Measuring RF Interference in Audio Circuits

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Introduction

The proliferation of wireless transceivers in portable applications has led to increased attention to an electronic circuits' ability to operate in the vicinity of high frequency radio transmitters. For example, in a Bluetooth headset using op amp for the voice band audio, special shielding in conjunction with good layout practice and RF suppression are needed to ensure interference-free operation of the headset. In this example, and in other gigahertz radio systems, the close proximity of the radio antenna to low frequency amplifier sub assemblies, can result in the demodulation of the radio signal causing a disruptive interference in the receiving circuit.

Test Description

Radio transceivers transmit voice and data signals by modulating a high frequency RF carrier signal with a much lower frequency signal. Sensitive circuits located near the antenna (Figure 1) must be designed to reject interference caused by RF signals bleeding into the audio circuits. Layout and proximity to the transmitter can result in several different receiving sites on the circuit board that can cause interference at different frequencies.

This application note describes a test platform using standard equipment found in most high frequency analog labs, that can effectively characterize the interference sensitivity of an amplifier sub circuit.

The test platform described was built to troubleshoot a Bluetooth headset with an excessive noise problem at the headset amplifier output caused by the RF transmitter. Although the noise caused by the Bluetooth transmitter was readily observed at the amplifier output, the frequency hopping RF combined with the complex encoded modulation of the voice signal produced an interference signal that was too complex to analyze.

The test platform re-creates the interference environment by replacing the complex Bluetooth signal with a swept RF frequency source modulated by a 1kHz modulation signal. The 1kHz modulation signal is used to track the source of RF entry and the signal path to the audio amplifier's output. This enables the user to observe the interference under closely controlled conditions of the RF carrier field strength, carrier frequency and modulation frequency.

Test Results

Using this test platform and procedures, comparisons were made between two different op amps in the same audio headset amplifier circuit. One amplifier had a bipolar input stage and the other a MOS input stage. The results showed different parts of the circuit in an amplifier assembly can act as receivers at different RF frequencies, thus producing multiple interference sources acting at the same time. Susceptibility differences between the two types of amplifiers are reported as well as the results of circuit suppression techniques.

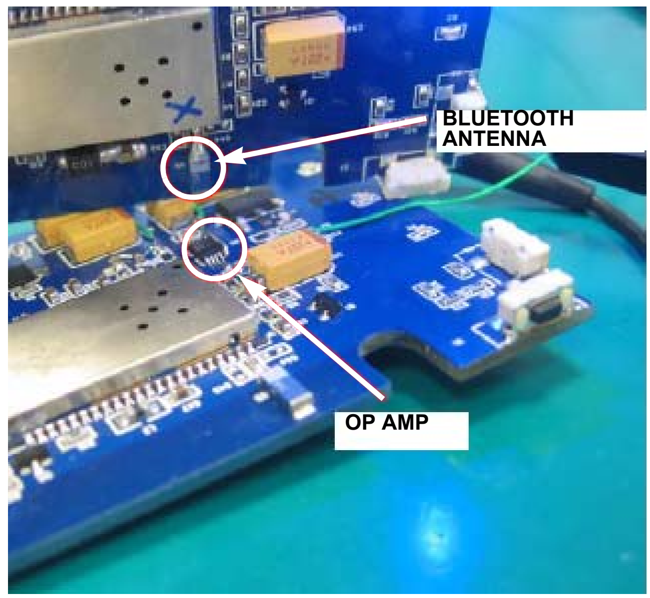

FIGURE 1. BLUETOOTH ANTENNA IN CLOSE PROXIMITY (~1") TO THE AUDIO AMPLIFIER

Test Platform

Modulated Sweep Test Hardware

The RF modulated test platform (Figure 2) was built using a HP8753D network analyzer (0.1MHz to 6GHz) as a variable RF source, a sine wave modulating signal source, and a HP3310A function generator to synchronize the sweep generator with the oscilloscope. A 20 second sweep time was used for both the sweep generator and the oscilloscope horizontal time base. The function generator was set to generate a repetitive 0.05Hz trigger for the scope and the network analyzer, so the scope horizontal display could be calibrated to the RF frequency sweep (Figure 2A).

