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MULTIPORT MODULATOR

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For modulation, the six-port correlator can be used together with variable impedance loads to generate the modulated radio frequency (RF) signal [1, 3, 4, 8], see Fig. 1. The variable impedance loads are controlled by a baseband signal and are used to generate different reflection coefficients on the respective ports on the six-port correlator. The variable reflection coefficients modulate an applied carrier signal. The variable impedance loads are usually implemented either by using switches [1, 4], transistors [2, 6, 8] or diodes [5, 7].

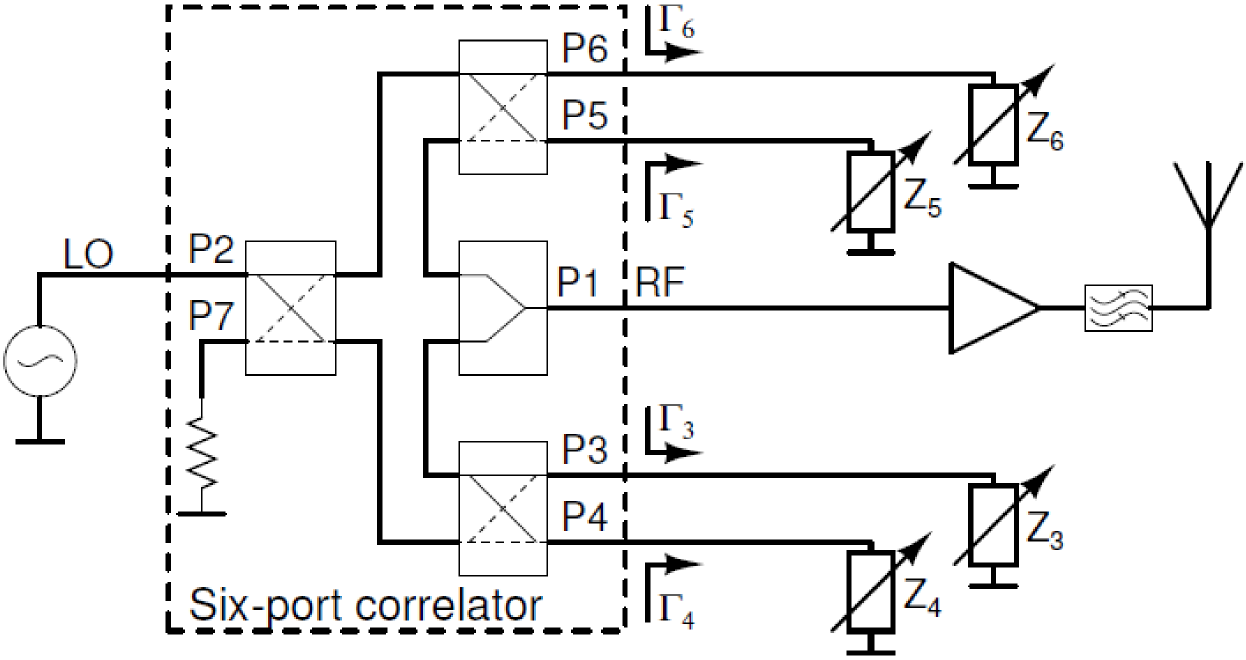

Fig. 1: Schematic of six-port modulator/transmitter

Carrier leakage is a problem that is likely present when using variable impedance loads together with a six-port correlator for modulation [3, 6], and leakage degrades the performance of the transmitter-receiver chain [3]. To limit the effect of carrier leakage, balanced modulators can be used [8].

The six-port modulator can be divided into two independent building blocks: the six-port correlator and the reflection coefficient generator. Combining these two blocks, the theory of the six-port modulator can be explained.

In a six-port modulator, as shown in Fig. 1, an local oscillator (LO) source is connected to port P2 and generates an incident wave (a_2), this wave experiences different phase shifts and attenuations when it passes the six-port correlator to each of the four output ports (P3 - P6). The transmitted or outgoing waves b_x on ports (P3 - P6) travel towards the impedance load Zx where it gets reflected. The reflected waves are now at the input on ports (P3 - P6) and a part of it is transferred to the output port P1. Owing to the phase relations in the six-port correlator, and depending on how the impedance loads are selected, a modulated signal including both *I* and *Q* data can be generated. In an ideal six-port correlator, it is shown in Section 2 that the (complex) modulated output wave b_1 at port P1 is

$$b_1 = \frac{-a_2}{4}\left[(\Gamma_3 + \Gamma_4) + j(\Gamma_5 + \Gamma_6)\right]$$

where a_2 is the forward wave at port P2. Γ_3, Γ_4, Γ_5 and Γ_6 are the reflection coefficients at ports P3, P4, P5 and P6, as shown in Fig. 1. For modulation to occur, the value on Γ_3 - Γ_6 must change as a function of time.

