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STUDY OF THREE PHASE DEMODULATOR BASED DIRECT CONVERSION RECEIVER

Hirenkumar A. Tailor[1], Milind S. Shah[2], Ashvin R. Patel[3], Vivek N. Maurya[4]
Assistant Professor, EC Dept., SNPIT & RC, Umrakh, Bardoli, Gujarat, India[1]
Asso. Prof., EC Dept., Dr.S & S S Ghandhy Govt. Engg. College, Surat, Gujarat, India[2]
ME, EC Dept., Dr.S & SS Ghandhy Govt. Engg. College, Surat, Gujarat, India[3]
ME, EC Dept., Dr.S & SS Ghandhy Govt. Engg. College, Surat, Gujarat, India[4]

Abstract: Direct-conversion is an alternative wireless receiver architecture to the well-established superheterodyne architecture, particularly for highly integrated, low-power terminals. However direct conversion receivers have few issues like dc offset, even-order distortion and I/Q mismatch which degrade its performance. In this paper, the study of three-phase demodulator (TPD) is carried out and theoretical analysis have done for improvement in performance of direct conversion receiver.

Keywords: **Direct conversion receiver, I/Q mismatch, three phase demodulator, wireless receiver.**

INTRODUCTION

Superhetrodyne architecture has been the classical radio frequency (RF) architecture in radio communications, due to its selectivity and sensitivity characteristics [1]. However, due to image frequency problem, superheterodyne receivers are complex and expensive, and they require a large number of external components. On the contrary, homodyne direct conversion receiver shown in figure 1 downconverts the RF-signal directly down to base-band. For that purpose, the local oscillator (LO) is set to the carrier frequency $\omega_{LO} = \omega_{RF}$ of the wanted channel [2]. Thus it remove the image problem and it have important competitive advantages, such as simplicity, compact size, flexibility, reconfigurability, and high level of integration [3]. Nevertheless, direct conversion architectures have some limitations. In the case of direct conversion receivers, these limitations include dc-offset, second-order intermodulation distortion (IMD2) and I/Q mismatch [3]. DC offset is generated due to the phenomenon called "LO leakage" and "self-mixing". Furthermore, even order distortion also becomes problematic because of zero IF and nonlinear behavior of LNA and mixers. Another limitation of DCR is I/Q mismatch which increases the bit error rate. I/Q mismatch is due the amount of gain and phase errors between the I and Q path. Moreover, the trend towards high-data-rate services will require very large bandwidth, which become possible at high frequencies. However, I-Q demodulators need a nearly perfect 90° phase shift between their I-Q paths, which cannot be guaranteed over a very broad bandwidth. Therefore, the use of direct conversion architecture is limited due to the above mentioned distortions.

