Comb / Square Wave Generator Board

Introduction:

The comb / square wave generator was designed and constructed by Schutten Technical Consulting LLC. The purpose of the comb generator is to produce harmonic multiples of a fundamental frequency. This can be used for RF and EMI testing. The fundamental frequency can be varied between 10 kHz to 30 MHz selecting the appropriate switch range (÷100, ÷10, ÷1) and rotating the coarse and fine frequency adjust potentiometers on the board. The comb / square wave generator board is designed to provide significant harmonic content beyond 500 MHz.

Figure 1: Comb Generator

Power:

The unit is powered from a single 9V battery, the battery holder is on the bottom side of the board. A toggle switch in the upper right-hand corner of the board turns the unit on. The switched "+9V" voltage can be measured using test points on the board. The board requires 10 mA of current in comb mode, and about 20 mA is square wave mode. A typical 9V alkaline battery is rated for 500 mA-Hr, so the battery should power the board for 25-50 hours.

The board has two LEDs. The green LED "Power On" is illuminated when the power is switched on. The blue LED "Power OK" is lit when the battery voltage is greater than about 5.4 V. When the blue "Power OK" LED does not light up, the 9V battery should be replaced.

The unregulated 9 V then goes into the input of a 5 V low dropout (LDO) linear regulator. If the battery voltage is greater than 5.2 V, then the LDO will maintain a regulated 5 V for the comb generator circuit. This regulated "+5V" can be measured using test points on the board.

The circuit board current draw from the 9V battery can be measured by putting a voltmeter across R2, a 2 Ω resistor, located just below the power switch. All the circuit board current from the 9V battery flows through this resistor. Thus, if the board is pulling 10 mA, then the voltage across R2 would be 20 mV. If the current draw is greater than 70 mA, then there is a problem with the board.

Comb / Square Wave Generator Board:

The circuit consists of an adjustable precision oscillator. The oscillator frequency can be varied between 10 kHz and 30 MHz by rotating the coarse and fine frequency adjust potentiometers and setting the three-position slide switch to the appropriate position (÷1, ÷10, ÷100). Rotating the potentiometers clockwise increases the fundamental frequency.

The oscillator output goes into a 74LVC1G17 CMOS buffer with fast switching edges. This signal then goes to a pair of 74LVC1G08 "And gates". A two-position slide switch selects whether the comb generator or square wave generator is enabled.

Comb Generator:

With the slide switch set to the "Comb" position, the comb generator circuit is enabled. The very fast switching output of a 74LVC1G08 "And gate" is connected to one side of a 22 pF capacitor. The other side of this capacitor connects to a pair of anti-parallel ultrafast diodes (BAS316) and a 50 Ω resistor. There are two SMA connector outputs for the comb generator, one mounted horizontally at the edge of the circuit board, and the other mounted vertically. The vertical SMA connector is not populated.

Figure 2 shows the positive and negative edges of the comb generator signal. The positive impulse voltage magnitude is about 1.8 V, the negative impulse voltage is also about 1.8 V. Any small difference is due to the slight asymmetry in the CMOS inverter (74LVC1G04) rise/fall times and variation in its output impedance during rise/fall times.

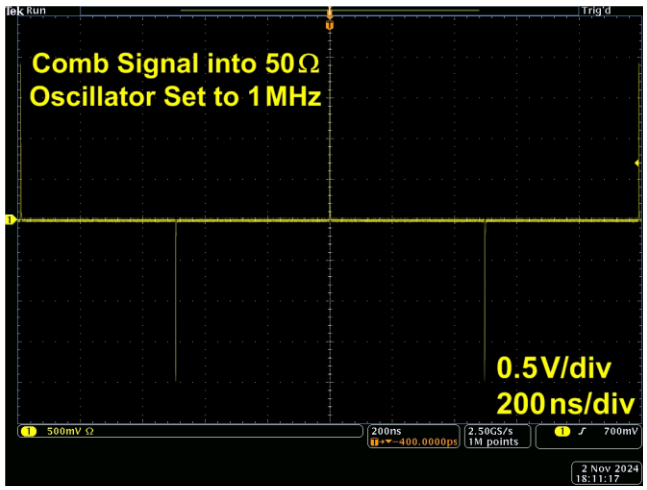

Figure 2: Comb Generator Oscillator Set to 1 MHz

Figure 3 displays that the “rise time” is about 500 ps. This edge is actually faster, but is limited by the bandwidth of the Tektronix MDO4104B oscilloscope. The falling edge for the pulse is about 900 ps. These fast transitions ensure that the comb generator has significant harmonics beyond 500 MHz.

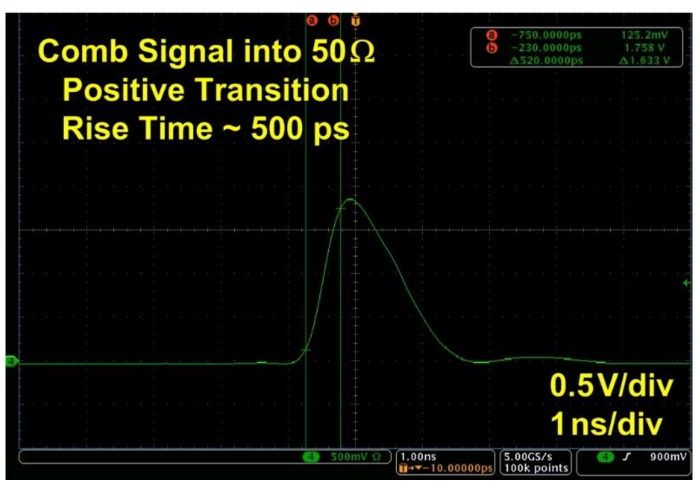

Figure 3: Comb Generator Edges

Figure 4 - Figure 8 show the harmonic content of the comb generator using a Signal Hound BB60C EMI receiver. The measurements are performed over a frequency range of 150 kHz to 500 MHz, they are performed with a 9 kHz resolution bandwidth (RBW) and use a peak detector. The LTC1799 oscillator is set at 100 kHz for Figure 4, 300 kHz for Figure 5, 1 MHz for Figure 6, 3 MHz for Figure 7, and 10MHz for Figure 8. The figures clearly show that the best performance is when the switch is in the "÷100" position, with a frequency range of 10 kHz to 300 kHz.

It is recommended to keep the comb generator operating in the "÷100" or "÷10" mode when possible, that is with the fundamental below 3 MHz. When the unit is operating in the "÷1" mode, then a frequency jitter starts to appear. The jitter in the "÷1" operating mode is not very significant below 10 MHz. Above 15 MHz the square wave generator IC has significant jitter, which degrades the performance of both the comb generator and the square wave generator.

