Comparing EMI Performance of LPV802 with Other Devices in a Gas Sensor Application

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ABSTRACT

Passing the IEC61000-4-3 Radiated EMI test is a requirement for preparing a product for many industrial, medical and consumer markets. This application note presents the results of a simple comparison of the LPV802 nanopower operational amplifier and two other competing devices in a Carbon Monoxide gas sensor circuit while subjected to IEC61000-4-3 EMC test conditions.

Contents

List of Figures

List of Tables

1 Introduction

All monolithic operational amplifiers will react, to some degree, to the application of high intensity, high frequency radio energy, also known as Electromagnetic Interference (EMI). Operational amplifiers that have released in the last few years have EMI filtering added as part of the design to help minimize the effects of EMI.

LPV80x devices do not however include the full input EMI filter as seen on many recently released operational amplifiers. This was done intentionally as adding this EMI filter greatly increases the input capacitance, which can cause peaking in sub microampere circuitry with large feedback resistor values and source impedances. Instead, internal (proprietary) precautions were employed in the layout and internal design of the LPV8xx to make it as EMI hardened as possible.

To verify the effectiveness of this approach, the LPV802 was tested and compared against two popular and comparable competitor devices that do not have EMI protection. Under all the conditions, the circuit that used LPV802 demonstrated better EMI immunity than circuits that used competitive devices.

The most common standard EMI test is the IEC61000-4-3 EMC Radiated Test, which defines the test conditions and test setup.

The Equipment Under Test (EUT) is subjected to a calibrated RF field over a 80MHz to 6GHz frequency range as defined by IEC61000-4-3 EMC standard.

To compare the EMI tolerance of the three devices, all three devices were exposed at the same time in identical circuits with their output monitored for deviations.

Additionally, to test the effectiveness of a commonly used EMI filtering technique, two sets of boards were tested. One set of boards had added external input EMI capacitors added, and one set did not have the EMI capacitors present.

This application note describes the test conditions and compares the results of the three devices under test. It is not a full IEC61000-4-3 certification.

2 IEC61000-4-3 Test Conditions

The IEC61000-4-3 standard defines a "radiated" RF electromagnetic field test. In short, a directional broadband antenna is placed at a distance of 3 meters away and focused on the EUT. RF power is applied at the specified power and frequency levels.

The IEC test conditions describe the physical setup, conditions, calibration, frequency range and required power levels.

The next section briefly summarizes the IEC61000-4-3 standard conditions and required setup.

2.1 Physical Setup

The test is generally performed in a screened RF anechoic chamber to absorb reflections and prevent RF interference to the surrounding outside environment (applied powers can be up to 1 kW).

The EUT is placed on a non-conductive 0.8m high platform (table) within a 1.5m x 1.5m square uniform field area (UFA).

A wideband directional antenna (log-periodic or similar) is placed 3 meters from the platform and focused on the uniform field area.

The EUT is set-up to operate normally within the uniform field area while being monitored for failures. Any required external peripherals or accessories should also be included. If there are any peripheral, monitoring or power cables, 3 meters of the cable(s) must exposed to the field (1 meter minimum if the cables are <3m). The cables are usually passed through a RF filter before passing into the control point.

Field monitors are placed near the EUT to monitor the actual field levels.

2.2 Test Conditions

2.2.1 Frequency

The standard specifies a frequency sweep of 80MHz to 6GHz, with frequency steps no larger than 1% of the previous step. The range between 1.4 GHz and 6 GHz may be reduced to cover particular band segments where interference is expected (DCS, DECT, RFID, WiFi, etc).

Time between steps should be no less than 0.5 second, but not longer than the time to verify proper EUT operation.

2.2.2 Power Levels

The standard specifies four power levels, measured in Volts per Meter (V/m):

Table 1. Defined Power Levels

Power Level	Field Strength	Theoretical Transmit Power Required (0 dBi radiator at 3 meters)
1	1 V/m	300 mW
2	3 V/m	2.7 W
3	10 V/m	30 W
4	30 V/m	270 W
x	100 V/m *	3000 W

* 100V/m is not part of the IEC standard, but some safety critical designs may be tested at this level.

As a point of reference, assuming 3m distance and no transmitting antenna gain (0dBi) and no path or cable losses, Table 1 shows the theoretical transmitter power required. Of course, these are theoretical calculations and will vary depending on actual antenna forward gain, cable losses, path loss and reflections. Actual field values should be verified with a isotropic field monitor.

During the tests, a 1KHz, 80% sinusoidal AM modulation is applied to the transmitted signal. The IEC specification gives limits on amplifier distortion and harmonic content allowances.

2.2.3 Polarity

Tests must be done with both vertical and horizontal polarity (but not at the same time!). This means the antenna plane must be switched and the test sweep sequence repeated.

2.2.4 Position

Tests must be done on all four sides of the EUT. This requires the EUT to be physically turned 90° and the entire test sequence repeated again for all remaining sides.

2.2.5 Calibration

The setup must be calibrated at 16 points within the uniform field area with a CW signal at 1.8X the test power levels (to make up for the lack of AM modulation). A "calibration run" is usually done before the acceptance tests and the actual required amplifier power level recorded for each point and recalled to speed up the test measurement time.

2.2.6 Conditions Summary

As can be seen, with the numerous frequency points at four power levels, at two polarities and four sides, the length of the test can be substantial, lasting several hours to days.

3 Test Conditions Selected to Test EMI Performance of EUT

Because the intention was not trying to fully certify this design to IEC standards, but only to compare the behavior of unique devices on identical boards under the IEC conditions, it was decided to use a subset of frequencies using the IEC test setup conditions.

To reduce the large number of 1% frequency steps, 14 individual "spot" frequencies were chosen so that they were located in strategic parts of the RF spectrum (where troublesome interference would be expected).

Table 2. Selected "Spot" Frequencies

Step	Frequency	Services Affected
1	80 MHz	FM Radio, Mobile Radio, TV
2	100 MHz	FM Radio, Aeronautical
3	140 MHz	Mobile Radio
4	200 MHz	Mobile Radio, TV, DAB
5	300 MHz	TV, Aeronautical
6	450 MHz	Mobile Radio, TV, GSM
7	600 MHz	TV
8	700 MHz	TV, Mobile Radio, GSM, 4G
9	750 MHz	4G, Mobile Radio
10	800 MHz	Mobile Radio, GSM
11	850 MHz	1G/2G/3G GSM, Mobile Radio
12	900 MHz	Mobile Radio, ISM, GSM
13	950 MHz	GSM, Mobile Radio, Radar
14	1 GHz	GSM, Radar

The EMI hardening of the LPV8xx is designed to be effective at frequencies above 300MHz. This makes all the devices susceptible to frequencies below 300MHz and rely on external filtering for this range. For this reason, frequencies below 300MHz tend to be the most influenced by external layout and are of the main interest of this investigation. Frequencies above 1GHz were not measured as the responses are characterized in the EMIRR performance tests and preliminary tests showed little influence (and also required a second expensive test setup).

Since this is a small board, and are comparing like devices, TI chose to test only one side and one polarity (horizontal).

4 Test Setup

4.1 Test Circuit

The test circuit is a conventional transimpedance amplifier with reference voltage buffer, commonly used with gas sensors. The buffer is required to supply the varying currents required by the sensor that would otherwise load down a simple resistor divider network and cause errors.

