A Resistive HEMT Image Reject Upconverter with Tunable LO Suppression

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Abstract

A simple, yet efficient, method to improve the local oscillator suppression of mixers based on transistors in the cold modus is presented. The paper presents two approaches. Both are tested on a 7 GHz resistive HEMT image reject upconverter. In the first approach it is shown how the gate-biases on the four HEMT transistors may be used to electrically control the LO suppression. In the second approach four PIN-diodes are added to make the control easier and more robust.

Introduction

In modern communication systems the mixer is an important element. The mixers should be designed carefully to provide an undisturbed transformation with negligible addition of spurious signals. To provide a clean transformation a most possible linear mixing element should be used together with quite a high local oscillator (LO) power. The two most dominating spurious signals are the unwanted sideband (US) and the LO-RF-leakage (LOL). These need to be carefully minimized.

If the LO and RF frequency bands are overlapping (low IF), it is not possible to apply filters for removing US and LOL. Both may then be minimized by using balanced mixer configurations [1]. When this structure is used to minimize US, it is called an image reject mixer. However, lack of full balance in the hybrid-structure and in the pair of mixing elements limits the suppression to 25 - 30 dB over about 10 % bandwidth. To remove more, some kind of adjustment need to be provided. In the IF-part of the mixer it is easy to implement an amplitude and phase balance circuit, and then the US may be adjusted to its minimum. It is somewhat harder to implement a similar function for the cancellation of the LOL, because this has to be done in the high frequency part of the mixer. In 1983 Schiller [2] suggested a solution for a diode mixer. Schillers mixer was an image reject mixer with two balanced mixers that contained two connected diodes each. By adjusting the dc voltage level between each of the diode-pairs, the balance in the reflected LO could be adjusted in such a way that the LOL was canceled. The basic idea in Schiller's method is adopted, changed a bit and applied in the proposed method in this paper. Instead of using diodes as mixing-elements, HEMTs in the cold modus [3] are being used. Compared with diodes, these mixing-elements are much more linear, cheaper to buy and mount, and is better suited for MMIC-design.

Basic Concept

In a real balanced mixer, there will always be a non-zero LOL. This LOL has a magnitude and phase so it might be illustrated as a point in the phase-diagram in fig. 1b. This LOL-point appears when the balanced mixer is not adjusted (NA). A certain variation of the LOL will appear if it is possible to vary the magnitude of the LOL from each of the mixer-elements independently. This variation might be illustrated as the curve in fig. 1b. The element that provides the possibility of regulating the LOL is illustrated as the block before each of the mixer-elements in fig. 1a.

Two balanced mixers may now be combined in an image reject mixer configuration as illustrated in fig. 2a. External connectors, necessary for the implementation of the adjustments, are not shown in the figure. The varying LOLs from each of the balanced mixers are 90 degrees out of phase as shown in fig. 2b. These two leakages – named LOL1 and LOL2 – are added before the RF-port. It is obvious from the figure that there are two distinct points, one on each LOL-curve, for which the resulting leakage will be cancelled. These points are named A and B.

This new method is especially suitable for realization with mixers based on transistors. In this paper a HEMT biased in the cold modus is applied. Two solutions based on this mixer-element are presented in the further material.

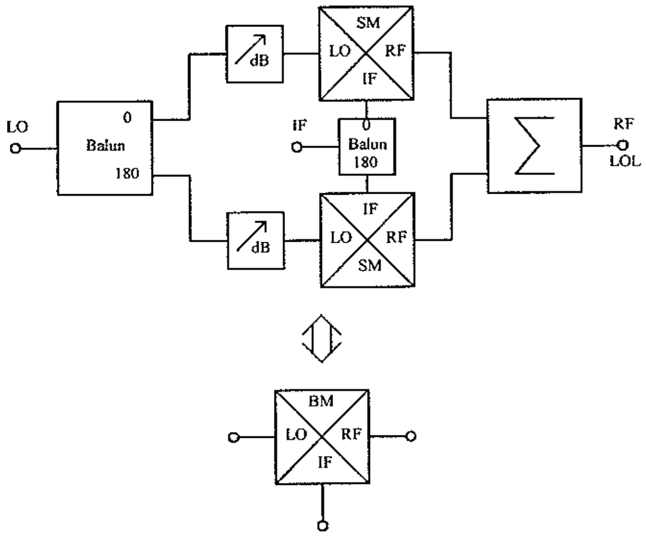

Fig. 1a Balanced mixer.