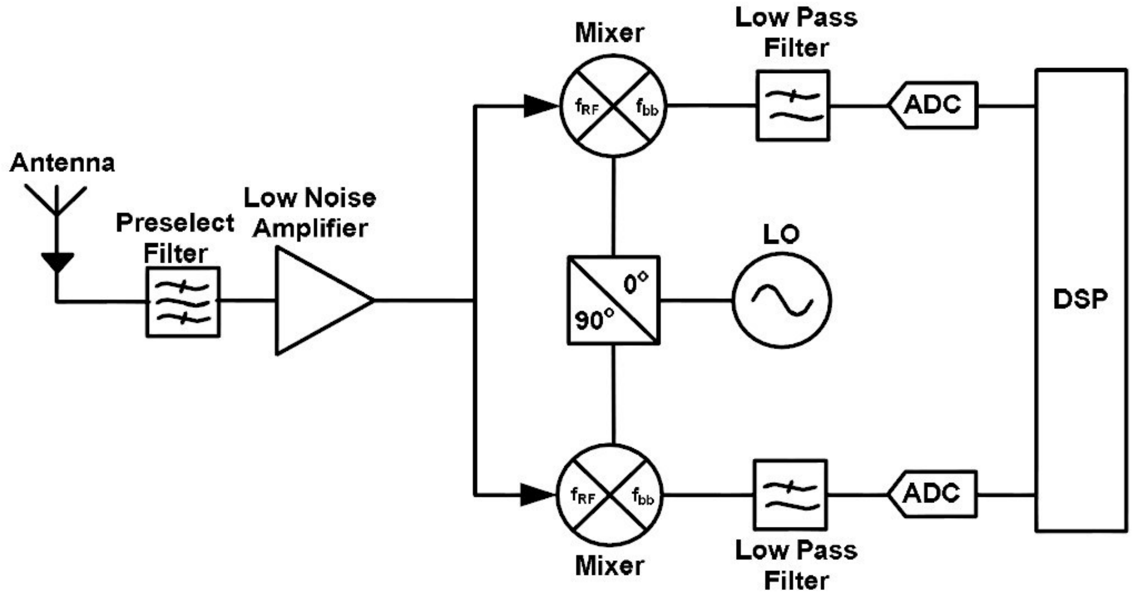

Figure 1: Direct Conversion Receiver

An alternative to the classical direct conversion architecture is the six (five)-port architecture [4], either with these of a six-port circuit [5], a five-port circuit [6], or a three phase demodulator circuit [7]. The main characteristic of the six (five)-port architecture is its extremely large bandwidth, which involves multiband and multimode capabilities [5], [8]. Five-port networks can operate at very high frequencies, being a serious alternative for millimeter-wave frequencies and high-data-rate applications [9]. Nevertheless, as it happens with the conventional zero-IF architecture, dc-offset, I/Q mismatch and IMD2 are its drawbacks.

In this paper, an architectural solution for reduction in I/Q mismatch using three-phase demodulator is studied. This paper theoretically demonstrates that three-phase receiver have potential for reduction in I/Q mismatch by using suitable calibration coefficients.

This paper is composed of four sections. After the introduction, Section II presents the three-phase demodulator (TPD) architecture as well as baseband output signal expressions. Section III presents the comparison between conventional direct conversion receiver and three phase demodulator based direct conversion receiver. Finally, we provide our conclusion on this study in Section IV.

THREE-PHASE DEMODULATOR BASED DIRECT CONVERSION RECEIVER

The direct conversion receiver based on three phase demodulator circuit is shown in Figure 2. The circuit has 2 inputs: local oscillator (LO) and RF signals and 3 low frequency outputs: $V_1(t)$, $V_2(t)$, and $V_3(t)$ [7]. Initially, the signal at the LO input is divided into three signals. Each one of these signals is phase shifted by an angle and applied to the mixer LO input. In the same way, the received RF signal is divided into three paths and applied to the RF mixer input. At the three mixers' outputs, three signals are obtained from the product of the signals applied to the LO and RF demodulator inputs. The low-pass filter (LPF) located after the IF mixer outputs eliminates the high frequencies. Finally, TPD provides three baseband signals at the three outputs, which are fed to the analog to digital converters and digital signal processor for the calibration procedure.

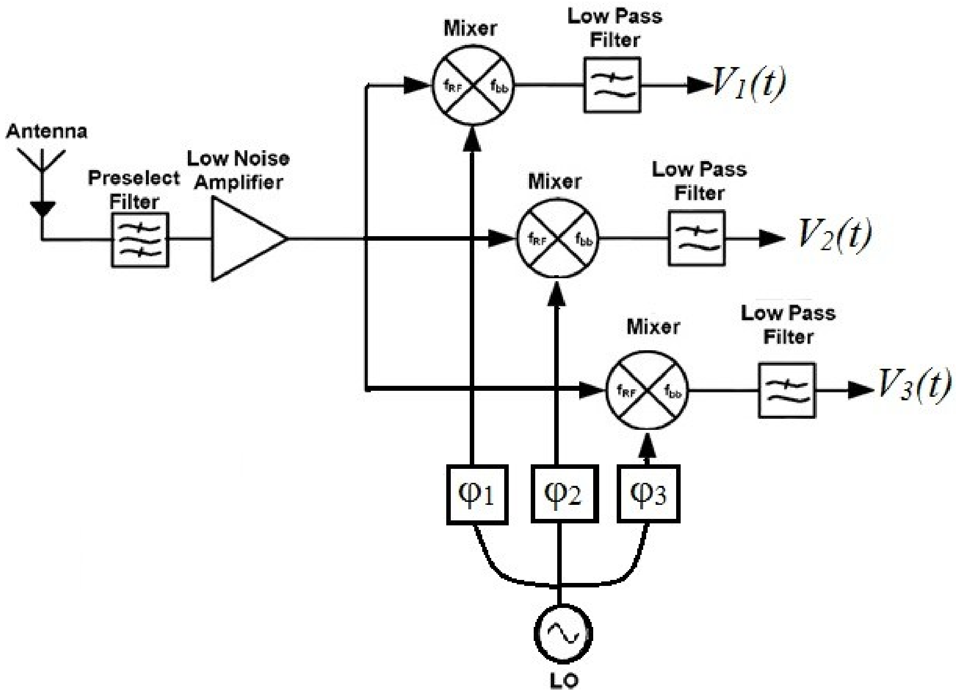

Figure 2: Three phase receiver

The RF and LO signals are expressed respectively by

$$V_{RF}(t) = A_{RF}\,[I(t)\cos(2\pi f_{RF}t) - Q(t)\sin(2\pi f_{RF}t)] \quad (1)$$

$$V_{LO}(t) = A_{LO}\cos(2\pi f_{LO}t) \quad (2)$$

Where, A_{RF} is the amplitude of received RF signal with carrier frequency f_{RF}, A_{LO} is the amplitude of LO signal with frequency f_{LO}.

