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Guidelines for Improving the RF Immunity of Audio Amplifiers

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This article discusses design and measurement techniques to optimize the RF immunity performance of audio amplifier ICs

RF immunity, or RF susceptibility, is quickly becoming as important a design consideration as PSRR, THD+N, and SNR in the audio portions of cellular phones, MP3 players and notebook computers. Bluetooth is proliferating as a wireless-serial-cable replacement for headsets and microphones in mobile applications. Wireless LAN (WLAN), using the IEEE 802.11b/g protocol, is practically standard in PC and laptop computers. The TDMA multiplexing scheme found in GSM, PCS and DECT technologies remains a considerable RF nuisance. Today's dense RF environment raises concerns regarding an electronic circuit's susceptibility to RF and RF's impact on the integrity of the overall system. The audio amplifier is a system block that can be susceptible to RF.

An audio amplifier can demodulate the RF carrier and reproduce the modulated signal and its harmonic components at the output. Some of the frequencies fall into the audio baseband, producing unwanted audible noises at the system's speaker or headphone output. To avoid this problem, a system designer must fully understand the limitations of the selected amplifier IC and its respective PCB layout. This article will guide designers to optimize the RF immunity performance of an audio amplifier at the board level.

Finding the Source of RF Noise

The key to a successful layout (i.e., high immunity to RF) is first to identify the source of RF noise coupling. If an evaluation kit is available for the selected audio amplifier, use it to identify the pins susceptible to RF. Pick a frequency of interest in a system: for example, 2.4 GHz in a WLAN application. Antenna theory states that a trace length of ~1.2 inches (3 cm) is a quarter wavelength ($\lambda/4$) at 2.4 GHz, and would be a highly efficient antenna. To compute this length at other frequencies, use

$$l = c \,/\, (4f)$$

where l = length in meters, $c = 3\times10^8$, f = frequency in Hz.

Cut a 1.2 in. wire and solder it directly to a pin on the IC. Measure the IC's RF immunity performance at the frequency of interest, 2.4 MHz ±10% in this case. Remove the 1.2 in. wire and solder it to a different pin on the amplifier. Repeat the RF measurement remembering that it is important to ensure that the test setup is identical for each test run. Continue in this fashion until the 1.2 in. wire has been placed at every amplifier pin and an RF measurement recorded at the frequency of interest. Finally, measure the IC's RF immunity performance without the 1.2 in. wire antenna connected to the pins. (MAXIM's test setup is described later in this article.)

This last test run provides a baseline for the amplifier's performance. Compare this result to the previous series of test runs. The comparison will identify the amplifier pins most susceptible to RF demodulation. Given this data, a PCB can be optimized to reduce the amount of RF energy coupled into the amplifier pins.

The Role of the Capacitor

Take, for example, the BIAS pin of the selected IC. Assume that the BIAS pin

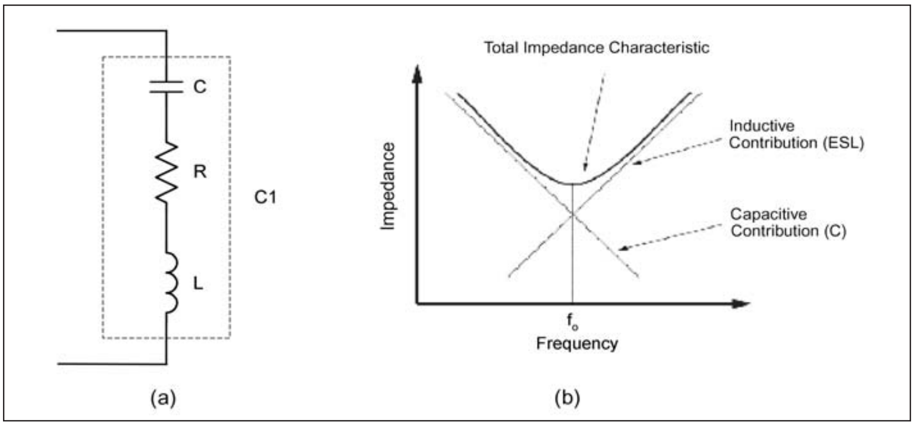

Figure 1 · (a) Nonideal capacitor model; (b) impedance profile of the nonideal capacitor model.