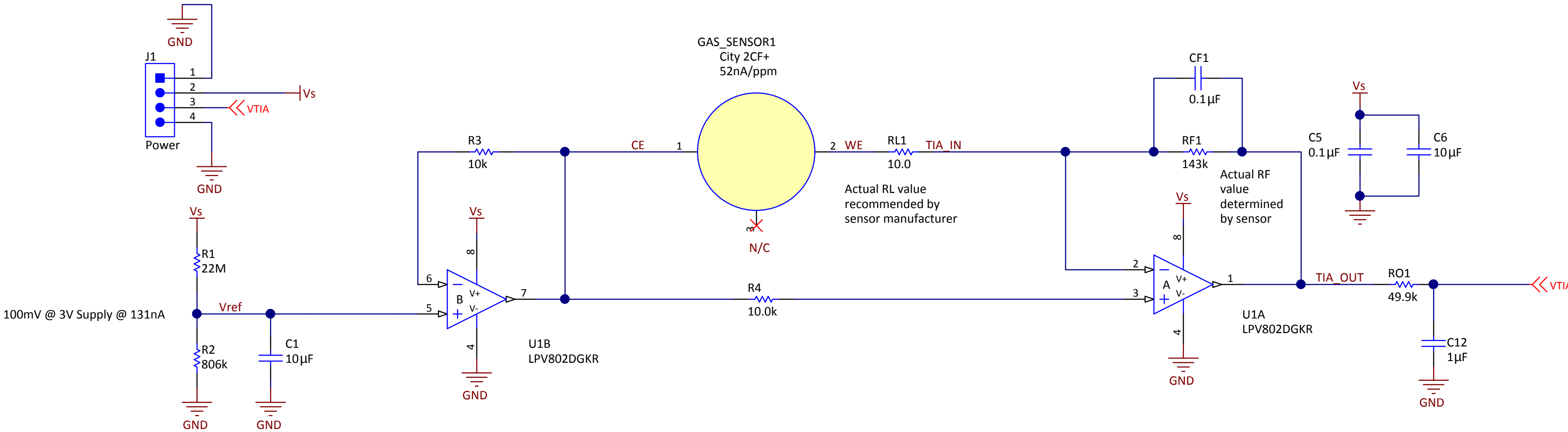

Figure 1. Basic Schematic

The circuit was built on a standard 62mil, 2-layer FR4 board with ground planes on both sides. A 4-pin connector was used to allow quick board changes. The sensor pins are socketed to allow easy removal of the sensor (and soldering of the sensor pins is not recommended by the manufacturer).

Figure 2. Test Board with Sensor

The sensor used is a City Technology ECO-Sure 4 Series two terminal Carbon Monoxide Sensor (City PN# 2112B3000A).

The zero current reference level was approximately 120mV while running off two AA batteries. This allows the measurement of bipolar (±) currents from the sensor and allows observation of sensor health which may not be possible with a ground referenced design. The feedback time constant was kept small to allow observation of small transients and fast settling time to minimize time between measurement steps.

The board layout was purposely not "optimized' for RF rejection (traces have long surface traces and no ferrite beads), to allow some introduction of RF signals to ensure some interaction.

4.2 EMI Filter Capacitors

A common EMI-hardening technique is to add small (15pf to 33pF) capacitors across the inputs in a "delta" formation (from each input to RF GND, and one between the inputs). Provisions were made for these capacitors to test the effectiveness of this technique. Figure 3 shows these 15pF capacitors added to the schematic as C2-C4, C9-C11, C7, C8 and C13.

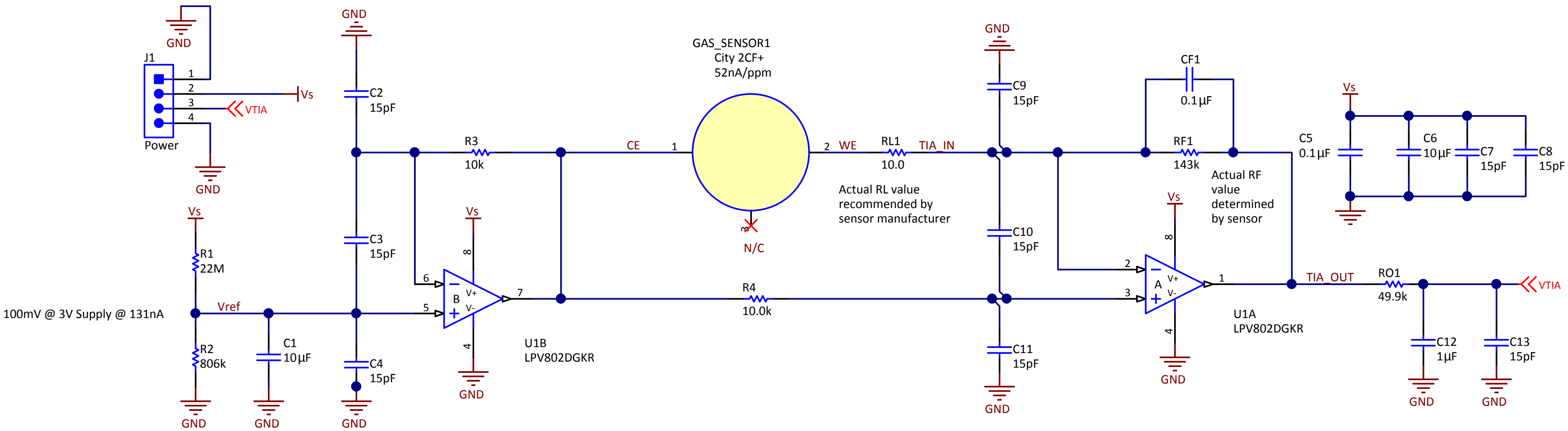

Figure 3. Schematic with EMI Capacitors Added

Eight boards were produced to make two sets of four boards. Four boards would be tested at the same time. One entire board was a "spare" LPV802 in a grounded reference configuration and is not used in this report.

One set of boards (#1 to #4) contained the external 15pF EMI capacitors, and one set (#5 to #8) did not have the EMI capacitors populated.

The same sensors were used for each set of boards and were swapped-out between runs.

4.3 Chamber Setup

The boards were distributed evenly within the calibrated test area, as shown in Figure 4.

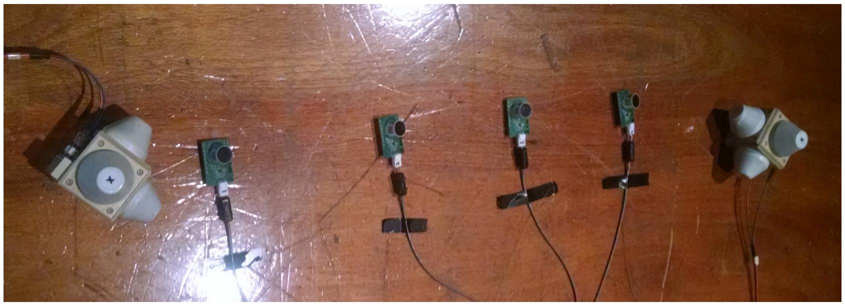

Figure 4. Test Setup In Chamber

Each of the boards was connected to a central battery box (2 x AA cells) through one meter of four conductor shielded cable with EMI chokes on both ends. The battery box was connected to the control room via 15 meters of UTP CAT-5 cable, with appropriate EMI chokes, to deliver the output voltages to the logging system.

The two white boxes with the cones are the field sensors for monitoring the field during the test.

4.4 Test Sequence

The tests performed in the following sequence:

1. Boards 1-4 with sensors installed
2. Boards 1-4 with sensors removed
3. Boards 5-8 with sensors installed
4. Boards 5-8, with sensors removed

The sensors and/or the capacitors were removed to provide a data point on how much the they contributed to the overall performance.

