АВТОМАТИЗИРОВАННЫЕ СИСТЕМЫ НАУЧНЫХ ИССЛЕДОВАНИЙ

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CARRIER LEAKAGE SUPPRESSION IN MULTIPORT BASED SDR SYSTEMS

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Introduction

For modulation, the six-port correlator can be used together with variable impedance loads (see Fig. 1) to generate the modulated RF signal, as discussed in [1]. The use of variable impedance loads is known to create problem with carrier leakage [2, 3].

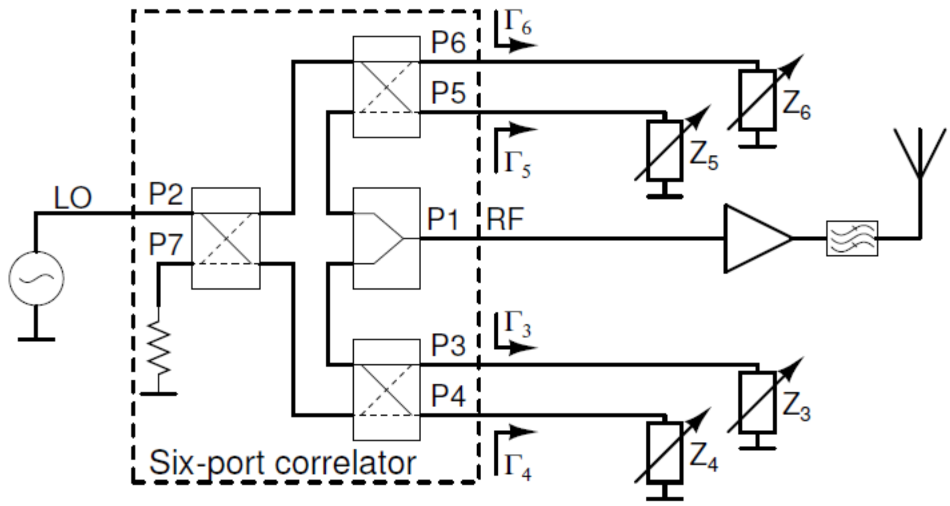


Fig. 1. Schematic of six-port modulator/transmitter

Carrier leakage is a problem that may be present when using variable loads together with a six-port correlator for modulation [2, 3]. The carrier leakage degrades the performance of the transmitter-receiver chain [2, 4, 5]. One approach to limit the effect of carrier leakage is to use balanced modulators [6, 7, 8]. However, balanced modulators require a complex circuit implementation. Here a simple yet efficient method to suppress the carrier leakage is presented.

Theory

It was shown in [1] that the presence of a static component of Γ, i.e., $\Gamma_{CM} \neq 0$ generates an unwanted carrier signal at the output port P1 of the six-port modulator.

$$b_1 = -\frac{a_2}{2}\left(\Gamma_I + j\Gamma_Q\right) = -\frac{a_2}{2}\left[\underbrace{\Gamma_{CM}(1+j)}_{Carrier\ leakage} + \underbrace{\delta\left(\Delta\nu_I + j\Delta\nu_Q\right)}_{RF\ modulated}\right]$$

In general the following holds

$$b_1 = -\frac{a_2}{4}\left[(\Gamma_3 + \Gamma_4) + j(\Gamma_5 + \Gamma_6)\right], \quad (1)$$

where Γ_x is the reflection coefficient looking out at port Px of the six-port correlator. The value of Γ_x is dependent on three parameters: a) the load input impedance $Z_{load,x}$ (V_x), b) the characteristic impedance $Z_{0,x}$ of the transmission line (TL) and c) the length l_x of the TL connecting the output at port Px to the load.

$$\Gamma_{load,x}(V_x) = \frac{Z_{load,x}(V_x) - Z_{0,x}}{Z_{load,x}(Vx) + Z_{0,x}}$$

$$\Gamma_x = \Gamma_{load,x} e^{-j2\beta l_x} = \Gamma_{load,x} e^{-j\theta_x}$$

where $\theta_x = 2\beta l_x$, $\beta = 2\pi/\lambda$, $\lambda = v_p/f$ and v_p the phase velocity. V_x is a control voltage or baseband signal to change the impedance $Z_{load,x}$ to allow modulation. The same impedance load device (such as a diode or transistor) is assumed to be used at ports P3 - P6 and, therefore, $\Gamma_{load,x} = \Gamma$, where Γ is the reflection coefficient at the load to TL interface and modeled by

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

Hence,

$$\Gamma_x = (\Gamma_{CM} + \Delta\Gamma_x)e^{-j\theta_x} = |\Gamma_{CM} + \Delta\Gamma_x| e^{j\angle(\Gamma_{CM} + \Delta\Gamma_x)} e^{-j\theta_x} = |\Gamma| e^{j\angle\Gamma} e^{-j\theta_x} \quad (2)$$

where $\Delta\Gamma_x = \delta\Delta v_x$ as previously discussed in [1, 9].