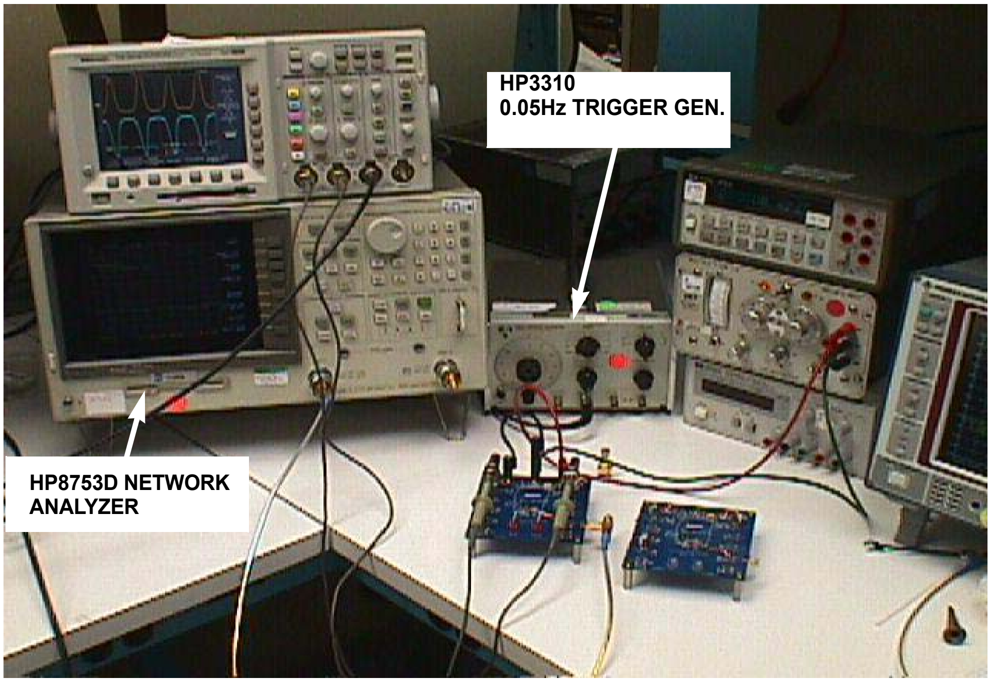

FIGURE 2. RF INTERFERENCE TEST SETUP

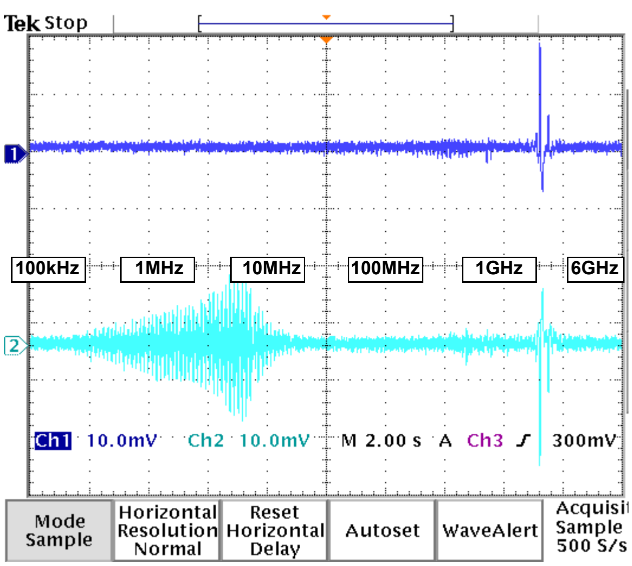

FIGURE 2A. MODULATED OUTPUT, 0.1MHz TO 6GHz SWEEP

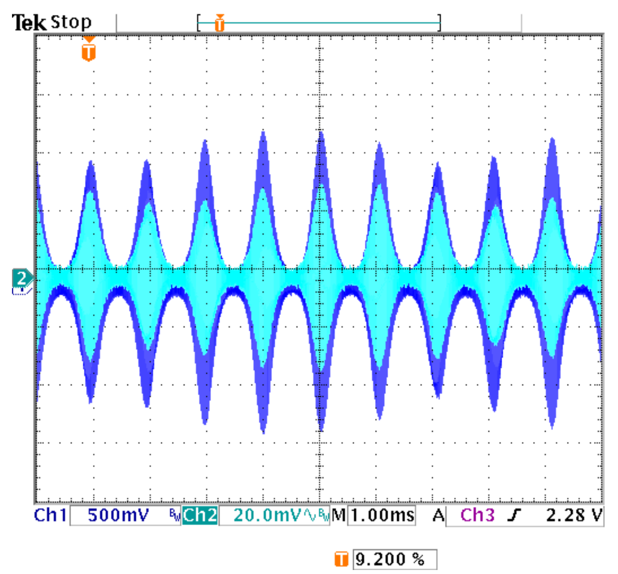

FIGURE 2B. MODULATED OUTPUT SINGLE CARRIER FREQUENCY

Audio Amplifier Test Boards

The audio amplifier test board implements a single-ended input to differential output headphone amplifier using a dual op amp operating from a single +5V supply (Figure 3). The first stage is connected unity gain (AV = 1) and the second stage creates the inverse output (AV = -1) for an output differential gain of 2. Figure 4 shows the two identical evaluation boards that were used to implement the audio amplifier schematic shown in Figure 3. One board has the bipolar input op amp and the other the MOSFET input op amp. Figure 5 shows the distance between the op amp and the antenna during the RFI tests (~1/4 in). Figure 1 shows the distance between the op amp and the antenna in an actual Bluetooth headset (~1 in).

