APPLICATION NOTE

System Design for RF Immunity

Audio Codec

With the growth of the portable electronic devices industry, radiated RF fields and potential interference have become greater owing to higher RF frequencies, more devices using RF, and stronger RF fields that may be very close to audio devices. As a result, traditional methods such as 220pf capacitor bypassing are no longer effective. The most severe RF problem is typically from GSM cellular telephones. In general, a design that has good immunity to GSM Buzz noise (also known as TDMA Buzz), will also have good immunity to other kinds of possible radiated RF interference. This document has a focus specifically on the most common and most difficult issues of GSM Buzz.

1. Tutorial Regarding the Cause of GSM Buzz

In GSM cellular networks, the mobile device may transmit on either an 800MHz or 1900MHz band, and with an RF input power up to 3 watts. In GSM transmissions, the mobile device pulses its RF transmitter on/off at a rate of approximately 217Hz, with an on/off duty cycle of approximately 10%.

This RF energy in normally completely inaudible. However, GSM radio frequencies can become audible if the RF energy passes through a non-linear component. This will cause the positive going cycles of the RF energy to pass with slightly different gain than the negative going cycles of the RF energy. This results in classical RF "detection," which is the term used for converting an AM radio signal into an audible signal by means of a rectifier (diode) type device.

Any semiconductor junction is a potential rectifier that will convert GSM radio into an audible noise. Other non-linear elements such as bad solder joints, touching metal parts, or low quality inductors/capacitors can also rectify a GSM RF signal, and make it become audible. This audible sound is a pulse wave at approximately 217Hz and with the same 10% duty cycle as the original RF signal. The small duty cycle makes the audio noise very rich in strong harmonics, with the first few harmonics being a similar strength to the 217Hz fundamental frequency.

1.1. Summary of GSM Buzz Control Methods

Three basic methods are typically used to reduce GSM Buzz noise. The best and preferred method is good RF immunity design that prevents significant RF energy from entering a non-linear element that then will convert that RF energy into audible energy. The next method is bilateral super symmetry. My making the part completely symmetrical and differential, the hope is that the GSM Buzz will be equally introduced into both halves of the symmetrical design. These two halves are then subtracted in the audio frequency domain, which will eliminate the GSM Buzz, leaving only the signal. The third method is filtering GSM Buzz in the audio band, after it has already been rectified into the audio band.

The weakness of super symmetry and differential design is that GSM Buzz is rarely equal in both halves, even in parts that are very close together and highly symmetrical. The weakness of audio band filtering, is that the 217Hz signal is rich in powerful harmonics, and each of these must be filtered. Typically, a notch type filter is used, but many notch filters are needed to eliminate the buzz sound. The filtering problem is made more difficult, because the higher harmonics are the most easily audible to human hearing, and these harmonics are at the same frequencies as the desired signal.

This document focuses on the preferred, and by far most effective, methods to eliminate the RF energy before it can be rectified into audio band energy.

1.2. RF Reduction by Shielding

The idea of shielding is to create a traditional Faraday Cage, which by theory and in reality will block all RF energy from entering the device. A practical problem exists that an ideal Faraday Cage has no holes (relative to the RF wavelength) or wires going into the inside of the cage, so a device completely encased in metal may not be a very useful product. Shielding is also very costly for consumer electronic equipment.

However, shielding critical component areas or subsystems can be practical and cost effective with careful application and design. This requires expert knowledge of how to build such shields, understanding details of allowed opening sizes, soldering points, materials, and seam folding-welding. Attention must also be given to any wires and/or components that link the inside area of the shield to the parts of the system that are outside of the shield or shielded areas.

1.3. RF Reduction by Antenna Reduction

The most important and effective RF management tool is to eliminate any unintended antennas that will receive the RF energy and insert it into a system circuit. If there is no receiving antenna, there will be no problem with RF interference.

Any wire, component, or PCB trace can be a potential antenna. The wavelength of the high GSM band is about 0.16 meters. Because the RF field strength can be very large, even a short antenna can receive significant RF energy. A good rule of thumb is that anything longer than about 1/16 wavelength (10mm) can be a significant antenna. Allowing for margin, harmonic energy, etc. this makes for a good overall rule that wires longer than 6mm (1/4 inch) can be a concern, especially in critical circuit areas. This rule can be relaxed if it is known that an RF transmitter antenna cannot be placed very close (a few centimeters) to the audio circuit and wiring that could be affected.