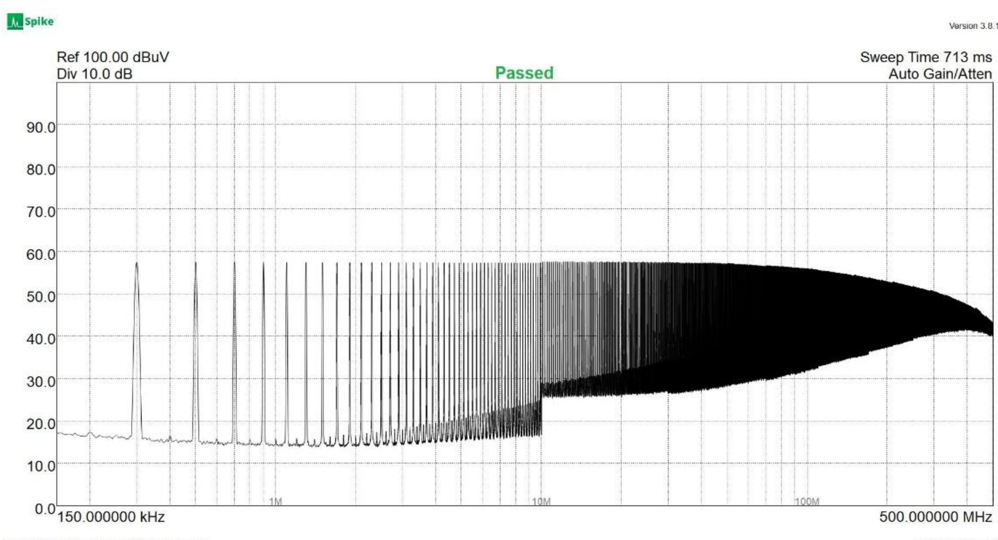

Figure 4: Oscillator Set to 100 kHz

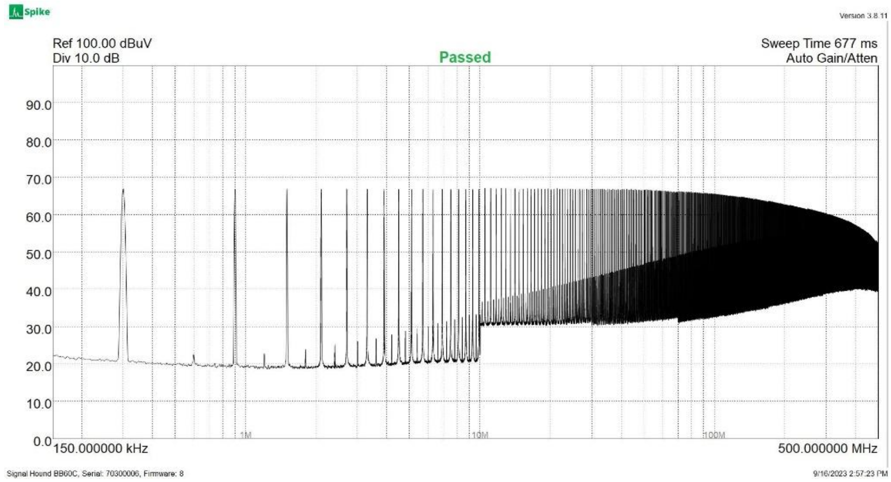

Figure 5: Oscillator Set to 300 kHz

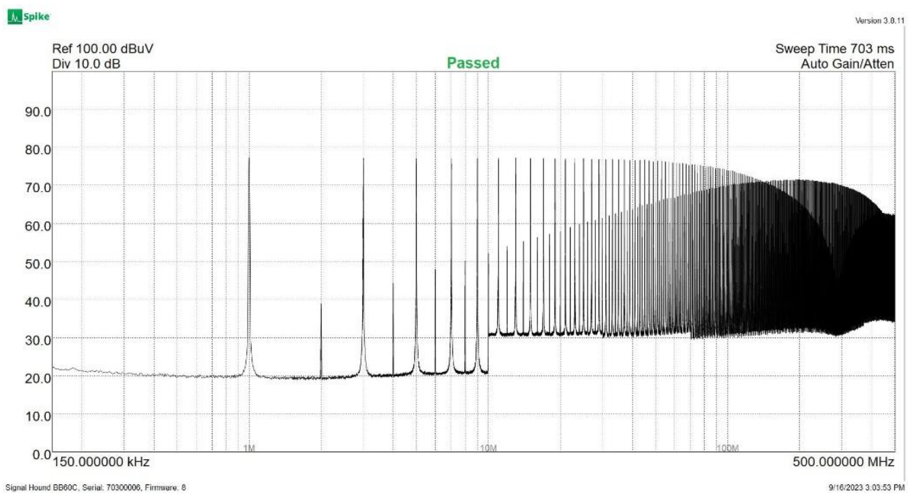

Figure 6: Oscillator Set to 1 MHz

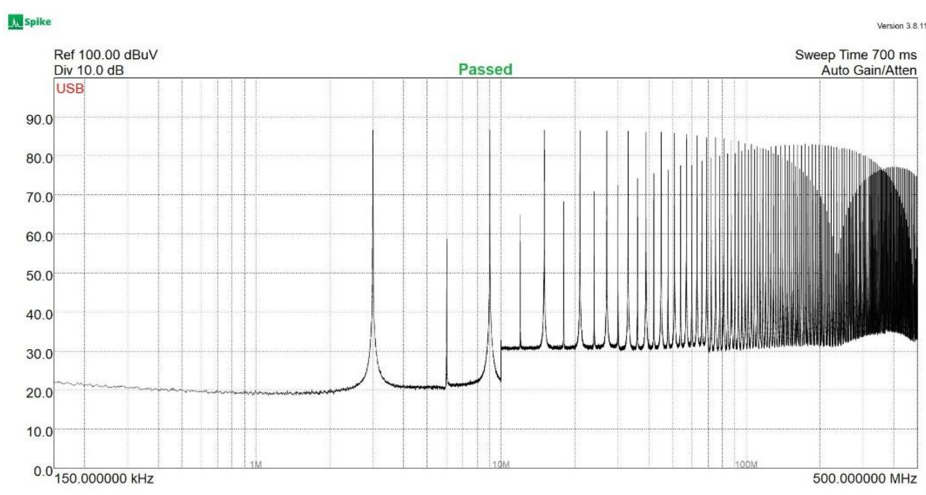

Figure 7: Oscillator Set to 3 MHz

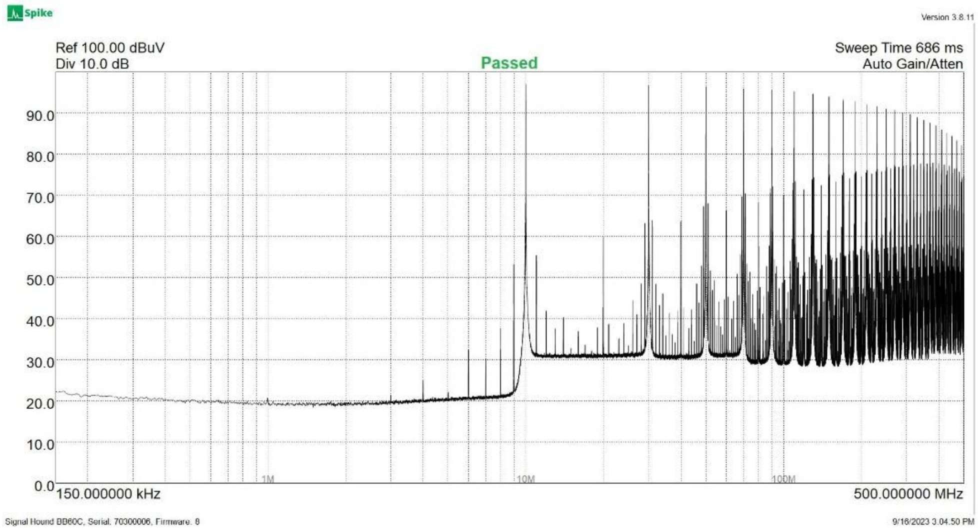

Figure 8: Oscillator Set to 10 MHz

Square Wave Generator:

