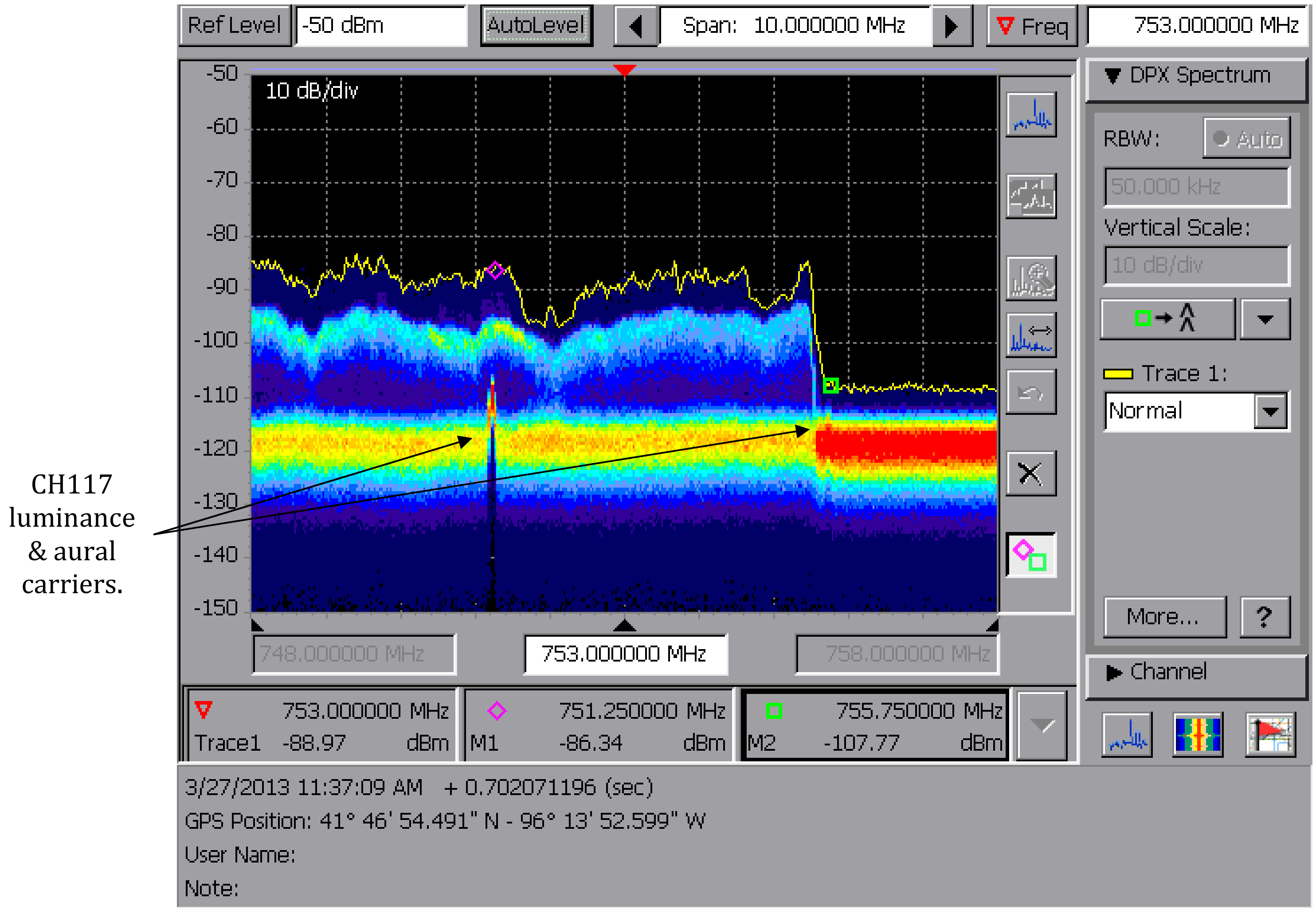


Now let's examine the same Wifi CH11 router in DPX mode. In this mode, the horizontal axis is frequency and the vertical axis is (still) RF power; however the 'range of colors' indicate the 'rate of occurrence' of the signal at a particular frequency and amplitude (each pixel location). Black indicates no spectral activity, through red which indicates a {near} continuous signal (example: thermal noise or a CW carrier). The predominance of spectral energy in blue (above) indicates the OFDM signals shown are present around 20 to 25% of the time. The color range (intensity) is set on the analyzer, and 'variable persistence' is also operator set – how long an intermittent signal stays visible on screen. The persistence can range from low (disappears very quickly) to infinite (once captured, it remains until the screen is reset). And regarding intermittent signals, the SA2600 with option EP1 has a 100% probability of capturing all signals ≥125 μseconds in duration. Although not captured in this waveform, activity between the router and various wireless devices can be easily be differentiated. Even Bluetooth traffic, at much lower power levels, can be easily observed and measured.

