DC OFFSET SUPPRESSION IN DOUBLE BALANCE DIRECT CONVERSION RECEIVERS

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Abstract

The double balance mixer scheme in-phase signal input and double-quadrature Local Oscillator (LO) is suggested for application on IQ direct conversion receivers. The influence of the gain and phase mismatches of splitters is investigated. It is shown that a similar scheme using square-law detectors is promising on optical applications.

Introduction

The increasing interest in direct conversion receivers (DCR) is based on several qualities of this type of reception which makes it very suitable for integration as well as multi-band multi-standard operation [Parssinen (1)]. The main advantage of DCR, contrary to the most widely used heterodyne reception, is an achievement of high image rejection avoiding the use of expensive bulky off-chip filters. Among the problems existing in DCR, limiting their wide application, DC offset is one of the most serious. DC offset caused by various phenomena contribute to the creation of DC signals. These phenomena can be separated on the three main groups, such as a) LO leakage to the LNA and mixers input due to substrate coupling, ground bounds, bond wire radiation etc., b) LO leakage to the antenna through the mixers and LNA due to their non-sufficient isolation, c) even-order nonlinearity of LNA and mixer. The strength of DC caused by the phenomena of group a) is influenced by chip technology and can be reduced by careful layout or by suitable post processing digital signal processing (DSP) at baseband. DSP removes the DC offset in a way that using cannot be duplicated in the analog domain. For the cases of DC caused by the phenomena of groups b) and c) reductions in DC signal can be achieved in the analog domain by special circuit design. This paper presents one such circuit.

Four-quadrant multiplier DCR

The basic diagram of the IQ DCR is given in Fig. 1. The possible DC offset due to LO self-mixing can be estimated using LO level in the mixers, LO-to-RF isolation and reflection from the RF interface mismatch. Take into account the typical value for LO-to-RF isolation of the mixer -20dB, reverse gain of the LNA -20 dB, corresponding to mismatch SWR=1.1 reflection -20 dB and required LO level approximately 0 dBm, the LO leakage -60 dBm at the LNA input can be obtained. This value of LO leakage power is 30 dB higher than required sensitivity threshold of the receiver. Leakage power after amplification of LNA and self-mixing with LO produced at the output of the mixer DC offset on the order of 10 mV which is enough high to saturate the following circuits.

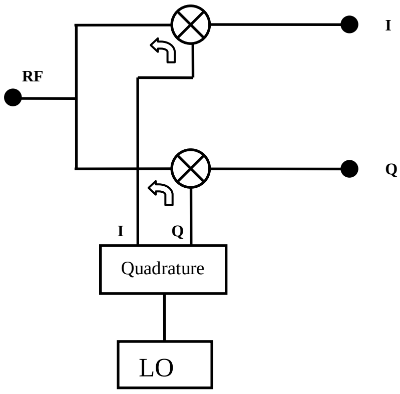

Figure 1: Direct Conversion Receiver

To solve this kind of DC offset problem various compensative and balance architectures have been suggested [(1), Razavi (2)]. To reduce the LO leakage and DC offset we suggest to use the scheme of analogue double balanced mixers presented in Fig. 2. As distinct from well known scheme with double-quadrature division of input RF and LO, [Crols and Steyaert (3)] here we use in-phase division of RF and quadrature-antiphase division of LO. Such construction allows to suppress LO leakage to the front end, because at the entry of in-phase splitter the two equal antiphase components has been summed. Presence of differential pairs (I,I') and (Q,Q') enables suppression of residual DC offsets at the I and Q outputs.

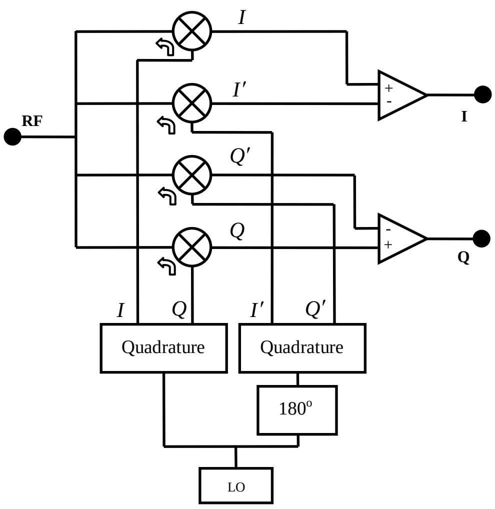

Figure 2: Double Balance DCR

Double Quadrature LO generation is however a critical part of this system due to gain and phase mismatch. To create influence of the gain (Δ) and phase (Θ)

