Provision Engineering Group
Company Proprietary

Attn: Colin Sanford

Date: Sept 14, 2018

From: Victor Jacek

Subject: ProVision HW Engineering – Antenna Module EMC Test Results Report

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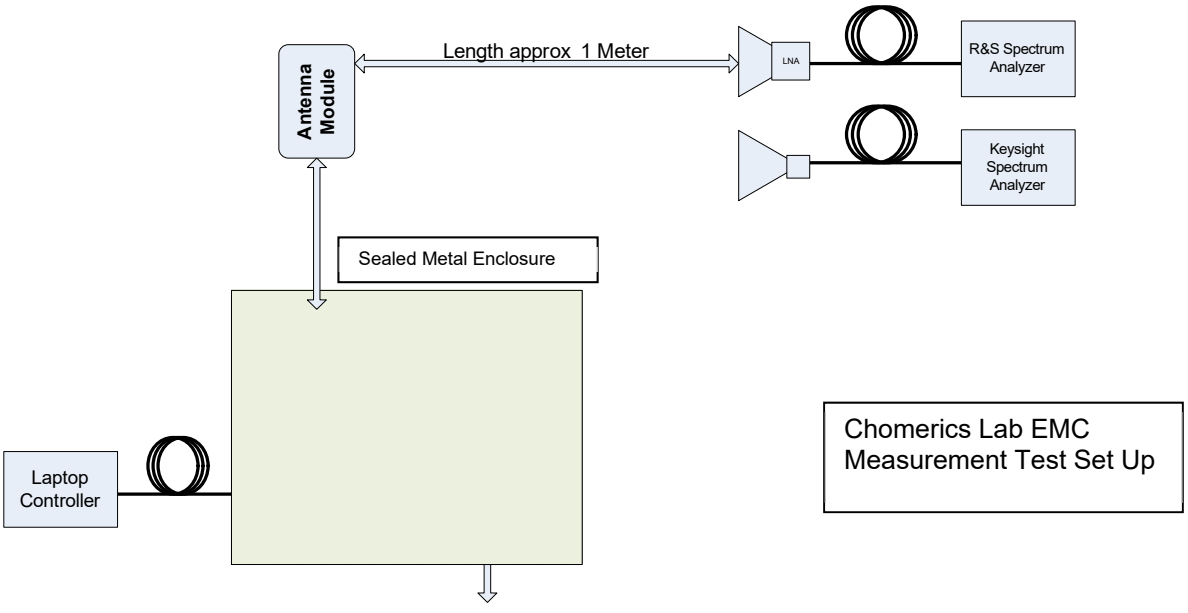
Introduction --- Setup and Measurement Procedure:

The EMC testing of the Mercury Antenna Module (AM) was done at the Parker/Chomerics facility on August 26th and 27th and utilized both the Chomerics R&S analyzer and the Keysight N9030B PXA Spectrum Analyzer. Essentially the Keysight analyzer was used to verify proper AM control, and the R&S analyzer was dedicated primarily to measurement activities although using both analyzers allowed increased confidence in the measurements through a correlation of the results. In order to establish crude path loss correction factors we used the E 8252D Signal Generator as the source transmitting into an identical horn at the receiver at the 1 meter set measurement distance. While Chomerics substituted several antennas to cover the spectral range, the L3 measurements were restricted to the 18GHz to 45GHz as determined by the performance of the NARDA 668A horn antennas. The basic test equipment setup is shown below and follows in general the test procedure that I wrote for this set of tests. The AM used was S/N M147273 which appeared to function normally in the pretest preparations'. In order to isolate the AM emissions from the rest of the system, the Power Supply ISU, and RFSM were placed in metal sealed boxes as drawn below. The testing began in the 18GHz to 40GHz region where we did a crude basic calibration of the path loss factors which are determining factors for the emissions performance as specified by the waiver. These calibration factors differed greatly between the R&S SA and L3 SA since the R&S SA Horn was directly preceded by a 50 dB LNA. Once calibration was completed we proceed to measure chirp levels and CW levels following as closely as possible the specified FCC measurement parameters for SA RBW, VBW, scan distance and sweep time. Since time in the lab was short, we elected next to make measurements in separate test facilities using the 30MHz to 1 GHz Yagi antenna in order to measure emissions in the digital clock and PS switching frequency region. The following figures 1 through 33 are critically selected samples plots of the measurements made throughout the entire 30MHz to 50GHz range as taken at the time. Taking into account the necessary calibration factors each plot is annotated with its respective limits according to the FCC waiver DA-06-1589 of Aug 3, 2006.



Conclusions:

Based on the measurements made at the Chomerics EMC test sight and the follow up investigation made at the Woburn labs the following observations and conclusions can be made.

1. The AM performed surprisingly well with respect to the FCC waiver allowable radiated emissions in the 1GHz to 45GHz range as measured and correlated by two different measurement systems. Based importantly on a sample of only one unit, limited test time and measurement data, we have found no FCC waver level violations in either the in band or out of band regions whether running in the chirp or CW modes. However much more precision will be required in determining the exact critical path loss for the FCC validation phase in order to determine the exact extent of the realizable margins.
2. All observed emissions detected out of band in the 10GHz to 45GHz region are attributable to the B4 version RFSM as confirmed in follow up measurements made in the Woburn Labs. This is due in part first to the lack of shielding at the board level and second, to the inherent VCO harmonic and slewing characteristics when the operational frequency is changed. This suggests that for best EMC performance, especially for the in band FCC CW performance testing, that the RFSM output should be muted through use of the existing switching during the frequency change periods to reduce these transients. Previous testing has indicated far better EMC performance with the B5 version of the RFSM housing has been achieved.
3. Figure 21 below illustrates an abrupt drop of about 10 dB less power in the 30GHz to 40GHz range as compared to the 20GHz to 30GHz range. This is more severe than the measured DVT data for the M147273 Antenna Module used as shown below. Additional measurements have shown that the reduced power level is not directly related to the RFSM drive levels, so the primary cause is unknown at this time. While the phase sensitive based system performance is not directly related to the RF level, it does affect the overall high band contribution to system performance due to reduced signal to noise and dynamic range. Further investigation would be required to asses any effect on the EMC results if this level roll-off with frequency proves to be highly variable.

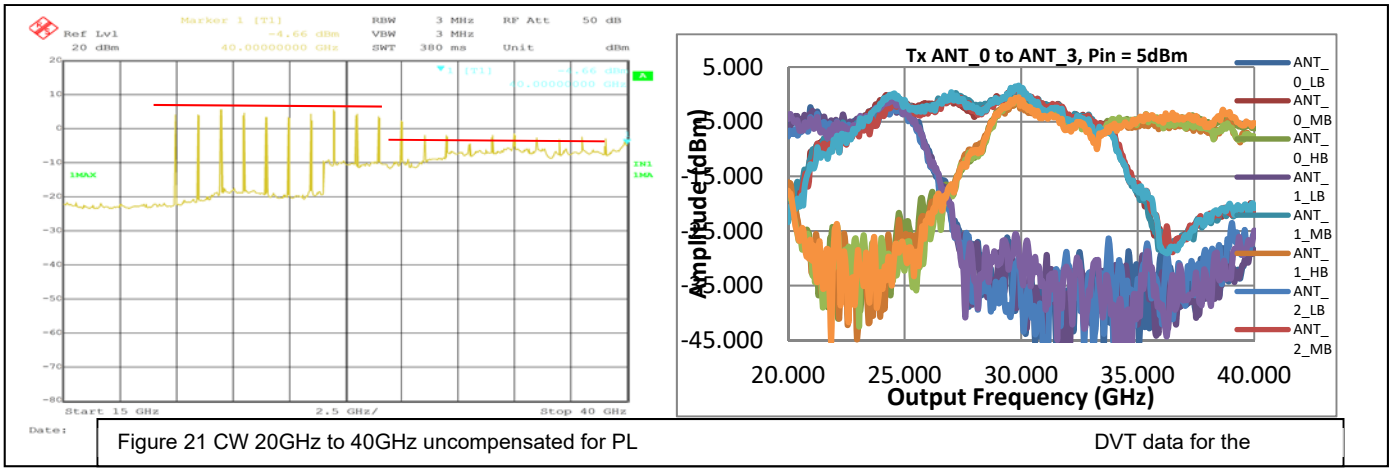


Figure 21 CW 20GHz to 40GHz uncompensated for PL DVT data for the

4. Additional follow up measurements made in the Woburn lab measurements have shown intermittent control of the VVA levels for unit M147273 using the latest version of the Field Test SW. It is not known when this problem occurred or if this was encountered during the Chomerics testing.
5. The AM unit was surprisingly free of spurious emissions in the 1GHz to 45GHz region. It seems that the RF gasketing used throughout the top RF board was very effective in this spectral region.
6. As observed in the 30MHz to 1GHz spectral zone, the AM was a significant contributor to the emissions in the 100MHz to 400MHz range. While no FCC limit violations were seen to occur, the minimal margins are of concern, particularly since we dealt with a sample of one unit, and the range of potential variations is unknown.

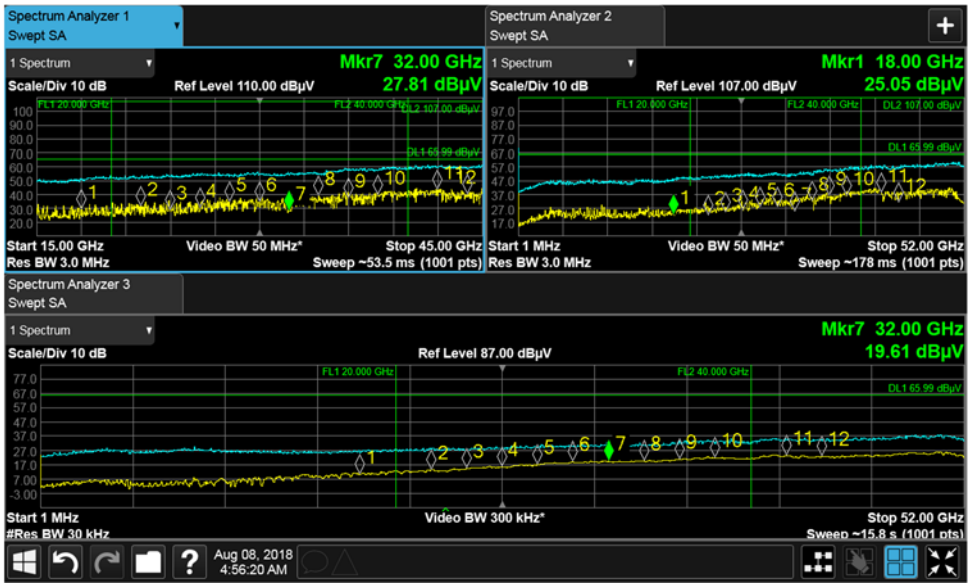


Figure 1 Screen Initial Test Setup

Before making measurements a background screen initial setup test was done and a brief analysis and estimation was performed to verify that reasonable power levels were emitted from the AM in the chirp mode. Figure 1 illustrates the combined saved instrument presets that were used to save significant setup time while in the Chomerics lab. The Keysight PXA allows simultaneous display of multiple screens, frequency ranges, detector settings, marker positioning, and reference display line setup. These features were used to save significant setup time and avoid setting and measurement errors that can occur in these circumstances.

