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Wireless Personal Area Networks

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Abstract	Preamble Design with regard to I/Q Images
Purpose	Discussion
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1 Introduction

Low-IF receiver architectures are very popular, especially for narrow band signals. However, a known problem of a low-IF receiver is related to I/Q imbalances introducing unwanted images. In particular, for any real world receiver architecture, the suppression of the unwanted image cannot be made arbitrarily good, considering a constrained complexity of the overall transceiver architecture. The image itself may lead to a distortion of the in-band signal, causing a blocking effect. Another undesirable effect is that the receiver may synchronize to an image transmitted at the frequency of an adjacent or alternate adjacent channel. This article addresses the latter problem with regard to preamble design.

2 I/Q image

Let $x(t) = x_r(t) + jx_i(t)$ be the complex baseband signal. Without loss of generality, the signal

$$x^{IQ}(t) = (1+\delta)x_r(t) + j(1-\delta)x_i(t) = x(t) + \delta x^*(t) \tag{1}$$

is the signal due to I/Q imbalance for some $1 > |\delta| > 0$. Apparently

$$X^{IQ}(j\omega) = X(j\omega) + \delta X^*(-j\omega) \tag{2}$$

where X is the Fourier transformed signal[1] of x [1].
Now assume $X(j\omega)$ is centered at $\omega = -\omega_{IF}$. Equation (2) implies that an image signal $\delta x^*(t)$ will be conjugate symmetrically mirrored to the right side and falls into the in-band at $\omega = \omega_{IF}$, see figure 1.

3 Avoiding synchronization on the image

For a real valued baseband signal (like BPSK), the image cannot be distinguished from a native in-band signal. Hence, care must be taken with respect to the choice of the IF, the desired channel spacing and the range of the frequency offset in order to assure that images fall out of the scope of the receive filter.[2]
For an FSK signal

$$x(t) = \exp\left(j2\pi\Delta f T \int_0^t \sum_{\ell=0}^{\infty} d(\ell)g(\tau - \ell T)d\tau + \phi\right)$$

the image $\delta x^*(t)$ shows opposite frequencies and could be distinguished from a native in-band signal, provided the range of frequency offset is not too large. However, during

[1] For simplicity we assume, $X(j\omega) = \int_{k=-\infty}^{\infty} x(t)e^{-jt\omega}$ exists for $-\infty < \omega < \infty$.
[2] The IEEE 802.15.4 BPSK DSSS PHY of the 915 MHz band is affected by this problem. The choice of BPSK modulation is undesirable w. r. t. the channel spacing of 2 MHz and the RF-bandwidth.

preamble search the relation to the byte alignment is not know. For instance, a preamble sequence

$$\{d(\ell)\} = \{\ldots, -1, +1, -1, +1, -1, +1, \ldots\}$$

cannot be distinguished from a preamble caused by an image. A receiver may notice being fooled by an image upon SFD search. Hence, care must be taken if multiple SFD values are to be considered. In particular, an image should cause an invalid SFD value and this image value should have sufficient Hamming (or Euclidean) distance to any valid SFD value.

However, it is beneficial to avoid a false preamble detection as early as possible, since during SFD search the receiver may not be sensitive to incoming native in-band signals. In order to improve robustness against false synchronization, the preamble should have the form

$$\{\ldots, \underline{z}, \underline{z}, \underline{z}, \ldots\}$$

where $\underline{z}$ is a finite length sequence with good auto-correlation properties, for example a Barker sequence or an (extended) maximum length sequence. In this case, an image will cause opposite peaks when correlating against the expected preamble.

An example of an extended maximum length sequence sequence of length 16 is given by:

$$\underline{z} = \{+1, -1, +1, +1, -1, -1, +1, -1, -1, -1, +1, +1, +1, +1, -1, -1\}$$

A robust preamble should have at least 4 repetitions of $\underline{z}$.

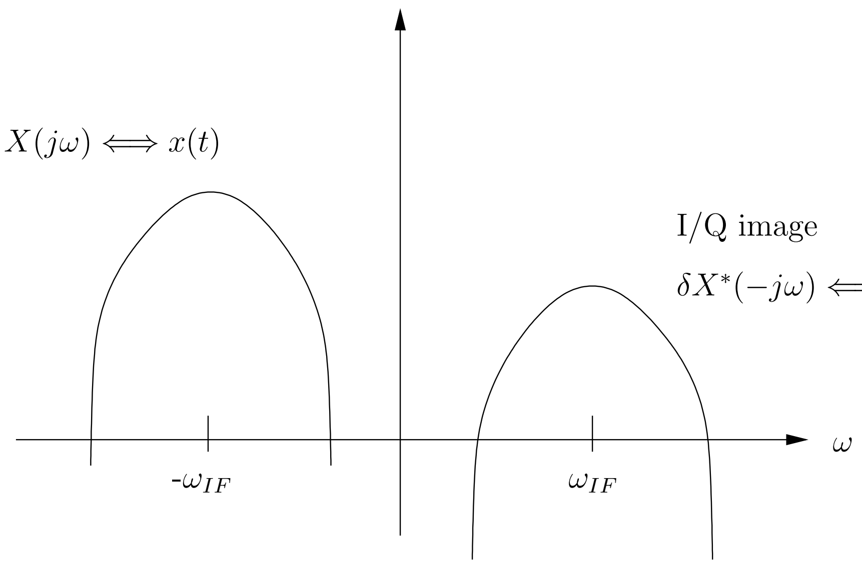

Figure 1: I/Q image due to I/Q imbalance.

References

[1] A. V. Oppenheim and R. W. Schafer, *Discrete-Time Signal Processing*, Prentice-Hall, Inc., 2nd edition, 1999.