5 Test Results

The following section show the results of the tests that were conducted.

It should be noted that the noise of the sensor causes the output voltage to change randomly up to ±10mV. So some random noise in the traces is expected from the sensor.

5.1 Test Results With EMI Capacitors and Sensor Mounted

The following tests are with the 15pF EMI capacitors fitted and gas sensor installed. This represents what is considered good engineering practice.

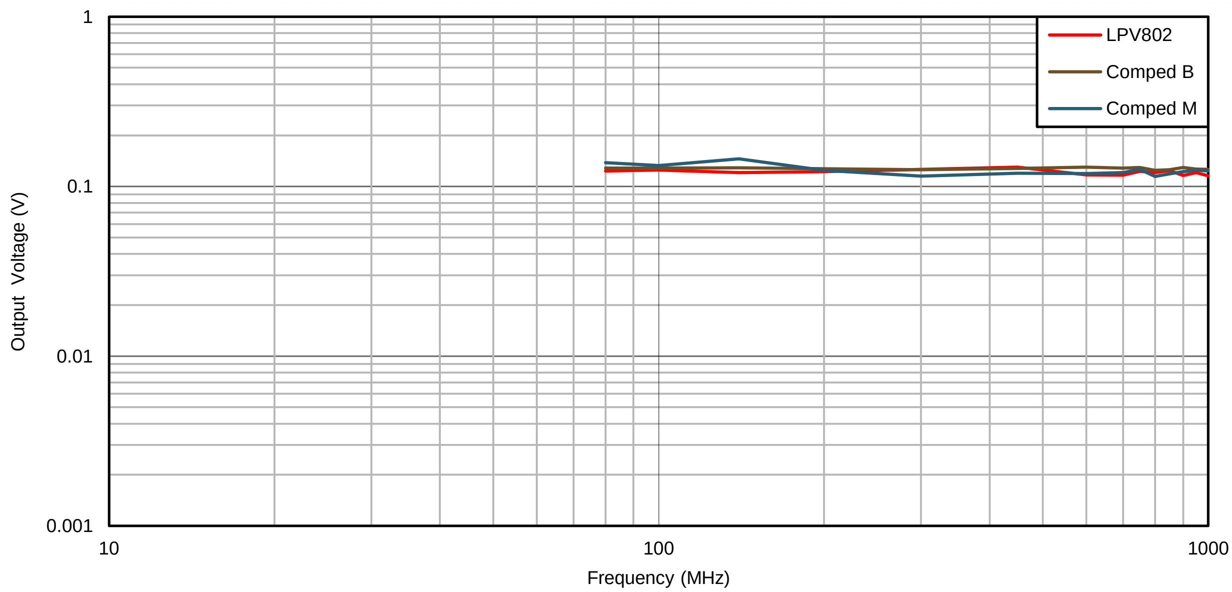

Figure 5. Test Results of 1 V/m With EMI Capacitors and Sensor Mounted

Figure 5 shows very little disturbance across the field. All devices are undisturbed.

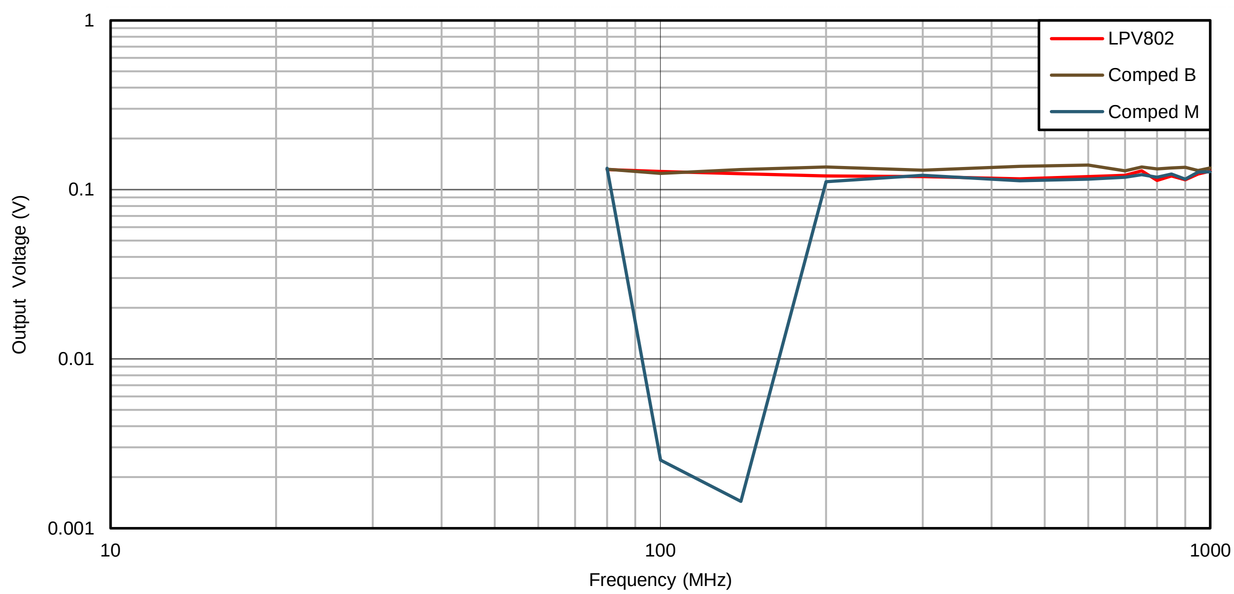

Figure 6. Test Results of 3 V/m With EMI Capacitors and Sensor Mounted

[Figure 6](#) starts to show some variations, with competitor "M" starting out properly at 80MHz, but failing at 100-200MHz. Competitor "B" and the LPV802 are fairly undisturbed.

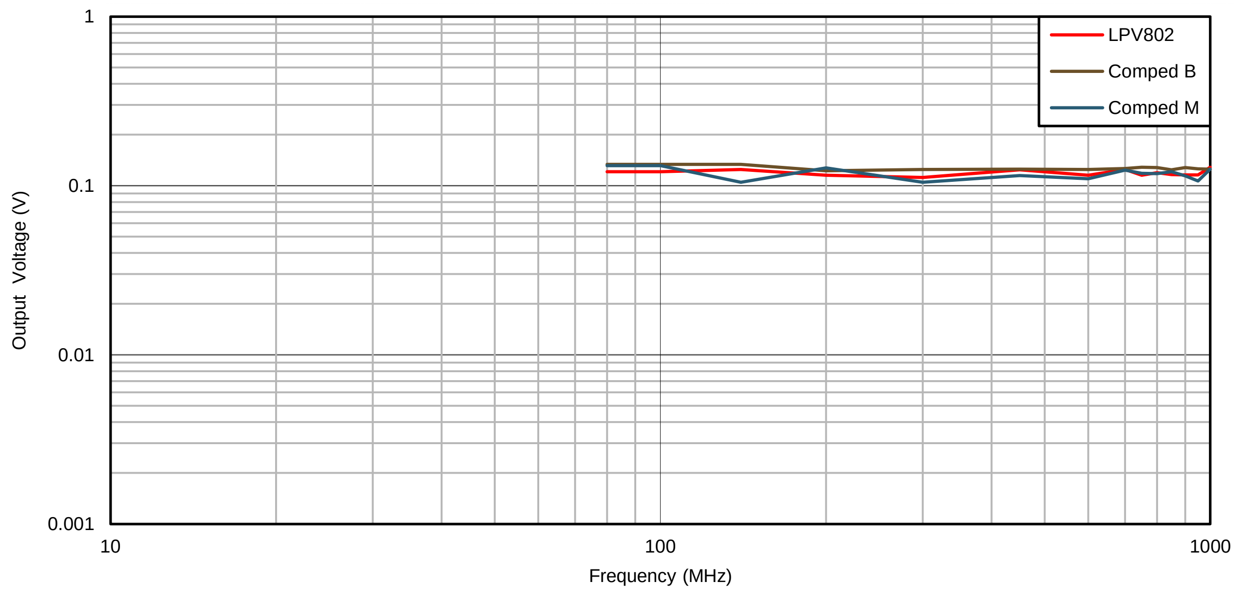

Figure 7. Test Results of 10 V/m With EMI Capacitors and Sensor Mounted

Figure 7 shows very little disturbance across the field. All devices are undisturbed. It is unknown why Competitor "M" failed the 3V/m but passed the 10V/m run.