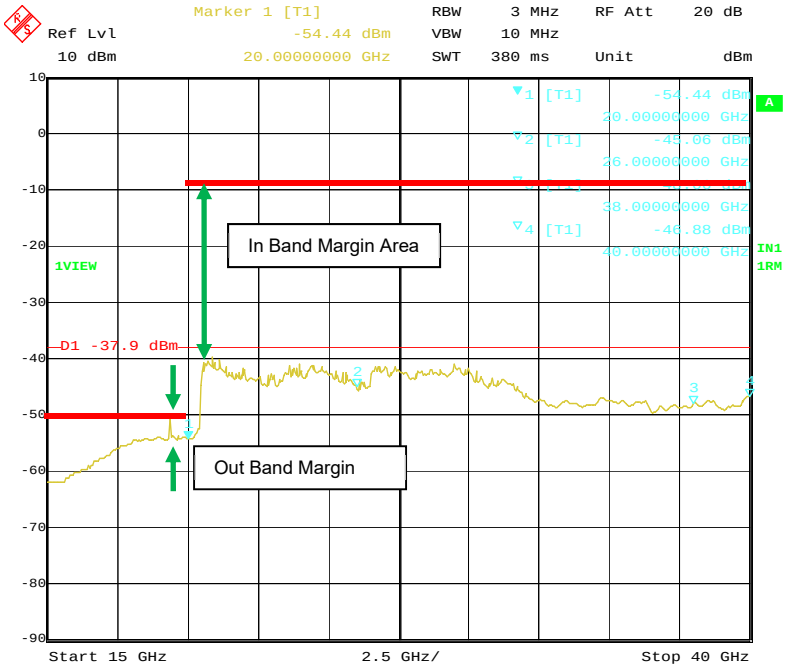
According to Mercury DVT results (see conclusions), the AM module has a typical output level of (-5 to 0) dBm at the module surface, this translates to an approximate power of (-17.0 to -12) dBm at 1 meter.

When chirping from 20GHz to 40GHz in 13.94uS the spectral density is -151.6 dBm/Hz or -91.6 dBm/MHz
-151.6 dBm/Hz (chirp spectral density @ 0dBm input level)
+64.8 dB (3MHz RBW factor)
+62.0 dB (FSPL @30GHz & 1m – varies with frequency and distance)
-24.8 dBm (factored output power level)

Approximate Correction factors;
-24.8 dBm (factored level)
+19.7 dB (cable loss @ 30 GHz approx. 1m – varies with frequency and distance)
-12.0 dB (Antenna Gain @ 30 GHz approx 1m – varies with frequency and distance)
+3.0 dB (Polarization Correction est)
-14.1 dBm (approx. expected calculated level at 1m ± Δ dB)

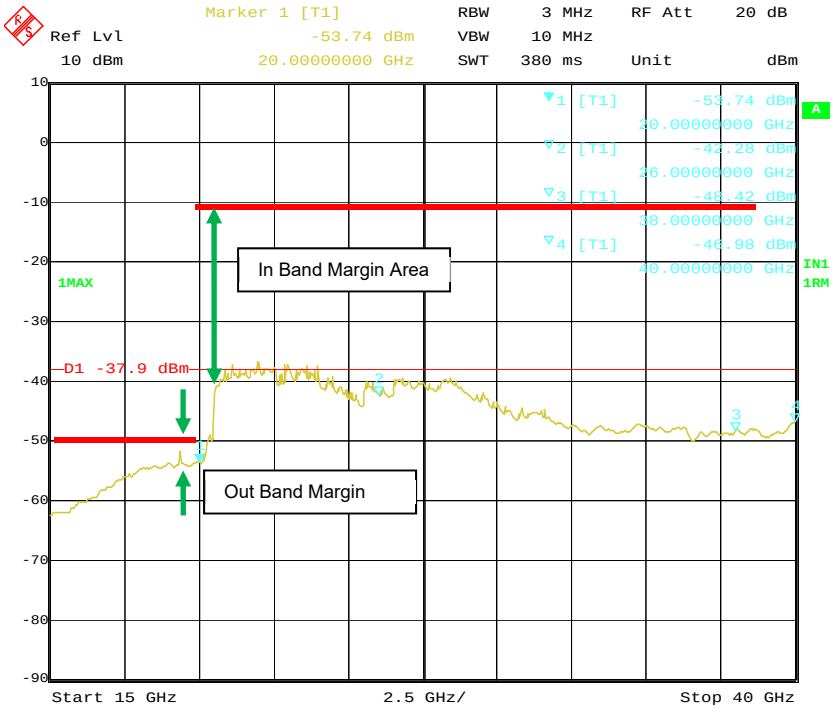
Therefore, based on this measured data the “typical chirp maximum level” at the example of 30GHz and 1Meter is within reasonable and expected range limits. Variations to the power levels over the wide band of frequencies are expected and due to measurement equipment limitations, path loss estimations, and other calibration factors.

The FCC waiver requirement for the chirp condition is 500uV/m at 3 meters in the range of 960MHz and above. This translates to an EIRP of -41 dBm/MHz of spectral density, or -101dBm/Hz. Since all relevant chirp measurements are made with a SA RBW of 1 MHz, the actual SA in band and out of band limit is -41dBm for the chirp emissions. In the broad band chirp plots below the actual path loss/gain is factored as noted along the right side the plot. In most cases we made identical measurements with the Chomerics and L3 Spectrum analyzers for correlation, extended range capabilities, and positive control verification. Although the pathloss/gain factors varied widely in each case the proper calibrated corrections have been applied, based on the best measured estimates at the time.
Figures 2 through 4 illustrate the max peek hold condition of the RMS Average condition as measured by the R&S Spectrum Analyzer (SA) . While each case shows margin there is a small unidentified spur out of band, which is probably not related to the AM. Figure 5 through 7 depict the max peak hold response on the R&S. The small spurious response found at about 19 GHz appears in figures 5 and 6 but not 7, indicating that it is likely not AM related.



Calibration Correction:
Path Loss/Gain
Adjustment to FCC
Limit = -9 dB

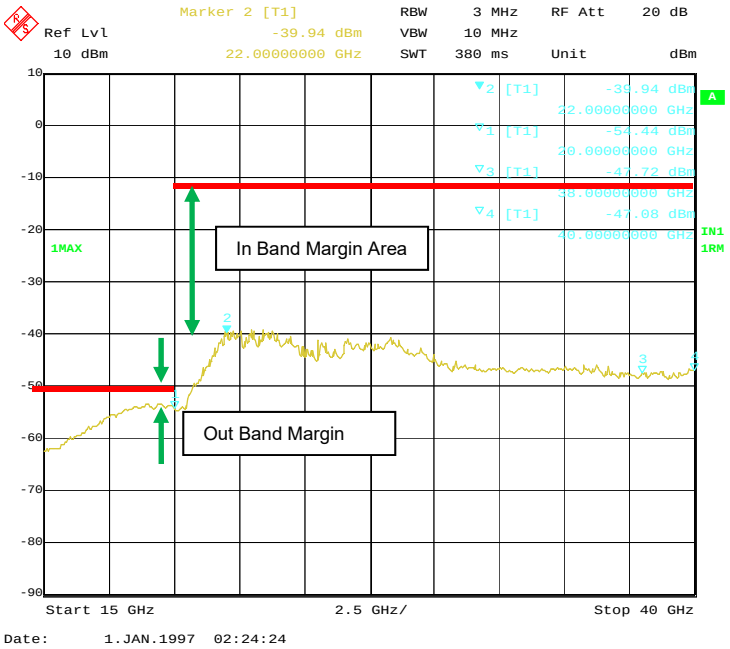
Figure 2 Max Peak Hold, Chirp, VVA = 0 AVG RMS, HOR, Chomerics 18-26GHz Antenna



Calibration Correction:
Path Loss/Gain
Adjustment to FCC
Limit = -9 dB

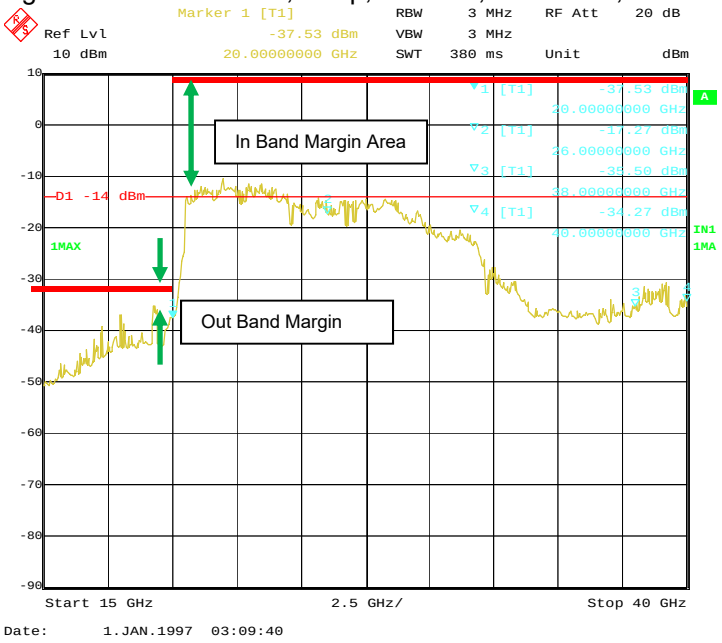
Radiated Power Level Check:
-38 dBm Peak Average Level
+9 measured Path Loss
+20 Peak-ave/ave conversion
-9 dBm calc reference output

