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# A Comparative Analysis between Homodyne and Heterodyne Receiver Architecture

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ABSTRACT

*Two available choices for receiver architecture in wireless communications are Homodyne and Heterodyne receivers. Among them, heterodyne receiver was the leading choice in the past compared to homodyne receiver regarding facing challenges in suppressing interference and noise. However, Direct Conversion is becoming popular for wireless communications due to its lower cost. The goal of this paper is to discuss the key problems and tradeoffs in the design of Heterodyne and Homodyne receiver.*

***Keywords:* *Homodyne, Heterodyne, Receiver, Architecture, Wireless, Communications.***

## I. INTRODUCTION

One of the most difficult design element in any communication system is the receiver. A receiver should have low noise figure, low intermodulation distortion, high dynamic range, satisfactory gain flatness across the band, low phase noise, sufficient selectivity and suitable BER [1]. Also every design has certain cost constrains. This can be considered the most critical specification for any architecture. The preferred receiver design should be lower in cost for successful implementation.

## II. Heterodyne Receiver

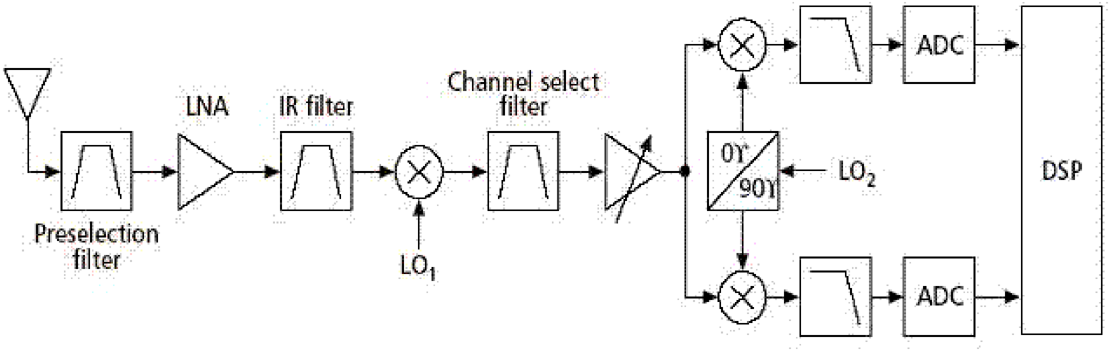

Figure 1. Heterodyne Receiver

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In a heterodyne architecture the signal frequency is translated to a lower but non-zero intermediate frequency (IF) where signal processing operations are performed. There are two frequency conversions in Heterodyne receiver. One from RF to IF and the another one from IF to base band. Again the IF section may be multiple blocks with several intermediate frequencies. Most receivers in wireless mobile use one IF block. Sufficient selectivity is achieved by fixed IF filters which are designed based on special technologies such as Surface Acoustic Wave (SAW), ceramic or crystal.

## A. Image Frequency

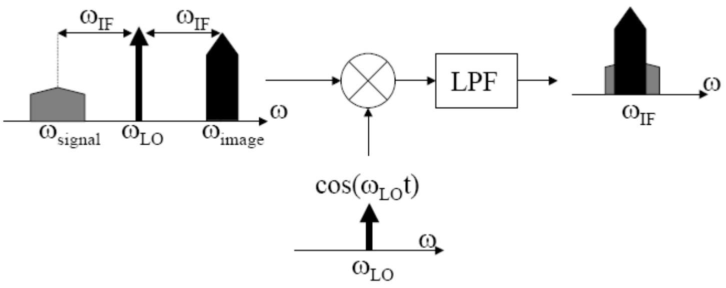


Figure 2. Image Frequency through mixer

In a heterodyne architecture, the bands symmetrically located above and below the LO frequency are down converted to the same center frequency. If the receiver band of interest is $\omega_1=\omega_{LO}-\omega_{IF}$, then the image is around $2\omega_{LO}-\omega_1=\omega_{LO}+\omega_{IF}$ [2]. Most common approach to suppress the image is putting an image reject filter in the receiver. Both image reject filter and IF filter require highly selective transfer function[3] for conventional heterodyne architecture. Since the image reject filter is placed off-chip the LNA needs to drive 50Ω load for this architecture.

## B. Half IF Frequency

In addition to the desired band of interest $\omega_{in}$, an interferer $(\omega_{in}+\omega_{LO})/2$ is also received by the Heterodyne receiver. If there is a second order distortion in the received signal and LO contains second order distortion as well, one of the component of IF signal will be $(\omega_{in}+\omega_{LO})-2\omega_{LO}=\omega_{IF.}$ This is the interference at the output of mixer caused by the half IF frequency[2].