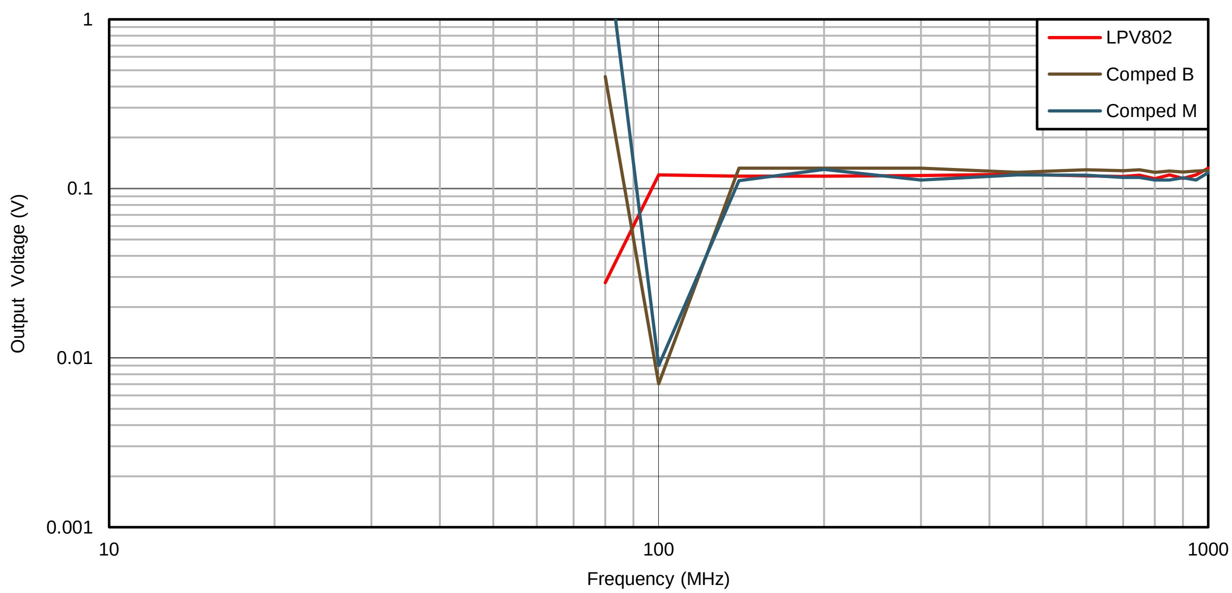

Figure 8. Test Results of 30 V/m With EMI Capacitors and Sensor Mounted

Now some major changes can be observed. Figure 8 shows both competitors started to fail at 140MHz, while the LPV802 held-on down to 100MHz. Remember that the lower frequencies are more troublesome.

5.2 Test Results With EMI Capacitors and No Sensor Mounted

The following tests have the EMI capacitors installed, but the sensor was removed. This test is to show how much the sensor contributes to the overall performance - either as an "antenna", or the sensor itself being affected. It also shows the low "noise floor" of the test circuit.

1 V/m test was skipped since it was known the effects would be minimal.

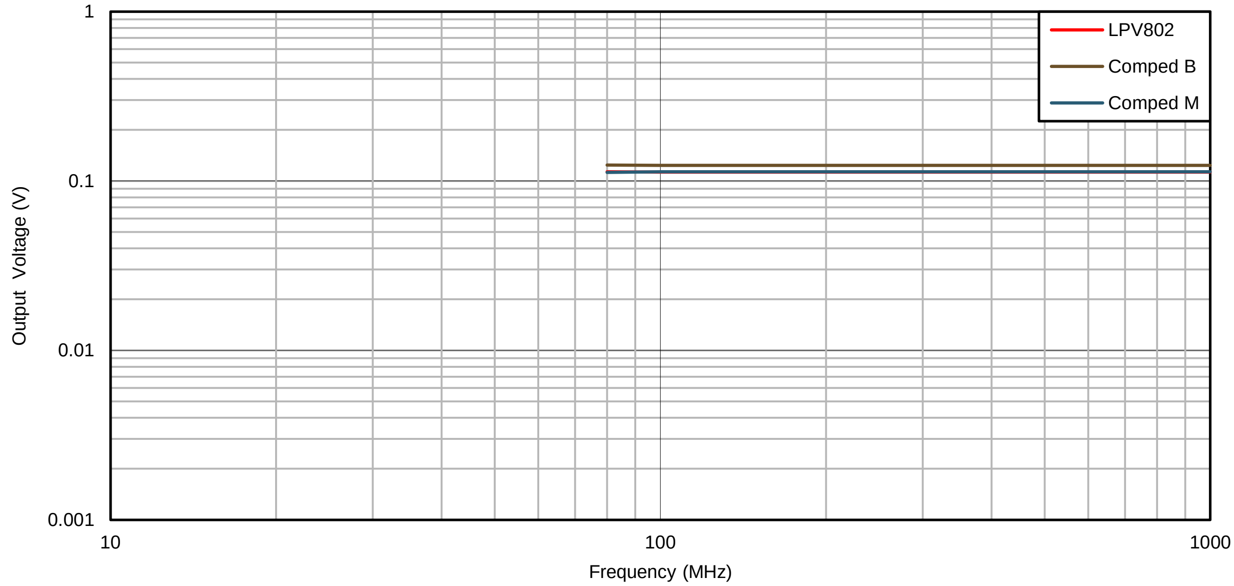

Figure 9. Test Results of 3 V/m With EMI Capacitors and No Sensor Mounted

As was expected, no change detected. Note how "flat' the traces are, this shows how much of the random variation is due to the sensor noise.