1.2. Reflection Coefficient Generator

For generation of different reflection coefficients Γ_x, where $x \in \{3,4,5,6\}$ is the port number, it is required to change the load impedance Z_x at ports (P3 - P6) as a function of a control voltage or baseband signal V_x. The reflection coefficient Γ_x is given by (1)

$$\Gamma_x(V_x) = \frac{Z_x(V_x) - Z_{0,x}}{Z_x(V_x) + Z_{0,x}} \tag{1}$$

where $Z_{0,x}$ is the characteristic impedance on the transmission line (TL) connecting impedance load Z_x to port P*x* on the six-port correlator. Observe that (1) is a nonlinear function of the impedance load.

To model the relation between the ports of the six-port correlator, S-parameters are used. The port numbers are defined as shown in Fig. 2.2. The output port for the modulated signal is defined to be P1, whereas P2 is defined to be the input port for the carrier (LO). Ports P3 and P4 constitute one output port pair (P3, P4) and ports P5 and P6 the second output port pair (P5, P6). Define a reflection coefficient (Γ), incoming (*a*) and transmitted wave (*b*) on each of the ports P3, P4, P5 and P6

$$b_x = S_{x2}a_2$$
$$a_x = \Gamma_x b_x$$
$$b_1 = S_{1x}a_x\,.$$

The three main steps to get a modulated output signal are: a) the incoming wave is transferred from the input port (P2) to all the other ports in the six-port correlator resulting in the terms $b_x = S_{x2}a_2$, b) the transmitted wave b_x is reflected on the load impedance Z_x and gives an input wave at port P*x*, $a_x = \Gamma_x b_x$, and c) the input wave is transferred to the output port (P1), i.e., $b_1 = S_{1x}a_x = S_{1x}\Gamma_x S_{x2}a_2$. The total output wave is the sum of the reflections from each of the loads at port P3 - P6:

$$\begin{aligned} b_1 &= a_2\sum_{x=3}^{6} S_{x2}\Gamma_x S_{1x} \\ &= a_2(S_{32}\Gamma_3 S_{13} + S_{42}\Gamma_4 S_{14} + S_{52}\Gamma_5 S_{15} + S_{62}\Gamma_6 S_{16}) \end{aligned}$$

Using the ideal S-parameters as given in [10], It results in

$$b_1 = \frac{-a_2}{4}\left[(\Gamma_3 + \Gamma_4) + j(\Gamma_5 + \Gamma_6)\right] \tag{2}$$

the value on the reflection coefficient Γ_x is in general complex. For modulation to occur, the value on Γ_x must change as a function of time. It is common that $\Gamma_3 = \Gamma_4$ and

$\Gamma_5 = \Gamma_6$. If the reflection coefficient is approximated as a linear function of the applied baseband voltage $V = V_{CM} + \Delta v$

$$\Gamma(V) = \Gamma(V_{CM} + \Delta v) = \Gamma_{CM} + \Delta\Gamma \approx \Gamma_{CM} + \delta\Delta v \tag{3}$$

where $\Gamma_{CM} = \Gamma(V_{CM})$ is generated by the constant common mode voltage V_{CM}, and δ is the first derivative of Γ at V_{CM}, i.e., $\delta = \left.\frac{d\Gamma}{dV}\right|_{\Delta v=0}$, and Δv the voltage deviation in the baseband signal that changes with time. Commonly the same type of impedance load is implemented on port pairs (P3, P4) and (P5, P6). If $\Gamma_3 = \Gamma_0 = \Gamma_I$ and $\Gamma_5 = \Gamma_6 = \Gamma_Q$ is used together with (3) and (3), then

$$b_1 = -\frac{a_2}{2}\left(\Gamma_I + j\Gamma_Q\right) = -\frac{a_2}{2}\left[\underbrace{\Gamma_{CM}(1+j)}_{Carrier\ leakage} + \underbrace{\delta\left(\Delta v_I + j\Delta v_Q\right)}_{RF\ \mathrm{mod}ulated}\right] \tag{4}$$

it is evident from (4) that only a part of the carrier signal a_2 is modulated to give the RF signal, whereas the other part gives an unwanted carrier leakage [5]. To avoid this leakage $\Gamma_{CM} = 0$ is required.

Two different configurations exist for the implementation of the six-port correlator for use in six-port modulators: a series or a parallel configuration [3]. The parallel configuration generally gives better modulation performance and hence most of the reported six-port modulators are based on the parallel configuration [1, 3, 4, 8]. The main difference between reported modulators is therefore found in terms of how the impedance loads are implemented and the modulation order they support. The three main types of impedance loads are:

- Switch matrices - vary the impedance in discrete steps.
- Transistors - vary the impedance in a continuous way by an analog control signal.
- Diodes - vary the impedance in a continuous way by an analog control signal.