With the slide switch set to the “Sq. Wave” position, the square wave generator circuit is enabled. The fast switching output of a 74LVC1G08 “And gate” is connected in series with a 170 Ω resistor (160 Ω resistor in series with 10 Ω output impedance of 74LVC1G08). The other side of the 160 Ω resistor is in series with a 70.6 Ω resistor (R11, R12) connected to ground. This node connects to an SMA connector, the SMA connector connects to a 50 Ω load.

The equivalent circuit of the circuit board is shown in Figure **9**. The 1 MHz time domain square wave signal is displayed in Figure 10, the peak amplitude is about 0.75V.

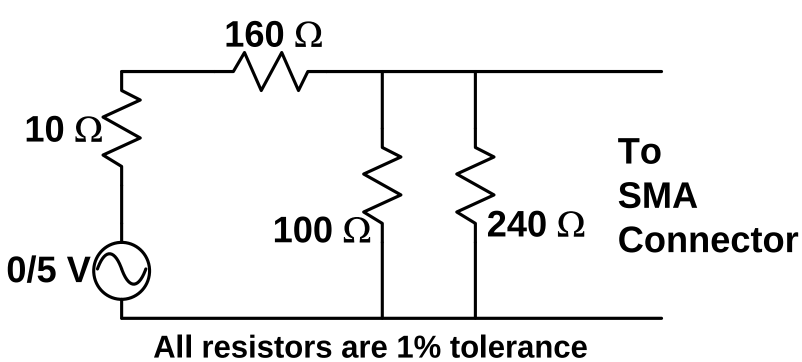

Figure 9: Square Wave Generator Circuit

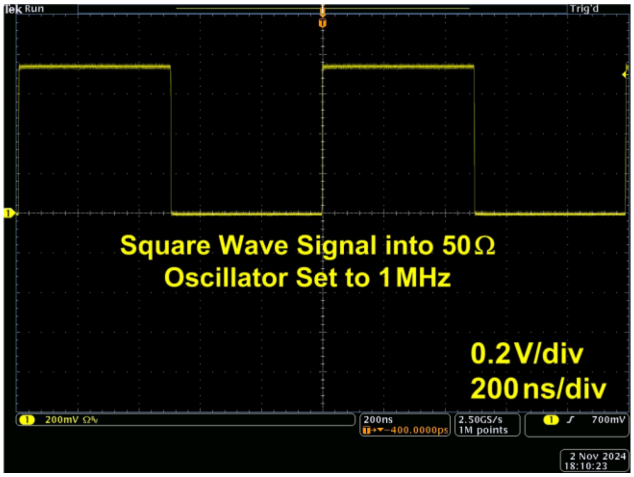

Figure 10: Square Wave Generator Output Signal

A custom circuit to calibrate a current transformer used the square wave generator connected to a measurement loop, and then it is in series with a 50 Ω resistor. The loop has a measured inductance of 81 nH.

A photo of the CT around the measurement loop, and the 50 Ω resistor is:

Figure 11: CT Around Measurement Loop (81 nH) and 50 Ω Resistor

The equivalent circuit of the square wave generator connected to the CT, loop, and 50 Ω resistor is:

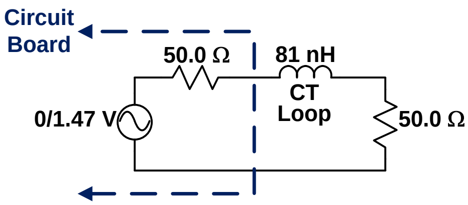

Figure 12: Equivalent Circuit with CT - Loop - 50 Ω

Figure 13 shows the complete setup for the CT calibration.

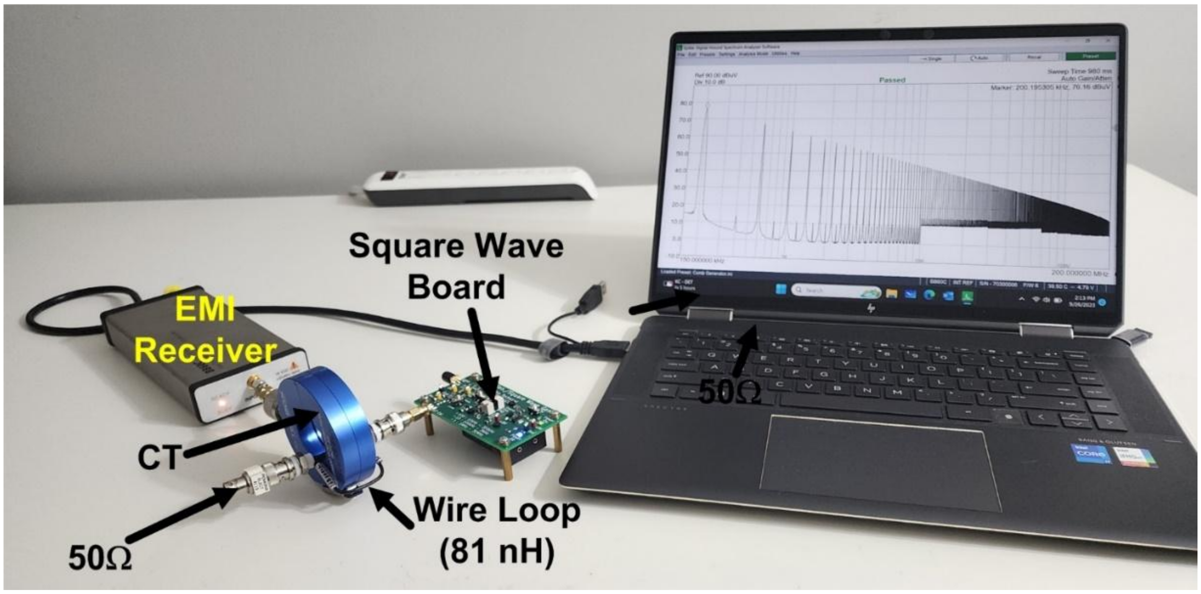

Figure 13: CT Calibration Setup

The 81 nH loop inductance degrades the high frequency performance of the test setup. Calculating when the inductance provides 1 dB (12.2%) error is a relatively easy calculation using a simple phasor diagram. The real axis of the phasor diagram is 100 Ω (50 Ω output impedance in series with 50 Ω termination resistor). The 1 dB error frequency occurs when the magnitude of the triangle hypotenuse is 112.2 Ω.

