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THE PULSE RATE FOR GSM IS WITHIN THE AUDIO BAND, AND THE DC CURRENT AND RF ENERGY READILY CONVERT INTO AN OBJECTIONABLE AUDIO "BUZZ" WITHIN THE PHONE'S CIRCUITRY. YOU CAN MINIMIZE THE BUZZ IF YOU TAKE PRECAUTIONS EARLY IN THE DESIGN STAGE.

Reducing audio "buzz" in GSM cell phones

Mobile-phone designers who build to the GSM standard must sufficiently reduce audio "buzz" so that it is inaudible to users. GSM cell phones use a TDMA (time-division multiple-access) time-slot sharing technique that results in high-power RF in the 800/900- or 1800/1900-MHz bands. The transmitter current, which can exceed 1A, pulses during a phone call at a repetition rate of 217 Hz and pulse width of about 0.5 msec. If current pulses couple to the audio circuitry, the harmonic-rich, 217-Hz signal results in an audible buzz.

Users rarely encounter an audible buzz with most quality mobile phones on the market today. However, when a wired headset's signal lead gets too close to the phone's antenna element, the problem emerges even in quality phones.

WHAT'S THE BUZZ?

Energy in the audio-frequency range, including the 217-Hz TDMA pulse-repetition rate and its harmonics, exists in the phone in two forms: as variations in the dc-supply current and as the RF signal's modulation envelope. The dc-supply current pulse waveform comes from the large current that the RF power amplifier draws during transmission time slots and the smaller current that the RF circuitry draws during the receive interval (**Figure 1**). These currents rise atop a varying baseline current that the phone draws for the processor and audio section that continues even while the RF circuitry is turned off to save energy between time slots.

The 217-Hz pulse waveform produces an audible buzz when it couples into the audio path and conducts to the speaker, earpiece, or microphone. The two primary mechanisms for coupling the current waveform into the audio circuits are supply and ground ripple, both at the 217-Hz rate. Additionally, a portion of the transmitted RF energy can couple into the audio circuits. The audio section can rectify the RF signal, which extracts the waveform envelope in the way an AM detector would.

A Fourier analysis of the periodic narrow pulse shows the 217-Hz fundamental and its harmonics—the typical TDMA-buzz spectrum (**Figure 2**).

The high current that the power amplifier requires to generate transmit signals occurs only during the transmit time slot, so a periodic battery-current waveform of 1A or more repeats at a 217-Hz rate with a 12% duty cycle. During the receive time slots, a lower current pulse occurs due to the power-saving technique of turning off unused circuitry, such as the receiver RF components, when they are not immediately required. IR drops across the battery's internal impedance and wiring and pc-trace resistances convert the current waveform into voltage waveform on the B+ supply that ultimately powers the audio circuitry.

A related effect is modulation of the ground potential due to IR drops in pc-ground traces as the transmit current returns to the battery source. This effect is most pronounced when there is a long distance between the battery terminals and the biggest current load, the power amplifier, and when the ground return path is not solid and direct (**Figure 3a**). With pulsating current flowing in the ground return from the amplifier to the battery, any circuitry between the two is grounded to a point that is not fixed at a constant voltage.

Under such conditions, the supply voltage across the phone's various elements likely differs for every component. Unless the layout engineer designs the phone's pc board with care, this varying voltage can directly modulate an objectionable buzz onto the audio paths. Even with ground impedance as low as

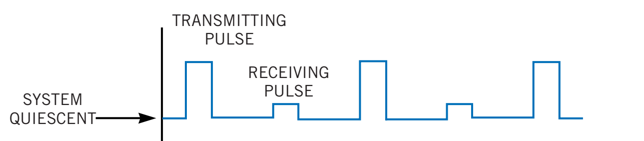

Figure 1 The periodic transmitting- and receiving-current pulse waveform can couple into a mobile telephone's audio circuitry, resulting in an audible buzz.

20 mΩ, and a voltage divider between the amplifier and the battery with the audio circuitry in the middle, the typical 1A current pulse creates a 10-mV disturbance on an audio component's ground pin, which could be audible. Audio amplifiers, switches, and other modules should exhibit good power-supply rejection and, if feasible, should take power from a regulator to attenuate fluctuations on the power rails before they translate into audio voltage signals.

Transmitted pulsing RF energy couples from the RF signal traces and antenna to other circuit elements in the phone and, ultimately, to lines that connect to the audio amplifiers. Semiconductor junctions can detect the conducted RF envelope in and around the audio circuits, signal lines, and power lines (**Figure 4**).

The highest power level setting, therefore is 32 dBm—more than 1W—of RF power in a typical phone, and testing indicates that levels as low as −40 dBm—less than 1 μW—impinging upon semiconductor junctions can create an audible buzz in the speaker at maximum volume.