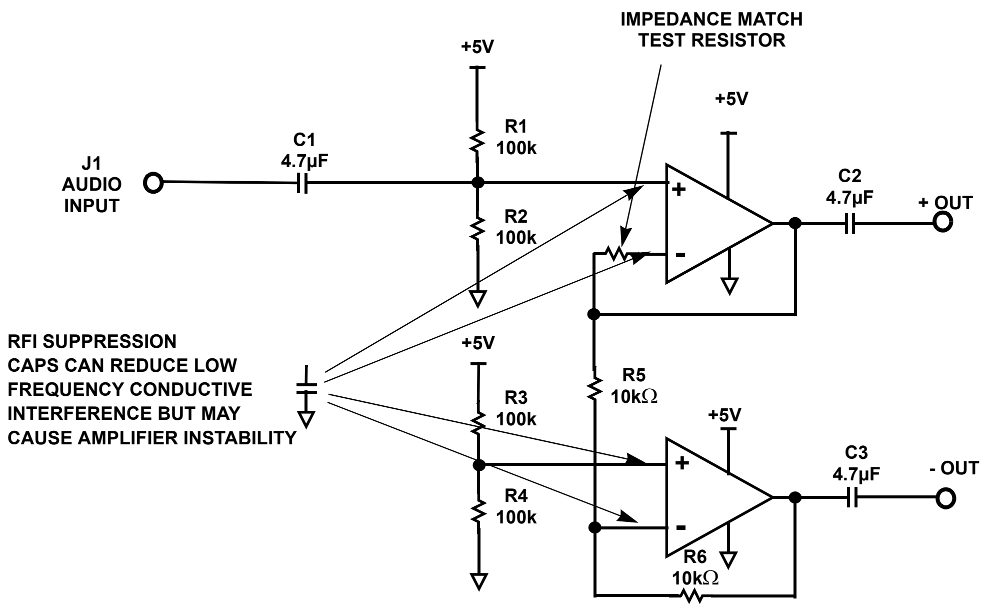

FIGURE 3. SCHEMATIC OF AUDIO TEST CIRCUIT

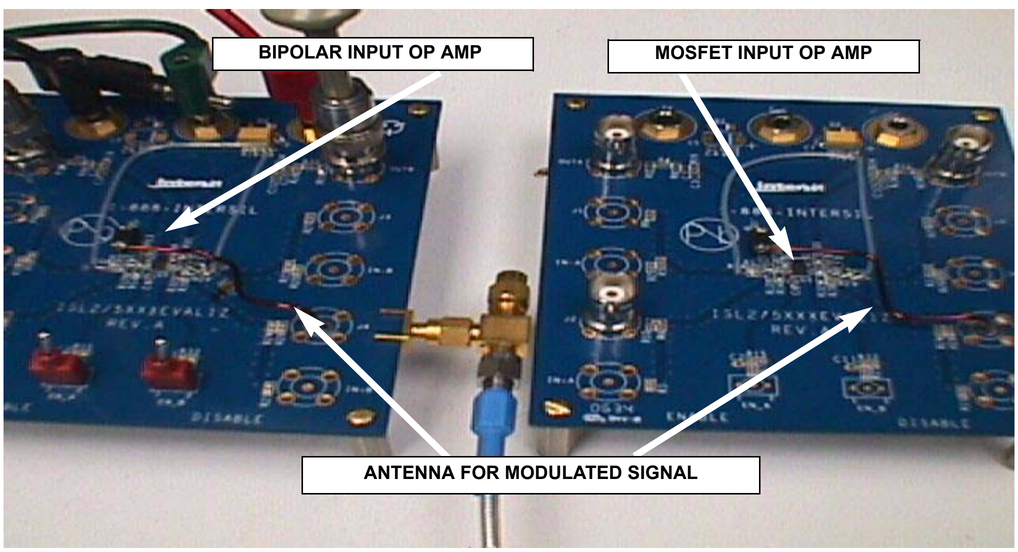

FIGURE 4. MODIFIED EVALUATION BOARDS TO SIMULATE CUSTOMERS CIRCUIT

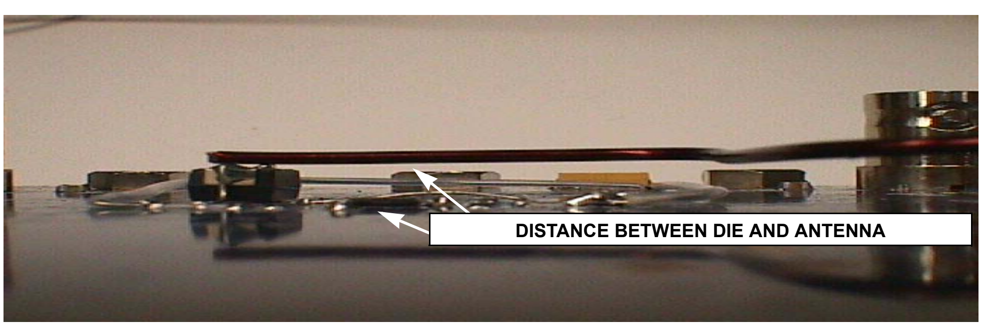

FIGURE 5. DISTANCE BETWEEN DIE AND ANTENNA DURING OUR LAB TESTS

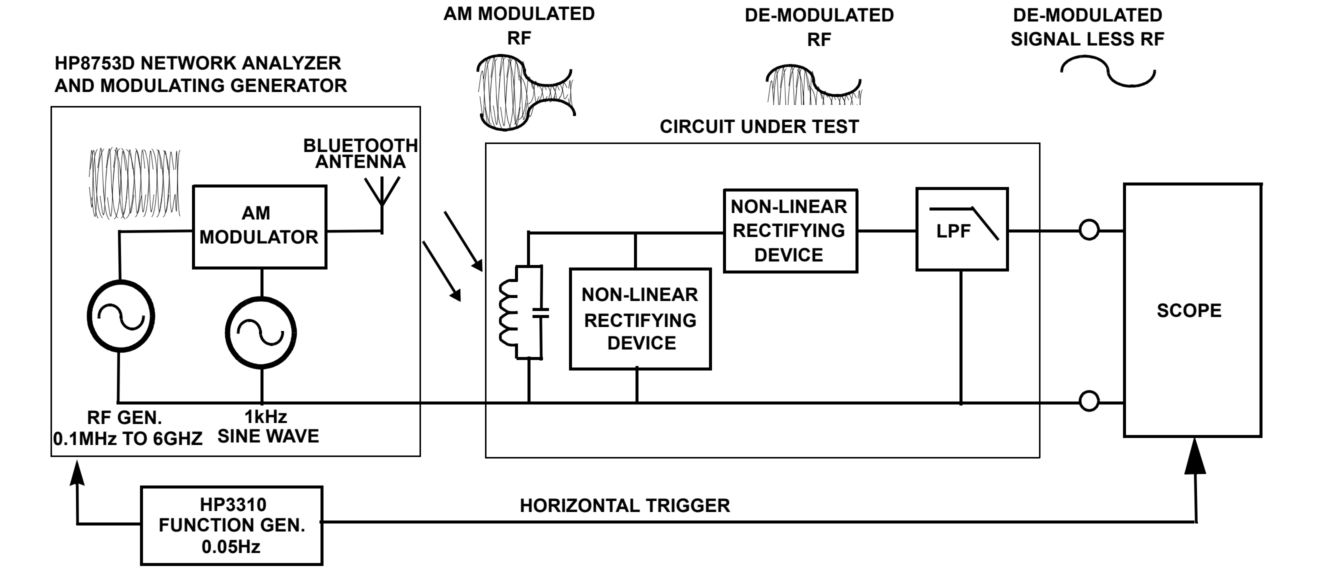

FIGURE 6. CONCEPT MODEL FOR THE RF INTERFERENCE TEST SET

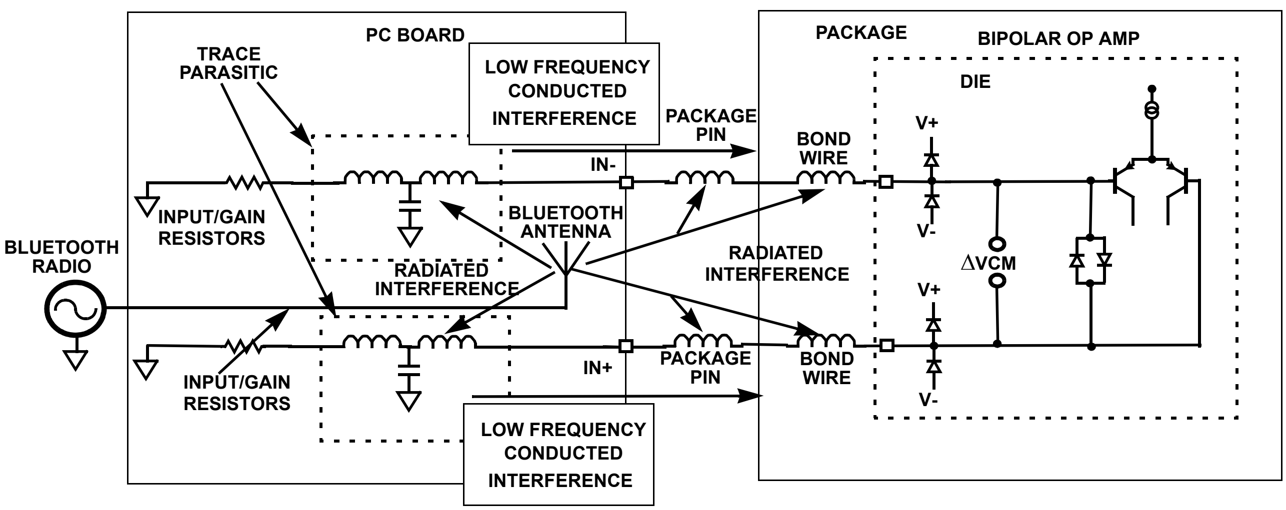

FIGURE 7. BLUETOOTH HEADSET AUDIO AMPLIFIER INTERFERENCE BEHAVIORAL MODEL

Interference Model

Figure 6 illustrates the concept model of the demodulation experiments. This model illustrates how the Bluetooth carrier is stripped off leaving behind the low frequency signal. Because the frequency of the Bluetooth RF carrier is 20 times higher than the bandwidth of the op amp under test (120MHz), the amplifier acts as the demodulator and filter resulting in a carrier-free low frequency replica of the modulating signal appearing as an interference signal at the output of the amplifier as shown in Figure 10.

