INTEGRATING WIRELESS COMMUNICATIONS WITH MICROPROCESSOR BASED PRODUCTS

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ABSTRACT

Almost since their emergence microprocessors have been integrated into radio communications products. Today that trend has largely been reversed in that off-the-peg radio communications modules: GSM, GPRS, GPS, 3G, WLAN and Bluetooth are being integrated into a wide variety of microprocessor based products. This paper discusses the EMC aspects of such integrations from conventional narrow-band to modern spread-spectrum techniques. There are two goals for the designer: (i) to prevent the communications module and microprocessor interfering with each other (internal EMC) and (ii) to comply with appropriate market access legislation (external EMC). Both issues are essential in getting reliable products to market but only the former is considered here. A systematic design approach for the successful integration of radio and microprocessor devices is proposed. The different implications on microprocessor design of narrow-band and spread spectrum communications are investigated. Similarly the affect of the spread-spectrum clocking of microprocessors on radio receivers is discussed.

INTRODUCTION

Microprocessors were first integrated into radio transceivers as a result of the emergence of RF synthesisers in the 1970s and 80s. The pioneers quickly discovered the undesirable EMI effects of this union and developed techniques to overcome these. With a single design authority taking responsibility for integration, compatibility techniques such as ‘clock bending’ could easily be applied and controlled.

Today’s designers have a harder task in integrating today’s microprocessors and radio communications modules for two main reasons:

(i) Microprocessors are more complex, faster and noisier.

(ii) Radio modules come as complex ‘black boxes’ of which the designer has little detailed knowledge and almost no control.

These factors require a systematic approach to the integration process. Just such an approach is described in this paper.

VICTIMS AND AGGRESSORS

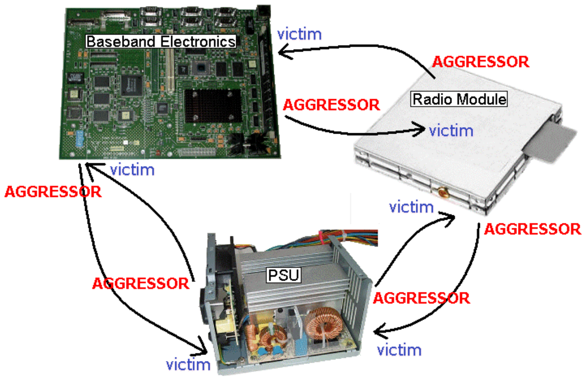
Decomposing the product as three main components:

(i) Host microprocessor-based sub-system (often referred to as the base-band electronics).

(ii) RF sub-system (radio modules).

(iii) Power supplies (PSUs)

Each needs to be considered as both an aggressor to, and victim of, the other components.



The author has found from experience that the ‘processor as aggressor and radio module as victim’ scenario is best considered first.

Radio Module as Victim

Radio receivers are necessarily sensitive in their reception band. Manufacturers quote a variety of parameters to specify a receivers performance and these can be used to draw up an ‘internal EMC’ specification. Where available the ‘blocking parameters’ should be used in preference to other parameters.

Blocking Parameters. Blocking Parameters are those defining the performance of a receiver tuned to a low-amplitude wanted radio signal in the presence of a variety of unwanted radio signals. Even if a manufacturer doesn’t give blocking parameters they can often be drawn from applicable standards. For example: the GSM radio transmission and reception standard[1] specifies the blocking parameters required for compliance. These can be used to derive an internal EMC specification for receivers known to comply with the standard. Figure 1 shows an internal EMC specification derived from the GSM900 requirements.

The in-band limit is derived from the co-channel blocking requirement of –99 dBm (8 dBuV). It is applied across the entire GSM900 reception band 933 to 960 MHz (UK). This is done because GSM modules don't report the frequency they are currently tuned to, so the only sensible EMC strategy is to prohibit emissions in the entire band to prevent internal interference.