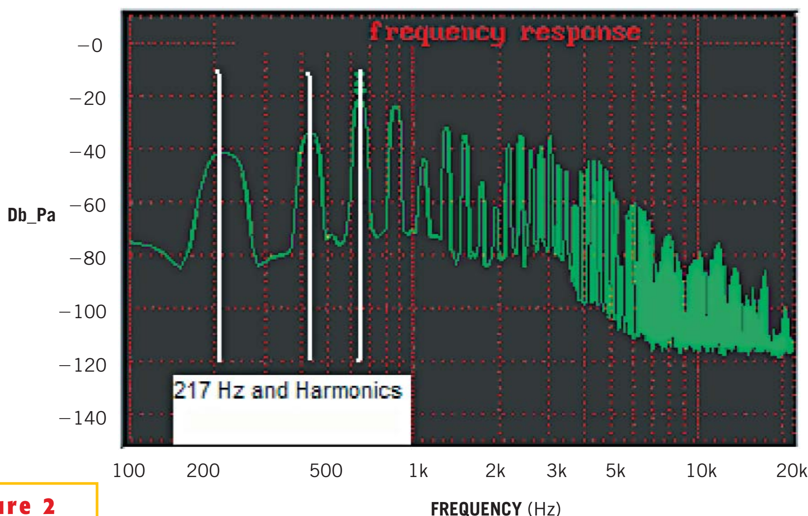

Figure 2 A Fourier analysis of the current pulse during the TDMA transmitting and receiving intervals reveals the spectral composition of the resulting buzz.

MITIGATING TECHNIQUES

The largest contributor to B+ line fluctuations due to load-current pulses is likely to be the battery's internal ESR (equivalent series resistance), but board trace resistance also is a contributor. To reduce the likelihood of B+ line fluctuations from board-trace IR drops, take care in the pc-board design. Make the high-current path from the battery to the power amplifier as short as possible with a low-impedance trace. Power other circuitry, particularly audio circuitry, from a separate power trace back to the battery contacts. This approach is particularly helpful for circuits not powered from regulators, such as the amplifier for the alert transducer or speakerphone, which typically take power directly from the battery to get the maximum peak voltage available.

In addition to isolating traces, using heavy copper traces, and using the widest traces that space allows, you must also exercise care in defining layers and in using vias. Route high-power supply currents on a layer adjacent to a ground layer. Also be sure to include a sufficient quantity of vias to connect the traces on different layers; otherwise, the limited via path can become a current bottleneck even though the traces on individual layers are thick enough.

A large, solid ground plane covering the entire board area gives the lowest impedance and best performance both at dc and at RF. You can realize the lowest impedance power-amplifier ground by placing that device close to the battery terminals. Improve isolation between the audio and the RF sections by locating the audio subsystem in another board location, so that ground currents from the amplifier do not pass under the audio circuitry (**Figure 3b**).

When multiple audio-source devices, such as an MP3 codec, a phone baseband section, and an FM radio all route to a common audio amplifier, be sure that an inactive device does not lose its inherent power-supply-rejection capability and conduct in-band power fluctuations onto an otherwise-clean audio path.

Another, albeit less likely, mechanism for coupling 217-Hz pulses into the audio circuitry is through inductive or capacitive coupling of the low-frequency pulsed dc. RF-filter components do not filter disturbances that couple onto audio-signal or power-supply leads in this way. Instead, employ sufficient spacing or guarding to prevent the coupling. One practice that can improve the spacing between high-current power-supply traces and audio

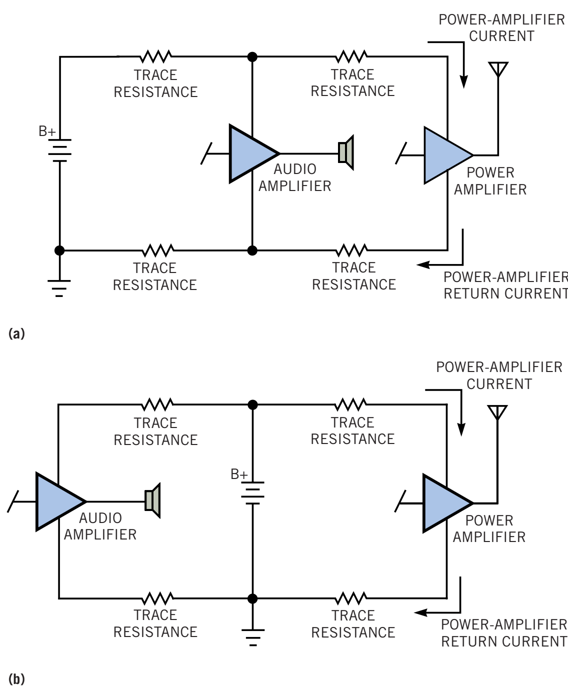

Figure 3 Poor supply and ground layout can result in current-dependent variations in supply and ground potentials (a). Thoughtful floorplanning and careful power- and ground-bus design help minimize opportunities for power fluctuations in the RF section to affect audio circuits (b).

lines, is to put them on opposite faces of the board.