Figure 3 Max Peak Hold, Chirp, VVA = 0, AVG RMS Chomerics 18-26GHz Antenna



Calibration Correction:
Path Loss/Gain
Adjustment to FCC
Limit = -9 dB

Figure 4 Max Peak Hold, Chirp, VVA = 0, AVG RMS, Chomerics 26-40GHz Antenna



Calibration Correction:
Path Loss/Gain
Adjustment to FCC
Limit = 9 dB

Figure 5 Max Peak Hold, Chirp, VVA = 0, Chomerics 18-26GHz Antenna

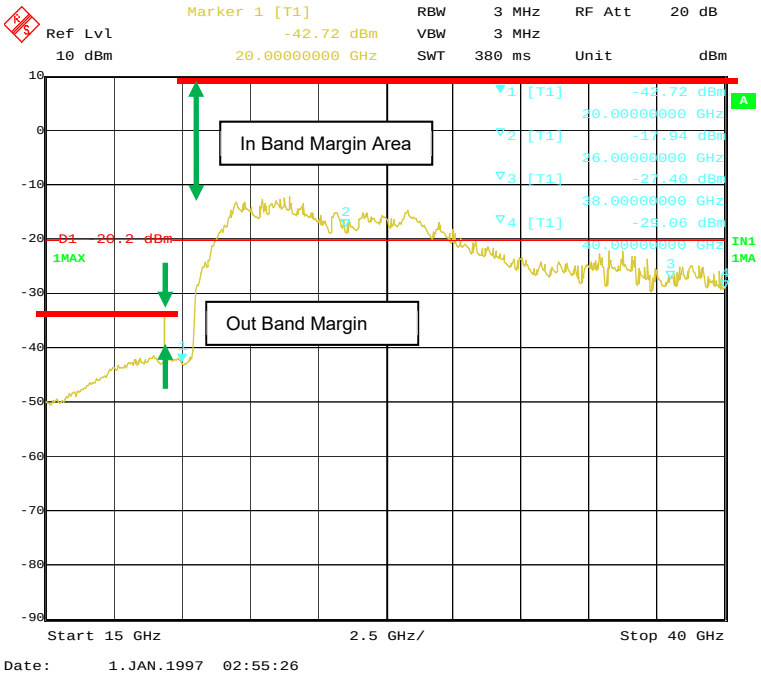


Figure 6 Max Peak Hold, Chirp, VVA = 0, Chomerics 26-40GHz Antenna

Calibration Correction:
Path Loss/Gain
Adjustment to FCC
Limit = 9 dB

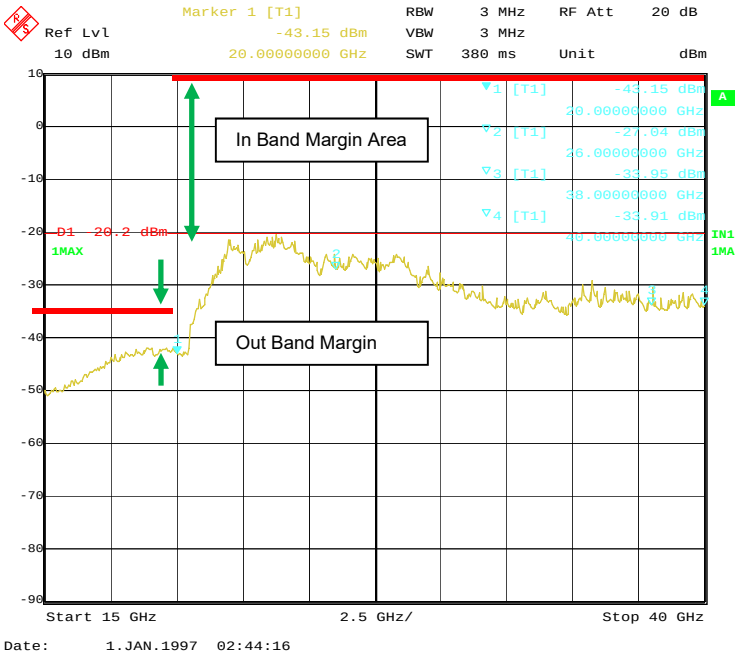


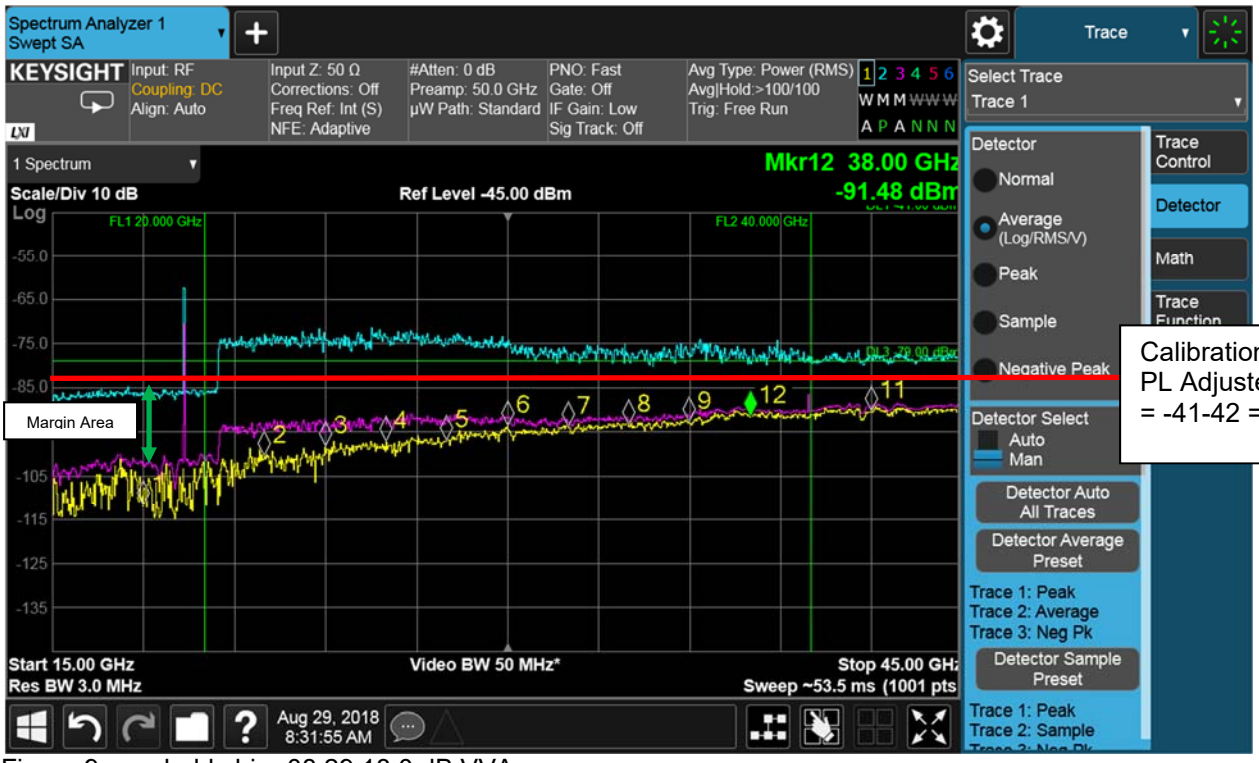
Figure 7 Max Peak Hold, Chirp, VVA = -10, Chomerics 26-40GHz Antenna

Calibration Correction:
Path Loss/Gain
Adjustment to FCC
Limit = 9 dB

Figure 8, 9, and 10 illustrate the combined responses of the chirp as viewed in the RMS Average, RMS Average Peak Hold and RMS Average hold condition. As in the R&S plots there is an approximately 19 GHz spur which appears in figure 9 but not in 8 or10. This is likely due to external or momentary switching spurs. Figures 11 and 12 give similar views with the marker frequencies and levels identified.

Calibration Correction:
PL Adjusted FCC Limit
= -41-42 = -83 dBm

Figure 8 max hold chirp 08.29.18 0 dB VVA Horizonal



Calibration Correction:
PL Adjusted FCC Limit
= -41-42 = -83 dBm

Figure 9 max hold chirp 08.29.18 0 dB VVA

Figure 10 max hold chirp 08.29.18 10 dB VVA

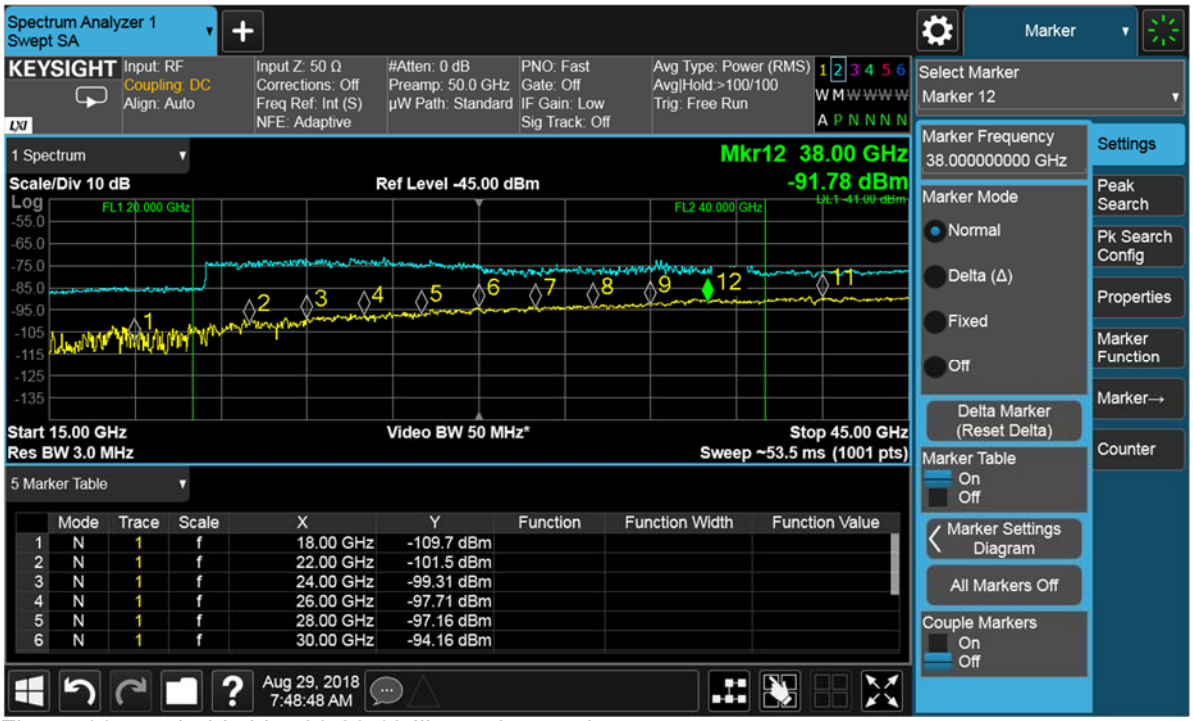


Figure 11 max hold chirp 08.29.18 Illustrating markers

Radiated Power Level Check:
-151.6 dBm spec dens @ 0 dBm
-(-95 dBm) meas level of the Max RMS average
+42 dB meas path loss
-14.6 dBm calc reference output level

Figure 12 max hold chirp rms aveage included 08.29.18

Figures 13, 14 ,15, and 16 depict the FCC Specified narrow band results of the chirp function at the center frequencies of 21GHz, 30 GHz, 32GHz, and 40GHz respectively as measured on the R&S SA. The calculated margins due to the measured path losses reveal the level performance margins. As a correlation, Figures 17, 18,19, and 20 show the same chirp function results as measured by the L3 equipment. The calculated margins are also noted and are in a comparable range.