Interference Testing

The oscilloscope was used to measure the differential outputs during the 20 second RF sweep from 0.1MHz to 6GHz (Figure 2A). The RF output power of the HP8753D was adjusted to the standard Bluetooth output power level of 0dBm. The modulation level was set to ~80%, which resulted in some distortion caused by the HP8753D network analyzer. (Figure 2B).

The ability to select a single modulating frequency and to control the RF frequency and level of the carrier signal provides the tool necessary to carry out a variety of controlled experiments needed to partition the interference sources. Close inspection of circuit behavior was possible by sweeping the carrier frequency and measuring the modulating signal at the output of the audio amplifier circuit. (Figures 8, 9, 11, 12).

Isolating Interference Sources

A significant observation from the frequency sweep tests showed two distinct frequency bands of interference; a low frequency band from 0.1MHz to 30MHz and a high frequency band from ~1GHz to 4GHz.

The amplifier circuit design and layout used for this test suggests an interference behavioral model shown in Figure 7. For the purpose of this discussion, conducted interference is defined as interference received by the PCB interconnect and external components (i.e. resistors, caps) and conducted onto the pins of the op amp. Radiated interference is defined as inductive coupling of the radiated RF signal onto the package pins, the bond wires, and the active circuitry of the op amp.

Circuit board layout and components external to the op amp are most likely responsible for the interference in the 0.1MHz to 30MHz. The long PCB traces are effective antennae at the low frequency end of the sweep. The received RF signal in the 0.1MHz to 30MHz range is passed to the op amp on the inverting and non-inverting inputs. Eliminating the low frequency source of interference may not be important if the transceiver frequency is the GHz range (including harmonics).

Sources of Radiated Interference

The interference in the high frequency band was caused by the op amp. The most likely path is the reception of the radiated RF by the op amp package pins, bond wires and active circuitry on the die coupling the modulated 2.4GHz signal as a common mode input to the differential pair. The mechanism for the demodulation and filtering is the input differential pair.

Sources of Conducted Interference

The interference in the low frequency band was caused by the PC board layout and external components. Different amplifier designs with the same frequency response and gain can produce different levels of susceptibility to conducted interference depending on their input circuitry. An amplifier with differential (inverting and non-inverting) inputs can have input circuitry arranged so the demodulated signal is presented to the amplifier as a common-mode signal. If the amplitudes and phase of both input signals are the same, then the resulting interference is reduced by the common-mode rejection ratio (CMRR) of the amplifier.

To test this, impedance differences at the op amp input stage due to the circuit schematic were compensated by adjusting the impedance of the input terminals. This was done by adding resistance to the inverting input terminal (Figure 3) which resulted in matching the input impedances which enabled more of the demodulated signal to be cancelled by the input differential pair. This reduced the susceptibility of the op amp to conducted interference from the PC board. Reference section titled “Results of RF Interference Experiments” on page 7 for lab results of this test.

Results

Bipolar

Figure 8 shows the result of a frequency sweep from 100kHz to 6GHz of the bipolar op amp. Across the frequency sweep, the output of Channel “A” (unity gain configuration) shows an interference peak of $25mV_{P-P}$ at ~2GHz with J_1 input grounded (Figure 3). The lower trace shows the output of Channel “B” (inverting gain of one) with a maximum of 30mVp-p in the frequency band of 500kHz to ~30MHz. From 30MHz to 6GHz there is a $5mV_{P-P}$ interference peak at ~800MHz and a series of peaks of $\sim 25mV_{P-P}$ over the 1.8GhHz to 3GHz range. It is obvious from Figure 8 why the bipolar op amp had a problem with the Bluetooth application.

Figure 10 shows the interference on Channel A and Channel B outputs with a fixed carrier frequency of 3.9GHz and a 1kHz 80% modulation. 3.9GHz was chosen because the bipolar input amp has an interference peak at this frequency.

