Integrating Bluetooth in the GSM cell phone infrastructure

Embedding a Bluetooth subsystem in a cellular telephone may be the first step toward complete wireless integration

By Steve Brown, Mark Lane, Dino Fernandez

We've all heard the distinct sound in elevators, at restaurants, during meetings, even at church: *the cell phone ring*. The sound pierces through the air as discernible as a mother calling for her children in a supermarket. The reaction is immediate: People dive into their pockets, rummage through purses or reach along belt buckles to check if the intrusion emanates from their person. It seems everybody has one: business people, housewives, janitors, kids, even nuns.

Integrating the future.

Business is won and lost. Personal relationships are strengthened or weakened. It's inescapable. Moreover, it's annoying. Nevertheless, that sound we hear is only a minor irritation. The noise we can't hear or see is the real nuisance. For engineers, it impedes our advancement, another roadblock the evolution of technology must conquer. It makes life difficult for the ones entrusted to make life easier.

One can only wish...

In a perfect RF world, a simple hand-held device such as a cell phone would work seamlessly to transmit and receive information to and from computers. It would open garage doors, set timers on VCRs, change channels on televisions, surf the Internet, and buy a soda from a vending machine — one device, endless possibilities. In a perfect RF world, there would be no wires to connect. In a perfect RF world, PC would communicate with Mac. In a perfect RF world, there would be no such thing as interference or noise. The airwaves would be serene, and everything would co-exist. HomeRF, 802.11x, and Bluetooth would lovingly share the 2.4-GHz band. And, RF would stand for "really friendly."

Currently, Bluetooth wireless technology is being touted as a de facto standard, as well as a global specification for wireless connectivity. It is a cable replacement technology that simplifies the communications between people, as well as mobile PCs, cell phones and other portable devices.

Bluetooth's markets and opportunities

Cell phones are one of Bluetooth's larger potential markets. In fact, Bluetooth's roots are in the global system for mobile communications (GSM) world, and forecasts predict fast growth of Bluetooth in the GSM markets. However, putting a powerful cellular radio next to a low-power Bluetooth radio in a cell phone requires careful design because of the possibility of RF transmit and receive interference between the two radios. Therefore, engineers must develop Bluetooth systems using special radio filters that can function despite internal noise from the GSM cell phone and spurious radio signal interference.

In reality, any Bluetooth module/unit will be exposed to an unfriendly RF environment. The Bluetooth system is designed to have a high tolerance to interference, but is not necessarily designed to have high sensitivity. The 2.4 GHz industrial, scientific and medical (ISM) band, which includes microwave ovens, presents serious forms of interference for Bluetooth communications. The biggest problem in adding Bluetooth to cell phones is the potential for the powerful cell phone transmitter blocking the Bluetooth receiver during transmission. While GSM hand-held transmitters produce 1 to 3 W, the Bluetooth receiver is intended to operate effectively with signals as low as 10 pW, or 1/100,000,000,000 of the power, resulting in the Bluetooth receiver being overwhelmed by its over-