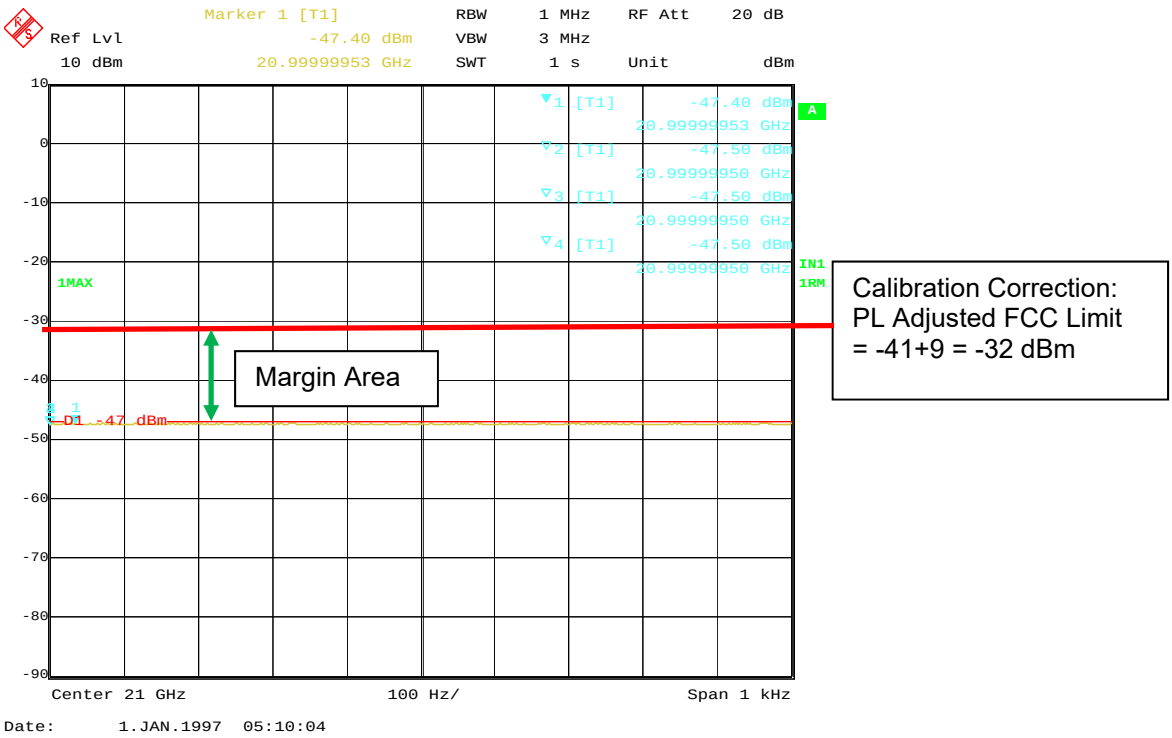


Figure 13 Max Peak Hold, Chirp, AVG RMS, 21GHz, Chomerics 18-26GHz Antenna

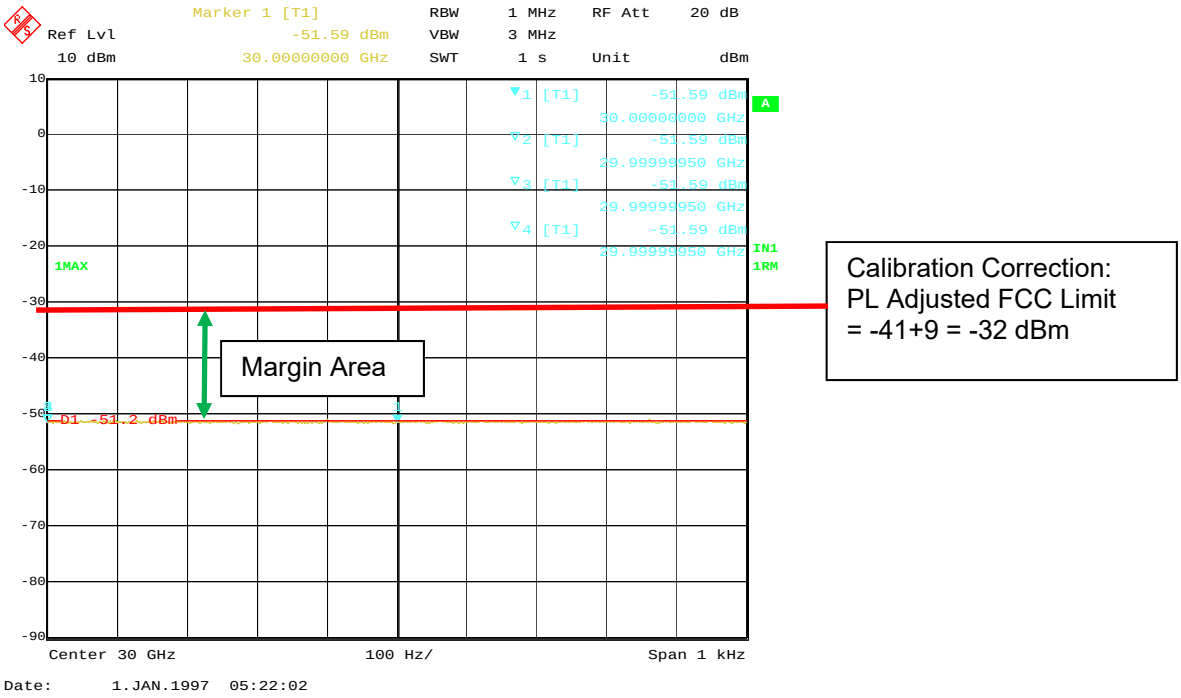


Figure 14 Max Peak Hold, Chirp, AVG RMS, 30GHz, Chomerics 26-40GHz Antenna

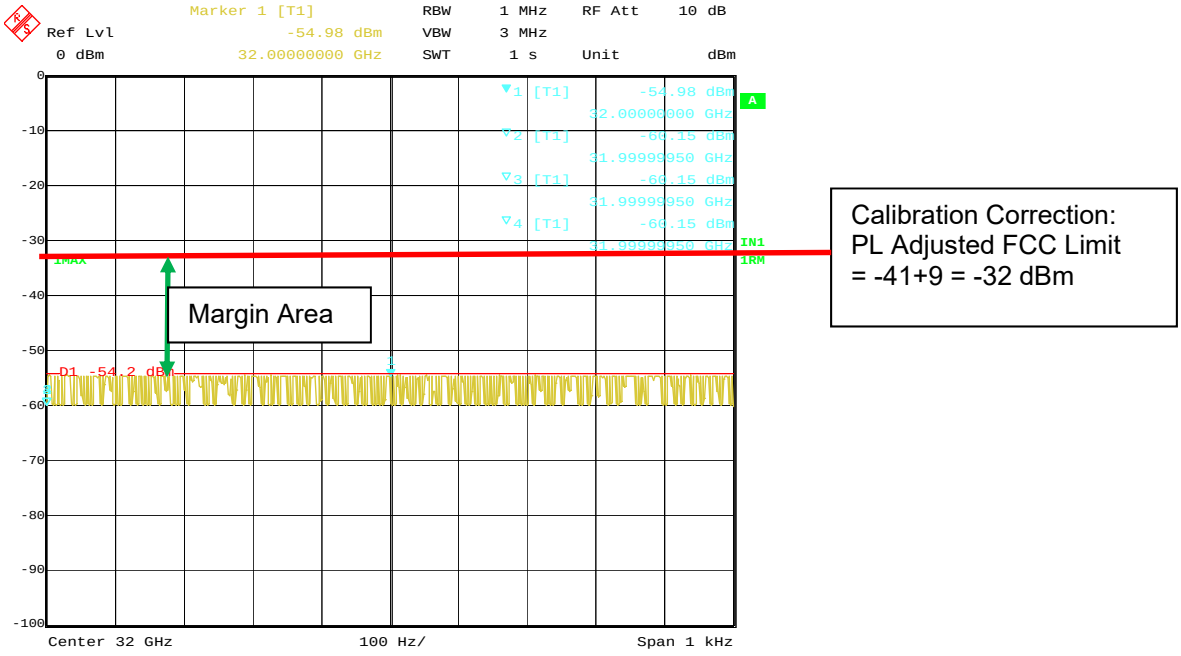


Figure 15 Max Peak Hold, Chirp, AVG RMS, 32GHz, Chomerics 26-40GHz Antenna

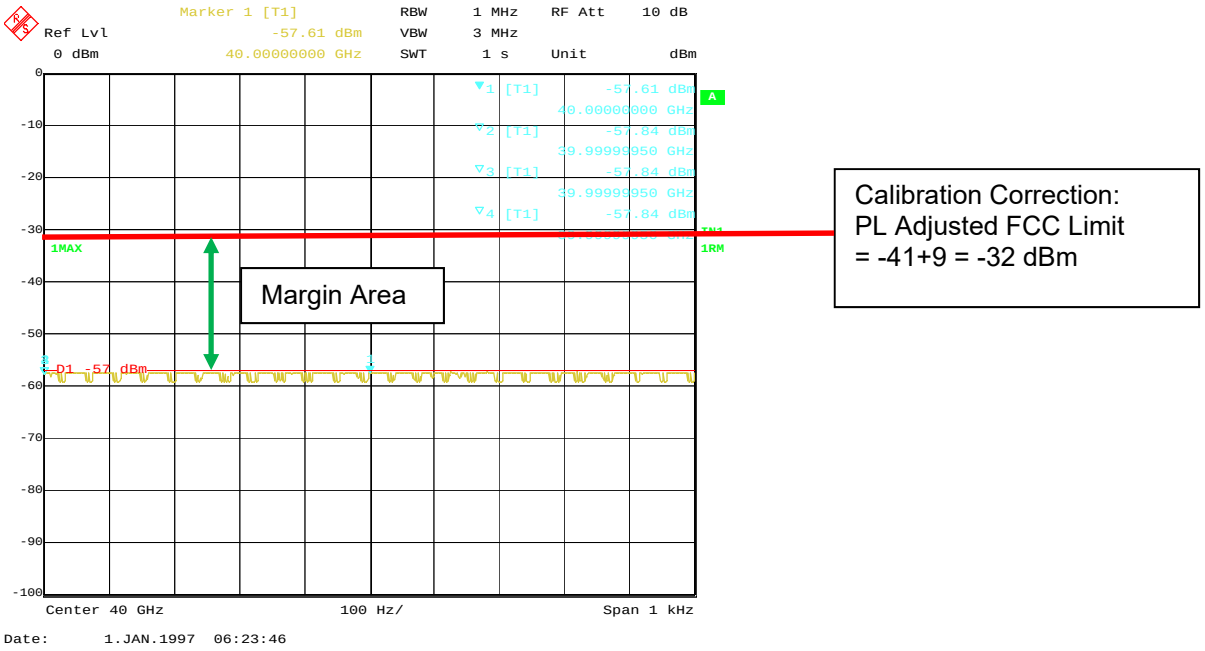


Figure 16 Max Peak Hold, Chirp, AVG RMS, 40GHz, Chomerics 26-40GHz Antenna

Figure 17 max hold chirp RMS @ 21 GHz 1KHz span

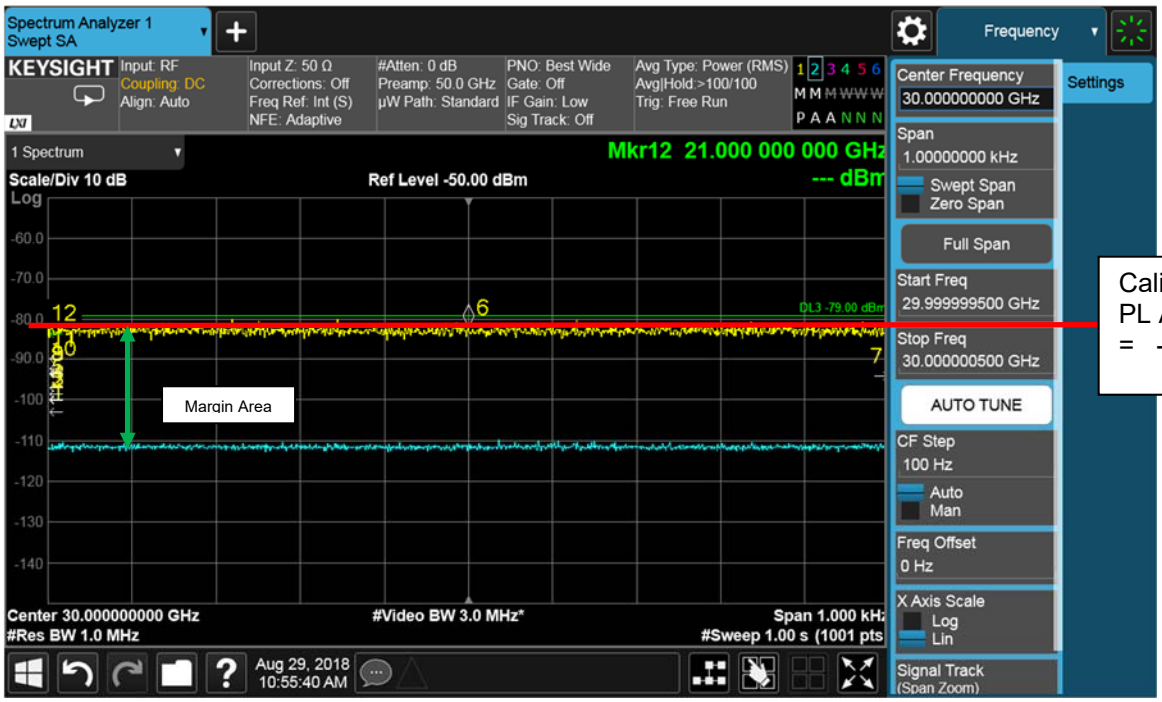


Figure 18 max hold chirp RMS @ 30 GHz 1KHz span

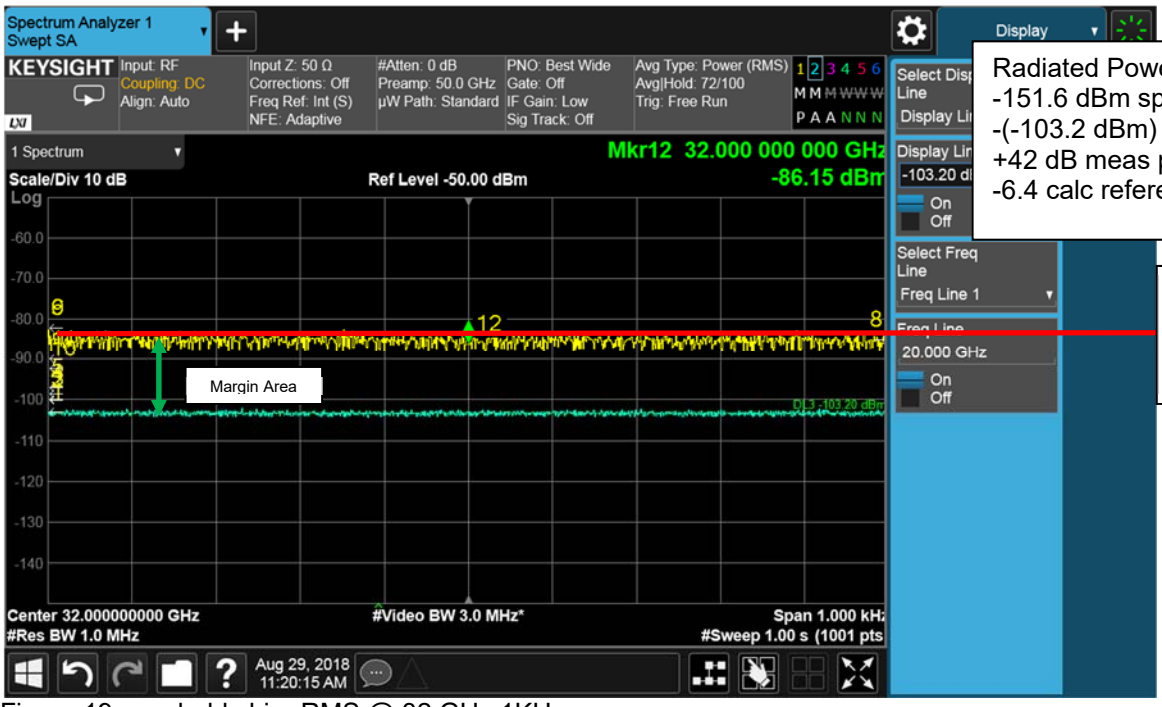


Figure 19 max hold chirp RMS @ 32 GHz 1KHz span

Figure 20 max hold chirp RMS @ 36 GHz 1KHz span

The FCC waiver requirement for the maximum CW restricts the output power to be no more than 41 dB above the -41 dBm/MHz limit. Figure 21 depicts the result of the CW response when the frequency of the AM s stepped by 1 GHz increments from 20GHz to 40GHz. After application of the PL correction factors only the CW frequencies between 20GHz and 30 GHz fall within the generally expected range. CW frequencies above about 30GHz are seen to be about 10dB lower are of some concern since they do not in general agree with the DVT results to date.