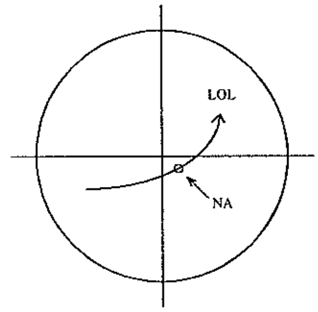

Fig. 1b LOL in phase-diagram.

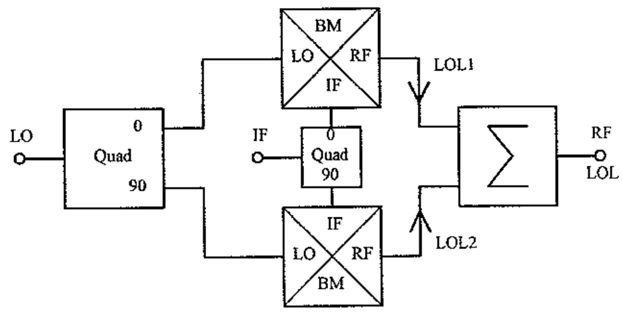

Fig. 2a Image reject mixer.

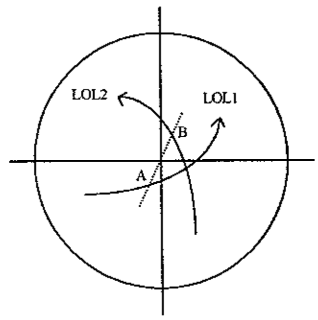

Fig. 2b LOL in phase-diagram.

First Approach

In a resistive HEMT mixer, the HEMT has no drain bias and is "cold". However, a gate bias Vg is usually applied. The LO is supplied to the gate, while the IF and RF exist at the drain. The LOL then depends on how the LO leaks through the HEMT (S21). In this approach one will seek to utilize Vg as the control-signal for the adjustment. A NEC HEMT NE325S01 is applied through this paper. In the phase-diagram in fig. 3b it is shown how the LOL from the cold HEMT, illustrated in fig. 3a, varies in amplitude and phase as a function of the gate voltage Vg when it is varied from -1.4 V to -0.4 V and the LO-power is 5 dBm. Before it is clear that the control shown in fig. 3 may be applied, it has to be checked out if there is any loss of performance for the mixer when this is done. RF-level and third order intermodulation (IMD_3) were measured for the mixer shown in fig. 3a as a function of Vg. The result is shown in table 1. It is clear that some variations exist, and that the linearity is degraded for Vg close to pinch-off. However, the worst linearity is more than 15 dB better compared with a well-designed diode-mixer with the same LO-power [3]. LOL-control by Vg seems to be a usable scheme.

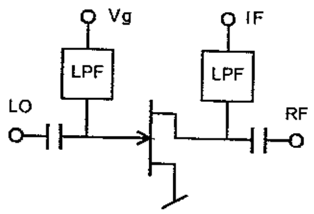

Fig. 3a Resistive HEMT mixer.

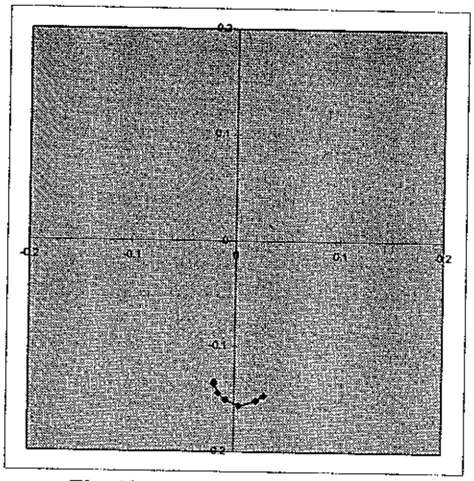

Fig. 3b LOL(Vg) at RF-port.