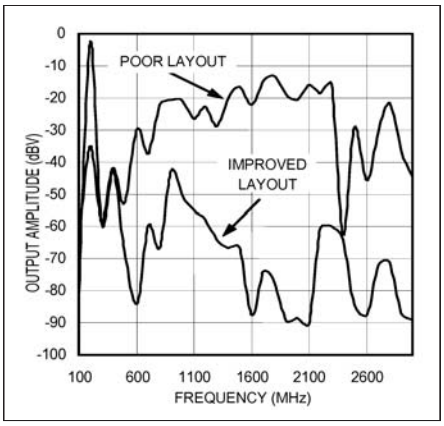

Figure 2 · RF immunity test results of the MAX9750C speaker amplifier; noise floor = –94.4 dBV.

exhibits poor RF immunity at the frequency of interest. The first and most obvious PCB consideration would be to limit the trace length from the BIAS pin to the decoupling capacitor. If the trace length is optimized and RF demodulation is still a concern, consider adding a small bypass capacitor (on the order of 10 pF to 100 pF) to GND at the amplifier pin. The capacitor's impedance profile can create a notch filter at the system's most sensitive frequency (in this case, 2.4 MHz). Refer to the impedance profile of a capacitor model (C1) in Figure 1(b).

If C1 were an ideal capacitor, the impedance would decrease as the frequency increased ($X_C = 1/[2\pi fC]$). Ideal capacitors do not, however, exist in a practical environment. The impedance of a nonideal capacitor model (Figure 1(b)) reaches a minimum at self-resonance [1] and then begins to increase with frequency. The inductive component takes over ($X_L = 2\pi fL$) at frequencies greater than f_0. To make matters worse, the PCB trace will likely add to the series inductance. This behavior may produce disappointing results if the capacitor is selected for a filter operating at frequencies near or above its self-resonance. However, the capacitance value can be selected so the self-resonance minimum will shunt high-frequency components to GND.

Controlling Noise at the Input Pins

An audio amplifier's input pins will always be a source of RF noise coupling. Ensure that the input trace lengths are shorter than λ/4 for the system's RF signal. A 'quiet ground plane' can also be implemented to reduce the amount of RF noise coupled into the input pins. When laying out the PCB, flood a ground plane around each input trace of the IC. This ground plane will aid in isolating any high-RF signals from the input pins of the selected audio amplifier.

The MAX9750 combination audio power amplifier and headphone amplifier provides an example of how to control the effects of RF noise. Engineering evaluation has identified nine pins on the MAX9750 that demonstrate susceptibility to RF: INL, INR, BIAS, VOL, BEEP, OUTL+, OUTR+, OUTL–, and OUTR–. A 33 pF capacitor added at the BIAS pin improved RF immunity performance on average by 3.6 dB. A 3x reduction of input trace length and a ground plane flood around the left, right, and PC-beep input pins further improved the RF immunity performance of the MAX9750 (Figure 2).

Figure 2 demonstrates the typical RF immunity performance of the MAX9750 IC. External factors such as antenna strength, cable length, speaker type, etc., can also affect the RF immunity performance.

Expensive methods such as LC filters on RF-susceptible amplifier pins or low-ESR capacitors added to the application diagram can also be implemented at board level. These methods are very effective, but costly. If the source of RF noise is identified and understood, expensive solutions can be avoided.

Summary

Poor RF immunity performance of an audio amplifier will impact the integrity of the overall system design. If the problem is identified and understood, corrective action can be taken to ensure that audible RF demodulation is avoided. In general, keep the input, output, bias, and power supply traces shorter than 1/4 wavelength for the system's RF signal. If a higher level of RF immunity is required, connect a small-value capacitor to ground directly at the pin of the IC (even when a larger value capacitor is already connected at the pin). Utilize ground plane floods near highly susceptible amplifier pins. Finally, physically place high-RF-energy system blocks away from highly susceptible audio amplifier pins. Equipped with this general understanding, the unwanted audible demodulation "buzz" can usually be minimized to an acceptable level.