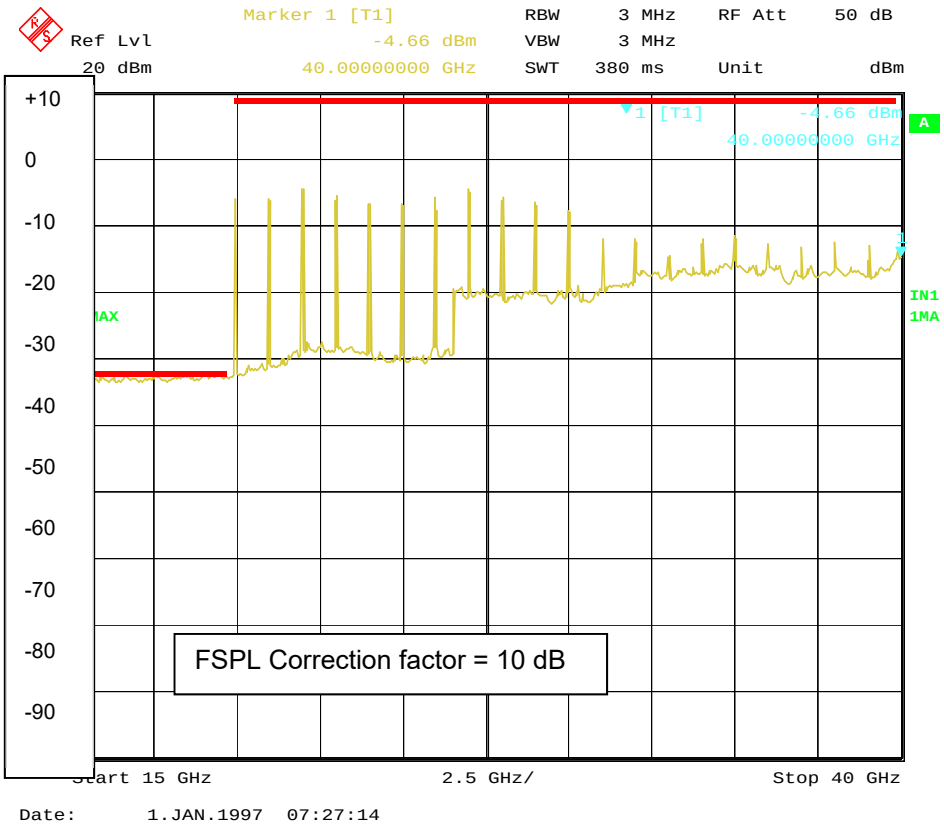


Figure 21 CW 20-40GHz

Figures 22 and 23 below illustrate the same basic CW response as measured on the L3 equipment.
Figure 23 is the PL corrected CSV version of 22. All CW components fall within the superimposed limits, however the trace has captured the spurs A, B and C as well. While B is of no consequence since it falls within the waver range, A and C are troublesome since like B they are not obviously harmonically related, and furthermore A and C fall out of band and are over the FCC limits. Since this is a critical matter, an independent follow up investigation was held at the Woburn Labs on 09.12.18. The testing revealed the following with an estimated 95% certainty. Spurs A, B, and C originate from the RFSM as determined by frequency differentiation, selective module shielding and by removing the power from the AM. The transients are created by the RFSM VCO and it harmonics, as it is slewed from one frequency to the next, and is then aligned by the internal synthesizer. It is expected that the B5 RFSM will greatly reduce if not eliminate these transient spurs as radiated by the housing. Additionally, because the transients are of short duration they would have negligible effect on the average radiated power as specified by the FCC waver.

