Atmel®

APPLICATION NOTE

RF System Architecture Considerations

ATAN0014

Description

Highly integrated and advanced radio designs available today, such as the Atmel® ATA5830 transceiver and Atmel ATA5780 receiver, enable the engineer to architect robust RF systems with greater levels of performance than ever before. In order to take advantage of these capabilities, it is important to understand how RF system architectures affect radio performance. This purpose of this document is to explore different RF system attributes and consider their implications to system performance.

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1. Interference and Jamming

Unwanted RF signals at or near the desired operating frequency can compromise the receiver's ability to accurately demodulate the desired RF data packet. Disturbers that occur *near* the desired operating frequency are considered "near-band" whereas those that occur *at* the desired operating frequency are considered "in-band". RF interferors appearing at a significant distance from the desired signal, such as 3 x F_{LO} or 5 x F_{LO} (where F_{LO} is the local oscillator frequency), are also capable of blocking proper demodulation. These are referred to as "Wide Band" interference. Different methods are required to mitigate each type of interfering signal. Common approaches are listed in the sections that follow.

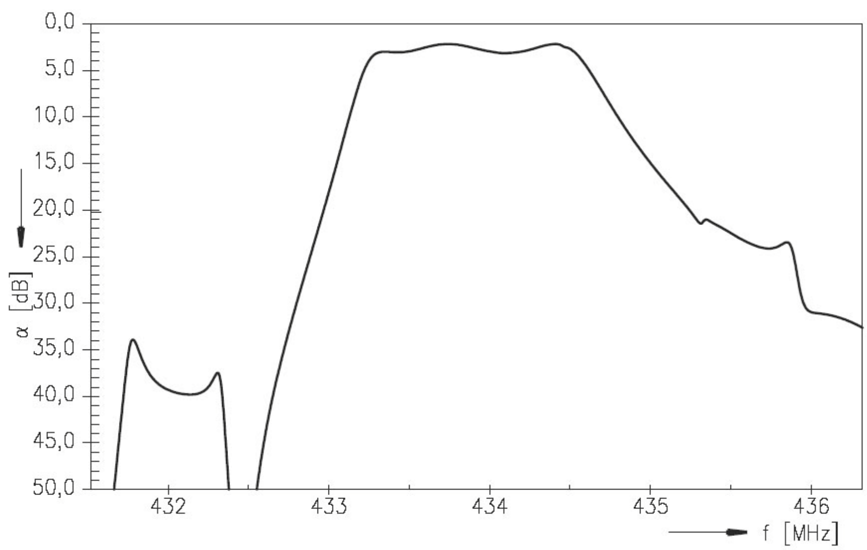
1.1 Near Band Interferors

Near band interference suppression focuses on improving the radio's selectivity / blocking characteristics. Selectivity is a term that describes the ability of the radio to select the desired signal from other RF spectrum. Blocking describes the ability of the IC to receive the wanted RF signal in the presence of a jamming (interference) signal.

1.1.1 SAW Filter

One approach to suppress interferors both near-band and wide-band would be to add a SAW filter between the receiver's antenna and RF front end. This has a bandpass effect which enables the desired signal to enter the radio with very little attenuation while subjecting the interferor to increased attenuation. Typical bandpass characteristics of a SAW filter are shown in Figure 1-1. In some cases, the additional suppression provided by a SAW filter may not be sufficient to fully block the interference. Additionally, this approach incurs added cost associated with the SAW filter.

Figure 1-1. Typical Frequency Response of SAW Filter



1.1.2 IF Bandwidth

Another approach to improve blocking would be the reduction of the receiver's intermediate frequency bandwidth (IFBW) or channel filter. To illustrate this point refer to Figure 1-2 and consider an interferor appearing 200kHz below the desired operating frequency. In this case, an IFBW of 366kHz where the corner frequency is 183kHz would only attenuate the disturber by 10dB. In contrast, using an IFBW of 25kHz would attenuate the disturber by 56dB, as shown in Figure 1-3.