mismatches on behavior of this scheme let us write the input RF signal as follows

$$LO_I = (1+\Delta_1)\cos(\omega_c t + \Theta_1) \quad (2a)$$
$$LO_{I'} = -(1-\Delta_1)\cos(\omega_c t - \Theta_1) \quad (2b)$$
$$LO_Q = (1+\Delta_2)\sin(\omega_c t + \Theta_2) \quad (2c)$$
$$LO_{Q'} = -(1-\Delta_2)\sin(\omega_c t - \Theta_2) \quad (2d)$$

Hence the LO leakage at RF port will be presented as

$$LO_L = L_R \cdot L_M \left(LO_I + LO_{I'} + LO_Q + LO_{Q'}\right) \quad (3)$$

The improvement of the LO leakage suppression (L_{4IQ}) in the suggested scheme compared to those in the non-balanced scheme (L_{IQ}) presented in Fig. 1 is shown in

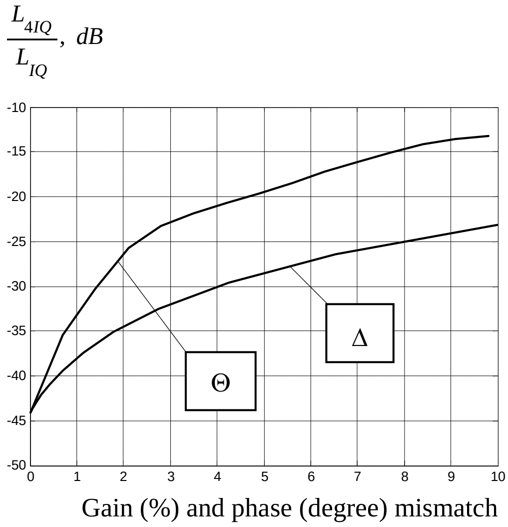

Figure 3: Leakage Suppression at RF Port in Double Balance DCR

Fig. 3. The output of the mixers after filtering of the double-frequency components are the following signals

$$I = \frac{1}{8}(1+\Delta_1)[a(t)\sin\Theta_1 + b(t)\cos\Theta_1] + DC_I \quad (4a)$$
$$I' = -\frac{1}{8}(1-\Delta_1)[-a(t)\sin\Theta_1 + b(t)\cos\Theta_1] + DC_{I'} \quad (4b)$$
$$Q = \frac{1}{8}(1+\Delta_2)[a(t)\cos\Theta_2 + b(t)\sin\Theta_2] + DC_Q \quad (4c)$$
$$Q' = -\frac{1}{8}(1-\Delta_2)[a(t)\cos\Theta_2 - b(t)\sin\Theta_2] + DC_{Q'} \quad (4d)$$

where DC_I, $DC_{I'}$, DC_Q, $DC_{Q'}$ are DC offsets at corresponding branches and can be calculated using (2) and (3). The improvement of the DC offset (DC_{4IQ}) in the suggested scheme compared to those in the non-balanced arrangement (DC_{IQ}) is shown in Fig. 4.

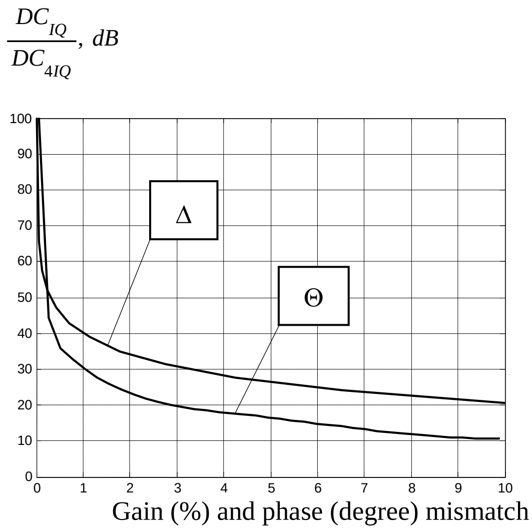

Figure 4: DC offset Improvement in double balanced DCR against the gain and phase mismatch