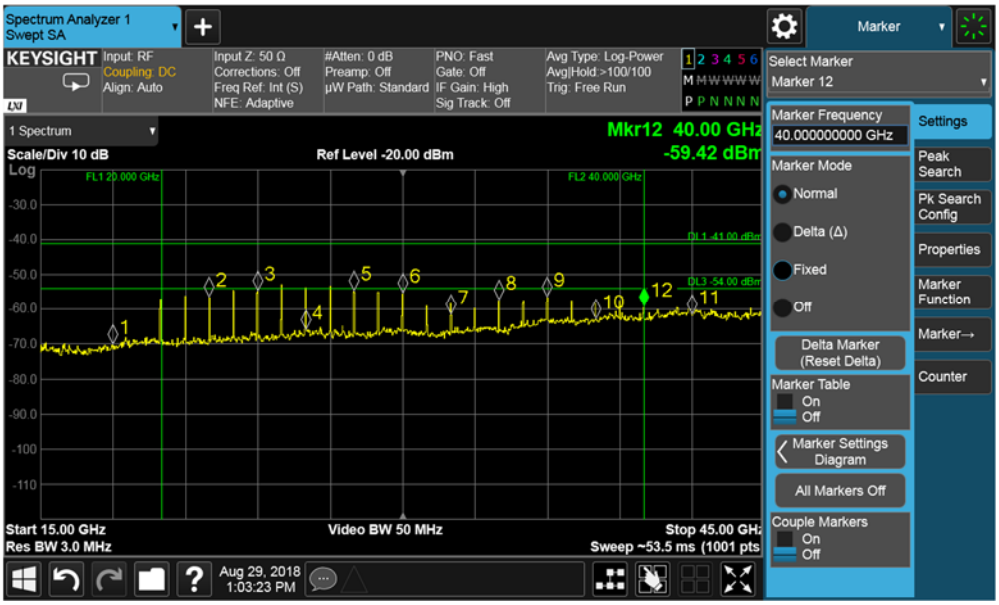


Figure 22 CW range from 20 GHz to 40GHz

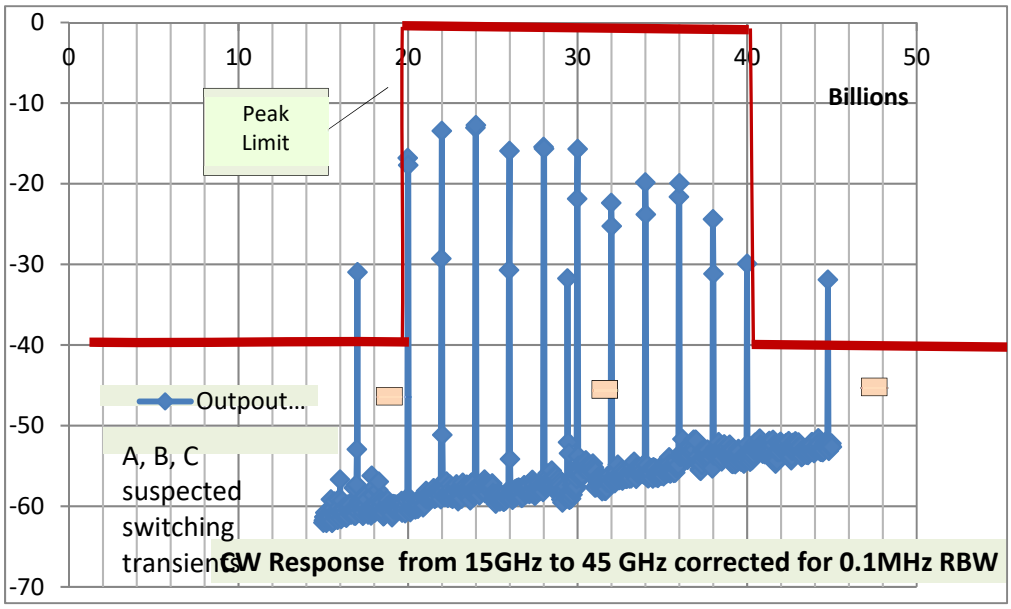


Figure 23 CW range from 20GHz to 40 GHz as reconstructed from CSV files.

Figures 24 through 29 plot the measurements made in the 1GHz to 18GHz spectral region. These horizontally and vertically polarized measurements were taken from the front, sides, top, and bottom of the AM housing to discover the unintentional EMC radiated power both from the antennas as well as the housing itself. As measured by both the R&S and Keysight SA's, in the semi-typical continuous chirp operational mode, there appears to be sufficient margin with respect to the FCC waiver. Each plot shows a spur at approximately 9.7GHz which is present with and without power to the L3 equipment and is therefore attributable to an external source.