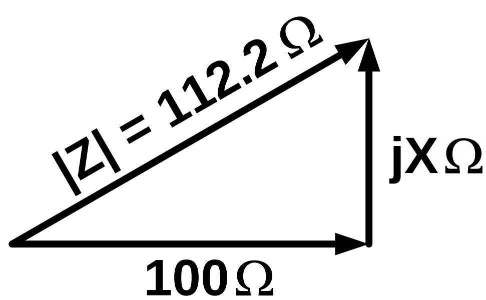

Figure 14: Impedance Diagram

Solving for the inductive component is:

$$X = \sqrt{112.2^2 - 100^2} = 50.9\ \Omega$$

This will happen when the 81 nH inductance has an impedance of j50.9 Ω, or:

$$j2\pi\mathrm{fL} = \mathrm{jX} \qquad \mathrm{f} = \frac{X}{2\pi L} \qquad f = \frac{50.9}{2\pi\ x\ 81\ x\ 10^{-9}} \approx 100\ MHz$$

Figure 15 to Figure 19 show the show the harmonic content of the square wave generator with the SMA output connector going to the Signal Hound BB60C EMI receiver, the receiver has a 50 Ω input impedance. The measurements are performed over a frequency range of 150 kHz to 500 MHz, they are performed with a 9 kHz resolution bandwidth (RBW) and use a peak detector. The LTC1799 oscillator is set at 200 kHz for Figure 15, 300 kHz for Figure 16, 1 MHz for Figure 17, 3 MHz for Figure 18, and 10MHz for Figure 19. The figures clearly show that the best performance is when the switch is in the ÷100, with a frequency range of 10 kHz to 300 kHz. The fundamental (first harmonic) amplitude is about 110.5 dBμV.