Figure 1-2. Blocking Characteristics of Atmel ATA5830 at 433.92MHz, IFBW = 366KHz

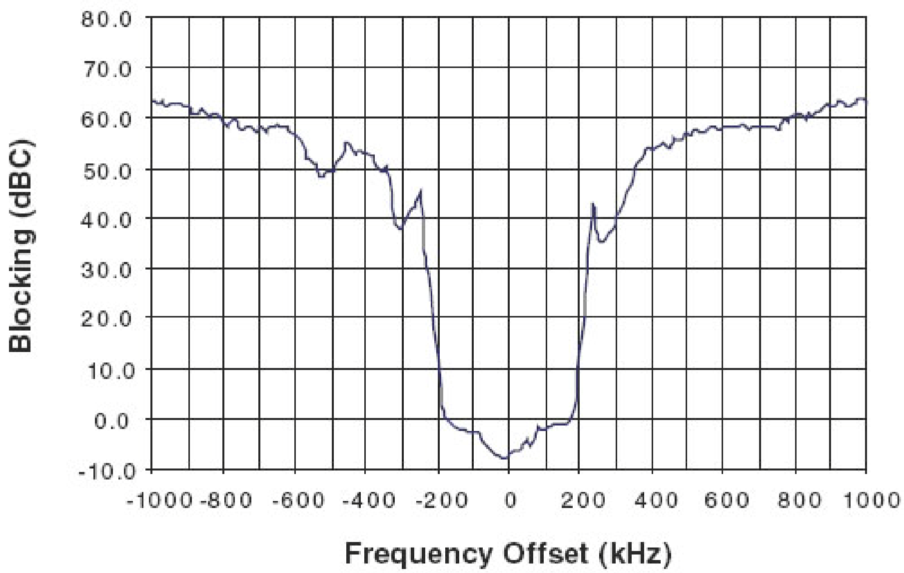
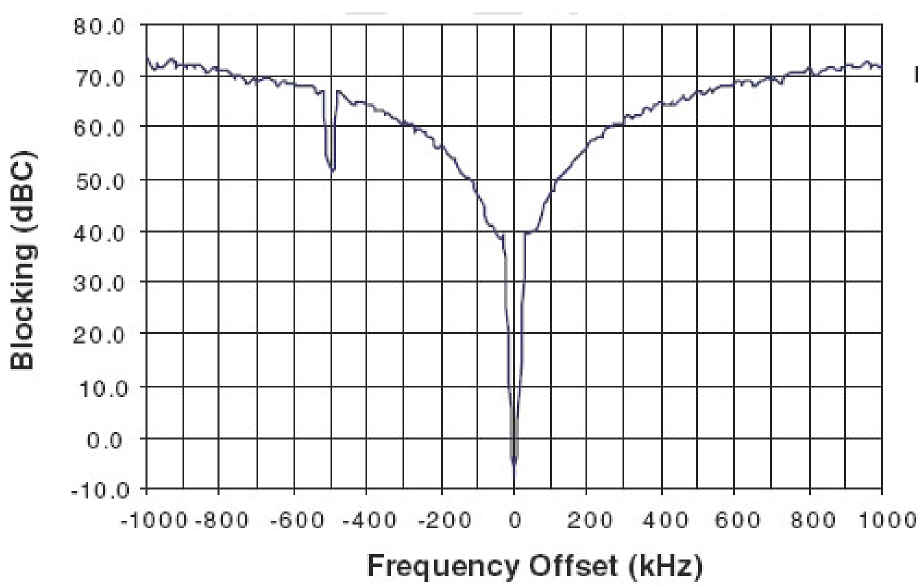


Figure 1-3. Blocking Characteristics of Atmel ATA5830 at 433.92MHz, IFBW = 25KHz



In the past, IFBW was fixed by the IC design. However, high performance Atmel devices such as the Atmel® ATA5830 and the Atmel ATA5780 enable adjustments to the IFBW through the use of an EEPROM based configuration table. The user configurable IFBW range spans from 25kHz to 366kHz and offers the engineer 26 different IFBW settings. During the optimization process, caution must be exercised to insure that the selected IFBW remains wide enough to account for variations in the RF frequency of both receiver and transmitter resulting from modulation and tolerance of internal frequency references. RF signals coming from the intentional radiator (e.g. transmitter) possess carrier frequency error terms due to initial tolerance, temperature, and aging. In addition to the worst case stack of crystal frequency tolerances on the receiver and the transmitter, selection of minimum IFBW must also consider the RF spectral bandwidth required to transmit the RF data packet at a desired baud rate and modulation as well.