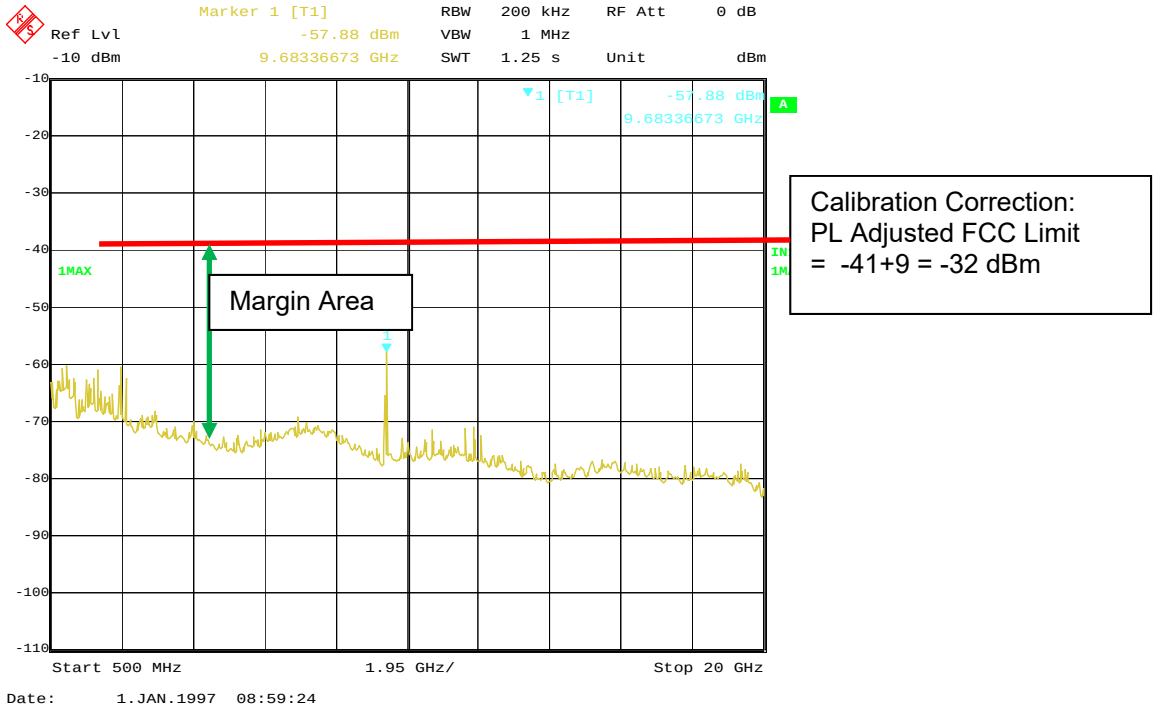


Figure 24 1-18GHz Emission with continuous Chirp Top Vertical Polarization

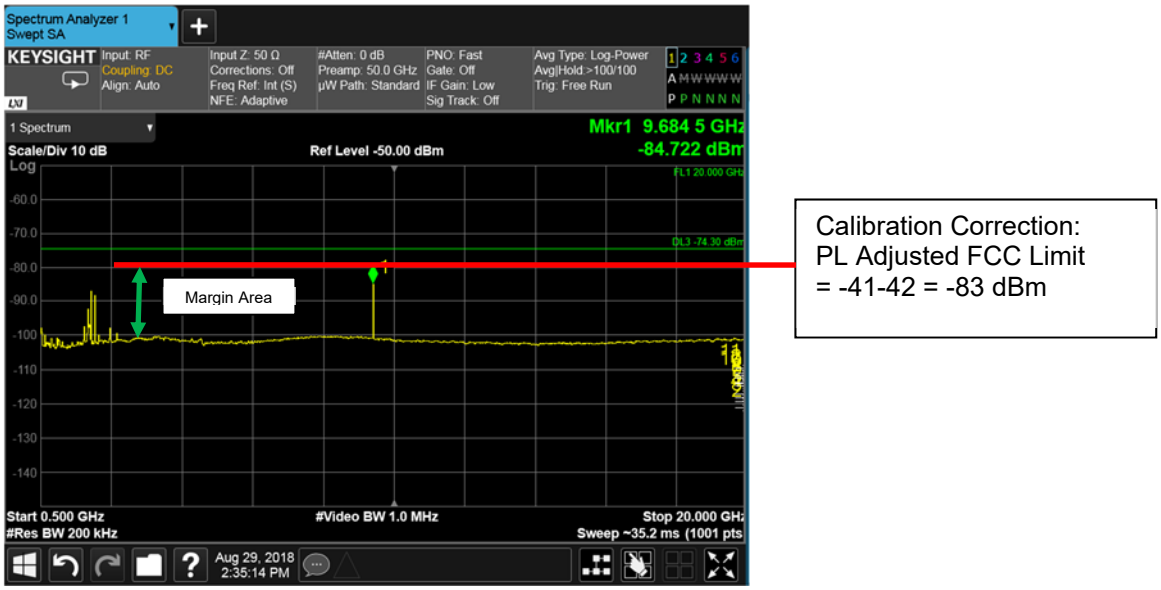
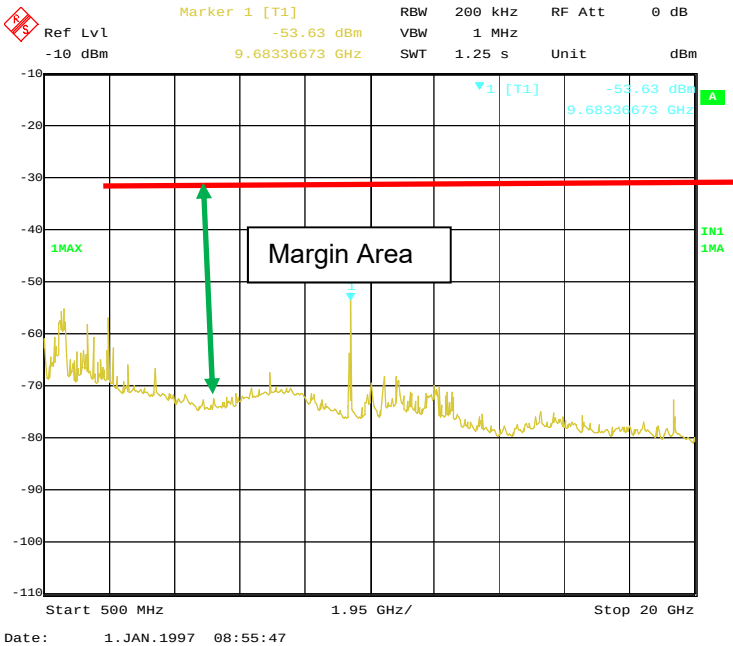


Figure 25 1-18GHz Emission with continuous Chirp Back Vertical Polarization

Calibration Correction:
PL Adjusted FCC Limit
= -41-42 = -83 dBm



Calibration Correction:
PL Adjusted FCC Limit
= -41+9 = -32 dBm

Figure 26,27 1-18GHz Emission with continuous Chirp Long Side Edge

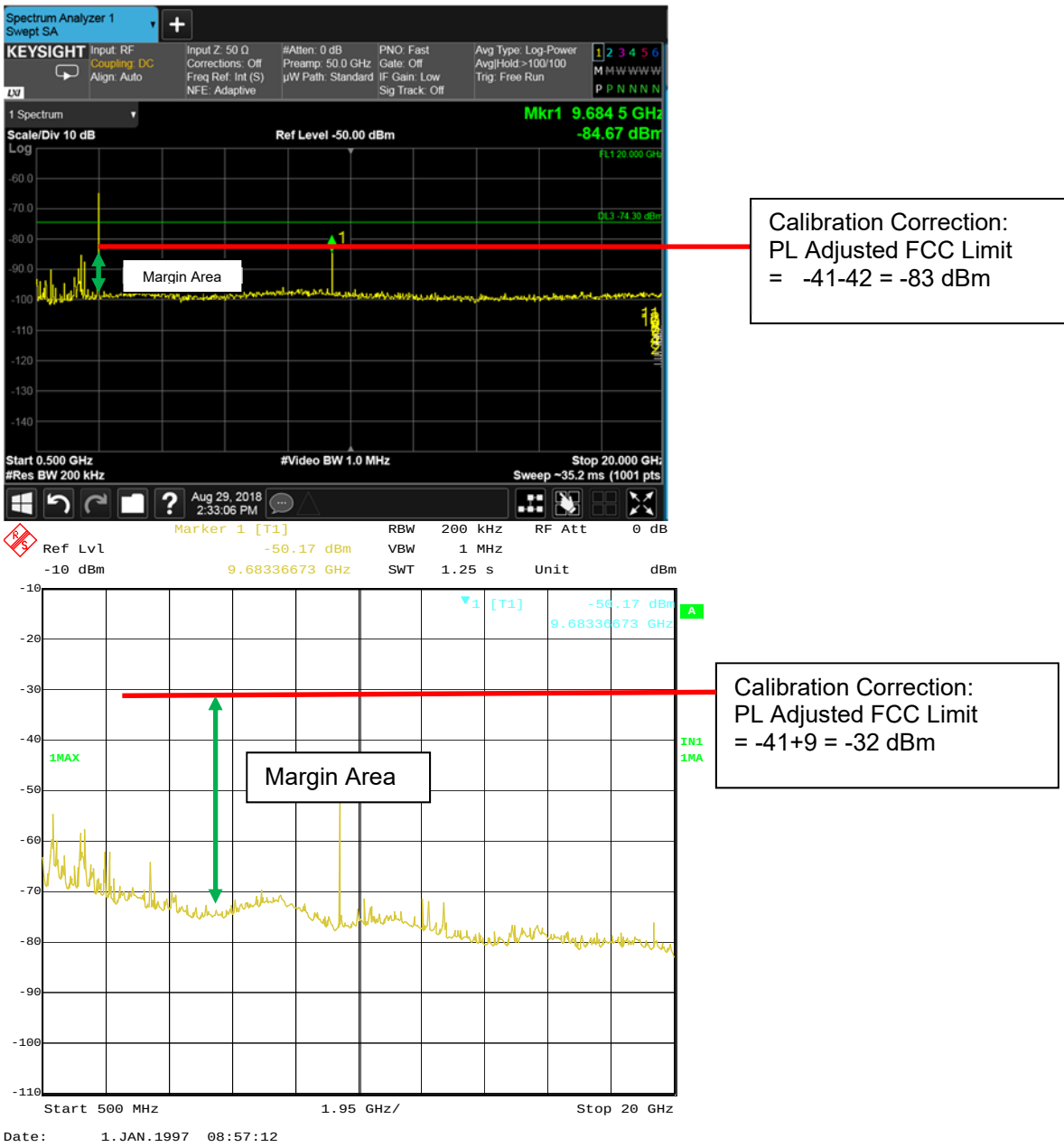


Figure 28, 29 1-18GHz Emission with continuous Chirp Top Vertical Polarization

The following measurements were made in the 30MHz to 1GHz region in the Chomerics calibrated test facility. These measurements require a large Yagi antenna in the conventional EMC test arrangement that allows rotation of the unit under test and antenna height positioning with both vertical and horizontal polarization. Chomerics deals extensively in this frequency region and all measurements were automated. Figure 30 and 31 plot the EMC radiated emissions for this band of frequencies in both the horizontal and vertical polarizations. In this case the horizontal emissions are the highest approaching but not exceeding the FCC limits that are attributable to the AM. Figure 32 and 33 compare the spectral images with the L3 equipment turned off in figure 32 to the equipment fully functional in figure 33. It is clear that the AM contributes spectral emissions in this spectrum especially in the 100MHz to 350MHz region, however there still remains a small margin to the FCC spec.

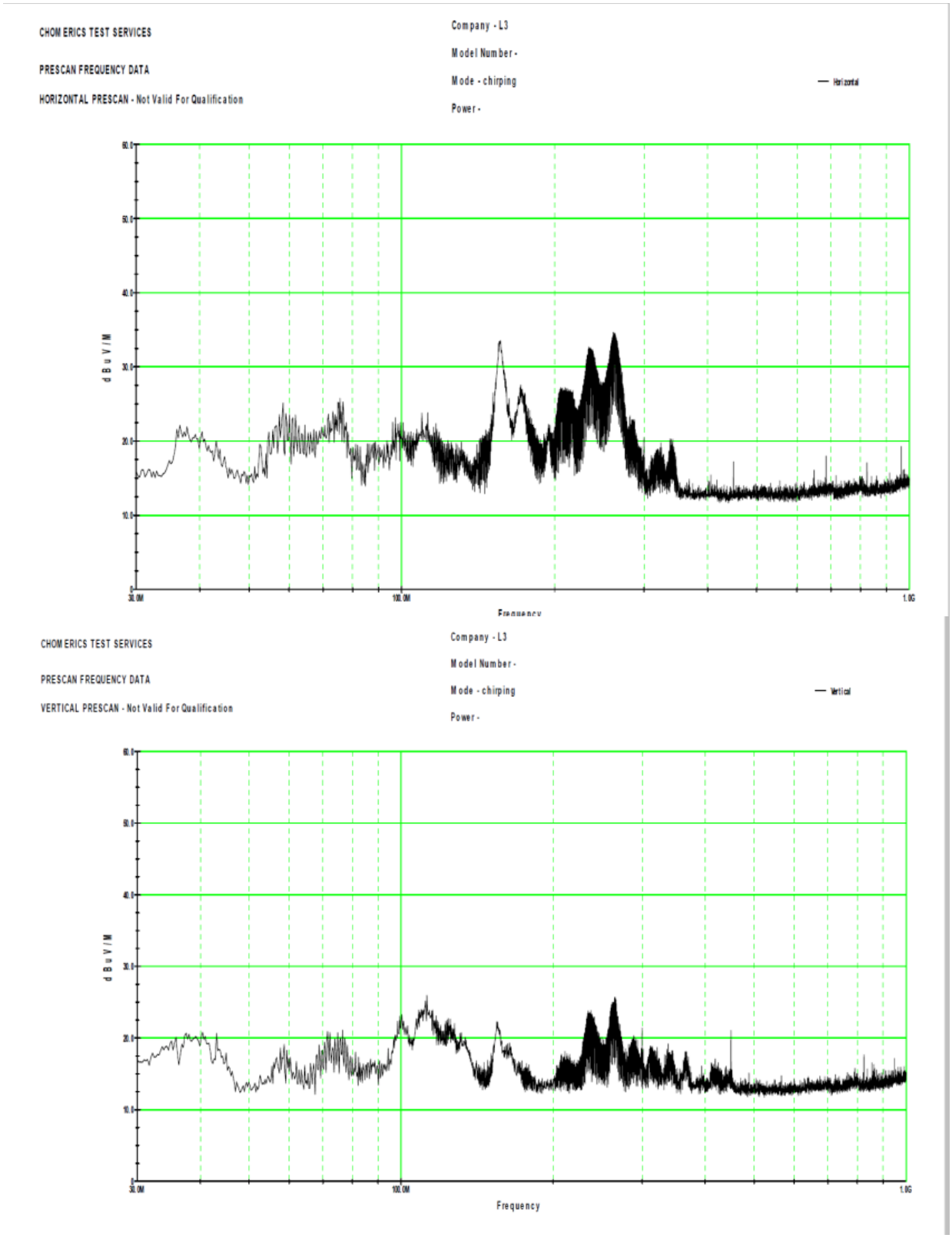


Figure 30,31 30MHz to 1GHz Emission with continuous Chirp Top Horizontal and Vertical Polarization