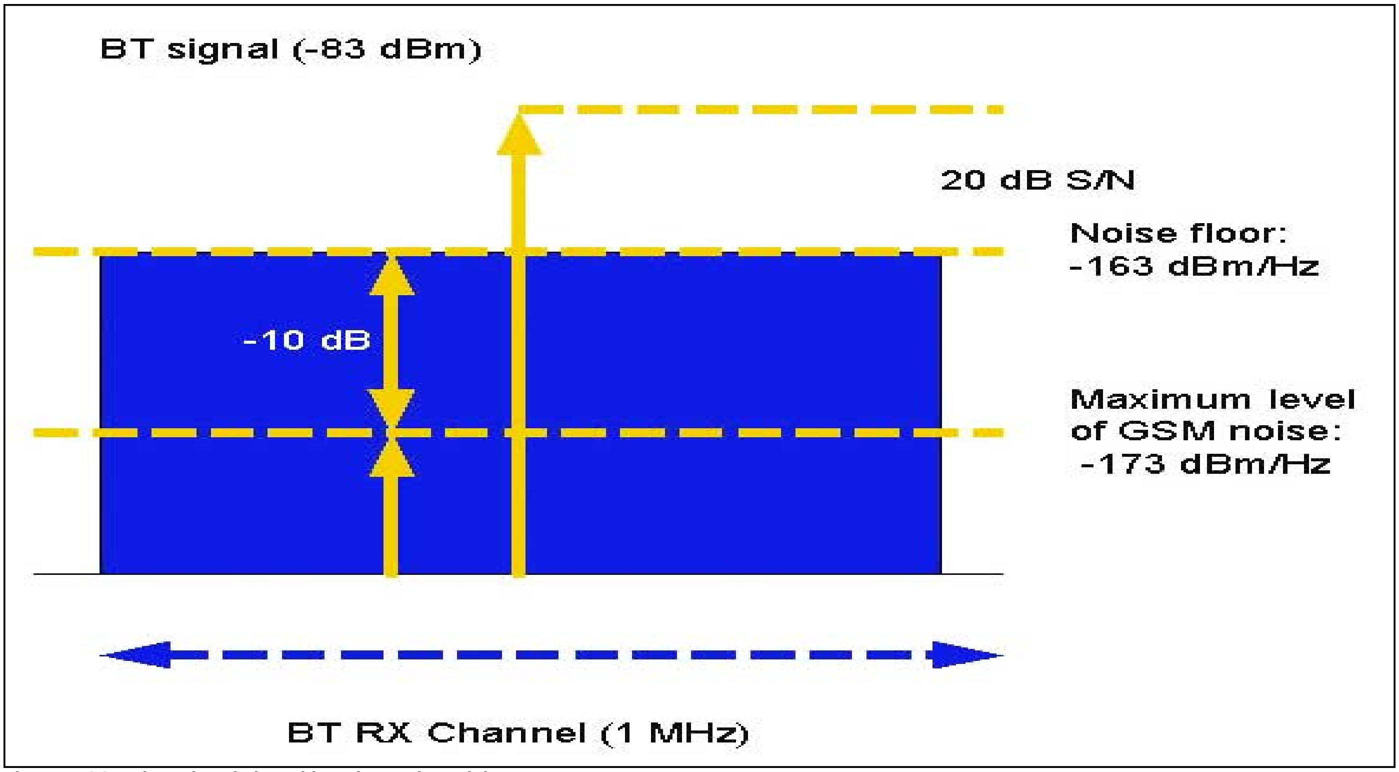

Figure 1. GSM phone interfering with a Bluetooth module.

bearing cell phone neighbor. The GSM transmitter may also generate significant noise, which could limit the range of Bluetooth operations.

The issues — tx/ rx

The fundamental problem is that a cell phone's transmitter transmits not only the required data signal, but a certain level of noise as well. Some of this noise will appear in the Bluetooth band. The level of this noise might be sufficient to interfere or block an incoming Bluetooth signal.

Wideband noise affects half-duplex cellular systems (the cellular radio either transmits or receives, but does not do both simultaneously). Such systems include the time-division-multiple-access-(TDMA) based GSM standard, as well as full-duplex systems (the cellular radio can simultaneously transmit and receive) such as code-division multiple access (CDMA).

To illustrate the problem, consider the situation of a GSM-based telephone and a Bluetooth module. For the GSM standard, three possible bands exist: GSM 900, PCS 1900, and DCS 1800. The output power for each standard is shown in Table 1.

For GSM applications, the biggest source of noise in conventional transmitter architectures is from the RF up-converter. The noise floor of the VCO used in the frequency synthesizer typically dominates this noise. In addition to VCO noise, the non-linearity of the amplifiers used in the transmit chain can result in noise intermodulating in the amplifiers (see Figure 1). This intermodulation can result in a type of spectral re-growth in the output spectrum. This re-growth is reduced in most transmitters by using a bandpass filter to reduce the out-of-band noise. The far-out noise will be a function of the VCO noise, the modulator noise figure, and the amount of rejection achievable in the RF transmit filters.