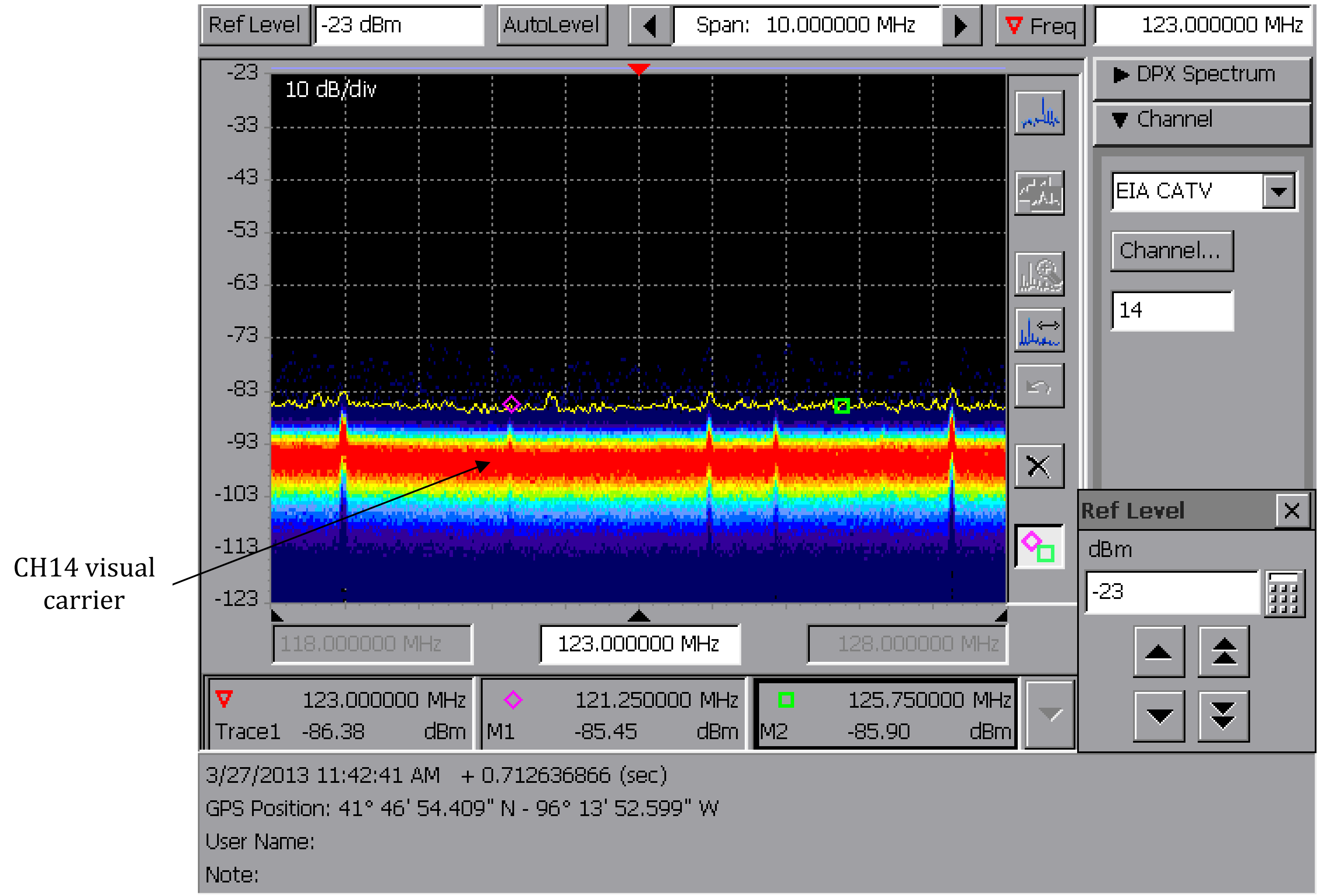
And now on to test system waveforms…..