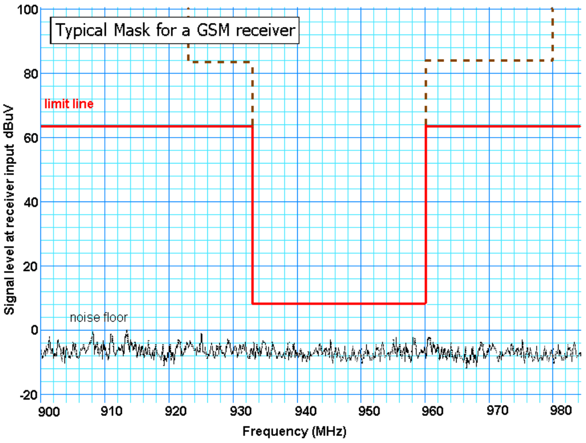


Figure 1 –EMC Mask for GSM900 Receiver

(The noise floor shown is typical of wideband measuring equipment)

The out of band limit is derived from the spurious blocking requirement of -43 dBm (64 dBuV). Although GSM900 specifies a higher blocking requirement out of band (the dashed line in figure 1) the standard[1] allows the manufacture to apply the lower spurious limit at up to six frequencies of choice. Therefore in the general case, where these frequencies are not known, it is necessary to use the spurious limit at all out of band frequencies.

NOTE: the receiver band in figure 1 is defined by the UK allocations listed below. The mask would have to be widened to support global coverage.

933-939.6 & 947-955 MHz Vodafone
939.8-947 & 955-960 MHz O^2

Other Parameters. It is not always possible to obtain blocking parameters for a receiver. Although most ETSI standards for radio performance specify blocking immunity requirements, compliance with them is not usually required for market access. An example is ETSI 300 220[2] (the standard used for short-range license-free telemetry), none of its receiver tests are required for market access. Therefore few manufacturers declare compliance to them. In such cases it is necessary to derive an internal EMC specification from other manufacturer supplied data.

An example of a typical 433.9 MHz telemetry receiver is shown in figure 2. This typical receiver has a sensitivity of -100 dBm (7 dBuV) and spurious rejection ratio of 60 dB. This is added to the sensitivity to give the out of band limit of 67 dBuV. The receiver is single-channel with a 3dB bandwidth of +/-120 KHz. The sensitivity rolls off at 18dB per octave (bandwidth) thus defining the slope of the mask.

More generally, limit lines can be constructed from the following commonly specified parameters:

Out of band limit = MIN(SPURIOUS,INTERMOD)
Band edges (near band) limit = ADJACENT
In band limit = SENSITIVITY

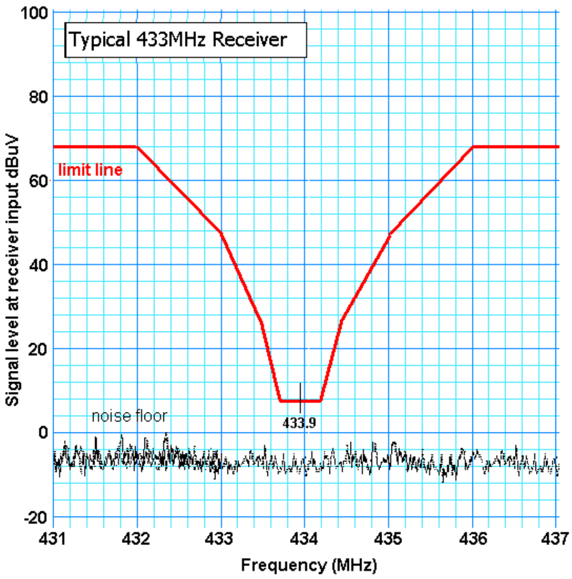


Figure 2 –EMC Mask for 433 MHz Receiver

The out-of-band limit is the sum of the spurious rejection ratio and the receiver sensitivity. Where spurious rejection is expressed as an absolute level then the sensitivity should not be added. Other figures often quoted are the third and fifth order inter-modulation rejection ratios. All receivers employ semiconductors with non-linear characteristics. These non-linear elements can mix out-of-band frequencies to produce in-band frequencies. These are termed IM products. The third and firth order IM product are defined by:

$\mathbf{f_0 = 2\cdot f_1 - f_2}$ -- third order
$\mathbf{f_0 = 3\cdot f_1 - 2\cdot f_2}$ -- fifth order

Where f0 (in-band) is generated by two out-of-band frequencies f1, f2.