Carrier Leakage Suppression Without Modulation

When there is no modulation, i.e., $\Delta v_x = 0$ and $\Delta\Gamma_x = 0$, the requirement on the output signal to have no carrier leakage is that $b_1 = 0$. Using $\Delta\Gamma_x = 0$, (1) and (2) result in

$$b_1 = -\frac{a_2}{4}|\Gamma_{CM}| e^{j\angle\Gamma_{CM}} \left[\left(e^{-j\theta_3} + e^{-j\theta_4}\right) + j\left(e^{-j\theta_5} + e^{-j\theta_6}\right)\right] \quad (3)$$

It is possible to select the values of θ_x in (3) to force both the real and imaginary parts to zero, and therefore fulfill $b_1 = 0$. The following two conditions must then be fulfilled:

$$e^{-j\theta_3} = -e^{-j\theta_4} = e^{\pm j\pi} e^{-j\theta_4}$$

$$e^{-j\theta_5} = -e^{-j\theta_6} = e^{\pm j\pi} e^{-j\theta_6}$$

hence

$$\theta_m = \theta_n \pm \pi$$

$$l_m = l_n \pm \frac{\lambda}{4} \quad (4)$$

From (4) it is clear that the minimum length difference between the TLs at ports (m, n), i.e., (P3, P4) and (P5, P6), must be $\lambda/4$ to avoid carrier leakage. A six-port modulator that fulfills these requirements is shown in Fig. 2. It should be noted that the same technique can be used to avoid carrier leakage to the RF port in a corresponding six-port demodulator.

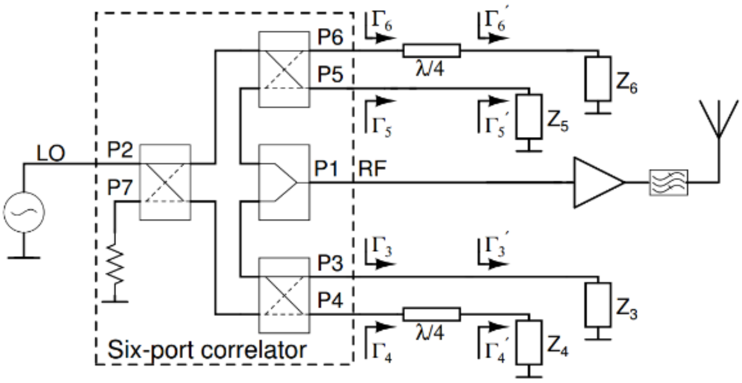


Fig. 2. Schematic of six-port transmitter with a carrier leakage suppression technique [9]

Carrier Leakage Suppression for Modulation

If the requirement for no carrier leakage is satisfied as derived in previous section, for example by selecting $\theta_3 = \theta_5 = 0$ and $\theta_4 = \theta_6 = \pi$, it follows from (2)

$$\Gamma_3 = (\Gamma_{CM} + \Delta\Gamma_3)$$

$$\Gamma_4 = (\Gamma_{CM} + \Delta\Gamma_4)$$

$$\Gamma_I = \Gamma_3 + \Gamma_4 = \Delta\Gamma_3 - \Delta\Gamma_4 = \delta(\Delta v_3 - \Delta v_4) \quad (5)$$

The common and unwanted part Γ_{CM} cancels out and only the modulating part $\Delta\Gamma_x$ remains. The same principle holds for the Q channel, i.e., ΓQ. To avoid offsetting the IQ constellation, and also to avoid a carrier leakage, the expected (mean) value of I and Q channel must be zero, i.e.,

$$E\{\Gamma_I\} = E\{\Gamma_Q\} = 0$$

If the voltages on the I-channel are selected according to.