Plan “B”

GSM designers have recently turned to architectures with no modulator by using translational loops. This relies on a high-frequency PLL. In this case, the VCO noise floor and the attenuation profile of a low-pass filter limit the wideband noise. In all three systems, the wideband noise from the transmitter that falls in the certain bands is restricted.

The specifications

Outside of these bands, all the telephones need to meet the following requirements:

- *ETSI requirements for spurious emissions other than those described above.*
- *<1 GHz: wideband noise must be <–36 dBm.*
- *>1 GHz: wideband noise must be <–30 dBm.*

Although the figures above are encouraging, the wideband noise in the 2.4 GHz ISM band remains undefined. Thus far, the FCC/ETSI requirements ignore the case of having a 2.4 GHz device inside a 900, 1800, or 1900 MHz device.

The Feds say...

The FCC allows users to operate wireless products without obtaining FCC licenses if the products meet certain requirements. For example, there is no limit on antenna gain so long as the radio operates under 1 W of transmitter output power. Because the FCC rules are market-based, they allow for flexibility within the band. This is a good thing because no one model will fit all situations. For example, in rural areas, spectrum interference is lower, but a higher radiation power (for greater range) is required. In urban areas where populations are denser, the need to eliminate interference is great.

The deregulation of this frequency spectrum does away with the need for

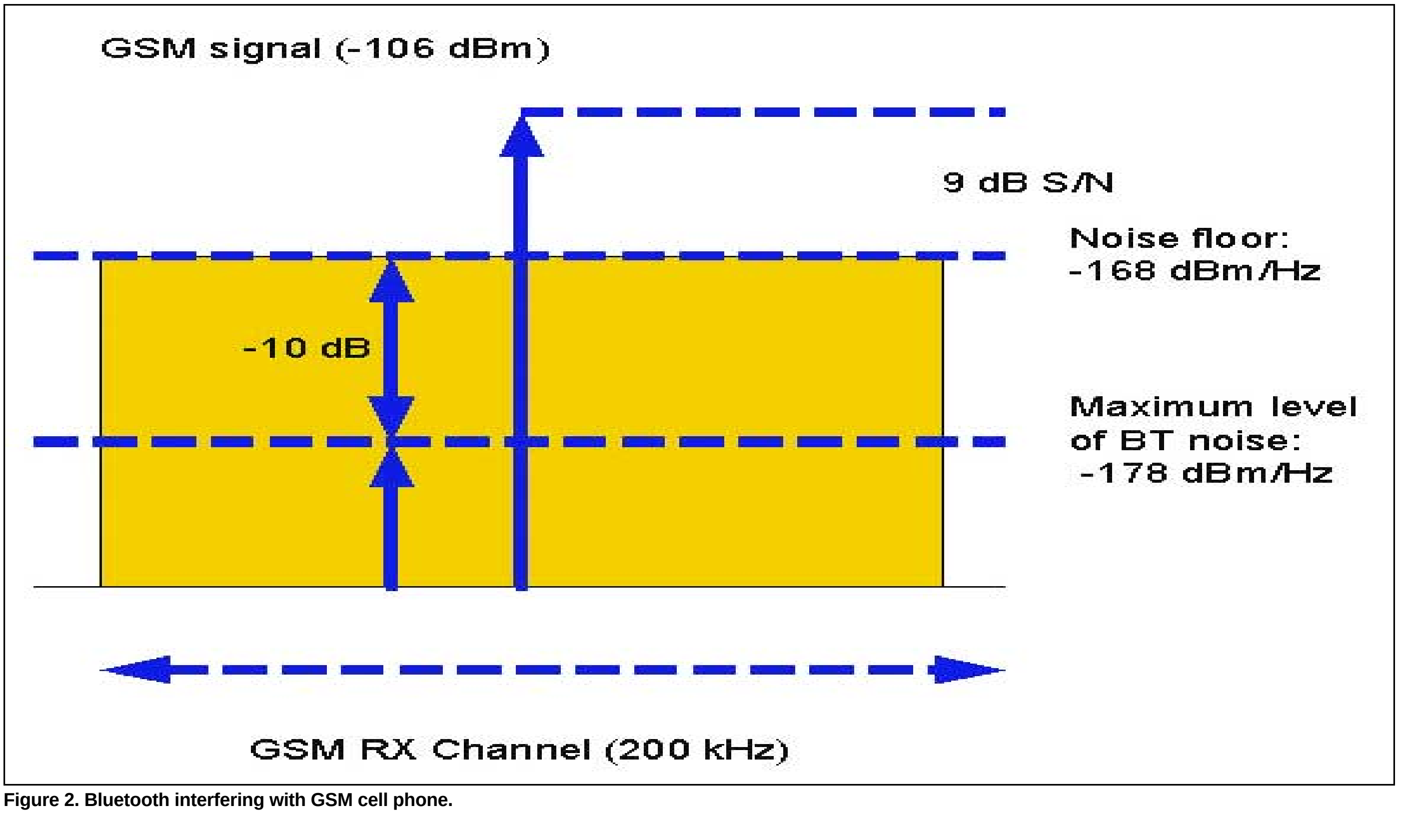

Figure 2. Bluetooth interfering with GSM cell phone.

user organizations to perform costly and time-consuming frequency planning to coordinate radio installations that will avoid interference with existing radio systems.

For companies developing wireless communications, the door is wide open because it allows companies to develop products without worrying about licensing products in new bands and stimulates competition between organizations to bring to market better overall products. More available bandwidth in the higher frequency bands translates into higher data rates. Thus, the creation of ad hoc networks is easier; one of the objectives of Bluetooth.