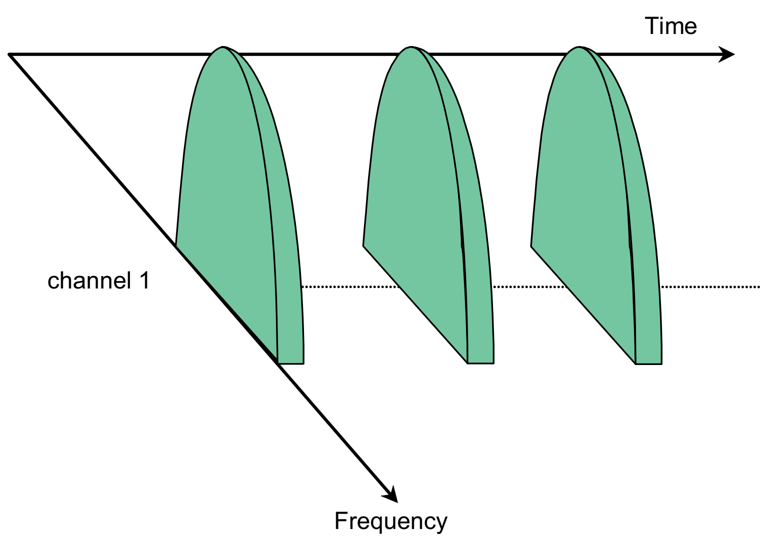
1.2 In Band Interferors

Unwanted RF signals within the desired operating frequency spectrum must be approached differently since it is not possible to differentiate between a very strong source of interference and the intended RF data packet. In this case, redundant information is the only method to mitigate this problem. Two methods to convey redundant information are used today; A) time domain redundancy or B) both time and frequency domain redundancy.

1.2.1 Time Domain Redundancy (Single Channel)

When the source of interference is intermittent, it is possible to send multiple copies of the same RF data packet, delayed by a finite amount of time (see Figure 1-4). This is the most straightforward approach and it enables the use of a single RF carrier frequency for both the transmitter and receiver sides of the RF system. This is common today due to its simplicity and low cost. However, it is ineffective if the disturber has a continuous presence. However, with the recent release of advanced and inexpensive integrated radio ICs, such as the Atmel ATA5830N and the Atmel ATA5789N, this approach is loosing ground to time and frequency redundancy methods.