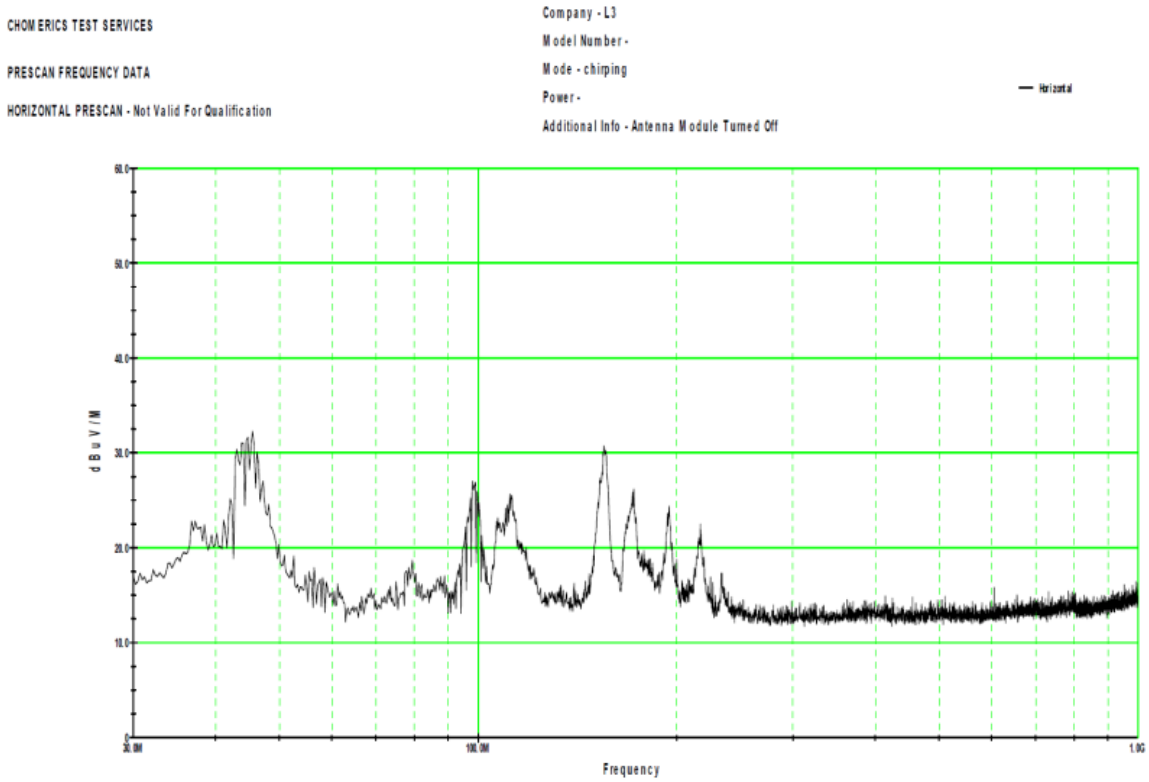


Figure 32 30MHz to 1GHz Emission with AM module powered down

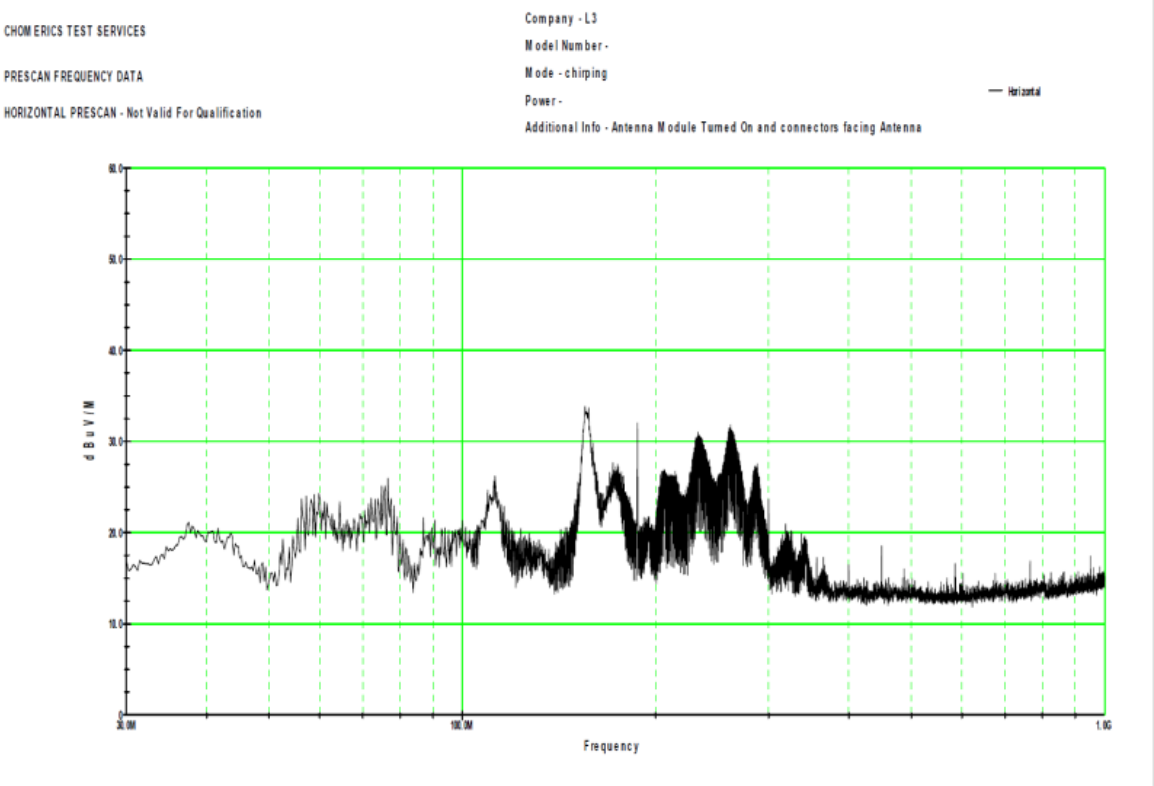


Figure 33 30MHz to 1GHz Emission with AM module facing Yagi antenna

Radiated Emission Summary Tables in the 30MHz to 1GHz Spectral Region.

The tables below are the automated summary of the data displayed in figure 30 through 33. The top table lists the significant spurs, and calculates the applicable margin according to the FCC requirements. Based on the comparison with the bottom table with the AM turned off, the numbers in red indicate the spectral power contributions of the AM. In several cases, primarily in the 180MHz to 380MHz spectral region the AM contributes significant emissions sufficient to bring the margin down to 2 or 3 dB which is of some concern considering expected unit to unit variations and test equipment tolerances.

RADIATED E FIELD EMISSION MEASUREMENTS

Customer: L3
Equipment: PV Next Gen
Tested By: Nick Orphanos
Operating Mode: Normal
Bandwidth: [X] 100 kHz (Peak)/120 kHz (QP)
Frequency Range: [X] 30 MHz – 1 GHz
Other (specify)

Date: 2018-08-30
Test Number: 1
Coupling Device: Antenna
Test Spec: FCC Part 15.209
Procedure: ANSI C63.4
Antenna Distance: [ ] 3 Meters
[X] 10 Meters

Frequency MHz	Quasi-Peak Measured Level dBuV	Antenna Height (Meters)	Turntable Azimuth (Degrees)	Antenna H/V	Antenna Fac/Cable Loss dB	Field Level dBuV/m ✧	Limit dBuV/m (QP)	Margin dB	dBm AM added Power
34.318	14.0	1.00	0	V	21.2	35.2	29.5	5.7	0.5
BBP 133.099	11.5	1.00	315	V	14.2	25.7	33	-7.3	
BB 166.700	19.0	1.00	45	V	16.6	35.6	33	2.6	
BB 167.500	18.5	1.00	45	V	16.7	35.2	33	2.2	
187.506	13.5	4.00	315	H	17.5	31.0	33	-2.0	12.5
BBP 232.229	9.5	1.00	180	V	19.7	29.2	35.5	-6.3	11.0
BBP 264.396	10.5	1.00	90	V	20.9	31.4	35.5	-4.1	11.5
BBP 363.234	7.5	2.25	45	H	25.1	32.6	35.5	-2.9	8.8
BBP 365.034	7.5	2.25	45	H	25.1	32.6	35.5	-2.9	10.5

RADIATED E FIELD EMISSION MEASUREMENTS

Customer: L3
Equipment: @

Date: 2018-08-30
Test Number: 1

Frequency MHz	Quasi-Peak Measured Level dBuV	Antenna Height (Meters)	Turntable Azimuth (Degrees)	Antenna H/V	Antenna Fac/Cable Loss dB	Field Level dBuV/m ✧	Limit dBuV/m (QP)	Margin dB
Full system On and antenna module off								
BBP 34.318	13.5	1.00	180	V	21.2	34.7	29.5	5.2
BB 165.700	22.0	1.00	45	V	16.6	38.6	33	5.6
BB 166.700	20.5	1.00	45	V	16.6	37.1	33	4.1
BB 167.500	19.0	1.00	45	V	16.7	35.7	33	2.7
NF 187.506	1.0	4.00	315	H	17.5	18.5	33	-14.5
NF 232.229	-1.5	1.00	180	V	19.7	18.2	35.5	-17.3
NF 264.396	-1.0	1.00	90	V	20.9	19.9	35.5	-15.6
NF 363.234	-1.0	2.25	45	H	25.1	24.1	35.5	-11.4
NF 365.034	-3.0	2.25	45	H	25.1	22.1	35.5	-13.4