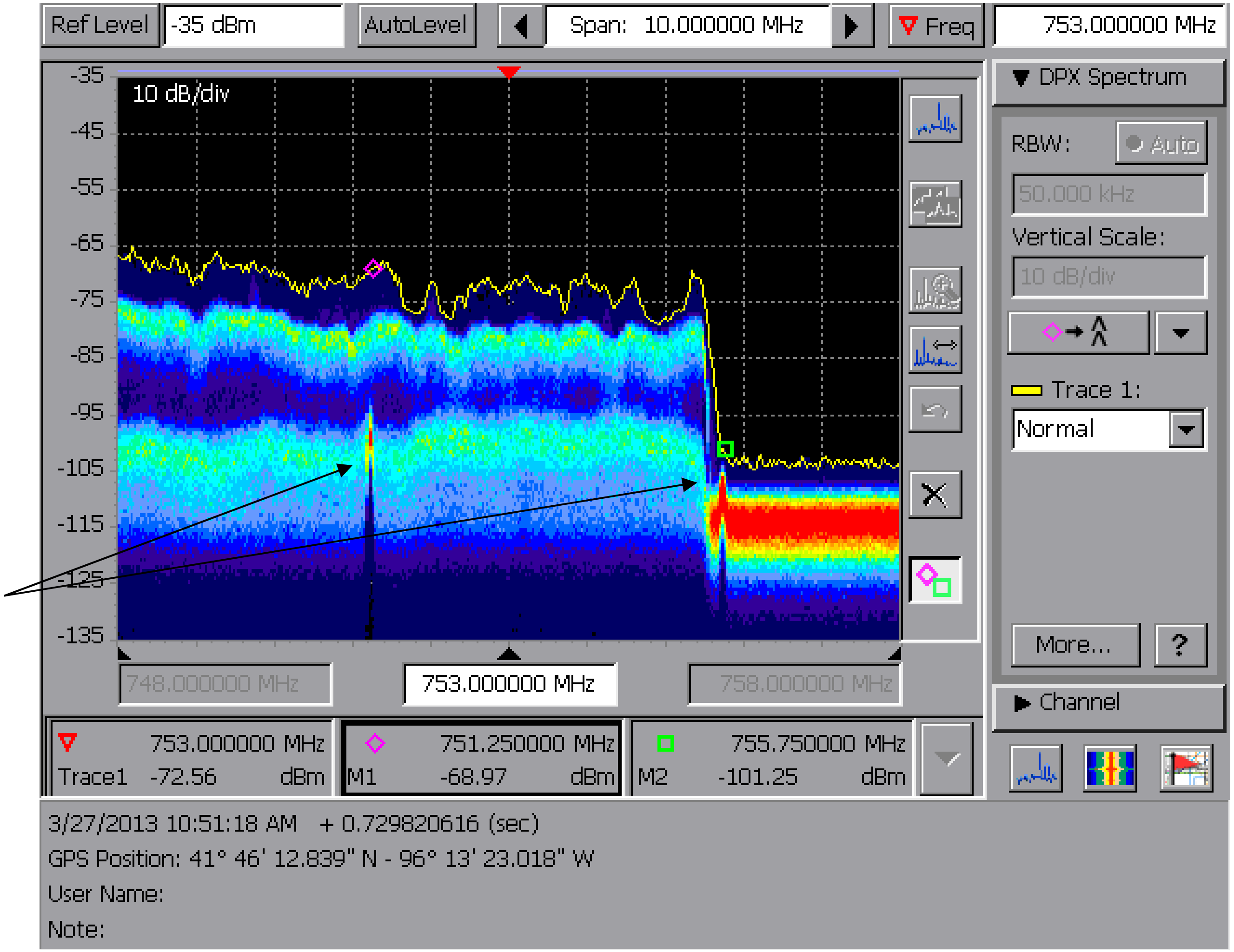
This first screen capture shows the high field strength levels of local Verizon Band 13 LTE traffic, with the test vehicle parked approx. 2 blocks from the tower. Field strength readings were approx. 2000 μvolts/meter average and 3640 μvolts/meter peak. At these levels, leakage into the HFC plant (ingress) becomes the primary concern when system integrity is compromised. Also note that my field strength readings are taken on only that spectral portion of the LTE traffic that lands within CH117, not on Verizon's full 10 MHz spectral slot (field strength was measured between 750 & 756 MHz). The purple diamond and green square markers note the visual and aural frequency assignments for the CH117 analog carrier. With sufficient LTE levels and in the case of ingress into the system, performance of the CH116 QAM could be affected.



Test Location #1: This DPX screen shot depicts the 'typical' very-low-level leak found, where CH117 analog was evident within the LTE Band 13 spectrum. The aural carrier is just barely visible. Note that the OFDM modulation would completely mask the analog video carrier in normal spectrum analyzer view. My estimate is that approx. 20 to 25% of the tap locations I patrolled in 'total' showed this <u>very</u> low-level leakage. Field strength readings were entirely from the LTE OFDM signals, as field strength readings were identical at this location compared to moving just enough so that the CH117 leakage was no longer visible.