Description of Maxim's RF Immunity Test System

To obtain accurate and repeatable test results, the device under test (DUT) must be exposed to a known RF field strength. Maxim has developed a test method for quantifying repeatable RF susceptibility results by use of an anechoic test chamber, signal generator, RF amplifiers, and a field-strength sensor.

Figure A represents a typical test setup. The DUT in this case is an operational amplifier. The amplifier's non-inverting input is shorted to GND, using a 1.5 in. wire loop to simulate a PCB trace length. A standard 1.5 in. input trace length is selected so that RF immunity performance can be compared across several Maxim amplifiers. Note that an input trace from the DUT to the input source may act as an antenna. The amplifier's output is loaded with the rated impedance. Next, the amplifier is placed in a test chamber, which subjects its contents to a near-uniform field strength, and a modulated RF carrier is applied to the test chamber. The demodulated signal is monitored at the amplifier's output while Maxim's RF Test System simulates an RF-rich environment.

Figure B illustrates Maxim's RF Test System. The test chamber is housed in a Faraday cage, isolating the DUT from external fields. The complete test set-up is comprised of the following equipment:

- Signal generator: SML-03, 9 kHz to 3.3 GHz
- RF power amplifier: 20 MHz to 1,000 MHz, 20 W
- RF power amplifier: 1 GHz to 3 GHz, 50 W
- Power meter: 25 MHz to 1 GHz
- Parallel wired cell (test chamber)
- Electric field-strength sensor
- Computer (PC)
- DMM (dBV meter)

The PC sets the range of frequencies, modulation percentage, modulation type supplied by the signal generator, and the power delivered by the RF power amplifier. The modulated signal is fed to the appropriate power amplifier. The amplifier output is monitored with a directional coupler and a power meter. The subsequent RF field is uniformly applied inside the test chamber.

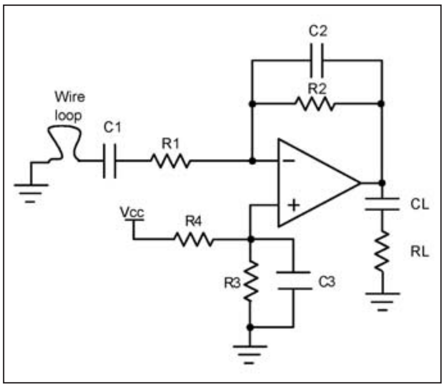

Figure A · RF immunity test circuit for a typical operational amplifier.

At Maxim, the DUT is placed in the center of the shielded chamber. A field-strength sensor consistently measures a 50 V/m [2] electric field strength close to the DUT. An RF carrier wave with its frequency varied between 100 MHz and 3 GHz is 100% amplitude modulated with an audio frequency of 1 kHz. Access ports on the side of the chamber provide power to the DUT and a means to connect an output monitor. In this case, a digital multimeter (configured to report units in dBV) monitors the demodulated, 1 kHz signal amplitude in real-time. As the RF carrier wave frequency is varied between 100 MHz and 3 GHz in predetermined steps, the DMM measurements are recorded. A sample 800 MHz to 1,000 MHz sweep is reported in Figure C.