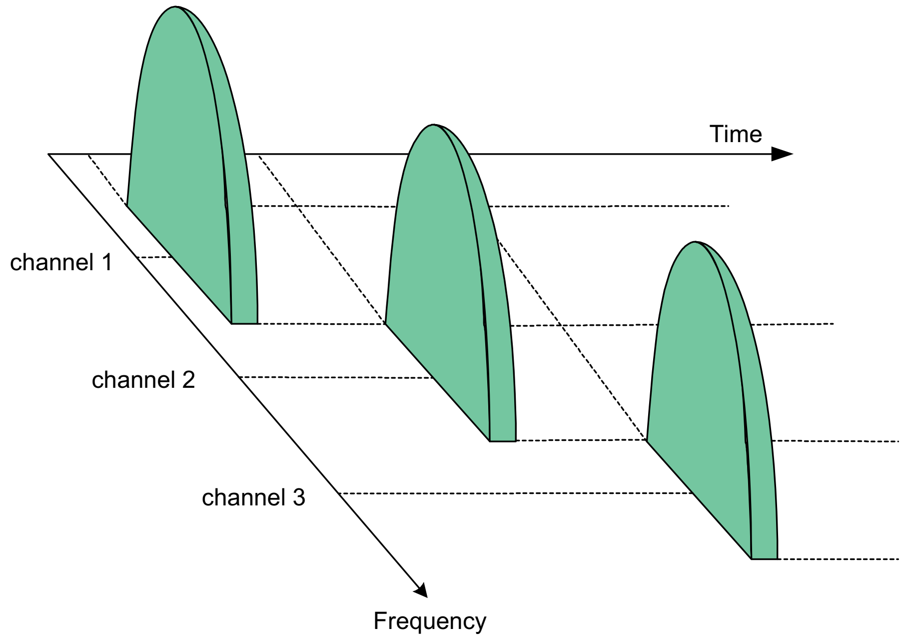
Figure 1-4. Time Domain Redundancy



1.2.2 Time and Frequency Domain Redundancy (Multi-Channel)

By adding the dimension of frequency to the existing time domain redundancy, it is possible to completely avoid a continuous RF disturber if the disturber's spectrum occupies a small frequency range. If the disturber occupies a wider frequency range than the channel spacing allows, problems may still occur. This approach offers a substantial improvement in radio performance and has the added benefit of being independent of the carrier modulation method. Graphically, this is shown in Figure 1-5. The time domain is represented in the horizontal axis and shows redundant data packets that occur after a finite time delay. The frequency domain is represented in the vertical axis and shows redundant RF spectral content appearing on different frequencies e.g. channels 1-3.

Figure 1-5. Time and Frequency Domain Redundancy



Channel frequency spacing must be at least as wide as the RF spectral content of the basic RF data packet to prevent channel overlap. In the case of Atmel® ATA5830N and Atmel ATA5780N, a channel spacing of at least 2 x IFBW is recommended. In automotive Remote and Passive Keyless Entry Systems today, channel spacing is typically in the range of 400kHz to 450kHz.

Factors influencing the selection of RF data packet spacing delay in the time domain include a) settling time to change channel frequency b) managing the average amount of RF carrier "ON" time c) overall system response time. Typically the channel frequency settling times are less than 1mS and are only of second order concern. The primary factor is managing RF energy in order to optimize range while maintaining local regulatory compliance. Through duty-cycle averaging, it is possible to transmit higher peak RF power levels provided the average power falls below the local regulatory agency's threshold. Obviously, higher output powers will enable RF systems to attain greater range.

Note: Range improvements can also be influenced on the receiver side of the system by specifying devices with high sensitivity such as the Atmel ATA5780N and Atmel ATA5830N.

In the U.S. RF transmissions are regulated by the Federal Communication Commission (FCC). The FCC allows the use of the following formula to apply a relaxation factor, up to 20dB, to the peak RF output power prior to determining whether the average RF output complies with the limit for a particular frequency:

$$\text{RelaxationFactor} = -20\log\left(\frac{\text{total RF on time}}{100_{\text{ms}}}\right)$$

For example, consider an FSK modulated data packet with duration of 10mS (RF carrier “ON” time) followed immediately followed by a 90mS blanking interval (RF carrier “OFF” time) and this sequence is repeated three times for redundancy. The relaxtion factor would be calculated as follows:

$$\text{RelaxationFactor} = -20\log\left(\frac{10_{\text{ms}}}{100_{\text{ms}}}\right) = 20\text{dB}$$

Clearly the length of the RF data packet and the type of modulation plays a roll in taking advantage of this method.

Multi-channel operation is enabled through high end radio architectures, such as the Atmel® ATA5830N and Atmel ATA5780N, which utilize a fractional-N PLL to establish the RF frequencies needed in both the receiver and transmitter blocks of an RF system. With the configurable approach these devices offer, it is easy to develop a receiver capable of quickly and accurately shifting the center frequency of operation (e.g. channel). These leading edge designs are fast becoming the RF system architecture of choice for automotive Remote and Passive Keyless Entry Systems.

2. RF Modulation

It's important to understand that Amplitude Shift Keying (ASK) and On-Off Keying (OOK) are not interchangeable terms. ASK is a special case of AM, while OOK can be considered an RF carrier that is gated On and Off. Upon closer examination of the equations for ASK and OOK, these fundamental difference should become clear.

Amplitude Modulation:

$F_{AM}(t) = \{1 + am(t)\} \times A\sin(\omega t)$

- **Asin(ωt)** is the RF carrier with amplitude A
- **m(t)** is the modulation signal ranging in value between –1 and +1, typically a sinewave
- **a** is the modulation index which can posses value between 0 and 1

Amplitude Shift Key Modulation (Special Case of AM):

$F_{ASK}(t) = \{1 + am(t)\} \times A\sin(\omega t)$

- ASK occurs under the following conditions:
  - modulation signal, **m(t)**, is a square wave, ranging in value between –1 and +1
  - modulation index, **a**, is 1
- Maximum amplitude is 2A
- Minimum amplitude is 0