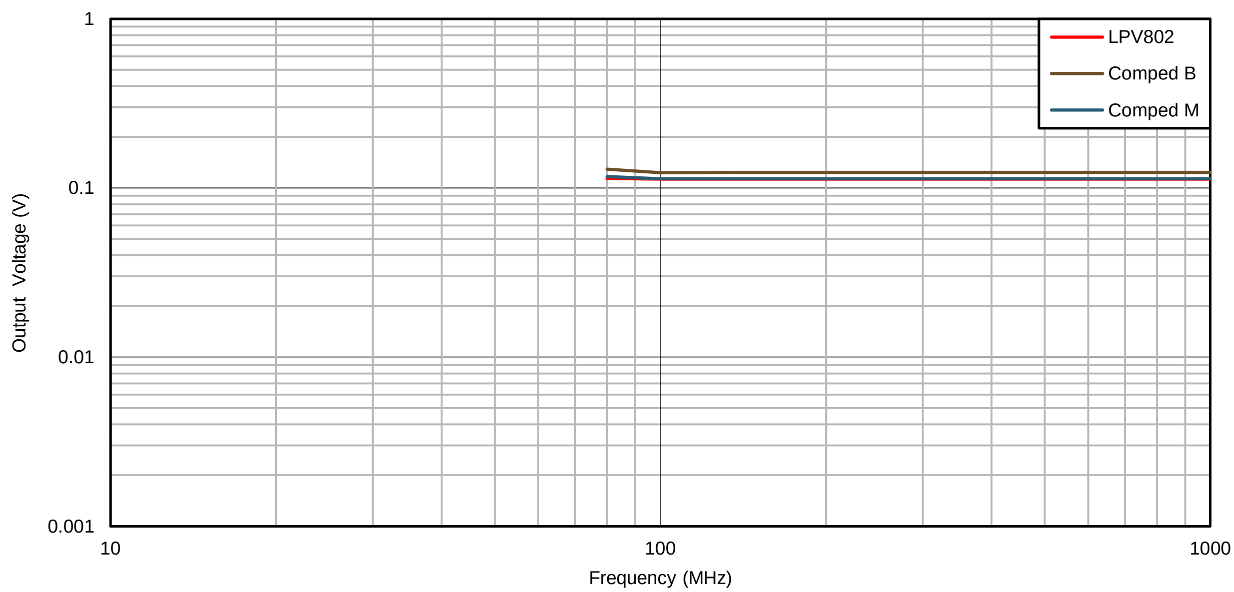

Figure 10. Test Results of 10 V/m With EMI Capacitors and No Sensor Mounted

All the competitive devices showed very slight variation at 80MHz at 10V/m, as shown in Figure 10. The LPV802 was undisturbed.

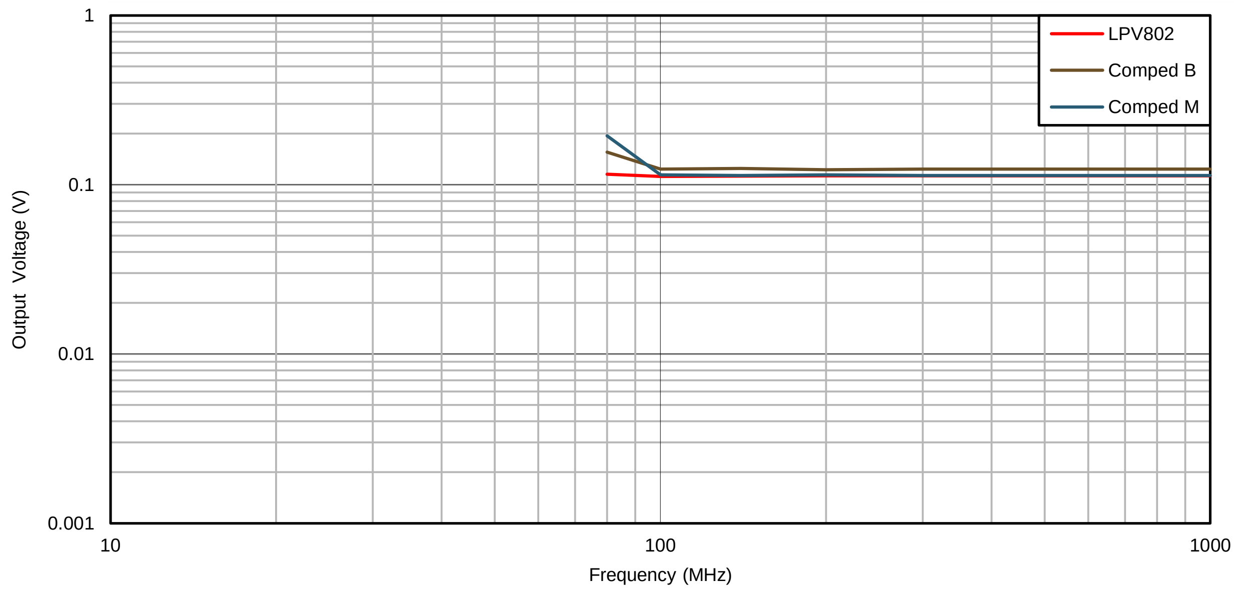

Figure 11. Test Results of 30 V/m With EMI Capacitors and No Sensor Mounted

Figure 11 shows the competitor devices with variation at 80MHz at 30V/m, while the LPV802 still remained undisturbed.

5.3 Test Results With No EMI Capacitors and Sensor Mounted

The following test have the 15pF EMI capacitors removed and sensor installed. This test represents a design where EMI has not been taken into consideration, and shows the effectiveness of the EMI capacitors.

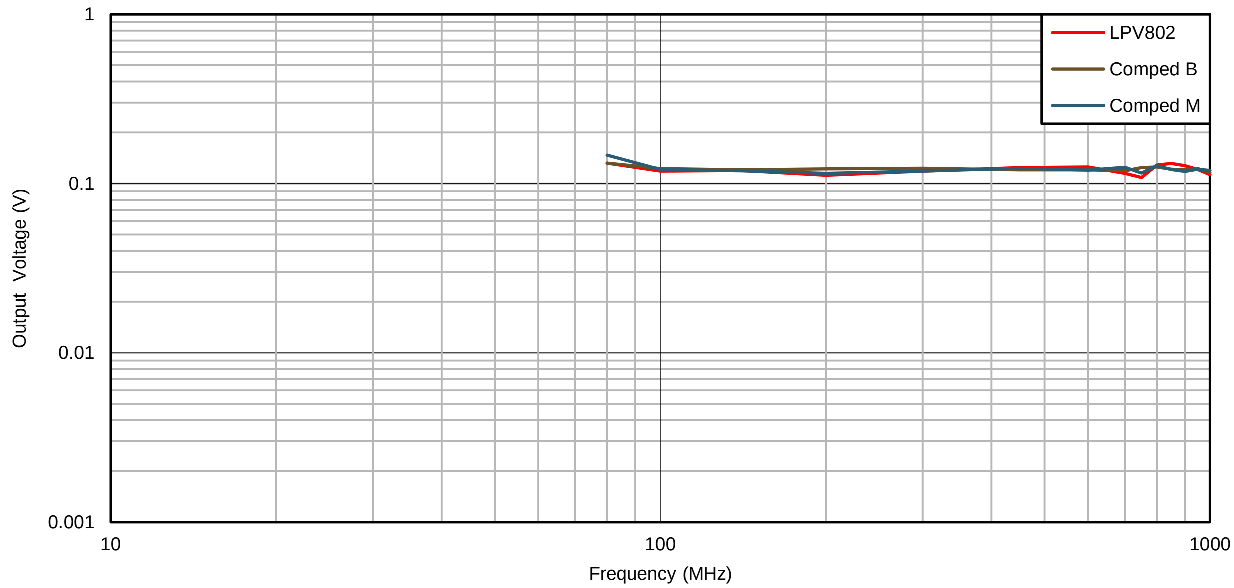

Figure 12. Test Results of 1 V/m With No EMI Capacitors and Sensor Mounted

Some variation is seen at 80MHz for all devices.