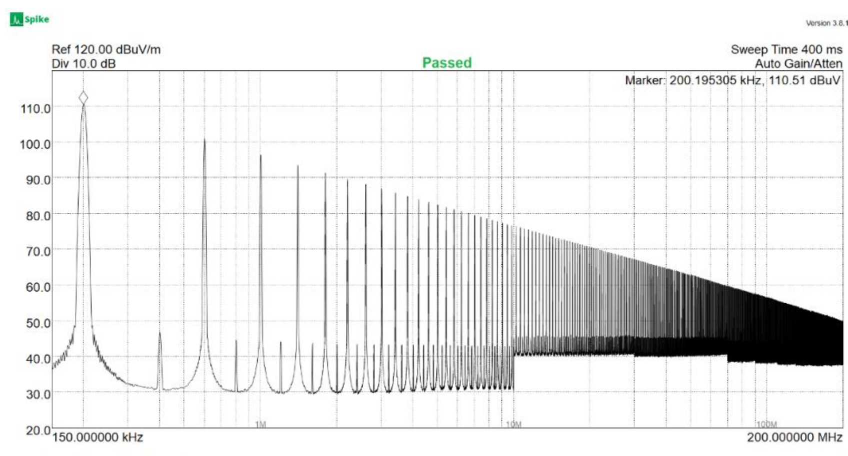

Figure 15: Square Wave Generator Spectrum at 200 kHz

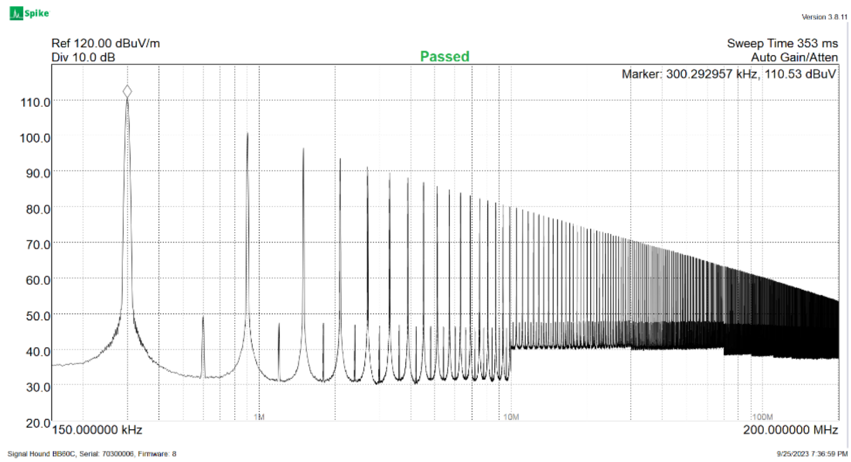

Figure 16: Square Wave Generator Spectrum at 300 kHz

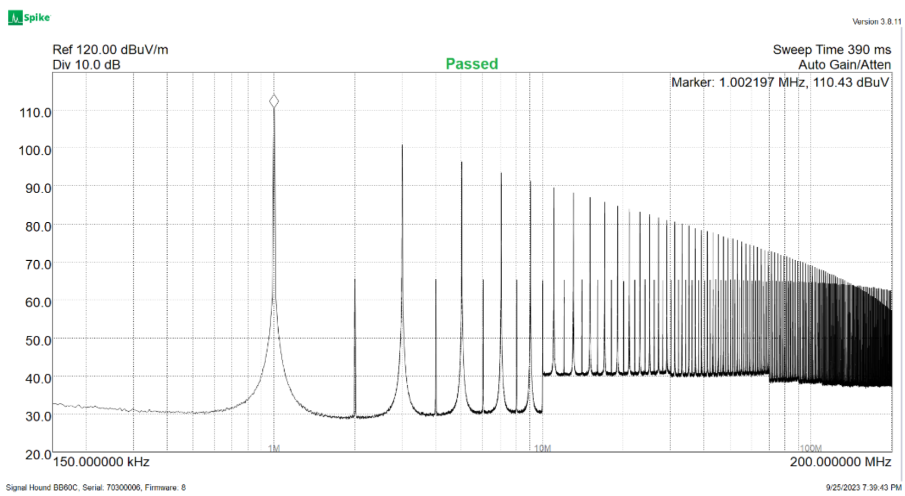

Figure 17: Square Wave Generator Spectrum at 1 MHz

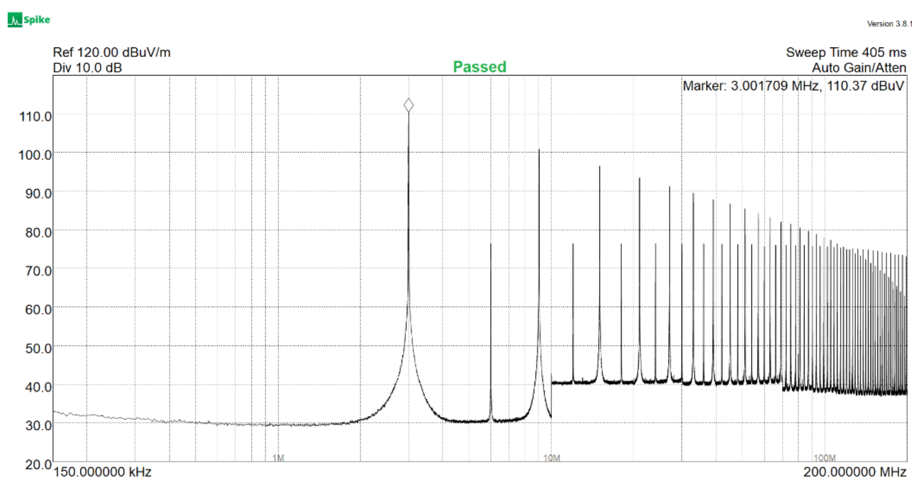

Figure 18: Square Wave Generator Spectrum at 3 MHz

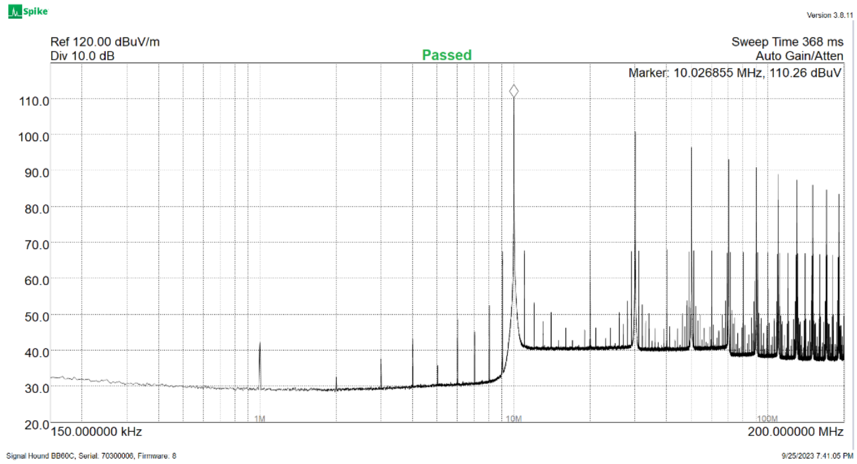

Figure 19: Square Wave Generator Spectrum at 10 MHz

Using the setup of Figure 13, measurements using the CT (Tekbox TBCP2_500) are shown in the figures below, the fundamental (first harmonic) amplitude is about 76.2 dBμV.