Some manufacturers quote adjacent channel or adjacent band rejection ratios that can be used to generate a near-band limit. Again ratios should be added to the sensitivity to create a limit. An example of a mask created using this method is given in figure 3.

In this example the receiver is channelised with a channel bandwidth of 25 KHz, sensitivity of -105 dBm, adjacent channel rejection ration of 50 dB, spurious rejection ratio of 70 dB and 3rd order IM rejection ratio of 65 dB. These figures lead to limit lines of:

Out of band limit = 67 dBuV
Near band limit = 52 dBuV
In band limit = 2 dBuV

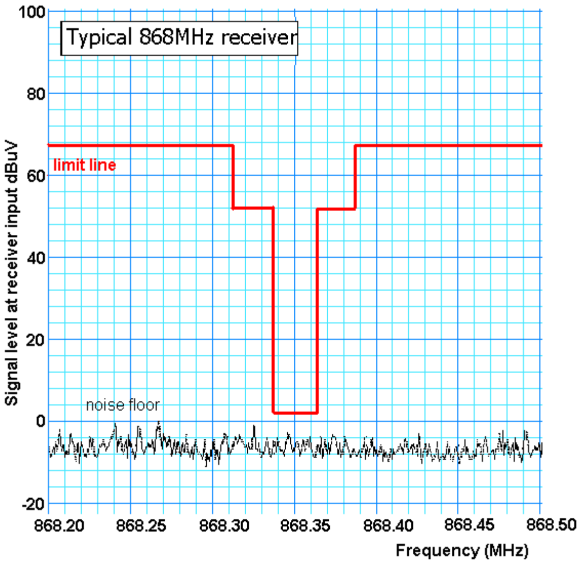


Figure 3 –EMC Mask for 868.35 MHz Receiver

Multi-Carrier Receivers. Multiple carriers are used to support higher data rates without the need for channel equalisers. This is achieved by splitting the data to be transmitted into low rate streams and modulating these streams onto adjacent channel carriers. Where the fundamental symbol duration is longer than the variation in multipath delays, then Inter-Symbol Interference (ISI) is not possible and channel equalisation not required. Digital Terrestrial TV Broadcast employs this technique.

Multiple carrier receivers are inherently more robust than single carrier receivers because even the complete loss of one data channel merely reduces the overall data throughput. An internal EMC specification for a multi-carrier receiver would start with the method already described, but the designer can allow for some in-band EMI to cross the limit line. To ensure the receiver is not excessively compromised the designer should additionally apply a Bit Error Rate (BER) or throughput limit. For example this method has been embodied in ADSL interoperability testing[3] (note: ADSL is a multi-carrier technology although not wireless).

Spread Spectrum Receivers. Improved noise and interference immunity is achieved by expanding the data to be transmitted to fill a larger bandwidth than is strictly needed. NASA[4] produced a useful specification for the immunity of direct-sequence spread-spectrum receivers. From this the author recommends using the method already described and then de-rating the limit line by interference margin I/S as defined by:

$$\mathbf{I/S = G_p - N_m}$$

Where:

G_p is the Process Gain of the receiver (in dB) estimated as 10·log(chips-per-data-bit). It's not always sensible to de-rate the limit line by G_p alone since spread-spectrum receivers generally operate to sensitivities below the noise floor hence the term N_m for the receiver noise margin. NASA define the noise margin as:

$$\mathbf{N_m = L_{sys} + S/N}$$

Where:

L_{sys} is the sum of receiver losses (i.e. noise figure plus correlator losses) and S/N the signal to noise level in the recovered data required to maintain a given minimum acceptable BER.

These figures may not be readily available and in most cases manufacturers will quote the receiver sensitivity including these losses. In such cases G_p can simply be added to the receiver sensitivity to determine a useful in-band limit.

Processor Electronics as Aggressor

Once an internal EMC specification has been derived from receiver characteristics it can be applied to the aggressor electronics e.g. the base-band electronics including (microprocessor, etc.). The best method for measuring emissions from the aggressor is to site the radio module's antenna in its intended place within the product. Then take measurements from the antenna using either a test receiver or spectrum analyser and pre-amplifier combination.