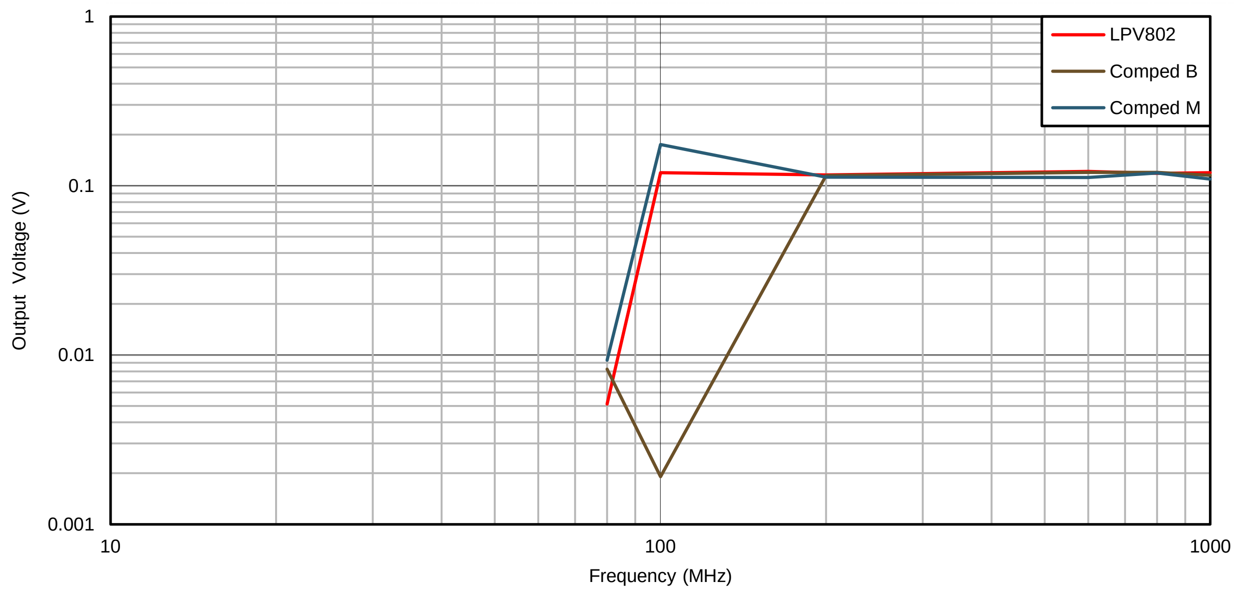

Figure 13. Test Results of 3 V/m With No EMI Capacitors and Sensor Mounted

All devices failed at 80MHz, though the LPV802 recovers at 100MHz. All have recovered by 200MHz.

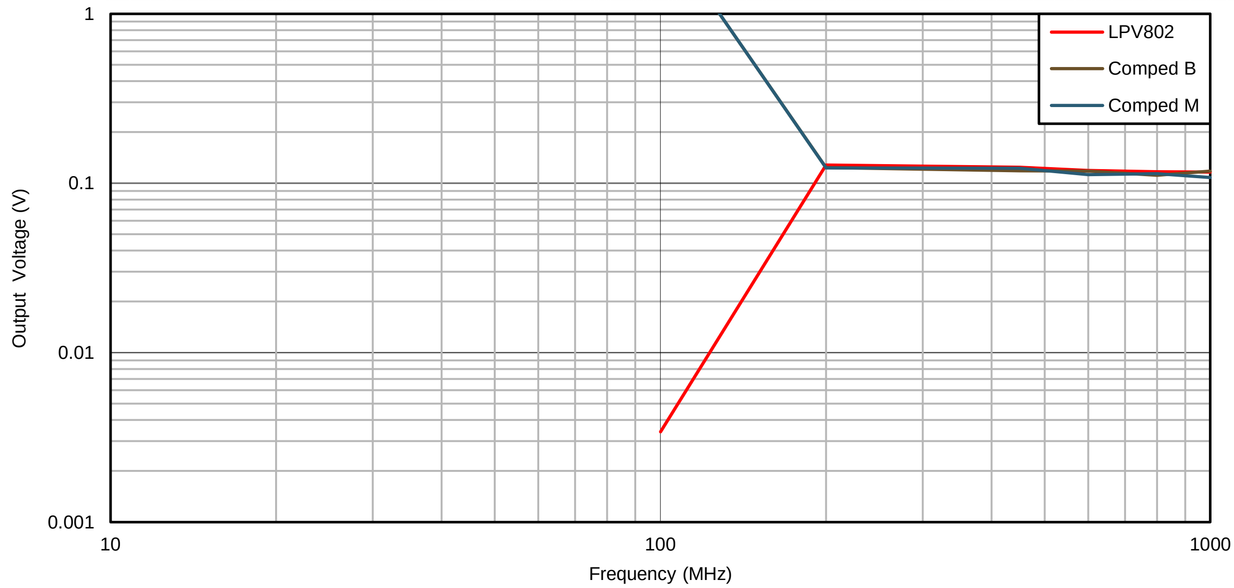

Figure 14. Test Results of 10 V/m With No EMI Capacitors and Sensor Mounted

All devices failed at 80MHz and 100MHz. All devices also show a error that decreases as the frequency increases up to 700MHz.

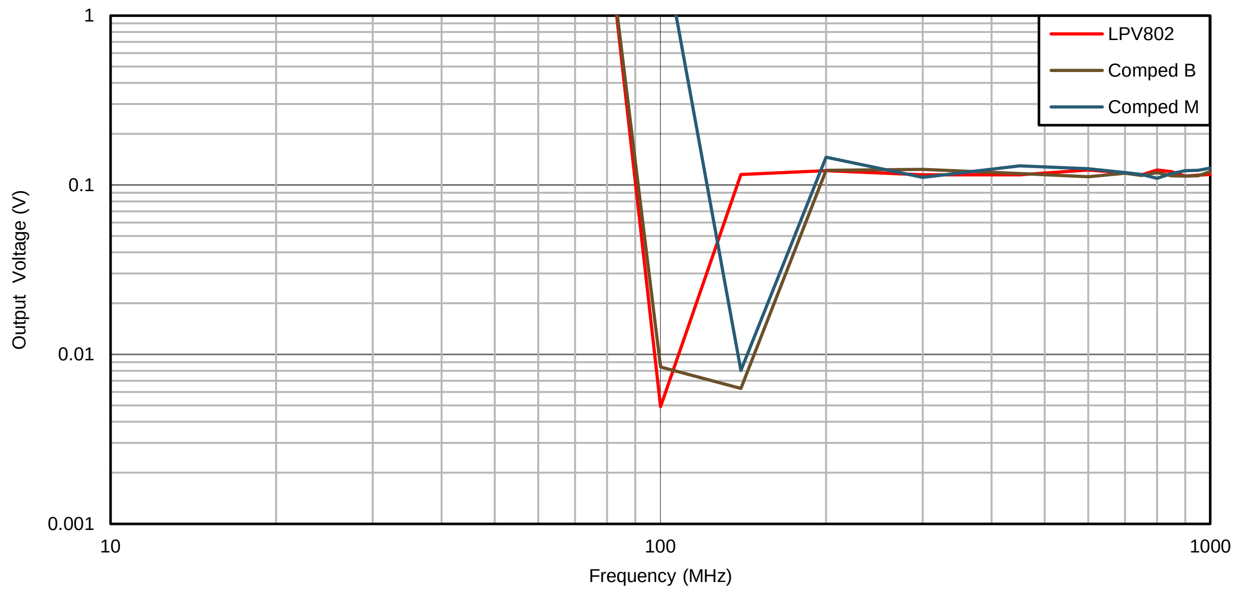

Figure 15. Test Results of 30 V/m With No EMI Capacitors and Sensor Mounted

All the devices fail at 80-100MHz. The LPV802 recovers at 140MHz and remains fairly flat to 1GHz. Competitor devices recover by 200MHz.

5.4 Test Results With No EMI Capacitors and No Sensor Mounted

This test is without the EMI capacitors and without the sensor. This test is meant to show the susceptibility of the amplifier and the board itself (minus the antenna effect of the sensor).