To ensure that the Bluetooth radio module will operate effectively inside a cell phone, the level of noise from the phone's transmitter must be measured and controlled. This is particularly true if the phone uses a filter at the output. It is important that this filter does not have a spurious response in the 2.4 GHz band.

In addition, designers need to build in a defense against interference. In radio engineering terms, the wideband noise, measured in a 1 MHz-wide band in the 2.4 GHz band, should be less than –100 dBm. If this is not the case, a trap should be placed at the output of the transmitter to attenuate energy in the 2.4 GHz band.

For Bluetooth, this will be relatively easy to add to today's phone designs, but may pose a problem for third-generation (3G) systems operating at 2.1 GHz because their signals are close to the 2.4-GHz band used by Bluetooth. The wideband noise requirements for a GSM transmitter in other bands of interest are given in Table 2. Note that there is no additional requirement for the 2 GHz ISM band.

To ensure that the Bluetooth unit/module will operate effectively inside a cell phone, the noise level from the transmitter of such telephones should be measured. This is particularly true if the telephone uses a filter at the output. It is important that this filter does not have a spurious response in the 2.4 GHz ISM band.

For a spurious emission of –83 dBm in the Bluetooth receiver band, the GSM spurious response requirements are given in Table 3.

System	Rx Freq. (MHz)	Tx Freq. (MHz)	Max. output power (dBm)
GSM 900	935 to 960	890 to 915	33 (3W)
PCS 1900	1930 to 1990	1850 to 1910	30 (1W)
DCS 1800	1805 to 1880	1710 to 1785	30 (1W)

Table 1. GSM output power.

System	935 to 960 MHz	1805 to 1880 MHz	1930 to 1990 MHz
GSM 900	–79 dBm	–71 dBm	–71 dBm
PCS 1900	–79 dBm	–71 dBm	–71 dBm
DCS 1800	–79 dBm	–71 dBm	–71 dBm

Table 2. GSM wideband transmission.