Alternatively (for example in situations where there is no product specific antenna) taking close-in field strength measurements in an EMC chamber is recommended. This is the method employed by the home office[5] when type approving electronic systems for use in police vehicles where the sensitivity and correct operation of police radios must not be adversely affected. The author recommends making measurements at 1 metre and employing the same limit line (albeit measured in dBuVM^{-1}@1M). There's no real empirical justification for this equivalence although the method has proved useful in practice in identifying problem emissions.

Other Victim – Aggressor Scenarios

There are a number of other scenarios to consider.

PSU as Aggressor. The power supply used to power a radio module can adversely affect a radio's performance and can also invalidate the conformance of a transmitter to its type approval specification.

Processor as Victim. The obvious scenario is of the radio module as aggressor when it is transmitting. The author has however rarely seen problems with modern radio modules which operate at transmit powers below 3W. GSM transmitters can cause some screen flicker with various display technologies.

Envelope demodulation in analogue electronics. Digital radio transmitters can wreak havoc on sensitive analogue electronics[6] particularly at risk are the A→D circuits often found in processor designs. All semiconductor junctions demodulate the AM components of incident RF energy. In low-level microphone circuits (for example) the unwanted audible component of the envelope (frame structure) of a digital transmission becomes superimposed on the wanted audible signal[7].

ENGINEERING COMPATIBILITY

Processor Emissions

Where a product has emissions exceeding the internal EMC limit line desensitisation or 'self quietening' occurs in the radio module. For example figure 4 shows a mask derived from the DCS1800 blocking requirements[1]. For the four channels that coincide with the processor emissions a receiver will be desensitised approximately by the level that the emission exceeds the limit line (e.g. 30 dB @ 1.8488 GHz).

Meeting the Internal EMC Specification. There are four techniques to achieve compatibility of which the first is usually best practice.

1 – Move the emissions out of the receiver band.
2 – Make the emissions 'incompatible'.
3 – Reduce the coupling from aggressor to victim.
4 – Reduce the emissions 'below the line'.

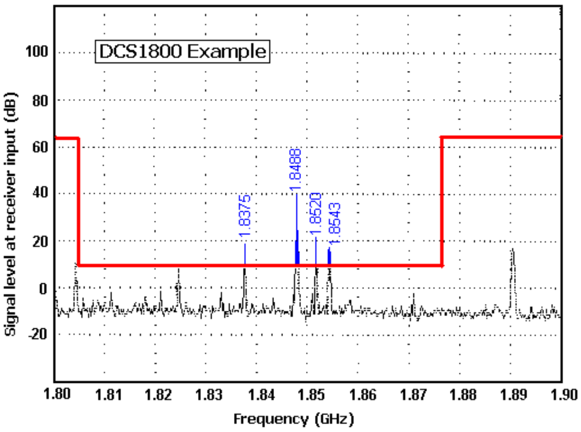


Figure 4 –DCS1800 Receiver Example

Moving Emissions out-of-band. This can be achieved by changing the frequency of crystal clock oscillators in microprocessor circuits. Usually only small adjustments are needed to move a given harmonic out of the receiver band but care must be taken not move another harmonic into it. Some processors have programmable internal clock speeds and so it may only be necessary to change software to engineer compatibility.

Clock Bending. Processor clocks can be moved dynamically in some applications to engineer compatibility (figure 5).

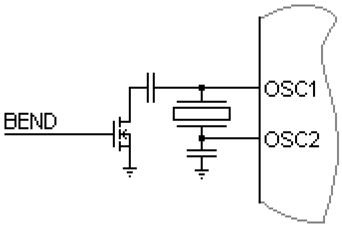


Figure 5 –A Crystal 'Clock Bender' Circuit

To employ this simple circuit effectively the engineer must have direct control/knowledge of the frequency the receiver is tuned to at all times. If that frequency is quietened by a processor harmonic then the BEND signal is asserted to move that harmonic to an adjacent channel. When the receiver re-tunes to another channel the BEND signal is relaxed. In the DCS1800 example (figure 4) the technique can't be use because the receiver channel is not divulged to the host system. It is likely however, that the designers of the radio module's own base-band electronics employed this frequently used technique.