CHECKLIST

Good layout must prevent RF energy from coupling into the audio and power traces that serve the baseband section or audio circuits within the phone. The design of these subsystems must block or bypass RF to ground so that it is not conducted to the semiconductor junctions of active audio components. RF energy can get from the RF circuitry to the audio circuitry through a variety of paths:

- radiation from the antenna to the audio or voltage regulator components or to traces or components connected to them;
- conduction from RF components through traces to the audio components;
- conduction through ground to the audio subsystem;
- trace-to-trace coupling between lines or from a line to ground on the same or adjacent layers; and
- coupling from line to component or component to component.

Prevention methods include shielding, ground design, and careful overall layout practice:

- Shield the audio section and its associated power-management and baseband sections to isolate them from stray RF. Shield the RF section to minimize the stray energy.
- Terminate the shield on a solid ground that is free of high dynamic currents.
- Isolate solid, largely unbroken audio ground on the layer below the audio section from pulsing current.
- Do not allow traces on the same layer to bisect ground.
- Connect components to the ground layer through multiple vias.
- Do not route traces carrying power or audio signals parallel to those containing RF or large dynamic supply currents. Maximize the spacing between sensitive traces and potential sources of interference.
- Isolate audio traces on inner layers from nonaudio traces by a ground trace with enough via holes to act as a faraday shield.
- Do not place traces containing RF or dynamic dc currents directly under audio components.
- Place audio-feedback and interstage-coupling components as close as possible to audio amplifiers, and isolate those components from RF-energy sources.

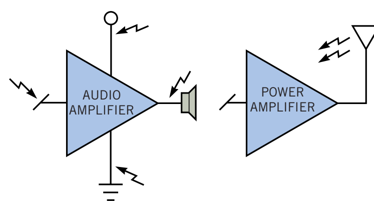

Figure 4 Radiated RF gets everywhere.

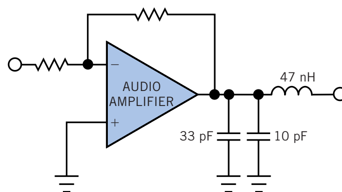

Figure 5 An L-section LC lowpass RF filter isolates semiconductors in the audio subsystem from coupled RF appearing on signal traces.

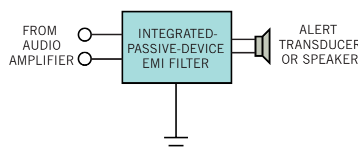

Figure 6 An integrated passive device can combine an RF filter and ESD protection for external connections.

Despite your best effort, some RF will couple onto audio traces. To prevent this energy from conducting into the audio amplifiers' semiconductor junctions, employ filtering methods. Using bypass capacitors to ground is a first step. They must bypass RF without affecting audio, so use appropriately small values. Because cell-phone RF occupies bands in the vicinity of 900 and 1800 MHz, the best choices are those capacitors that are self-resonant at those frequencies. Typical values for this application—10 and 39 pF—have negligible effect on audio signals. Use one each to shunt RF appearing at each audio-amplifier input, output, or power pin that you find sensitive to RF.

For further isolation, add an inductor to form an L-section LC lowpass filter, placing the filter components as close to the amplifier pin as possible (**Figure 5**). Add such filters to sensitive pins in the audio path whether they act as inputs or as outputs to the audio signal; either can exhibit sensitivity to RF energy. Again, the inductor should be self-resonant in the 800- to 1900-MHz range. Values of 39 to 47 nH are often effective in this role. For high-impedance pins, you can save cost by using an L-section RC filter instead of an LC lowpass filter.

During the prototype effort, test every filter component by removing it to verify whether it hurts or helps the buzz problem. Capacitors connecting a relatively clean signal line to a ground containing pulsing RF make the problem worse. Arrange inductors so that they do not act as antennas to radiated RF and cause more harm than good. In many cases, the physical location of the bypass capacitors and LC-filter elements is also critical to reducing buzz. Use filter components on both input and output audio paths and test both during the prototyping process.

It's often helpful to add LC or RC filters at the headset, charger, and data ports to prevent connecting cables from acting as antennas and conducting coupled transmitted power into those points, whence it can find its way back to the audio circuitry. A common approach uses an integrated passive device—a single component that includes an RF filter and often ESD protection. You can use these devices at the various interface points, such as the speaker, the headset jack, or the microphone, instead of or in addition to LC or RC filters.

Place the integrated passive device as close as feasible to the transducer or the jack. Use a separate device for each transducer or jack. For example, the speaker and the headset jack should each have its own device filter even if they share an audio amplifier on the board (**Figure 6**). Wireless products with circuitry on more than one pc board can benefit from bypass capacitors at the interface connector for the board-to-board interface.□

AUTHOR'S BIOGRAPHY

Bill Poole is a senior systems and applications engineer at the Radio Products Division of the Wireless and Mobile Systems Group at Freescale Semiconductor (Tempe, AZ). In his current position, Poole specializes in system and architecture development and application support for power-management ICs for 2G and 2.5G GSM cell-phone applications. He has a bachelor's degree in electrical engineering from Florida Atlantic University (Boca Raton).