Vg [V]	P_{RF} [dBm]	IMD_3 [dBc]
-0.4	-12.1	-59
-0.6	-11.9	-59
-0.8	-11.9	-58
-1.0	-11.6	-56
-1.2	-11.6	-54
-1.4	-12.1	-50

Table 1 Performance.

Now, when an electrical regulation of the LOL is established, the basic concept may be applied. First a balanced configuration is applied as shown in fig. 4a. If this configuration was ideal and two identical HEMTs as the one in fig. 3 were used, the curve called LOLT in fig. 4b would describe LOL as a function of V1 and V2. V1 = -(X+0.4) V and V2 = -0.4 V for X > 0 and V1 = -0.4 V and V2 = (X-0.4) V for X < 0. X is varied from -1 to +1. LOL1 is the measured result for a real circuit. The LO-power is 8 dBm for this circuit.

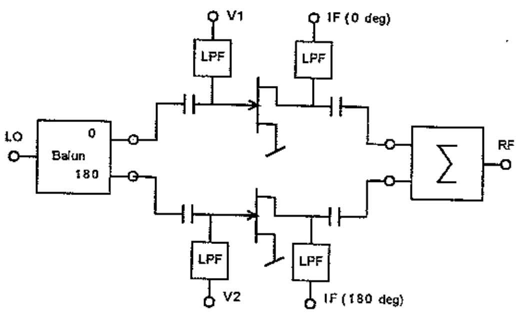

Fig. 4a Balanced resistive HEMT mixer.

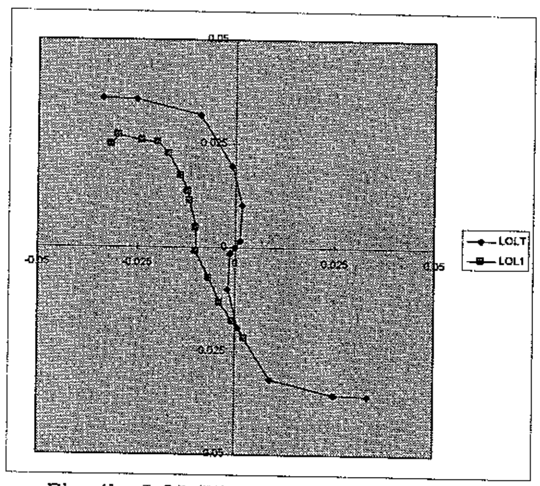

Fig. 4b LOL(X), X ∈ [-1,1] at RF-port.

Two balanced resistive FET mixers are now combined to make a resistive FET image reject mixer as shown in fig. 5a. This mixer will not only be able to reject or suppress US, but in addition be able to suppress the LOL. In fig. 5b is shown LOL from the two balanced mixers - LOL1 and LOL2. V1, V2, V3 and V4 are all regulated between -1.6 V and -0.4 V. The LO-power is 11 dBm. For two points in the phase-diagram opposite of the origin, the LOL1 and LOL2 will cancel each other and, theoretically, no LOL will exist.

The first approach of a resistive HEMT image reject upconverter was realized as shown in fig. 6. There is also shown the spectrum before and after adjustment of the LOL for LO-frequency 7.75 GHz. The lower sideband is preferred as RF. In table 2 is shown the performance of the mixer when LO-power is 11 dBm. It is clearly shown that it is possible to cancel the LOL over 8 % bandwidth.

This approach has simplicity in realization as the strongest property. The weak side is a little lack of robustness. If the LO-power is to low, resistive mixers have bad performance. If a resistive mixer based on this approach works with to high LO-power, the result shown in fig. 7 appears[1]. The measurements are done with three different LO-power levels. It is clearly demonstrated that the regulation area is reduced when higher LO-power is applied. With an LO-power higher than 11 dBm the approach will fail. This implies that using this approach, the LO-power tolerances have to be tight. The

[1] Fig. 7 is based on a similar circuit as the one fig. 4b is based on. However, tolerances in the parameters imply a difference in the two results.

transistors that are used need to have characteristics with tight tolerances as well. The next approach does not have these limitations.