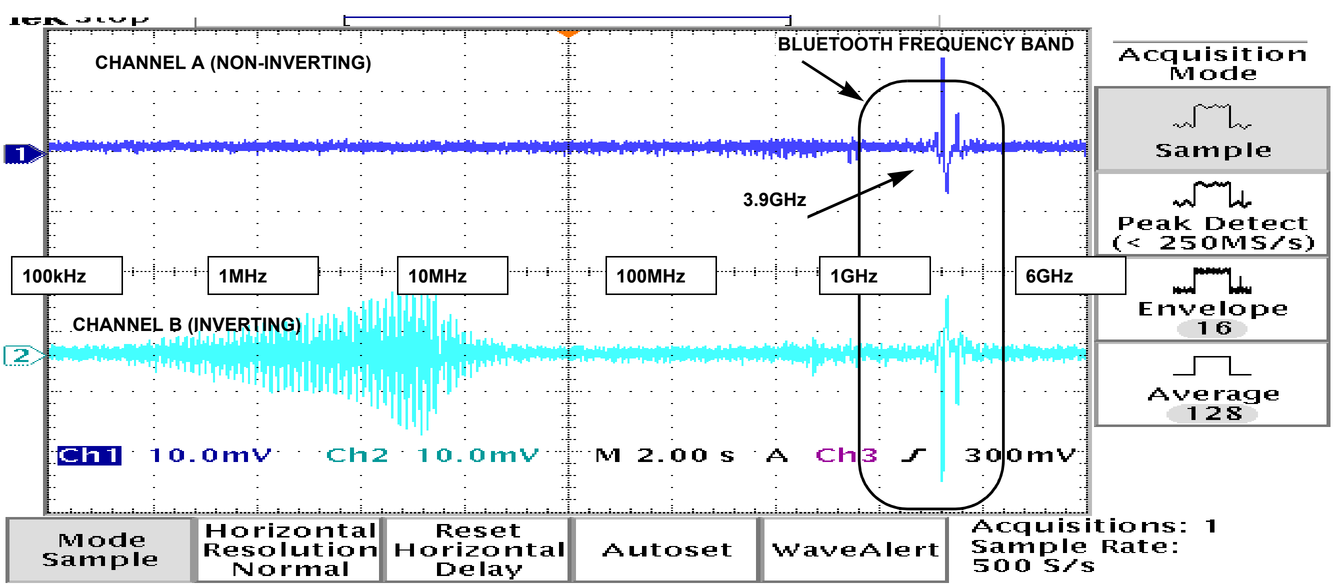

FIGURE 8. BIPOLAR OP AMP SWEEP WITH J_1 INPUT GROUNDED

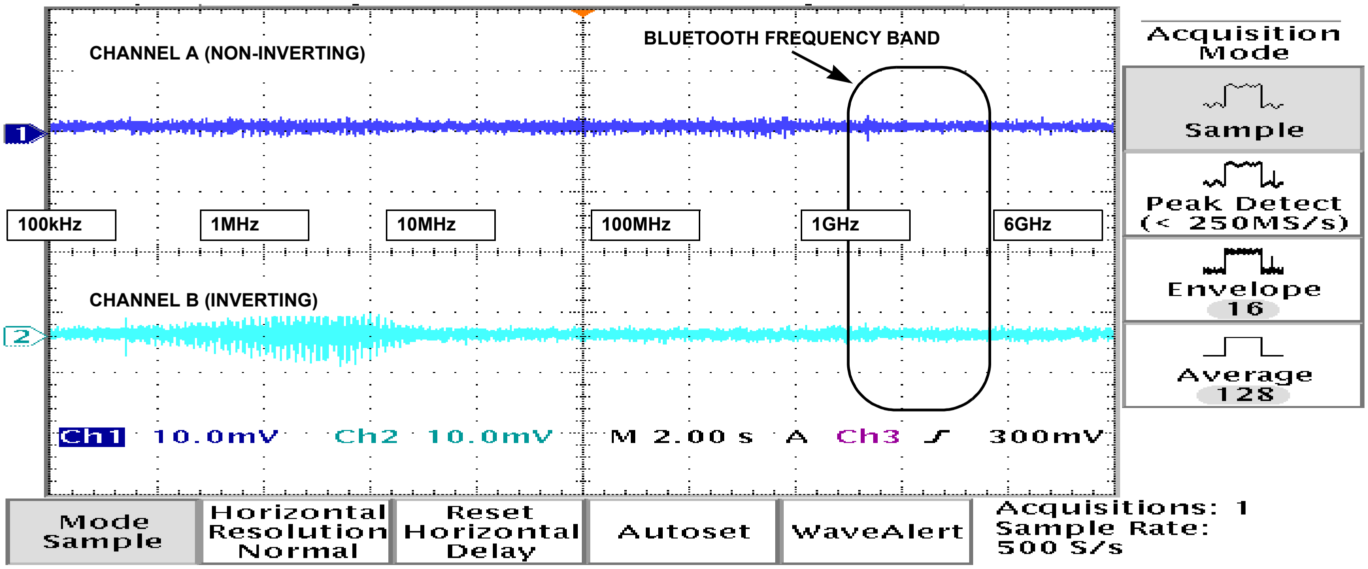

FIGURE 9. MOSFET INPUT OP AMP SWEEP WITH J_1 INPUT GROUNDED

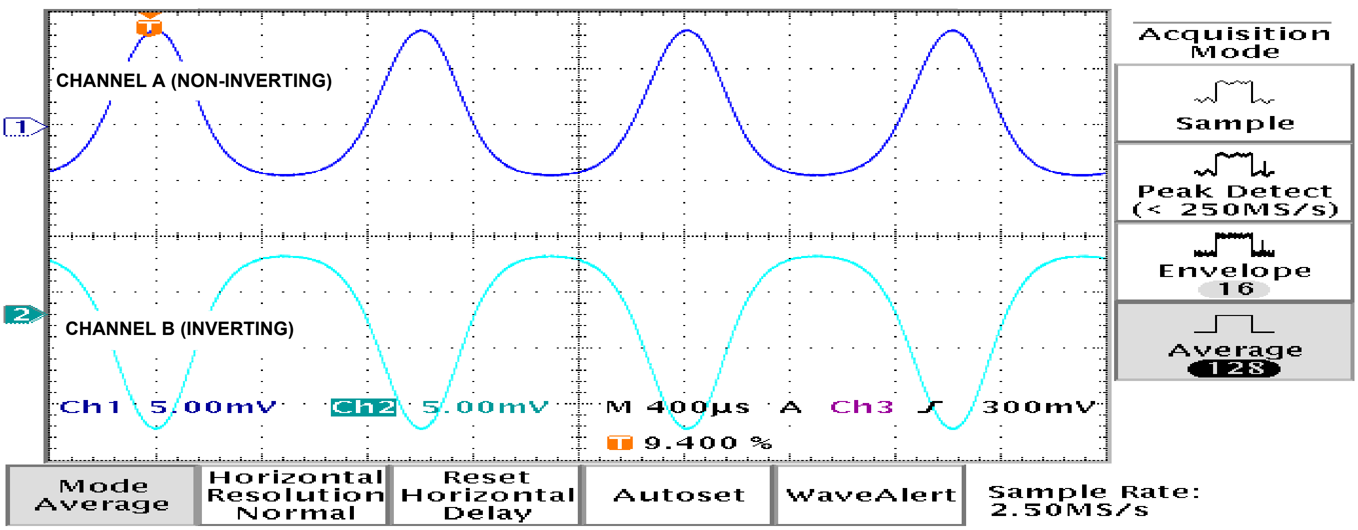

FIGURE 10. INTERFERENCE ON CHANNEL A AND CHANNEL B WITH A FIXED CARRIER FREQUENCY

Interference below 30MHz is conducted and within the bandwidth of the both the bipolar and MOSFET op amps. This interference results from PCB layout and not the device itself, and therefore not important to this discussion. The Interference in the GHz range is the focus of this evaluation.

MOS

Figure 9 shows the result of a frequency sweep from 100kHz to 6GHz of the MOSFET Input op amp. Across the frequency sweep, the output of Channel "A" (unity gain configuration) shows a total peak-peak voltage of less than $3mV_{P-P}$ with J_1 input grounded (Figure 3). The lower trace shows the output of Channel "B" (inverting gain of one) with a maximum of $10mV_{P-P}$ in the frequency band of 500kHz to ~5MHz. From 5MHz to 6GHz the total peak-peak voltage is less than $3mV_{P-P}$.

From Figure 9, it is obvious why the MOSFET input op amp did not have a problem with the Bluetooth application.

Results of RF Interference Experiments

1. Matching the input impedances using external series resistor.

Adding a 50k resistor in series with the inverting input of CHA reduced high frequency interference and increased the low frequency interference as shown in Figure 11.

In the GHz region (Figure 11), the reduction in the demodulated interference level varied from ~5mV$_{P-P}$ to 20mV$_{P-P}$,depending on the orientation of the antenna. This orientation sensitivity is thought to cause a mismatch in the signal level coupled on to the inverting and non-inverting bond wires. This difference in signal level presents a differential signal to the input pair which appears at the amplifiers output.

2. Using capacitors on the input pins of the amplifiers to kill the signal before it get inside the part.

10pF capacitors were added to the input pins of Channel “A” to ground. A series 10k resistor was added to the inverting input to kill an oscillation caused by adding the capacitors. It was not possible to add capacitors to the inverting amplifiers input without oscillations. Channel “A” in Figure 12 shows a reduction in the interference across the entire frequency band. The reduction in conducted interference up to 30MHz most likely resulted from the input filters created by the capacitors.