However the output generated at the local oscillator branches are not always ideal as it has some gain and phase errors. Also, the combination of phase shifters and mixers, filters and amplifiers in the quadrature downconverter will introduce gain and phase imbalances at the I and Q branches of the downconverted signal. Here, we are considering gain and phase errors generated in TPD based direct conversion receiver architecture.

If we consider a gain error (A_ε) and phase error (δ_i) at LO, then the output of the LO can be given by,

$$V_{LOi}(t) = A_{LOi}\cos(2\pi f_{LO}t + \gamma_i) \quad (3)$$

Where, $A_{LOi} = A_{LO}+A_\varepsilon$ and $\gamma_i = \varphi_i + \delta_i$

Here, angle φ_i is the ideal relative phase shift between the RF and LO signals and angle γ_i is the relative phase shift between the RF and LO signals including phase error δ_i.

After mixing and filtering, the voltages obtained at the LPF outputs are expressed as

$$V_i(t) = LPF\,[A_{RF}.\,A_{LOi}\,\{\,I(t)\cos(2\pi f_{RF}t)\,.\,\cos(2\pi f_{LO}t + \gamma_i) - Q(t)\sin(2\pi f_{RF}t)\,.\,\cos(2\pi f_{LO}t + \gamma_i)\,\}\,] \quad (4)$$

For DCR $f_{RF} = f_{LO} = f_c$, so,

$$V_i(t) = LPF\,[A_{RF}.\,A_{LOi}\,\{\,I(t)\cos(2\pi f_c t)\,.\,\cos(2\pi f_c t + \gamma_i) - Q(t)\sin(2\pi f_c t)\,.\,\cos(2\pi f_c t + \gamma_i)\,\}\,] \quad (5)$$

Therefore, after trigonometric operations, the voltages obtained at the LPF outputs are expressed as

$$V_i(t) = A_i\,[I(t)\cos(\gamma_i) + Q(t)\sin(\gamma_i)],\ \ i=1,2,3 \quad (6)$$

where, gain $A_i = \frac{A_{RF}\,A_{LOi}}{2}$.

Finally, the required baseband signal from three voltages can be find using the equation (6).

Now, to get required signals $S_I(t)$ and $S_Q(t)$, different I/Q regeneration methods are used such as precalibration [6], self-calibration [6] and blind calibration procedure [10].

For a precalibration method, the useful baseband signals S_I and S_Q can be expressed linearly using the TPD output voltages as [6]

$$S_I(t) = \sum_{i=1}^{3} \alpha_i V_i(t) \quad (7)$$

$$S_Q(t) = \sum_{i=1}^{3} \beta_i V_i(t) \quad (8)$$

Here α_i and β_i are coefficients that characterizes the receiver and are obtained via identification or calibration.

Thus, by finding appropriate value of calibration coefficients (α_i and β_i) and storing them in memory for different frequencies, we can compensate the gain and phase errors generated in TPD based direct conversion receiver.

COMPARISON BETWEEN DIRECT CONVERSION RECEIVER AND THREE PHASE DEMODULATOR

DCR and TPD based DCR are homodyne architectures and they provide the advantages of homodyne receivers like low cost, less complexity and no image problem. However in classic direct conversion receiver, the propagation of a higher frequency through quadrature mixers experiences greater mismatches which makes DCR more sensitive to amplitude and phase imbalances. But, three phase demodulator architecture is less sensitive due to multi-port and having potential to calibrate the baseband signal. Thus, TPD provide wide bandwidth. A comparison between three phase demodulator and classic direct conversion receiver is summarise in Table 1.

Direct Conversion Receiver	Three Phase Demodulator based DCR
No Image Problem	No Image Problem
Provide moderate bandwidth	Provide large bandwidth
Low complexity	Low complexity
On chip integration is easy	On chip integration is easy
High sensitivity to amplitude and phase imbalances	Low sensitivity to amplitude and phase imbalances
Moderate performance	High performance

Table 1. Comparison between three phase demodulator and classic direct conversion receiver.

CONCLUSION

In this paper, a comparison between performance of a direct conversion receiver and three-phase demodulator (TPD) based DCR was studied. Study shows that performance of conventional direct conversion receiver degrades due to the gain and phase errors. However, TPD have low sensitivity to amplitude and phase imbalances which improve its performance.

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