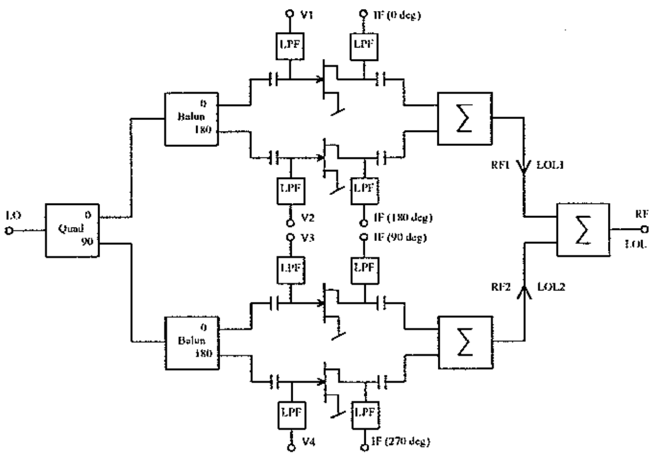

Fig. 5a Resistive FET image reject mixer.

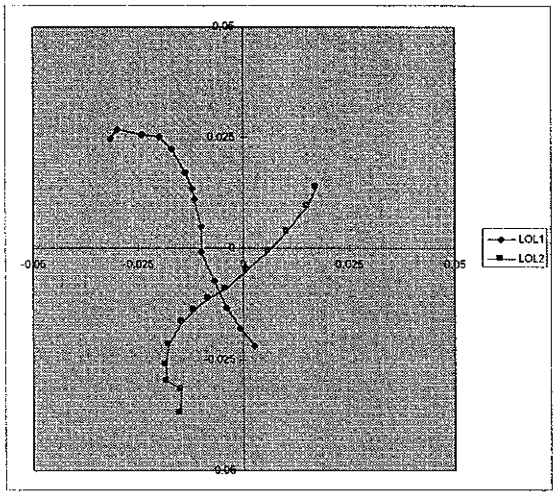

Fig. 5b LOL1(X1) and LOL2(X2).

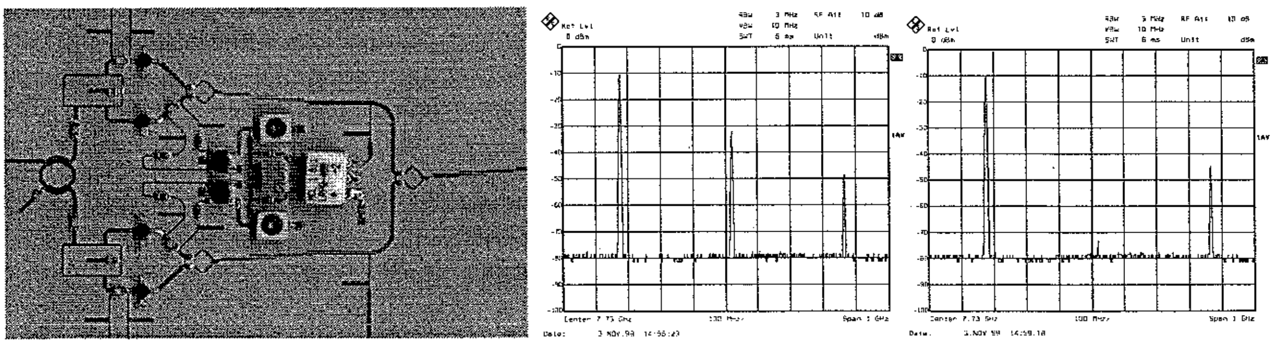

Fig. 6 Resistive HEMT image reject upconverter, first approach, with and without adjustment of LOL.

f_{LO} [GHz]	P_{RF} [dBm]	US [dBc]	LOL [dBm]	IMD_3 [dBc]	OIP3 [dBm]	V1 [V]	V2 [V]	V3 [V]	V4 [V]
7.45	-5.0	-13	< -60	-47	18	-0.12	-1.17	-0.46	-0.46
7.65	-5.2	-38	< -60	-42	16	-0.12	-0.30	-0.22	-0.23
7.85	-4.8	-30	< -60	-38	14	-0.09	-0.20	-0.22	-0.23
8.05	-4.9	-28	< -60	-40	15	-0.33	-0.03	-0.47	-0.37

Table 2 Performance of the 7 GHz resistive HEMT image reject upconverter, first approach.