If Maxim's RF test system is not readily available (this is the case in most situations), there are alternatives for testing the RF immunity performance of an audio amplifier. The first alternative utilizes commonly stocked lab equipment: a high frequency generator, an antenna, an Audio Precision (AP) unit, and a computer (PC). The high frequency generator simulates the energy present in an RF rich environment. The generator's high frequency signal is fed to an antenna positioned near the DUT (audio amplifier). The DUT's output is then fed to the input of the Audio Precision which is controlled by the PC. A continuous FFT is recorded while the peak voltage at the envelope or modulation frequency is logged. A higher peak voltage at the modulation frequency signifies poor

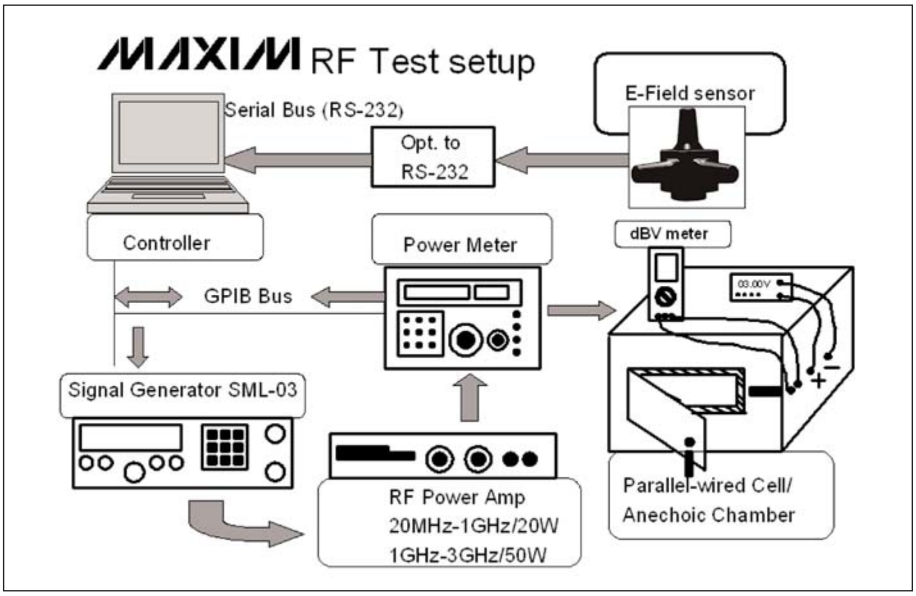

Figure B · Setup for Maxim's RF immunity test method.

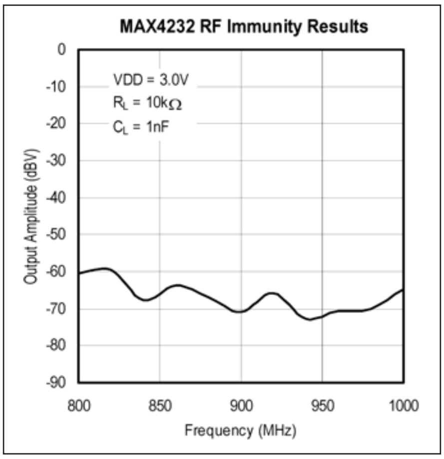

Figure C · MAX4232 test results.

performance of the audio amplifier. The frequency of the generator can be varied while the continuous FFT is recorded. The changing frequency makes it easier to identify the sensitive frequency band of the selected audio amplifier.

Alternatively, an RF immunity test can simply include a GSM cell phone, operating at frequencies between 800 MHz and 2,000 MHz with a 217 Hz envelope frequency, in a basic listening test. The cell phone can be placed close to the DUT while a call is placed. If the RF rejection of the selected amplifier is poor, the 217 Hz GSM modulation frequency can potentially be demodulated and your ears can monitor the RF rejection of the audio amplifier.

Once a specific test method is selected, it is important to ensure the test environment and test conditions are well-documented, so they are identical for all tested amplifiers. This will allow for repeatable and accurate test measurements which can be used for comparison.

Author Information

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Notes

1. At self-resonance, the capacitive and inductive impedances cancel each other out leaving only a resistive component. The self resonance is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

2. A typical mobile phone operating in the 1.8 GHz to 2.0 GHz region can emit up to a 100 V/m peak field strength (depending on the distance and orientation of the device to the field-strength sensor). A standard 50 V/m field strength was selected at Maxim as it provides useable data from various audio amplifiers with varying degrees of RF immunity.