## C. Third Order Distortion

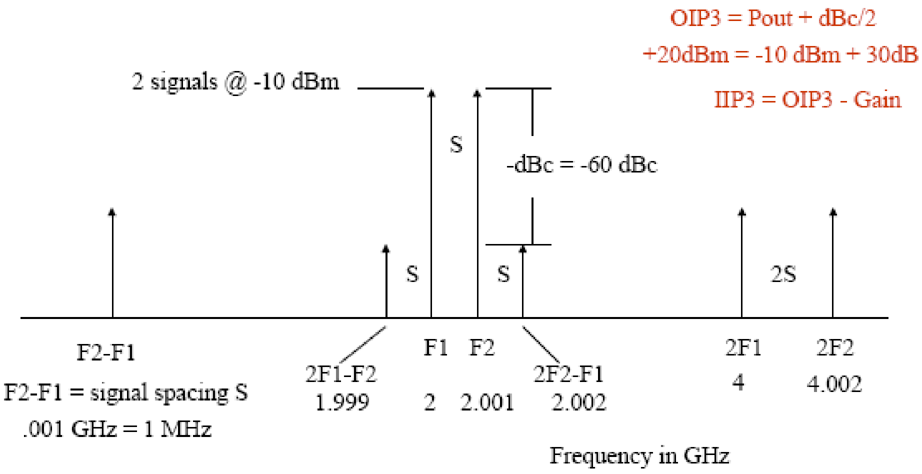


Figure 3. Third order product (2F1-F2) and (2F2-F1) from input frequencies F1 and F2

When two signals with different frequencies are applied to a nonlinear system, the output will show some non harmonic frequency components. This is called intermodulation (IM) In Heterodyne receiver linearity is measured based on third order distortion level of the receiver. If the difference between two interferer, $\omega_1$ and $\omega_{2,}$ is small, the product $(2\omega_1-\omega_2)$ or $(2\omega_2-\omega_1)$ will appear very close to $\omega_1$ and $\omega_2$. Due to this fact it is very hard to reject this interference even with a filter[4]. Moreover, for every dB increment of input power 3rd order product will increase by 3 dB. At low frequencies, it is common to quantify the nonlinearity of a circuit by indicating the distortion in the output signal [5].

## III. Homodyne Receiver

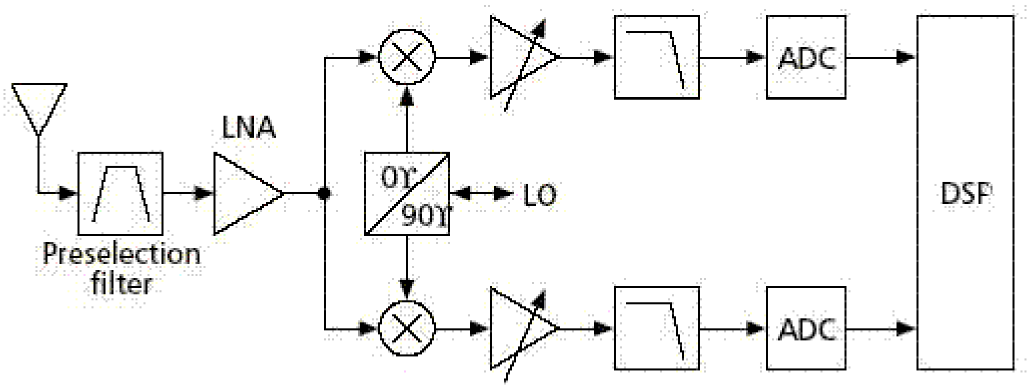


Figure 4. Homodyne Receiver

It is also called “direct conversion” or “zero IF” architecture, since the received signal is directly down converted to baseband. In a homodyne receiver, the desired signal is first selected by a filter, amplified by a LNA and then frequency translated by a mixer to DC. Direct conversion needs more linear mixer to attain the same performance as heterodyne [6]. Although the implementation looks much simpler than heterodyne, homodyne faces more challenges in noise suppression. The practical way to improve any receiver system performance is by improving the sensitivity and the selectivity to reduce interference from unwanted sources. [7]