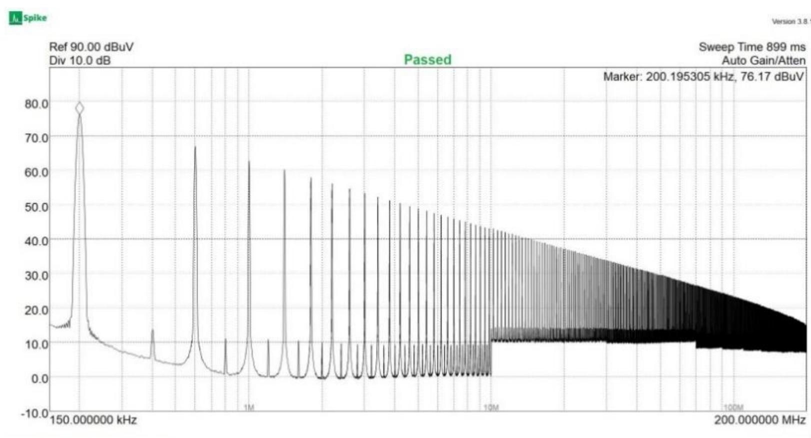

Figure 20: CT Measurement at 200 kHz

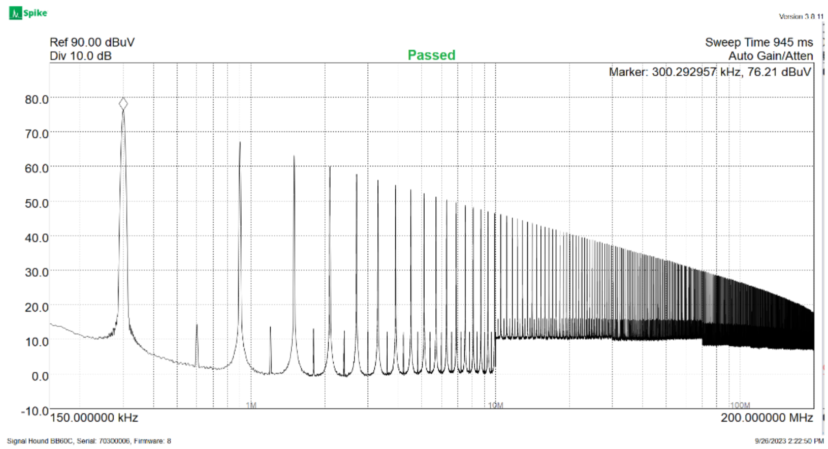

Figure 21: CT Measurement at 300 kHz

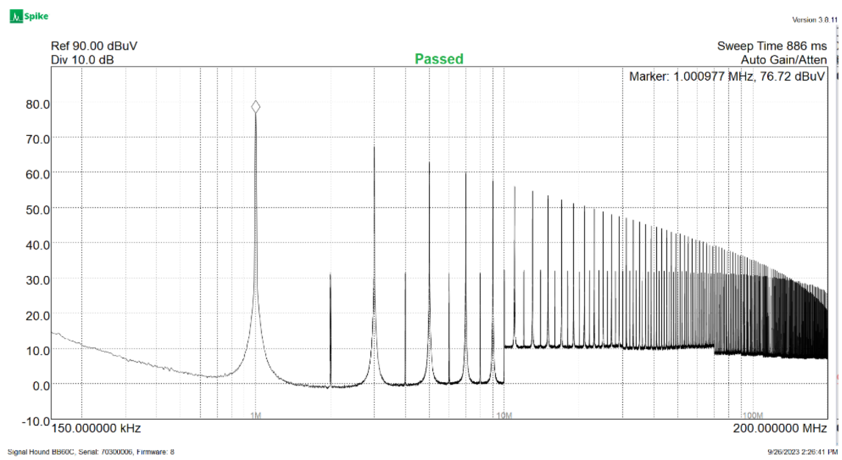

Figure 22: CT Measurement at 1 MHz

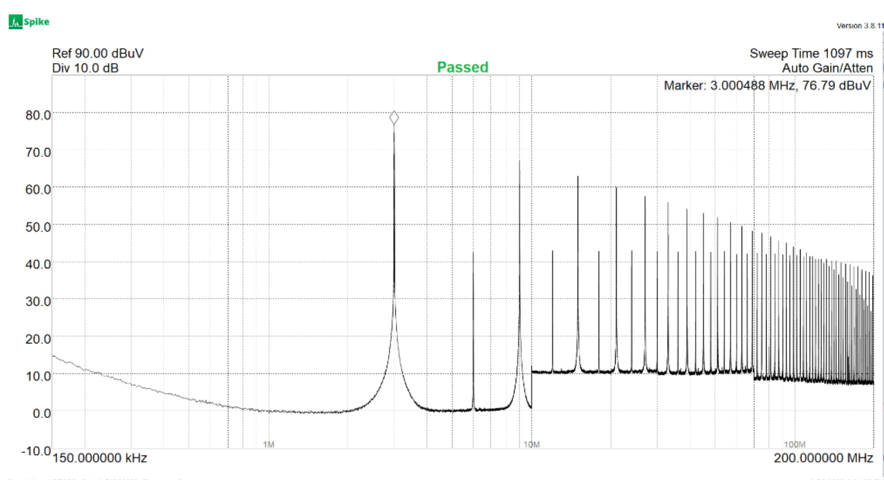

Figure 23: CT Measurement at 3 MHz

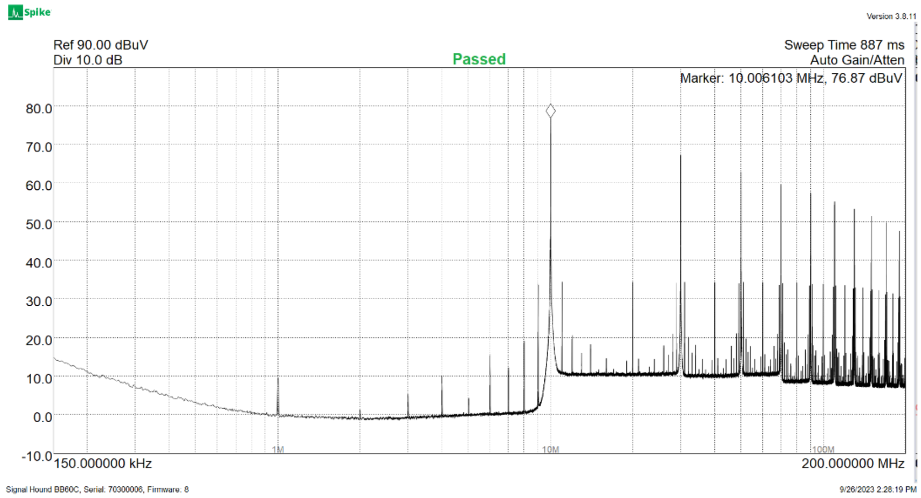

Figure 24: CT Measurement at 10 MHz

Radiation Measurements Using Comb Generator:

Radiation measurements using the comb generator are presented in this section. All radiation measurements were performed at 2 meter distance between the comb generator and the biconical antenna (Tekbox TBMA1). The biconical antenna uses the 3 m antenna factors for all the testing. The other setup parameters are:

Peak detector

9 kHz RBW

30-300 MHz measurement range

20 ms dwell time

Vertical antenna polarization

3 MHz Comb generator frequency

2 meter spacing between comb generator and antenna

The comb generator using an 18 inch antenna, and the board is mounted on the ground plane is shown in Figure 25. Figure 26 shows the biconical antenna (TBMA1).

Figure 25: Comb generator (3 MHz) with 18" antenna on ground plane

Figure 26: Biconical Antenna (TBMA1)