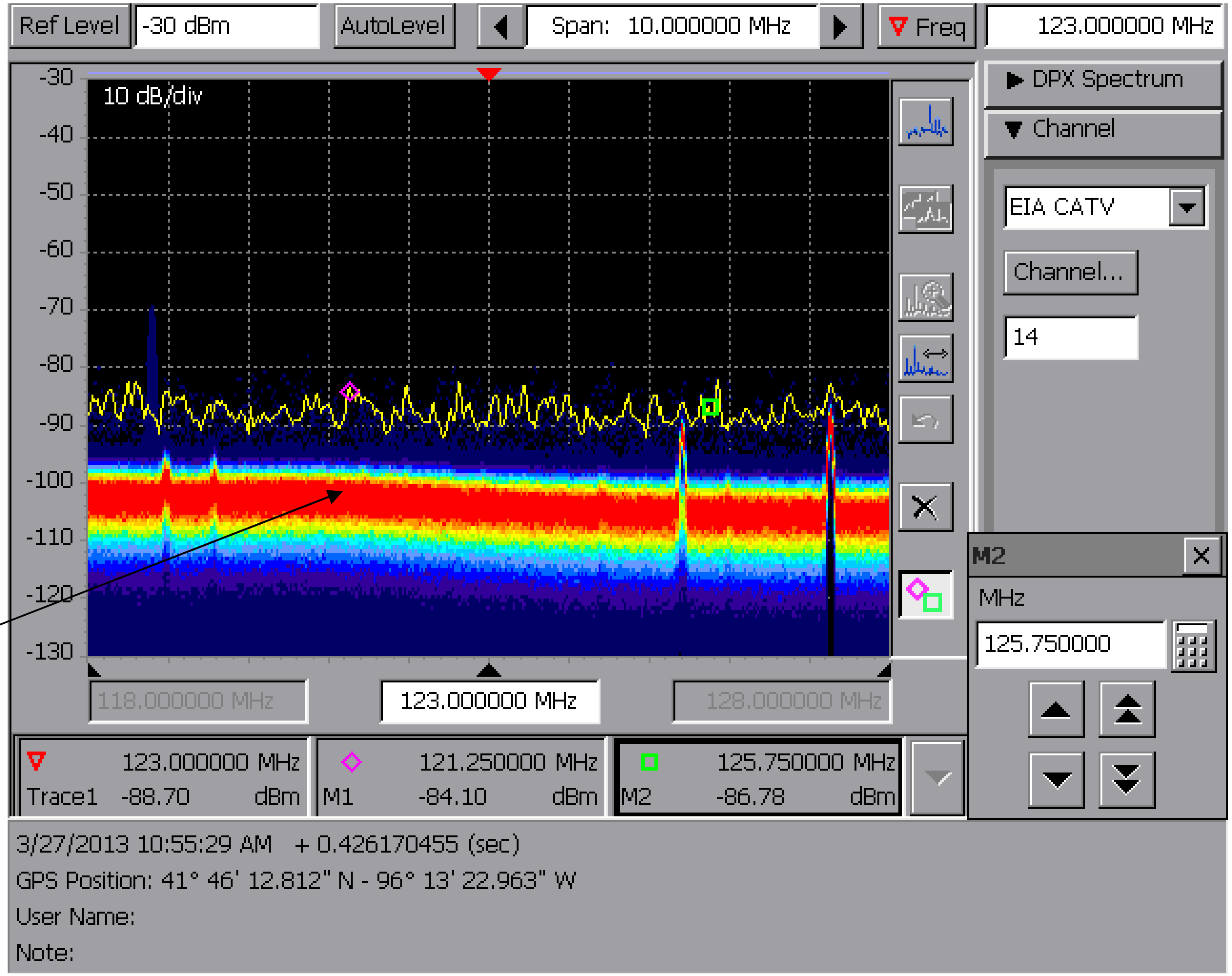


Test Location #1: This DPX screen shot is at the same CH117 low-level leak location; however now I'm measuring CH14. This location was a bit unusual, in that the CH14 visual carrier (purple diamond marker) is just barely visible, just 'poking' out of the thermal noise floor. Most leaks of this amplitude at CH117 (there were many) showed no corresponding leakage at CH14.