$$\Delta v_3 = kX_I \quad (6)$$

$$\Delta v_4 = -kX_I = -\Delta v_3 \quad (7)$$

where X_I is the modulating symbol for I-channel and k a scaling factor.
Using (6) - (7) in (5)

$$\Gamma_I = 2\delta kX_I$$

a similar result holds for the Q-channel

$$\Gamma_Q = 2\delta kX_Q$$

and it is assumed that $E\{\Gamma_I\} = E\{\Gamma_Q\} = 0$ so there is no carrier leakage. If there is a gain difference and an offset v_{offset} on Δv_4 compared to Δv_3, i.e.,

$$\Delta v_4 = -kX_I(1+\varepsilon) + v_{offset}$$

it follows from (5) that

$$\Gamma_I = \underbrace{\delta kX_Q(1+1+\varepsilon)}_{E\{\cdot\}=0} + \underbrace{\delta v_{offset}}_{E\{\cdot\}\neq 0}$$

which shows that a gain difference will not generate any carrier leakage. On the other hand, any offset $v_{offset} \neq 0$ will then contribute to the carrier leakage. Another observation is that if $\varepsilon = -1$ the value of Δv_4 = 0, so there is no need to modulate the load connected at port P4, i.e., a single ended baseband control signal can be used. A single ended baseband control signal may simplify the circuit, but will also lower the output power by 6 dB compared to the case when a differential baseband control signal is used (for $\varepsilon = 0$). In both cases the common mode voltage V_{CM} (that generates Γ_{CM}) must be the same to suppress the carrier leakage.

Results

A six-port modulator was implemented to verify the carrier leakage suppression technique proposed in this study. The six-port modulator uses an additional $\lambda/4$ transmission line at port P4 and P6 as shown in Fig. 2. The output power spectrum was measured for a QPSK signal at 100 Msymbol/s. As seen in Fig. 3 the carrier leakage is efficiently suppressed. Another benefit with the proposed carrier leakage suppression technique, when used with differential baseband control signals, is that it improves the linearity. This is illustrated in Fig. 4 for a 16-QAM modulated signal.

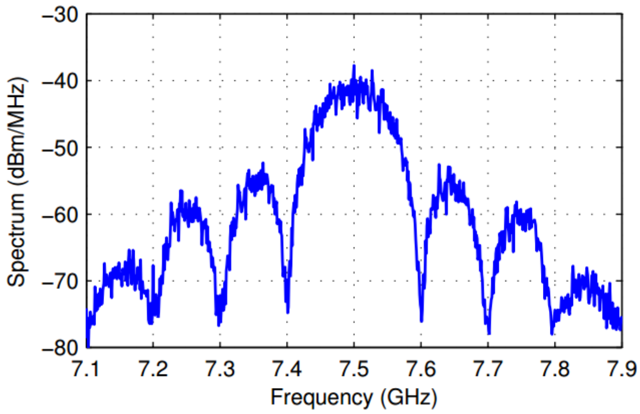
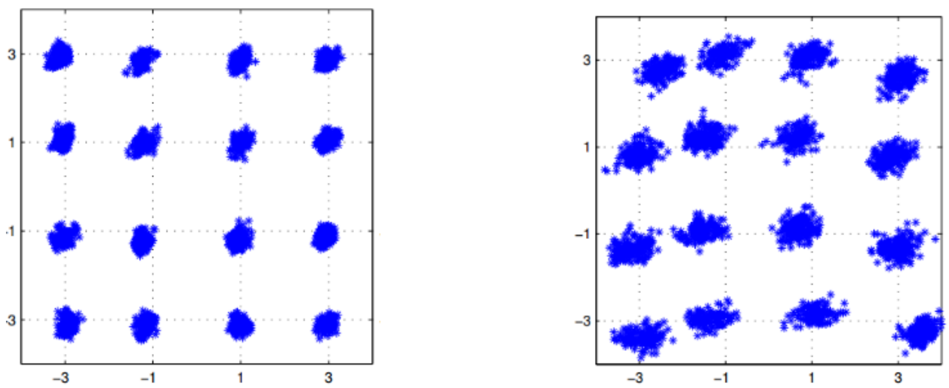


Fig. 3. Measured spectrum for a QPSK signal at 100 Msymbol/s. Owing to the use of $\lambda/4$ TL at specific ports the carrier leakage is suppressed [9]



(a) Differential control signal. (b) Non-differential control signal.

Fig. 4. Measured constellations for 16-QAM @ 100 Msymbol/s. When differential and non-differential control voltages are used [9]

Conclusion

The problem with carrier leakage in a six-port modulator was investigated and a solution presented. Our solution, based on a phase shifting network delivering a 90° phase difference between specific ports, is easy to implement. In its most simple form, a $\lambda/4$ TL may be used.

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IMPACT OF PHASE SHIFTING NETWORK ON CARRIER LEAKAGE SUPPRESSION AND ERROR VECTOR MAGNITUDE

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Introduction

One way to ensure low carrier leakage is to have a 90° phase shift between ports in each port pair (P3, P4) and (P5, P6), respectively. In general the phase shift and amplitude scaling between the ports in a port pair will deviate from their ideal