Spread Spectrum Clocks. Spread spectrum processor clocks are increasingly being used to reduce the emissions of digital electronics[8]. Figure 6 shows a typical SS clock spectra.

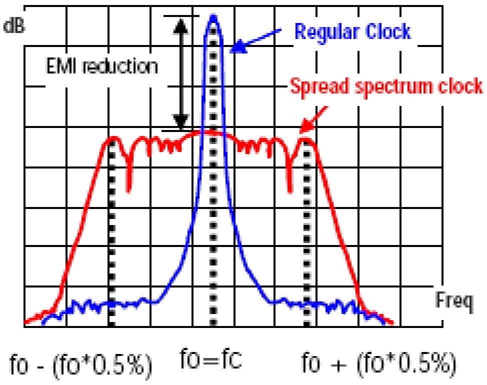


Figure 6 – Centre Spread Clock Example

If emissions can't easily be removed from a receiver's band or reduced in amplitude to below the limit line using conventional EMC engineering techniques, then spread spectrum clocking might be considered.

Spread spectrum clocking can however make matters worse in some applications because it pushes EMI into many receivers channels rather than confining it in a few. Nevertheless in the example of figure 4 spread-spectrum clocking is likely to reduce all but the 1.8488 MHz emission to below the limit line. It will however spread the 1.8488 MHz over many, rather than one, receiver channel. If a the spreading modulation signal is saw-tooth and the modulation frequency carefully chosen the side effect can be mitigated. The spreading modulation causes an affected channel to be quietened for a period t_b out of T where:

$$\mathbf{t_b = T \cdot B_c / B_s}$$
$$\mathbf{T = 1/2f_s}$$

Where:

B_c = receiver channel bandwidth,
B_s = bandwidth of in-band harmonic of spread clock, e.g. $0.01f_h$ for a 1% spread clock where f_h is the frequency of the in-band harmonic.
f_s = spreading frequency.

T and t_b are then so engineered that a corruption of t_b in T in the received data stream is correctable by the receivers Forward Error Correction (FEC). Note however that a contiguous period of $2t_b$ in 2T needs to be accommodated if either band edge of the spread spectrum harmonic falls in the receiver band.

Other good practice techniques. Many textbooks have been written on this subject and it is well beyond the scope of this paper to describe them in detail here. The author always employs the following good practice techniques when integrating radio transceivers with base-band digital electronics in the same product.

Separate DC Power. It's never good practice to power a radio module from the same supply used to feed the base-band electronics. Avoid using switched-mode supplies but if they have to be used then best practice is to add either an appropriate filter or a linear regulator between supply and radio module.

Control and Data Lines. All control and data lines connecting a radio module to its host should be filtered using one of the filters shown in figure 7.

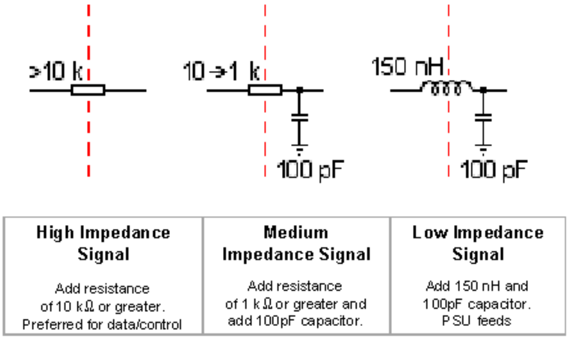


Figure 7 – Filtering Control and Data Lines

CONCLUSIONS

A systematic method for successfully incorporating radio communications modules in processor based digital electronics products has been presented. The method has been shown to be applicable to multi-carrier and spread-spectrum radio modules. Techniques for engineering compatibility between processor and radio modules have been explored.

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***T.P.Jarvis, March 2004** – Tim Jarvis is an independent consultant. His company RadioCAD (www.radiocad.com) assists clients in designing electronic products for compliance with European directives and worldwide standards. Tim has worked in the electronics industry since 1983 and specialises in RF design and EMC. t.jarvis@radiocad.co.uk.*