1.4. RF Reduction by Blocking

RF energy that has become electrical can be blocked by inductors. Inductors inhibit any rapidly changing electrical current. So, when wires cannot be made short and cannot be shielded from RF, adding a series inductance is the next effective and important technique to keep RF energy from entering audio circuits.

The main difficulty is that at 1GHz frequencies, many magnetic materials and become ineffective or unpredictable. It is important to use ferrite and inductive components specifically designed for these high frequencies. Because the inductance value is not constant with frequency, and other non-ideal properties come into play, these parts are typically specified by graphs of their effective resistance in the frequency range of interest. So, an inductor may be specified by a resistance value (commonly 600-ohms), rather than by an inductance value.

A lower cost alternative to inductors can be simple resistors. A specific chosen resistor should be evaluated for its effectiveness at high frequencies, but most surface mount resistors have adequate properties. A high value resistor (such as 2k-ohm) may be much more effective and lower cost than an inductor with an effective 600-ohm impedance at the RF frequencies.

Where ferrite inductors are used to block RF energy from an area, it is also important in the physical design to be aware of any coupling capacitance. Even a very small capacitive coupling can route RF energy around a blocking inductor, rendering it useless.

1.5. RF Reduction by Shunting

The next and final line of defense against RF energy is to shunt the energy to ground. This is achieved by RF bypass capacitors. As with other components, at these very high frequencies, non-ideal properties of components can be very important. For a blocking capacitor, the wire lead to the capacitive element is a significant inductor. The idea of the capacitor is to short-circuit RF energy to ground. If there is a series inductor (the lead to the capacitor), the inductor adds a large series impedance, and the effectiveness of the capacitor is defeated. At these very high frequencies, even the short body lead of surface mount capacitors has a significant and important lead-wire inductance.

For GSM frequencies, a common and effective technique is to use a 10pF and 33pF capacitor in parallel at each node in the circuit where RF shunting is desired. The 10pF is most effective for the 1900MHz band, and the 33pF capacitor is most effective for the 800MHz band (again, owing to the non-ideal effects of lead-wire inductance). A single compromise value of 22pF may be tried, but will not be as effective as the two capacitors working in parallel. Larger value capacitors will NOT be effective, because they typically have much greater lead-wire impedance that will make them useless at GSM frequencies.

1.6. Audio Chip Integration General Issues

High frequency RF energy can pass into any pin on an audio IC. Typically, multiple pins may be involved. When RF energy passes into an audio IC, the effects are unpredictable. As a generality, it should be assumed that RF can come into any pin (audio, power, logic, input, output). Once the energy is inside the audio IC, it may pass anywhere in the chip, and may even contaminate the entire chip substrate with RF noise energy. This energy can be rectified anywhere and at multiple locations inside the IC, and at each rectification location, create audio band GSM Buzz noise.

Although microphone inputs are often the focus of design efforts to eliminate GSM Buzz sounds, the unwanted RF energy may or may not be introduced at the microphone input. It is only believed by the engineer that the microphone input is the problem, because that is where there is a large amount of amplification. It can easily be the case that the original RF energy is actually entering the chip from a completely different pin, such as a loudspeaker output driver pin.

1.7. Summary of Audio Chip Integration Design Guidelines

1.7.1. Understand that RF energy may be coming in on any, many, or all pins of the audio IC.

1.7.2. Critical areas can, if necessary, be shielded by metal shields

1.7.3. It is best to keep all critical wire or PCB trace paths extremely short in distance, with the longest path being 6mm long or shorter.

1.7.4. Wires or PCB traces that cannot be made short in length can be passed through a series inductor or resistor to block any RF energy on that wire. A typical inductor would be a 600-ohm impedance ferrite at 1GHz. Impedance may be higher or lower as required at the frequency of interest. After the series element, any additional PCB traces should be kept as short as possible, and/or should be contained in a shielded area.

1.7.5. Sensitive pins can be best bypassed with a parallel combination of both a 10pf capacitor and a 33pF capacitor. Capacitors should be placed as close as possible to the pin. Most effective is to additionally and immediately precede path to the pin with a series inductor or resistor with the highest reasonable series impedance appropriate for that node.

1.8. Version History

VERSION	DATE	PAGE	DESCRIPTION
1.0	March 2008		- Preliminary Revision

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