### A. DC Offset

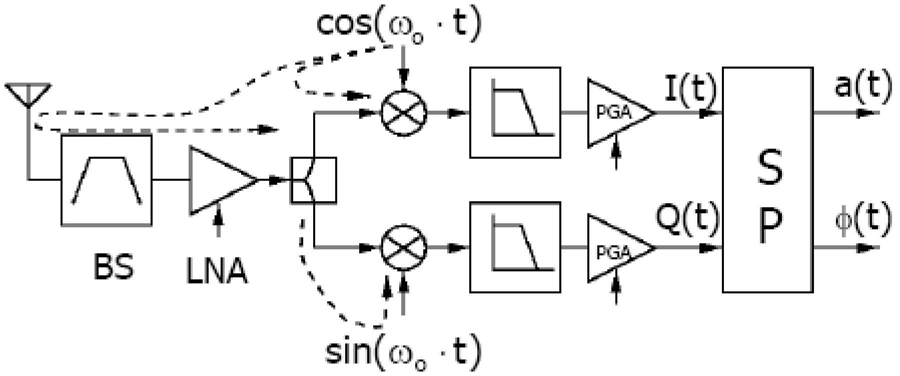
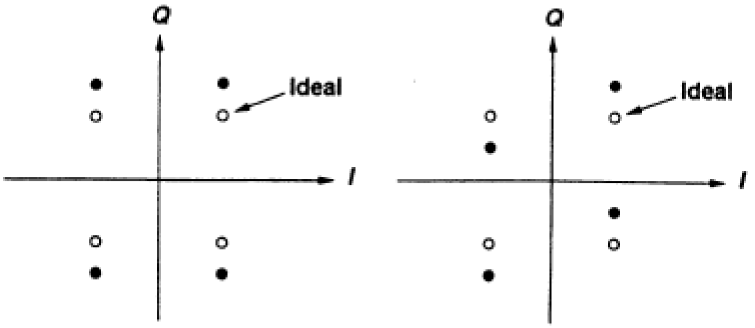


Figure 5. DC Offset leakage through mixer

As discussed above the homodyne receiver down converts the signal to zero frequency. As a result any additional DC offset voltage will corrupt the down converted signal[6]. Later stages in the receiver will be saturated due to this offset. DC offset in Homodyne Receiver is more severe than Heterodyne architecture since most of the signal gain in direct conversion is in the base band block[4]. DC-offset appears mainly due to LO leakage. Constant DC-offset can be compensated by measuring it without signal and then subtracting it during reception. However in TDMA systems, different channels may have different signal levels and DC-offsets, therefore compensation is difficult.

### B. I/Q Mismatch



(a) (b)

(b)

Figure 6. Effect of I-Q mismatch. Constellation (a) with gain error, (b) with phase error.

A homodyne receiver requires quadrature mixing. Mismatches between the amplitude of I and Q signal corrupt the down converted signal. Eventually it will raise the bit error rate. Heterodyne receiver may also have I/Q mismatch but their mismatch requirements are much more relaxed than homodyne[2]. I and Q paths are less sensitive to mismatches in this case.

### C. Even-order Distortion

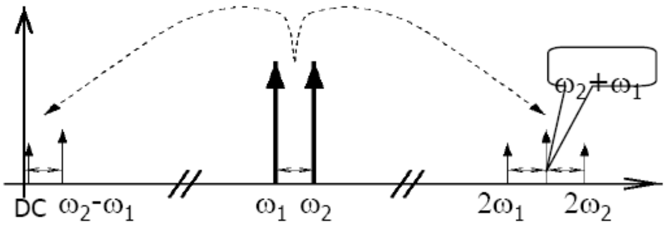


Figure 7. Even order product ($\omega_2$-$\omega_1$) very close to DC

Let's consider two strong narrowband interference $x(t)=A_1\mathrm{Cos}\omega_1 t + A_2\mathrm{Cos}\omega_2 t$ . A device with weak linearity can be represented by $y(t)=B_1x(t)+B_2x^2(t)$…… With input x(t), y(t) will contain a term $B_2A_1A_2\mathrm{Cos}(\omega_2-\omega_1)$. If $\omega_1$ is very close to $\omega_2$ it will introduce interference close to base band or zero frequency. Differential LNA and mixer can be designed to suppress second order distortion or IP2[4]. However it requires higher power dissipation than a single ended design. In heterodyne receivers 2nd-order products on the signal band are attenuated by the RF filter.

## IV. Conclusion

Heterodyne Receiver will have higher power consumption, since more stages are required in the architecture. Additional IF and RF filter requirement makes the integration low. In spite of these disadvantages Heterodyne receiver has been the primary choice for designers due to its better selectivity and ability to suppress image and other spurious emissions. Homodyne Receiver, on the other hand, has simple design architecture. It requires lower power consumption. ADC Dynamic range will have more margin due to limited filtering and integration will be high in practical implementation[3]. To obtain cost saving, direct conversion or homodyne receiver has become a popular architecture nowadays for wireless communication systems.

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