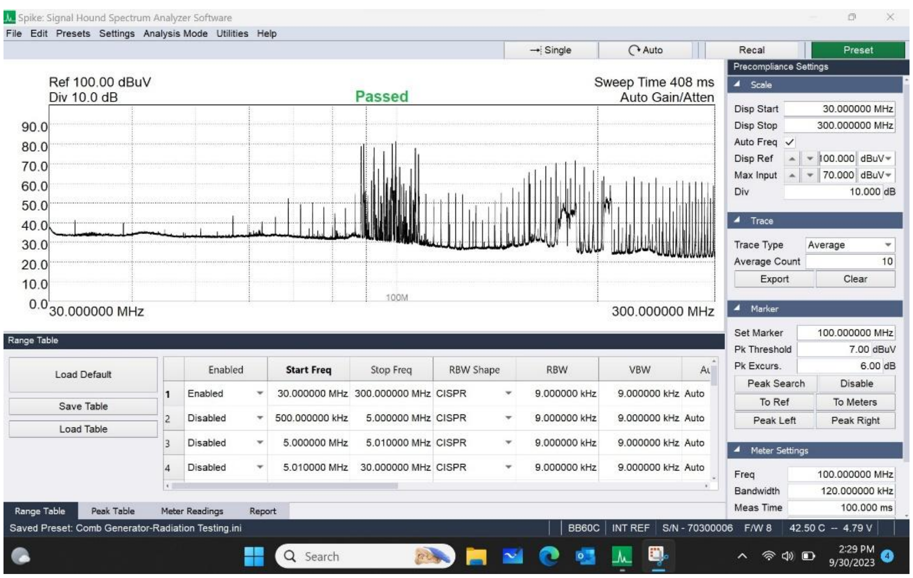

Figure 27: Signal Hound BB60C Setup Parameters

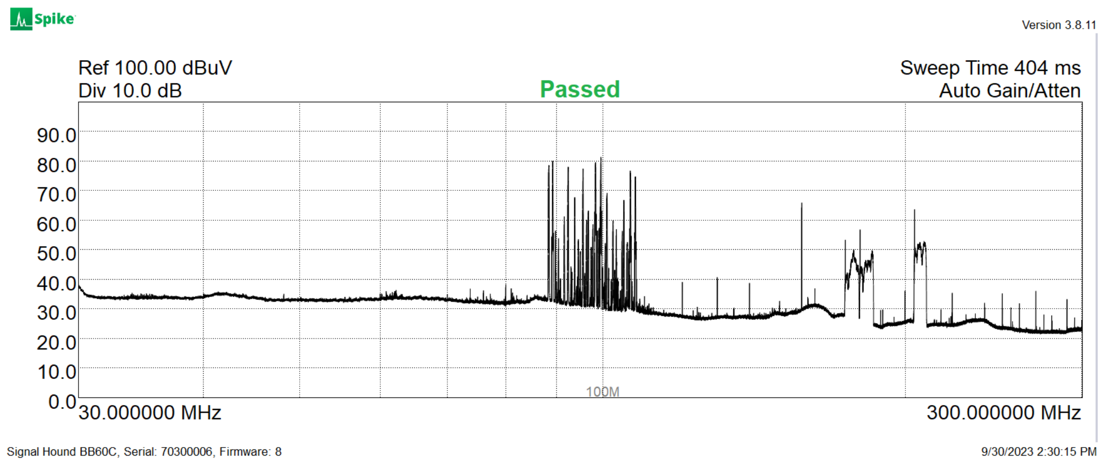

Figure 28: Ambient Measurement

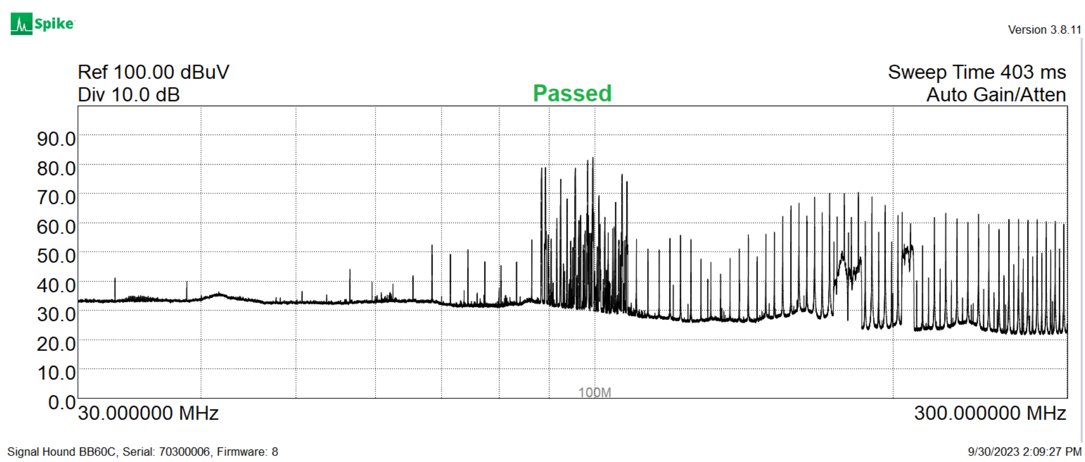

Figure 29: Board #1, 18" Antenna, Board Not On Ground Plane

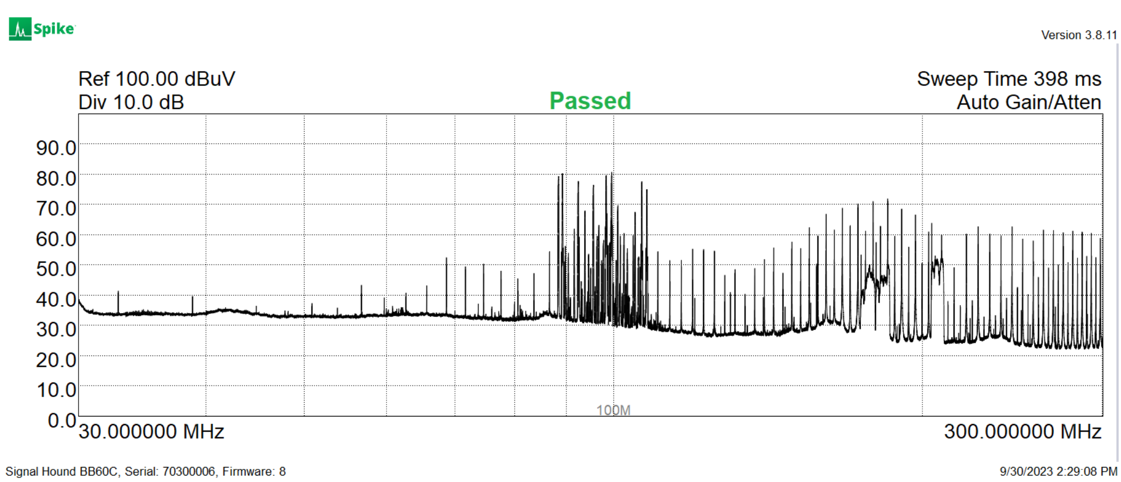

Figure 30: Board #2, 18" Antenna, Board Not On Ground Plane

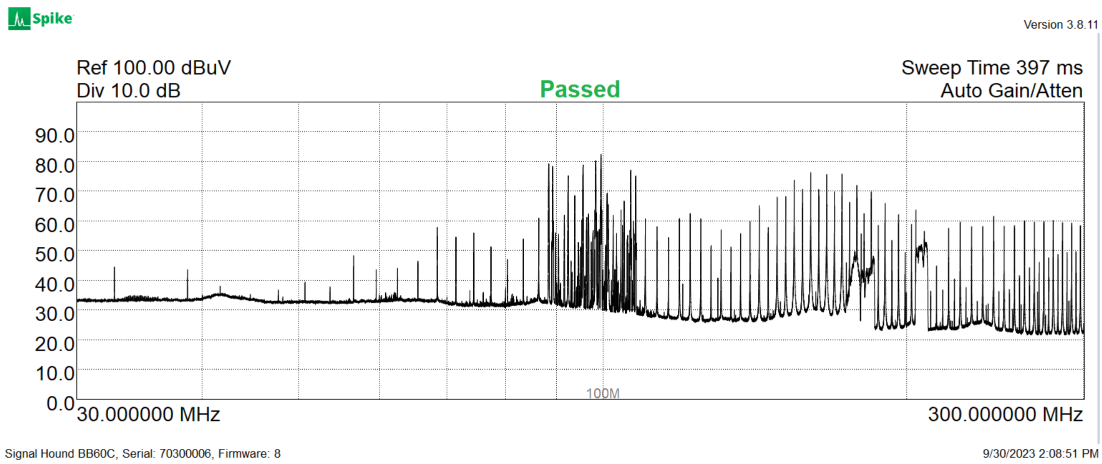

Figure 31: Board #1, 18" Antenna, Board On Ground Plane

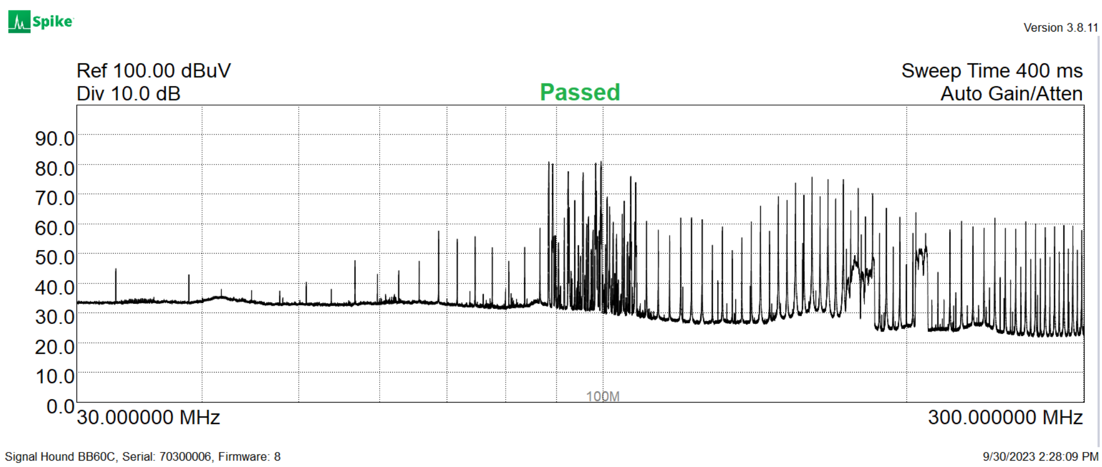

Figure 32: Board #2, 18" Antenna, Board On Ground Plane

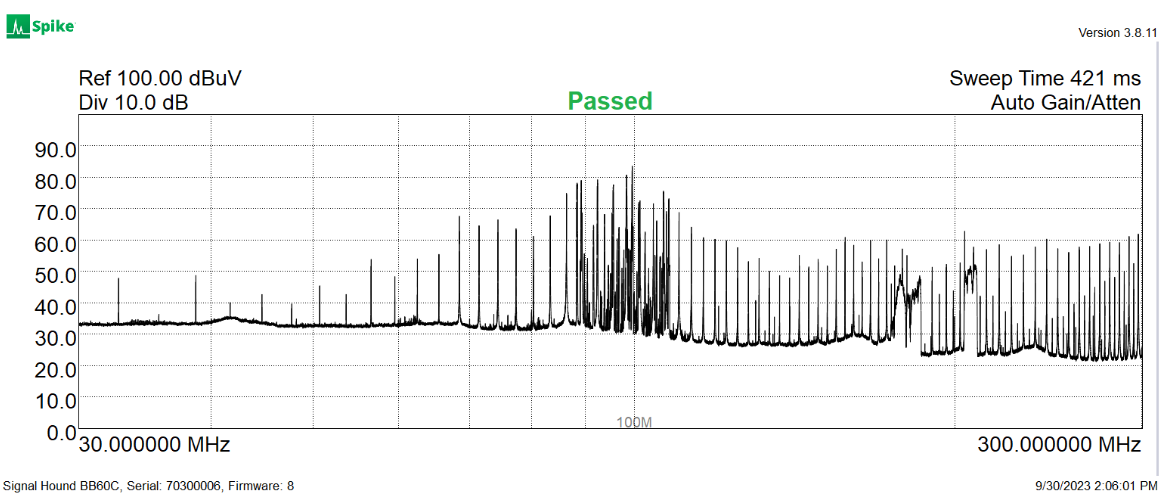

Figure 33: Board #1, 47" Antenna, Board Not On Ground Plane

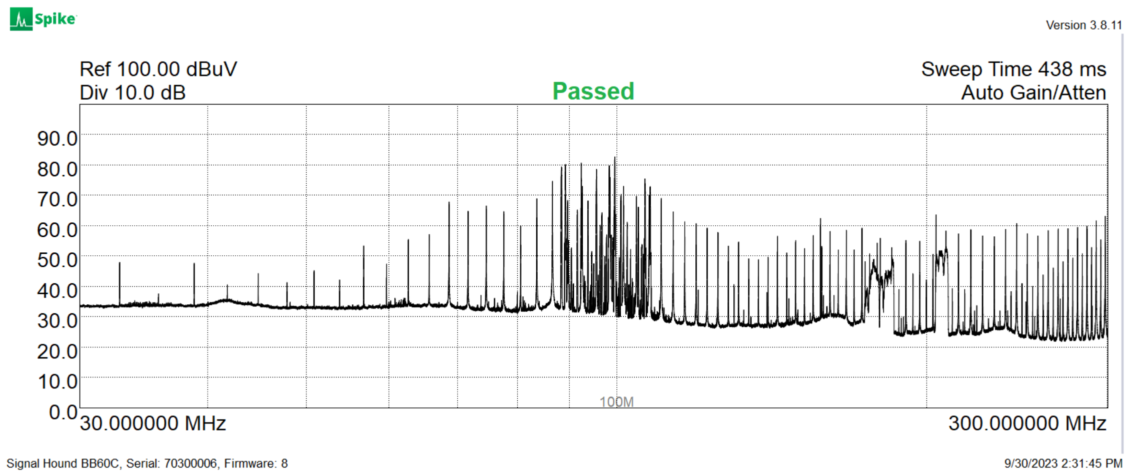