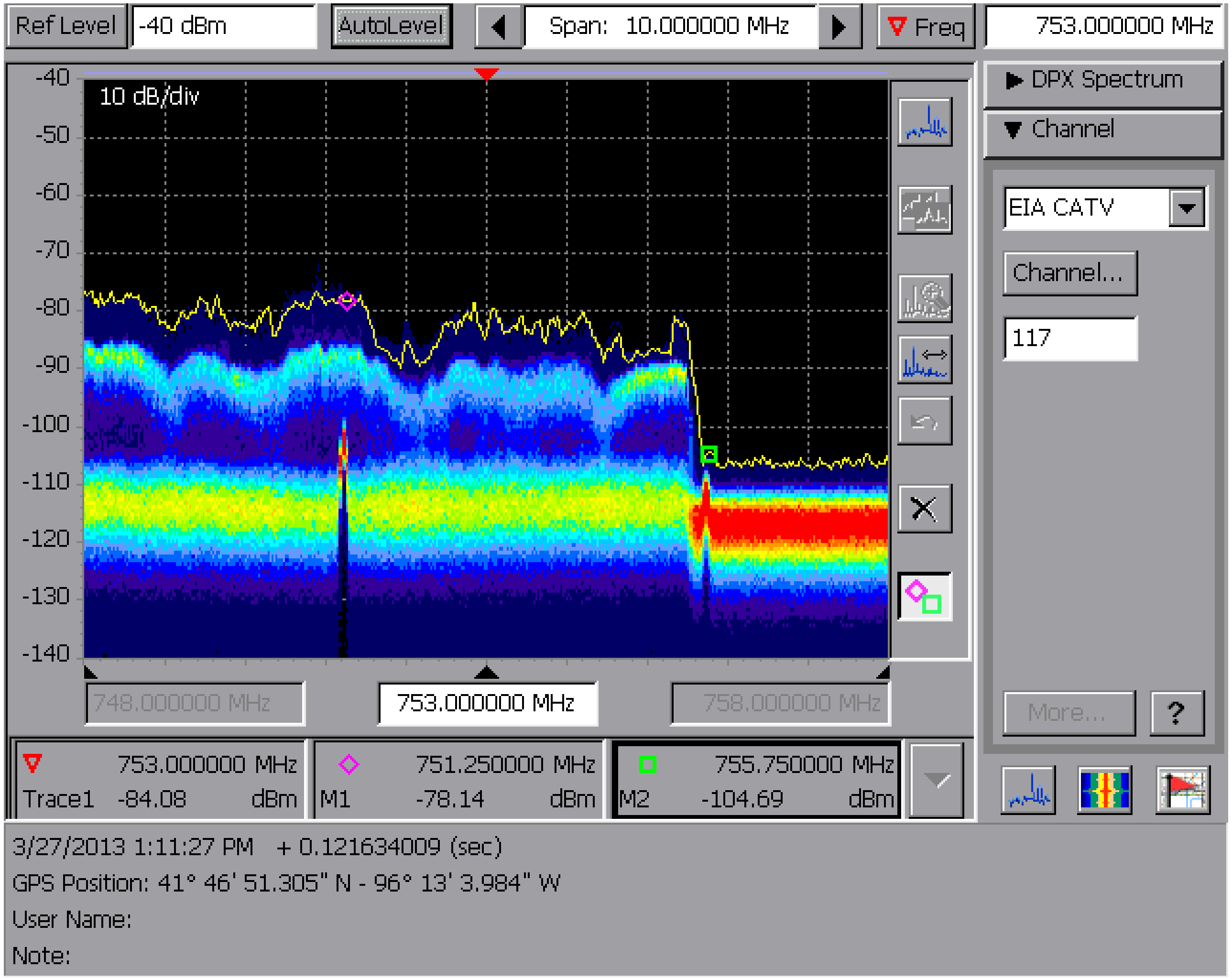
CH117 visual & aural carriers.

Test Location #2: This DPX screen shot illustrates a higher amplitude leak (but still quite low) from CH117. The aural carrier is more visible in this example. Levels are still too low for an accurate field strength reading, as almost all spectral energy is from the LTE signal. The next screen capture shows this same location, measuring leakage at CH14.