Problem: BT tx blocks GSM

The second problem in the cell phone application is the Bluetooth

Parameter	Specification
Required C/I (carrier-to-interference ratio)	20 dB
GSM spurious emission	–83 dB
Loss between BT and cell phone antenna	20 dB
Power into BT receiver	–103 dBm
Minimum discernable signal	–83 dBm

Table 3. GSM spurious response requirements in the Bluetooth RX band.

transmitter noise blocking the receiver of the cell phone (the "David and Goliath" problem). The Bluetooth transmitter must never interfere with the cell phone operation. This defeats the purpose of the Bluetooth application. Shown below and in Table 4, the level of noise from the Bluetooth transmitter in the relevant bands is calculated based on a maximum output power of 0 dBm. The aim is to keep the transmitted noise from the Bluetooth transmitter of the cellular telephone to ≤ the channel noise (the channel noise has a power spectral density (PSD) of –174 dBm/Hz).

In the GSM band, the Bluetooth transmitter will be able to achieve a PSD of –158 dBm/Hz into the Bluetooth antenna.

This, however, assumes the following:

1. Unfiltered transmitter noise is dominated by VCO phase noise/modulator noise at –125 dBc/Hz as the transmitter approaches a maximum power output of 0 dBm. This translates to –125 dBm/Hz.

2. The noise is attenuated at least 33 dB by the transmit filter.

Finally, if there is at least 20 db of coupling loss between the cell phone and the Bluetooth antenna, the level of the noise in the cell phones receiver will be -178 dB (see Figure 2), which is 10 dB below the noise floor of the GSM receiver. Hence this will cause < 1 dB desense of the GSM receiver. To accom-plish this, it is essential that the Bluetooth filter not have spurious responses at the cell phone receive fre-quencies.

Conclusions

Each cellular standard presents specific challenges to Bluetooth, and this analysis does not account for any other form of injected noise or interference such as that generated by digital logic circuitry, reference oscillators, liquid crystal displays (LCDs), and similar components. To smoothly integrate Bluetooth products into hand-held devices such as cell phones, power consumption must be minimal during active and standby modes and must be small enough to fit comfortably within the device. They must also be cost-effective so not to significantly increase the overall price of the device. Radio performance must have good sensitivity, low IP3 current, effective receiver blocking and transmitter sensitivity, low transmitter spurious response and low transmitter noise.

Band of Interest	PSD Noise	RBW = 30 kHz	RBW = 100 kHz
800 to 900 MHz	–158 dBm/Hz	–113 dBm	–108 dBm
1800 to 1900 MHz	–158 dBm/Hz	–113 dBm	–108 dBm
1400 to 1500 MHz	–158 dBm/Hz	–113 dBm	–108 dBm

Table 4. Transmitted noise levels from the Bluetooth transmitter.

As technology advances further (read: simpler; smaller; cost-effective), today's novelty items will become tomorrow's everyday appliances — domesticated devices that will be second nature. As the world continues to get smaller and communications systems improve, people will trade data and communicate seamlessly via airwaves. The fact that Bluetooth wireless technology is a standard and a technology with an ad-hoc nature makes this possible. Although Bluetooth has an innovative and well-thought-out architecture to survive in this unforgiving radio environment, extensive testing of real radios is the only way to ensure compatible high performance.

RF

About the author

Steve Brown is VP, general manager Bluetooth products at Silicon Wave. He has more than 10 years experience in design and management and holds a bachelor's degree in electronic and information engineering from Queens University Belfast, Northern Ireland.

Mark Lane is RF systems manager at Silicon Wave. Lane has three years of system design experience with Bluetooth and more than 10 years experience in the wireless industry. He holds a bachelor of electrical and electronic engineering with 1st Class honors from Auckland University New Zealand.

Dino Fernandez is a technical writer at Silicon Wave. Fernandez has been involved with the semiconductor industry for three years with seven years of analog design experience. He holds bachelor's degrees in electrical engineering, applied math, and English from San Diego State University.