As it can be seen from (2) I, I' and Q, Q' are represented as differential pairs. Hence the wanted signal can be obtained in the following way

$$I(t) = I - I'$$
$$Q(t) = Q - Q'.$$

The imbalance errors can be extracted as a sum of the I, I' and Q, Q' pairs

$$\varepsilon(I) = I + I'$$
$$\varepsilon(Q) = Q + Q'.$$

These values can be used for imbalance compensation at the source of the LO phase splitter, or digitally after A/D conversion.
As it is seen from the above discussion, LO leakage, DC offset and I/Q imbalance strongly depends on the gain and phase mismatches of the LO splitter. The use of a cascaded four-branch RC polyphase network [Gingell (4)] or polyphase oscillator [Buchwald and Martin (5)] makes it possible to reach 0.5° phase error and 0.5 dB amplitude error. For such mismatches the suggested scheme provides LO leakage suppression at the RF input of more than 90 dB which is sufficient for many applications of DCR.

Even-order nonlinearity

In most systems, the third-order intermodulation is of importance as it usually falls in-band, in the vicinity of the signals of interest, and is characterized by the third-order intercept point (IP3). In direct conversion, second-order nonlinearity becomes critical, as it produces baseband signals, which now appear as interfering signals in the down-converted desired signal. Large blocking signals also cause DC in the direct conversion receiver, whether on a spurious frequency or not. The DC is produced at the mixer output and amplified by the baseband stages. Assuming a nonlinearity modeled by a polynomial

$$y(x) = a_1 x + a_2 x^2 + a_3 x^3 \tag{5}$$

and input signal as

$$x(t) = A_1 \cos(\omega_1 t) + A_2 \cos(\omega_2 t)$$

we have after LPF

$$y(x) = a_2 A_1 A_2 \cos(\omega_2 - \omega_1)t + \frac{1}{2} a_2 \left(A_1^2 + A_2^2\right). \tag{6}$$

The first term represents an interfering signal at the desired baseband and second term represents DC offset. Note from this simplified model that all products of even-order nonlinearity are in-phase in all the mixers outputs. Taking into account that I, I' and Q, Q' are represented as differential pairs, cancellation of these products are expected. Like the previous consideration of the LO leakage suppression here the cancellation of even-order products will also depend on the gain and phase mismatch of the RF in-phase splitter. So, suppression of the even-order products in the suggested scheme can be obtained from data on Fig. 3 and Fig. 4.

Square-law multiplier

The suggested scheme gives the possibility of using square-law detectors (power detector) as the mixers of an IQ DCR. This fact is important especially for optical receivers where traditional multipliers are absent. On the other hand photodetectors can be considered as a power detector. The structure of an IQ DCR based on square-law detectors is presented in Fig. 5. If we consider superimposing optical waves with different frequencies and phases on a photodetector the total field is given by following

$$E_T = E_S e^{i\omega_S t} + E_{LO} e^{i(\omega_{LO} t + \varphi)}, \tag{7}$$

where E_S, ω_S and E_{LO}, ω_{LO}, φ are fields amplitude, frequency and phase of the signal and LO optical sources. The total intensity at the detector is given by

$$I = E_T E_T^* = E_S^2 + E_{LO}^2 + 2E_S E_{LO} \cos[(\omega_S - \omega_{LO})t + \varphi] \tag{8}$$

Since the output photocurrent of the detector is proportional to the input intensity and taking into account the quadrature nature of the LO we'll get a beat signal on the differential outputs

$$I - I' = 4E_S E_{LO} \cos(\omega_S - \omega_{LO}) \cdot t$$
$$Q - Q' = 4E_S E_{LO} \sin(\omega_S - \omega_{LO}) \cdot t \, .$$

Therefore the suggested scheme enables the possibility of extracting the optical beat signals in quadrature. This fact can be applicable for both optical communications and phase locked loops.

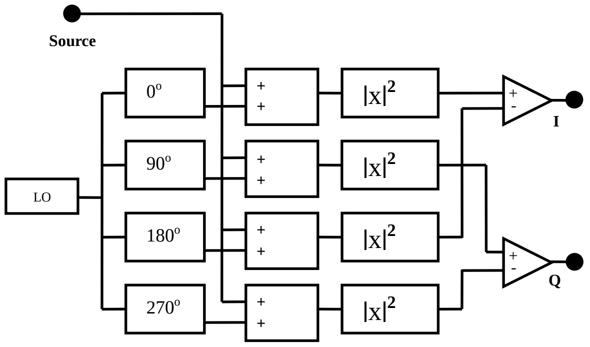

Figure 5: DCR Based on Photodetector

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