On Off Key Modulation:

$F_{OOK}(t) = g(t) \times A\sin(\omega t)$

- **Asin(ωt)** is the RF carrier with amplitude A
- **g(t)** is gating signal which is either ON with value 1 or OFF with value 0
- Maximum amplitude is A
- Minimum amplitude is 0

While both ASK and OOK share the same envelope profile, it is significant to point out that the amplitude of an ASK signal is twice as large as its OOK counterpart. This means when performing receiver sensitivity measurements with an ASK modulated input, it will yield a 6dB better value than the same receiver when measured using an OOK modulated signal. In practice, automotive RKE and PKE systems use OOK.

2.1 Receiver Sensitivity

Due to the fundamental differences in how ASK and OOK sensitivity measurements are made and also the inherent characteristics of the receiver itself, Frequency Shift Key (FSK) tends to have an overall sensitivity advantage of 4-6dB over a comparable OOK receiver.

2.2 Demodulation Errors

The selection of OOK or FSK modulation also has implications on the receiver's ability to perform in the midst of interference and jamming signals. In general for an OOK receiver, demodulation errors will appear (in the case of Atmel ICs when BER > 10^{-3}) if the disturber is greater than 10dB to 12dB below the desired RF signal. However, with an FSK receiver, the RF disturber must be larger before demodulation errors occur; typically at levels of 4dB to 6dB (η=1) below the useful signal. This suggests FSK modulation has the advantage with respect to robust performance in the midst of interferors.

3. RF Carrier Frequency

Much debate centers on the topic of which carrier frequency bands provide optimum performance for automotive Remote and Passive Keyless Entry Systems; high band (868-915MHz) or low band (315-434MHz). Insight on answering this question rests in a better understanding of fundamental characteristics of each frequency band. The following sections will explore these implications in greater detail.

3.1 Output Power

Most regulatory agencies allow higher radiated transmit powers in the high band which brings the perception of greater system range. However, this is a “double edged sword” because an unintended consequence of this is the occurrence of disturbers with higher power levels which can compromise RF system performance. It is important to note that high power disturbers also exist in the low band too. However, it stands to reason that the likelihood of being subjected to RF disturbers of higher amplitude is greater in the high band than in the low.

3.2 Path Loss

Another parameter to consider is the RF path loss, which increases with frequency. In order to compensate for the higher path loss, the transmitter’s effective radiated power must be increased. This is only possible through the selection of a transmitter with higher output power capability or through the use of an antenna with greater efficiency. When factoring path loss, transmit power, and antenna efficiency into an RF Link Budget analysis, it may turn out that the perceived benefit of higher transmit power in the high band will be of marginal impact on the operating range of the system.

3.3 Antenna

A benefit to high band operation is the ability to realize highly efficient antennas (dipoles) using much smaller physical geometries due to wavelengths that are 2-3 times shorter than in low band. This is attractive not only for handheld remote fob applications but also for vehicle side. However, high band RF tends to propagate more directionally and may not provide as consistent performance as low band systems around the contours of an automobile.

3.4 IFBW and Crystal Tolerance

When selecting and specifying a design’s reference frequency crystal and its associated tolerance, it is important to understand the influence this has within high-band and low-band systems. For example, a typical crystal with a 150PPM frequency tolerance will yield a high band transmitter output frequency of 915MHz ±137.25kHz whereas that same crystal (150PPM tolerance) when used in a low band transmitter will result in an output frequency of 315MHz ±47.25kHz. To accommodate this frequency variation, the IFBW of the high band receiver must be set to a value nearly three times wider than what is needed in the low band (137.25KHz/47.25KHz) to capture the transmitted spectrum. Since receiver sensitivity is generally inversely proportional to its IFBW, this will desensitize the high band system and reduce the operating range of the system.

Alternatively, to mitigate this effect, a crystal with lower tolerance, such as 50PPM, could be specified in the high band application to achieve a comparable IFBW setting e.g. 915MHz x 50PPM = 45.750kHz as compared to 315MHz x 150PPM = 47.25MHz. But, this will have cost implications.

4. Revision History

Please note that the following page numbers referred to in this section refer to the specific revision mentioned, not to this document.

Revision No.	History
9256B-RKE-03/15	• Put document in the latest template

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