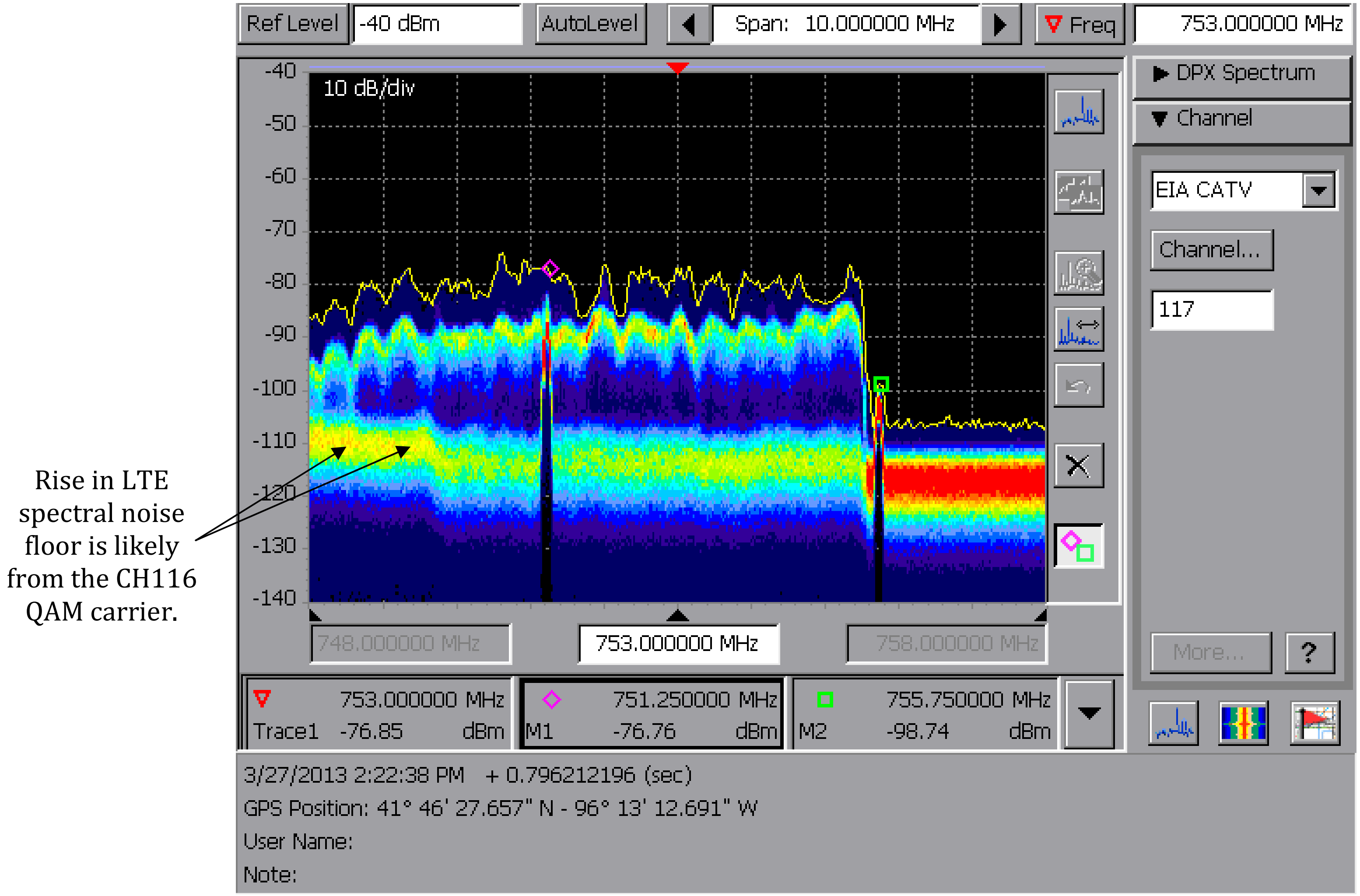


CH14 visual & aural carriers not present.

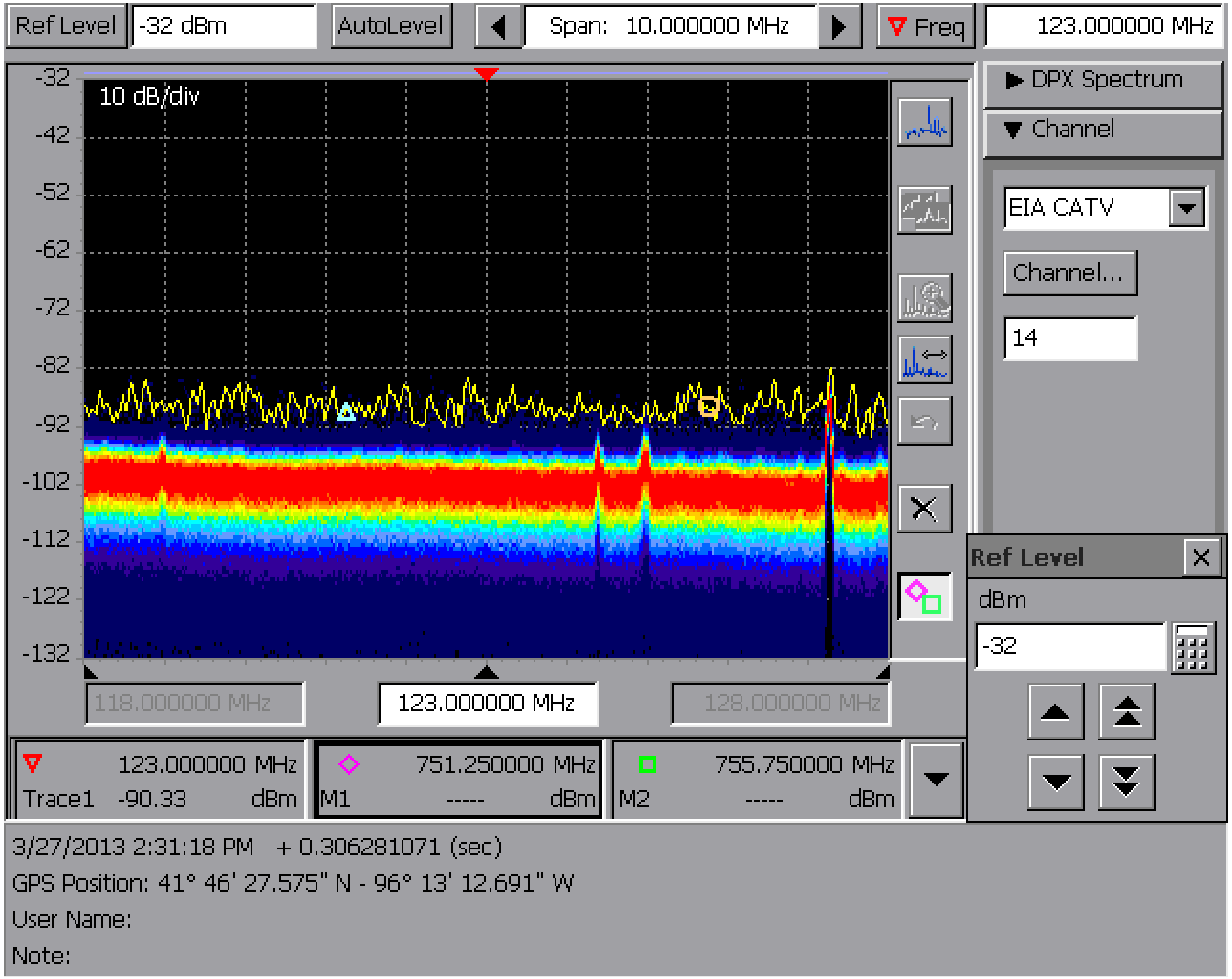
Test Location #2: Measuring at the same physical location but in the CH14 spectrum, even though the leakage levels were greater at CH117 at Test Location #1, no leakage is evident. This was the ‘norm’ (except for several locations); many low-level leaks were measured at CH117 but it was rare to see *any correlating leakage* in the 108 to 137 MHz aeronautical region.