Impedance loads implemented with switches posses a good linearity but, due to their limited speed, they are limited to low or moderate data rate applications [1,4]. Impedance loads implemented with transistors or diodes [2 ,6 ,7,8] allow high speed operation, but may have limited linearity. A common problem with six-port based modulators is carrier leakage. The carrier leakage gives rise to, for example, unwanted in-band emission of the LO and degrades the performance in the receiver that in turn may decrease the channel capacity [9]. To decrease the impact of any present carrier leakage and to improve the modulation performance, balanced vector modulators have been proposed [8]. Unfortunately, their implementation requires several couplers and impedance loads, which results in increased system complexity.

A six-port modulator generates the modulated RF signal directly from an LO source (carrier) in terms of the reflection coefficients at specific ports. The reflection coefficients are generated from variable impedance loads. Hence, if the impedance is controlled by a baseband signal, modulation is possible. This reflection based technique to generate a modulated signal is well known [8].

In a reflection based modulator (six-port), the baseband I and Q data control the reflection coefficient present at specific ports and the carrier wave is multiplied with these reflection coefficients to generate a modulated RF signal. In a mixer based modulator, the baseband I and Q channels are multiplied with the carrier by means of a mixer.

Because the six-port is a passive and linear device, the output power can be increased by increasing the LO power and the use of a power amplifier can to some extent be avoided. A typical mixer, based on diodes or transistors, is certainly nonlinear and has therefore limited power handling capability. The reflection based modulation technique that is used in a six-port modulator can be used with spectral shaping, linearization and digital predistortion techniques. A modulated output signal with good properties in time and frequency domain can thus be generated.

The relatively new modulator using the multiport architecture is proposed. It has the low cost as well as measurement accuracy. Moreover, this modulator can be realized on the combined multiport correlator, so it can be calibrated without precisely known loads.

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MULTIPORT DEMODULATOR

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For demodulation, the six-port correlator can be used together with power detection, i.e., utilizing second-order nonlinearity, to recover the baseband signal [1,2,4,5,24], see Fig. 1. Schottky diodes are commonly used for power detection and allow high date rate due to their high-speed property. To recover the baseband signal the modulated RF and a coherent LO are applied to the six-port correlator. In other words, we are using the sixport demodulator in a direct conversion receiver. The phase relations in the six-port correlator together with the nonlinear processing allow to separate the I and Q baseband channels. The separated I and Q channels will, due to the nonlinear processing, not only contain the wanted baseband I and Q signals, but also a dc offset. It is well known that dc offset is a serious problem in a direct conversion receiver because the dc offset overlaps the wanted baseband signal [7]. However, by taking the difference between port pairs (P3, P4) and (P5, P6) the dc offset can be effectively suppressed in the detected baseband I and Q channels.

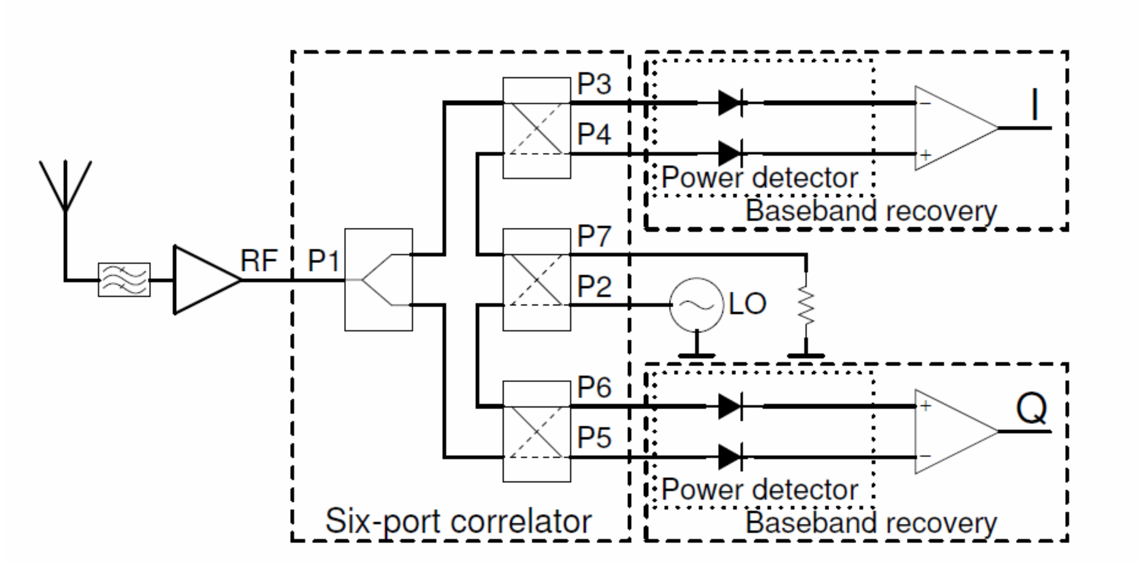

Fig. 1: Schematic of six-port receiver. The main building blocks are shown in rectangles, i.e., the six-port correlator, power detectors and baseband recovery circuit