Only the 10V/m and 30V/m tests were run to save time.

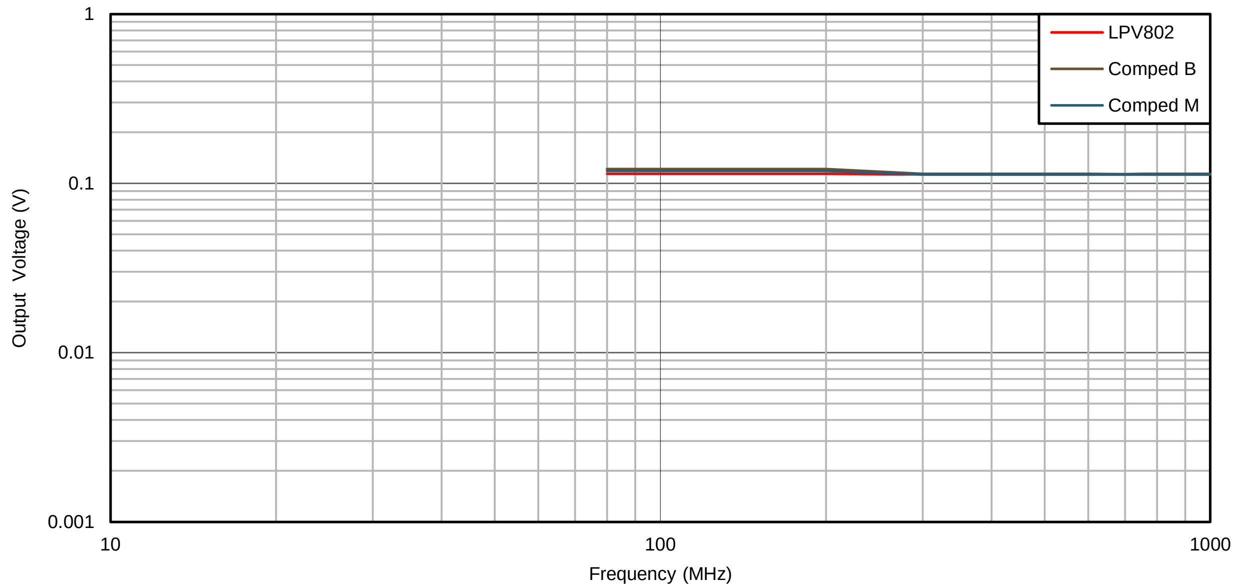

Figure 16. Test Results of 10 V/m With No EMI Capacitors and No Sensor Mounted

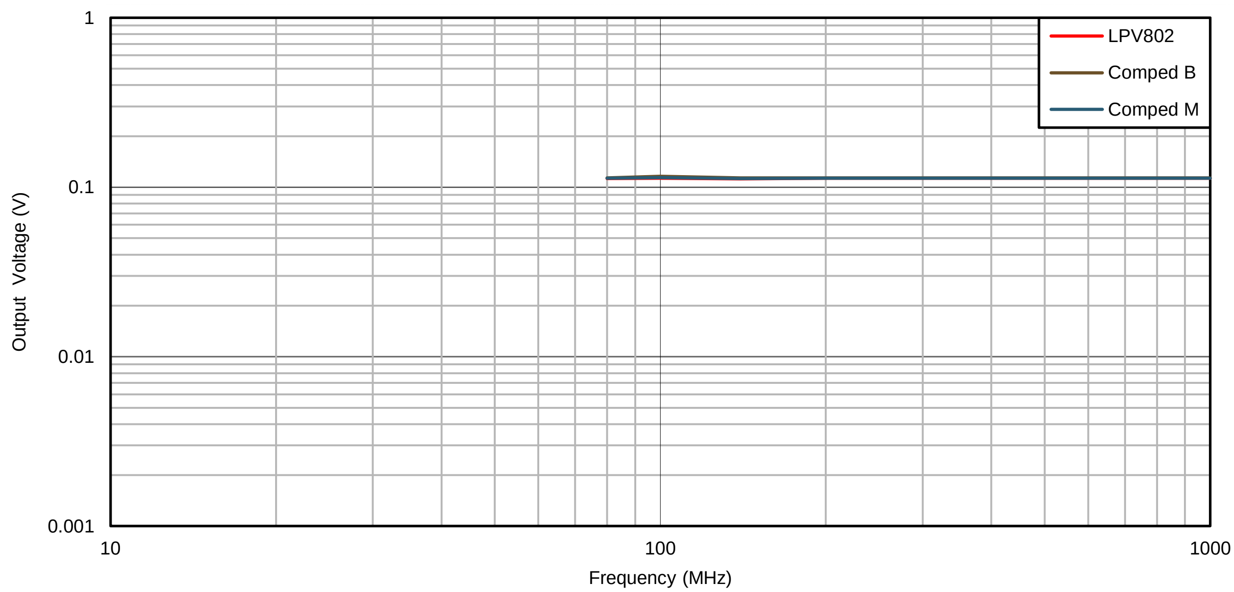

Figure 17. Test Results of 30 V/m With No EMI Capacitors and No Sensor Mounted

5.5 Observations

During the tests, it was found that it was best to sweep the frequency from high to low until the devices failed. When the devices failed, the sensors could take anywhere from seconds to tens of minutes to recover from the overload. This delay is caused by the malfunctioning amplifier placing voltage across the sensor, which causes a long delay as the sensor "recovers" back to zero current.

If it is known that the circuit will fail at the low frequencies, starting at the high frequencies will maximize the amount of data points collected. Maximizing test time is important when paying for chamber time by the hour, and waiting several minutes for a sensor to recover can be expensive!

5.6 Summary

The LPV8xx showed a definite advantage over the non-EMI hardened devices, particularly in the 100-200MHz range. All of the devices were mostly unaffected by the upper (>400 MHz) frequencies. Frequencies below 200MHz are mostly reliant on the external filtering.

Adding the external EMI input capacitors also helped overall performance, and should be added as part of normal design process.

EMI protection does not completely eliminate the effects of EMI, but it does help to reduce the effects. Adding the external filtering further reduces the effects, and external filtering is recommended even with the use of EMI protected devices.

The LPV8xx devices help the System Designer to reliably pass EMC tests helps eliminate the need for expensive redesigns to comply with EMI standards. This in turn ensures the successful to market launch of products.