Figure 34: Board #2, 47” Antenna, Board Not On Ground Plane

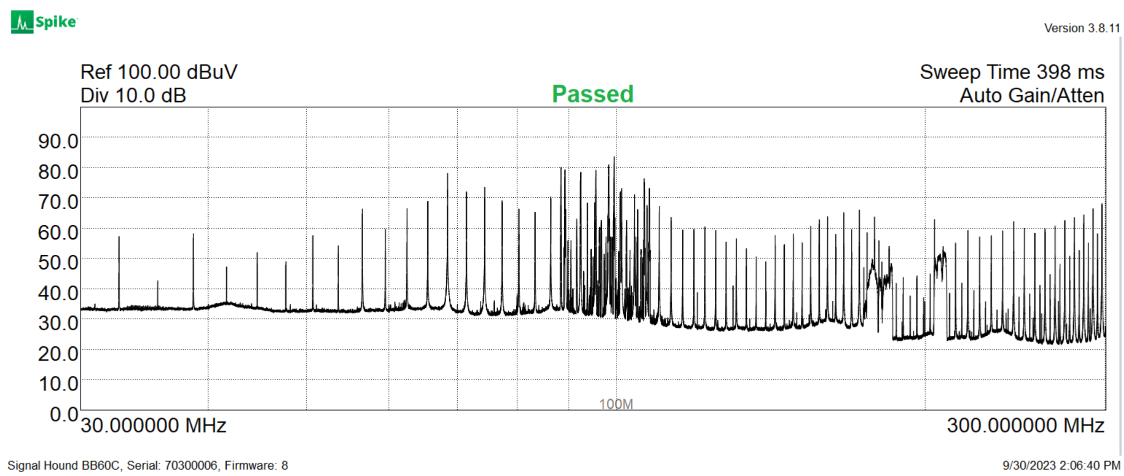

Figure 35: Board #1, 47” Antenna, Board On Ground Plane

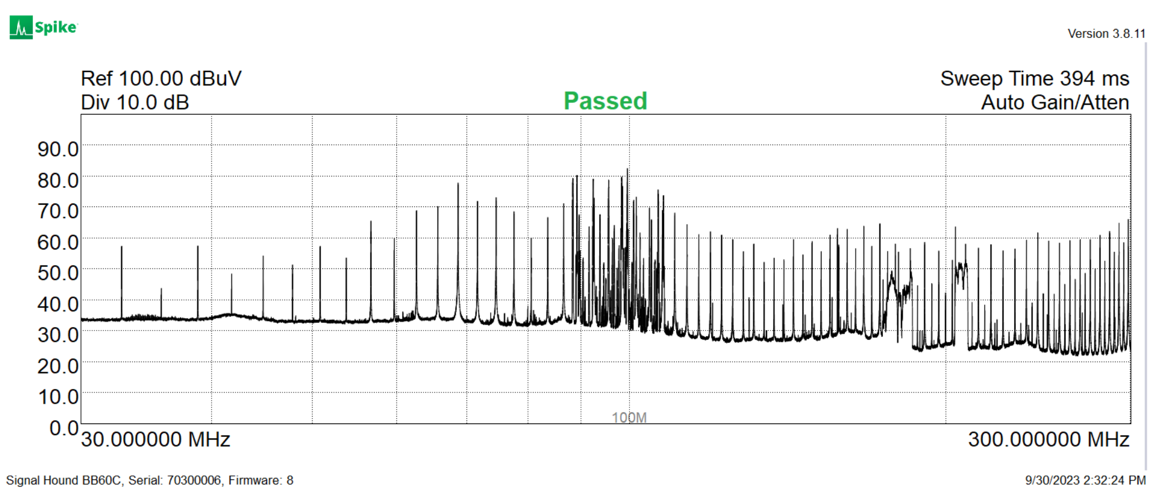

Figure 36: Board #2, 47” Antenna, Board On Ground Plane

Warning:

This comb generator is an intentional radiator, and covers a wide frequency operating range. It is designed for EMI/EMC testing. The radiated energy from the comb generator can interfere with radio signals and other electronic equipment. In the case of interference either turn off the power to the comb generator, or increase the distance to reduce interference.

Parts:

An equivalent for the 18 inch antenna used in this report is Amazon part #B0CLRS2Z6L.