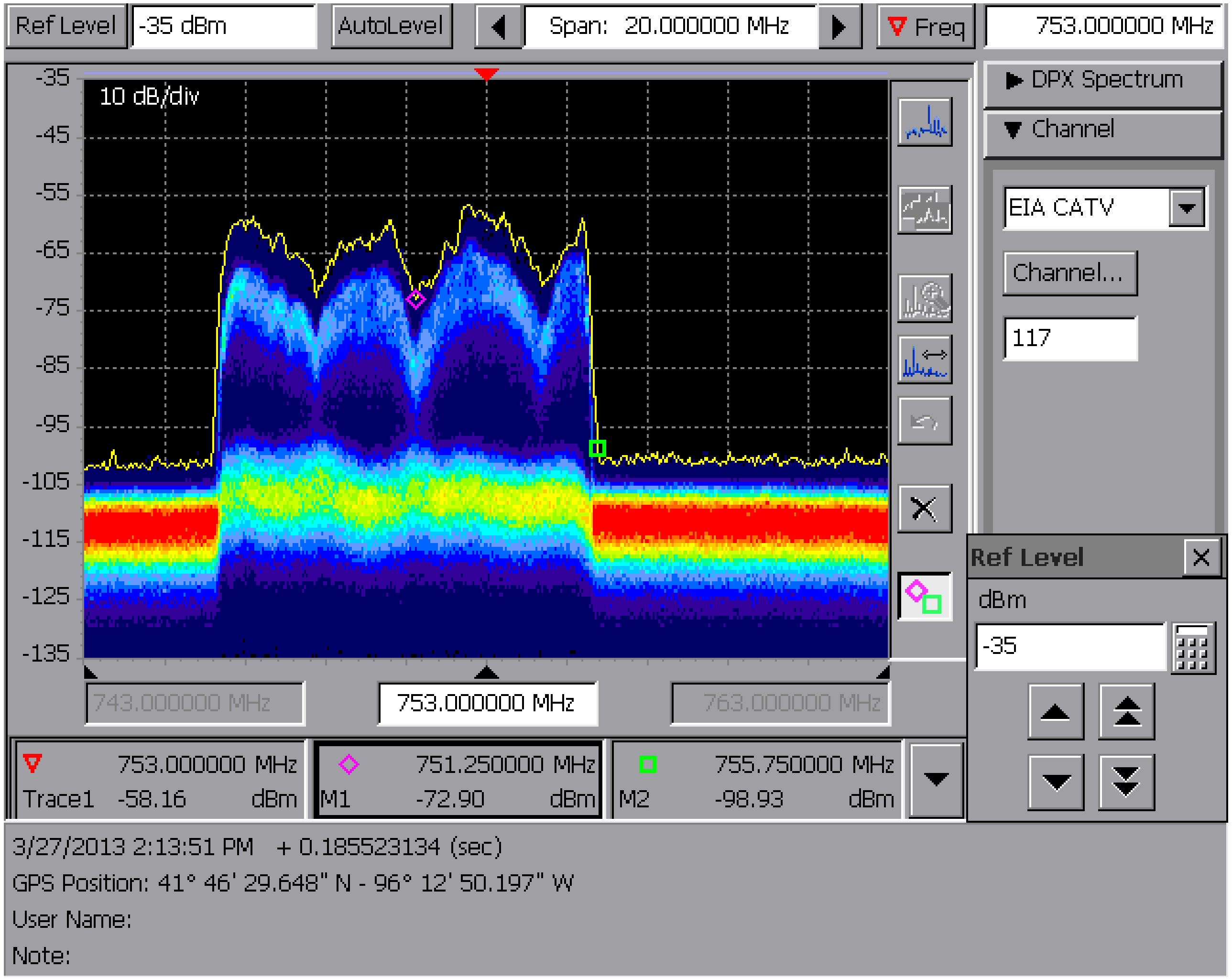
Test Location #3: This DPX screen shot depicts one of the higher level leaks found at CH117; however (again) there was no corresponding leakage found in channels 14, 15 or 16. Field strength readings within the CH117 spectrum were 38 μvolts/meter average; 86 μvolts/meter peak – however this all comes from the LTE OFDM signal and not from the very low-level analog leakage. I verified this by carefully repositioning the test vehicle just enough to eliminate the leak and then re-measured field strength levels.