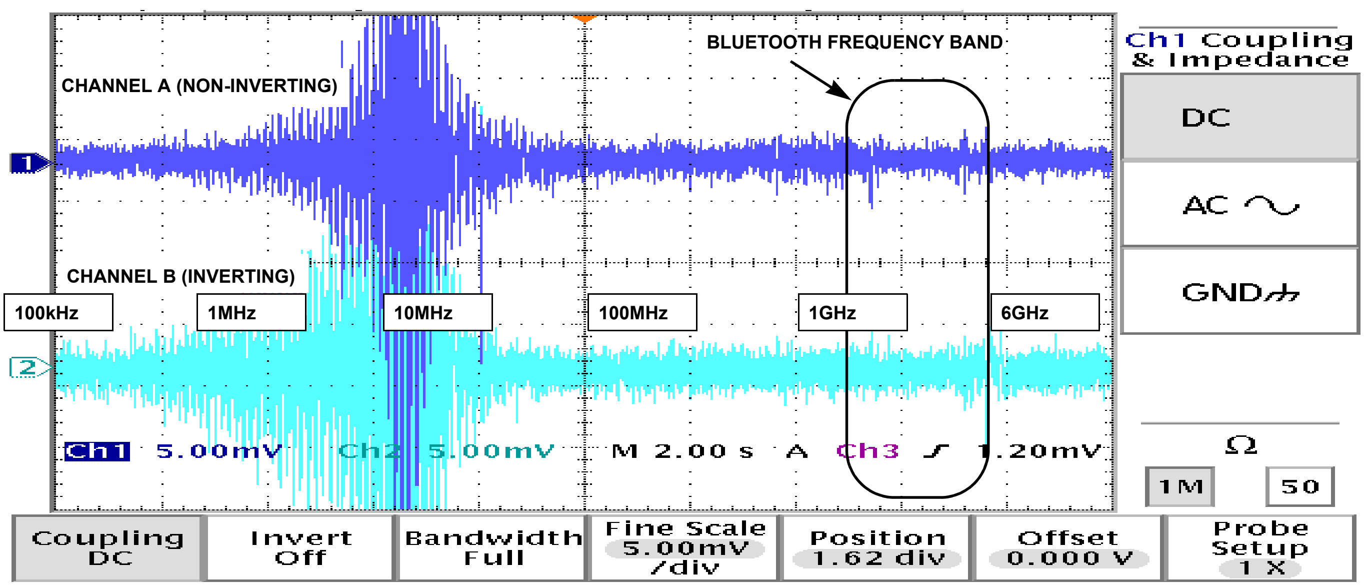

FIGURE 11. BIPOLAR OP AMPLIFIER SWEEP WITH ADDED RESISTOR ON INPUT OF CHANNEL A’s NEGATIVE INPUT PIN AND J$_1$ INPUT GROUNDED

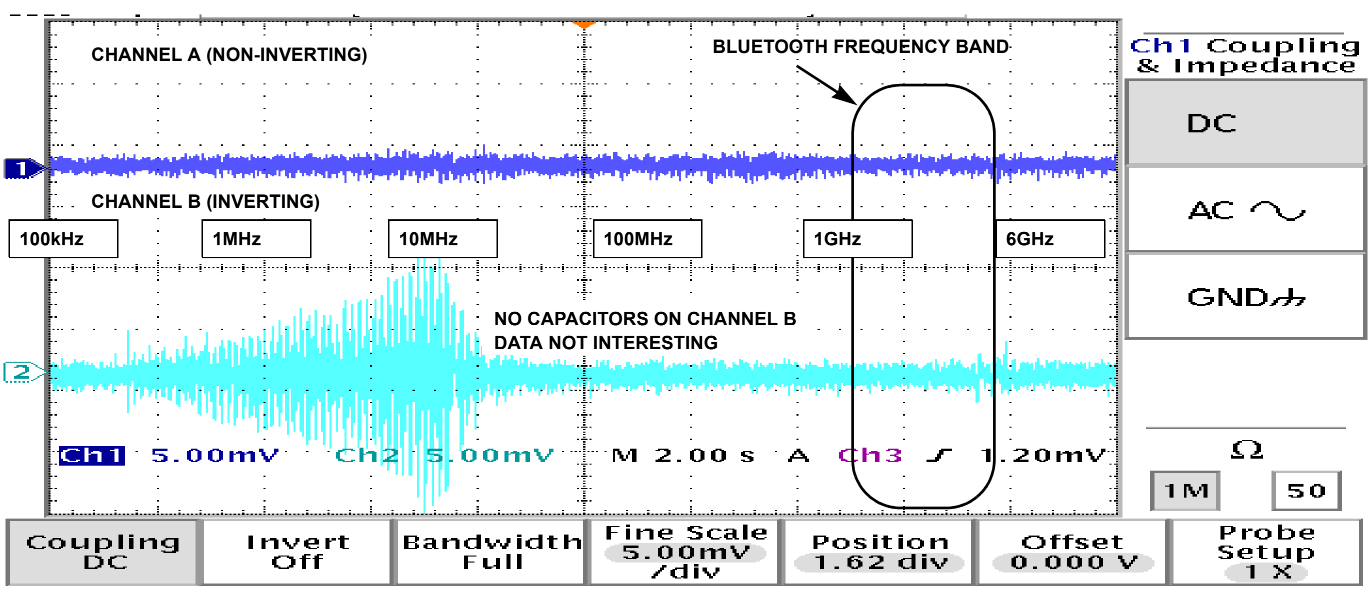

FIGURE 12. BIPOLAR OP AMPLIFIER WITH ADDED 10pF CAP ON THE INPUT PINS OF CHANNEL A

CONCLUSION

The Modulated Sweep test platform is an effective way to generate a controlled RF interference source to measure the RFI rejection ability of a amplifier circuit. It was shown that circuit layout, circuit design and the amplifiers architecture are all contributing factors to RF interference.

The RF sweep feature enables evaluation of low frequency and high frequency carrier interference. The system also has the ability to test a single frequency so that specific solutions can be evaluated.

In the Bluetooth example, the interference was caused by demodulation of the high frequency signal within the input stage of the amplifiers. Bipolar input stages are active at 2.4GHz frequency and demodulate the RF signal to the amplifier output. MOS input stages are not active at 2.4GHz and do not make good demodulators.

If the slower speed and higher voltage noise of the MOS input stage gives acceptable performance, then the preferred input stage for RF tolerant parts would be the MOS input stage. If higher speed and lower voltage noise is required, then care must be taken in the design to minimize input impedance differences and shielding of the op amp to minimize the radiated interference at the output of the amplifier.

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