6 Appendix

6.1 Full Schematic

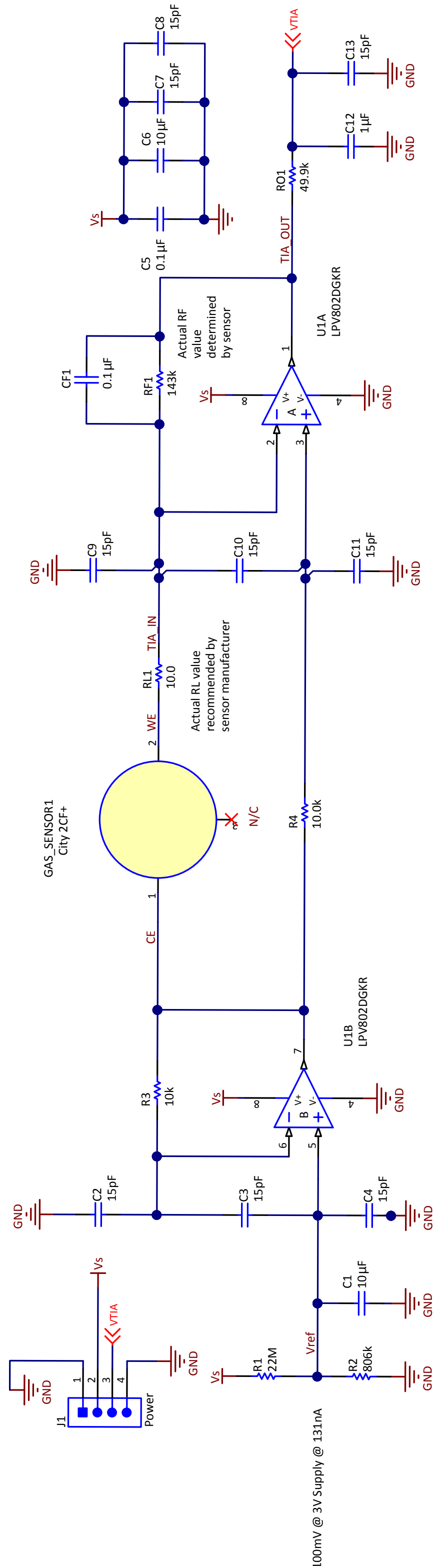

Figure 18. Full Schematic

6.2 Board Layout

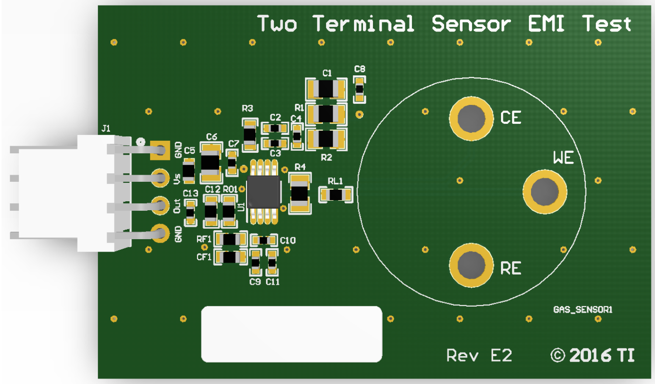

Figure 19. Top 3D Board View (Flipped)

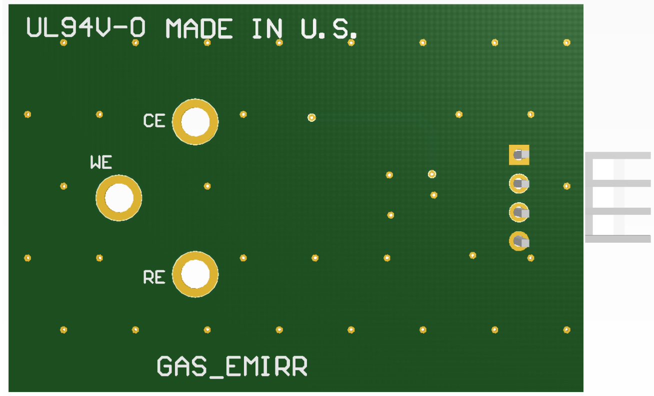

Figure 20. Bottom 3D Board View

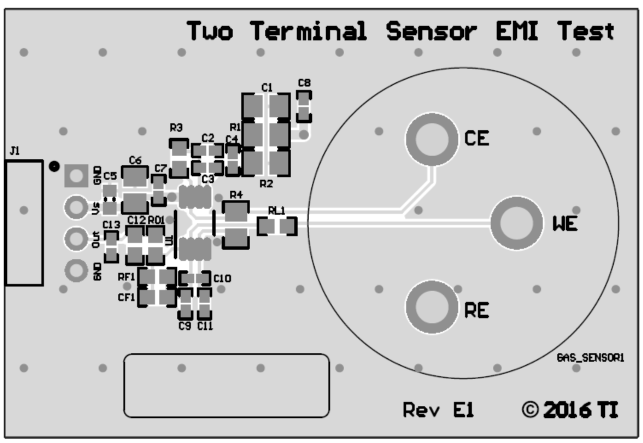

Figure 21. Top Component View

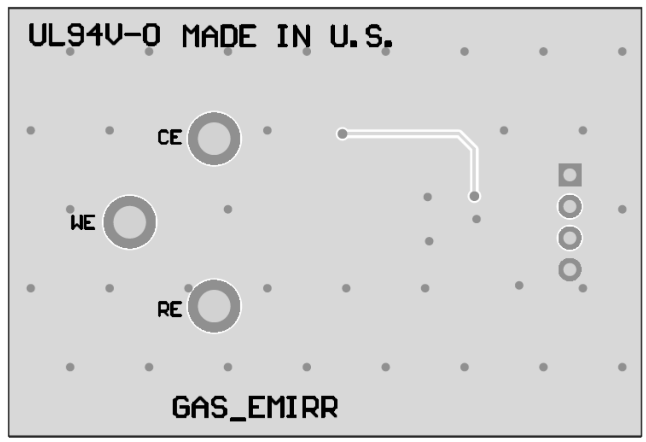

Figure 22. Bottom Component View (Flipped)

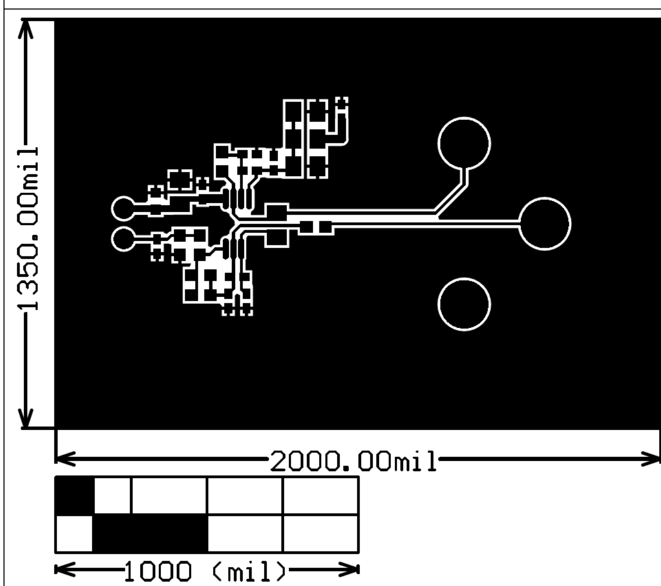

Figure 23. Top Layer

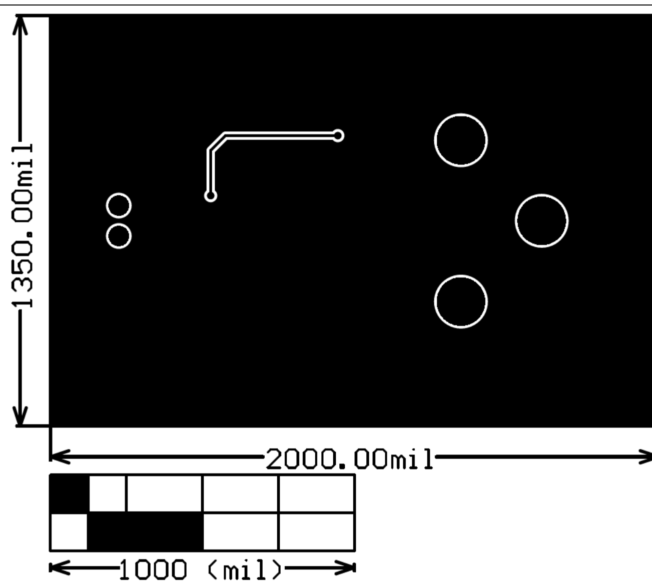

Figure 24. Bottom Layer

7 References

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8 Acknowledgments

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