Test Location #4: This DPX screen shot depicts the highest level leak found during my patrol of the approx. 9 to 10 miles of plant. Field strength measurements at CH117 were 50 µvolts/meter average and 109 µvolts/meter peak; again with this measurement that of the field strength of the LTE signal. I noted leakage in the alley, the back of the house and the front of the house; with internal/external wiring suspected in this instance. Also note the rise in spectral energy in the lower portion of the LTE Band 13 spectrum, indicating probable leakage of the CH116 QAM signal at this location.



Test Location #4: This screen capture at the same location shows no leakage at CH14, although there were times when I saw the CH14 luminance carrier briefly ‘come and go’ (at blue triangle marker).



TP Location #5: This final screen shot is included as a point of interest and not because leakage was found. I was patrolling in an area that was perhaps a half mile from the Verizon tower and with several metal grain bins approx. ½ block away. Note the LTE waveform above, with the high peak-to-valley response due to the presence of high-level reflected signals from the grain bins. This illustrates one of the many reasons why the use of OFDM is so important in modern digital communications [DOCSIS 3.1 will utilize OFDM], with its inherent ability to deal with these types of anomalies. A good tutorial on OFDM is helpful in understanding the inherent advantages of OFDM under these types of adverse reception conditions.

Conclusions

Again, a brief summary of this 'experiment', attempting to quantify and compare leakage in the aeronautical band versus that found in the 700 MHz range is as follow:

- There were only two leaks found where I saw any evidence of correlation between leakage at CH14 and CH117, and that correlation was poor at best.
- Many very low-level leaks were noted in numerous locations at CH117, but only two correlated to any measurable leakage at CH14; and all leaks found were within FCC limits at both frequencies.
- In this particular system, ingress into the system is I believe of greater concern, assuming the breach in plant integrity is minor. (The LTE Band 13 OFDM signal is a potential source of interference to the CH116 QAM carrier.)
- If I were to conduct this exercise again (and I may), I suspect that results in a system with the HFC plant not as well maintained and where cellular coverage is poor, would likely yield entirely different results.
- Finally, I believe my experience raises the issue of 'how' one is to perform accurate field strength measurements, where there is a low-level leak from the HFC plant, but higher power LTE signals ultimately comprise the bulk of the spectral energy and thus the field strength value calculated. In other words, how does one make an accurate measurement of the leakage carrier until its energy (power) is high enough that it comprises a significant percentage of the FS measurement made? Signal *amplitude* of the interfering carrier can certainly be made and they were during my patrol, but *field strength* measurements must be adjusted for frequency & bandwidth, and thus the LTE signal must be included in the calculation when present. One solution, with several test equipment manufacturers taking this approach, is to inject one or several high frequency carriers on the cable system where wireless spectrum is not likely to be in use (making for a more accurate field measurement); but in the crowded electromagnetic environment we presently operate in, wireless spectral areas not in use are becoming scarce at best!

Be sure to contact me if you have questions regarding RTA technology and how it can be applied to the challenges of maintaining and troubleshooting the modern cable network.

Take care and best regards.

Mark Bowers
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Cablesoft Engineering, Inc.