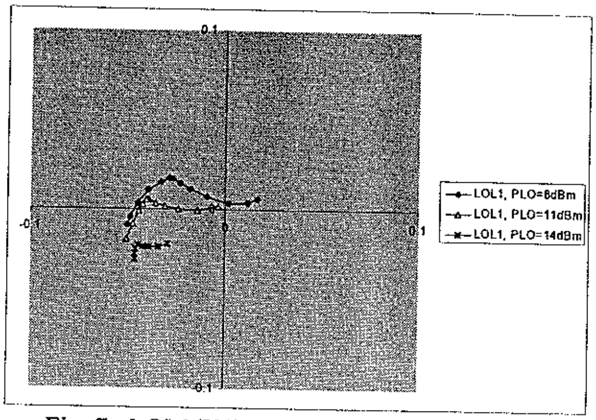

Fig. 7 LOL1(X1) with three LO-power levels.

Second Approach

The first approach is limited by the fact that the LO-power needed to drive the mixer-element into a well-behaved modus at the same time limits the dynamic in the regulations. The solution is to get parameters usable for the regulation that are not overlapping the ones used to control performance. These new parameters are provided by four PIN-diodes mounted as shown in fig. 8a. Only one control-voltage is needed for each balanced mixer (Vd1 and Vd2). Making it positive, activates one of the diodes in the balanced mixer; making it negative activates the other. To get best possible dynamic in the regulation, the electrical distance between the transistors and the diodes has to be such as the LO-signal sees a highest possible impedance in parallel with the PIN-diodes. In fig. 8b the control-voltage Vd1 is regulated such as the diode-current varies between –1.4 mA to +1.4mA. The gate-voltages are set equal, and are not used in the regulation (V1=V2=V3=V4=Vconstant). It is clearly shown that this approach works well for a wide variety of LO-powers. It should be more robust for variations in the transistor characteristics as well.

The second approach of a resistive HEMT image reject upconverter was realized as shown in fig. 9. There is also shown the spectrum before and after adjustment of the LOL for LO-frequency 7.75 GHz. The lower sideband is preferred as RF. In table 3 is shown the performance of the mixer when LO-power is 14 dBm. It is clearly shown that it is possible to cancel the LOL over 8 % bandwidth, even with such high LO-power.

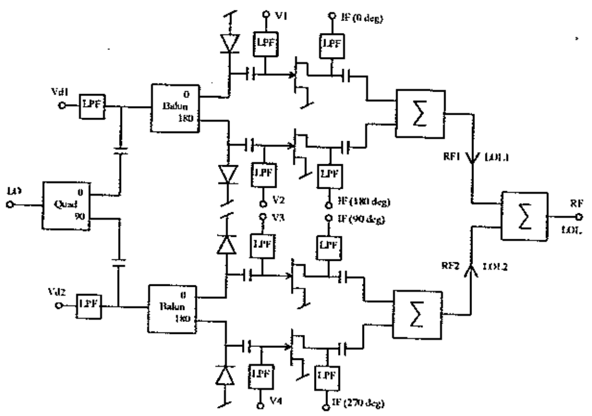

Fig. 8a Resistive FET image reject mixer.

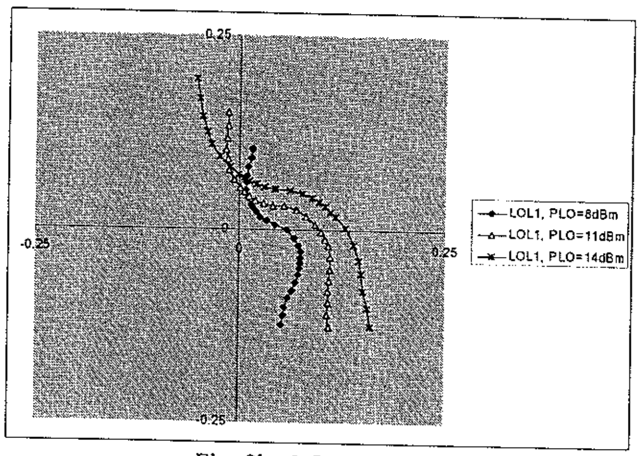

Fig. 8b LOL1(Vd1).

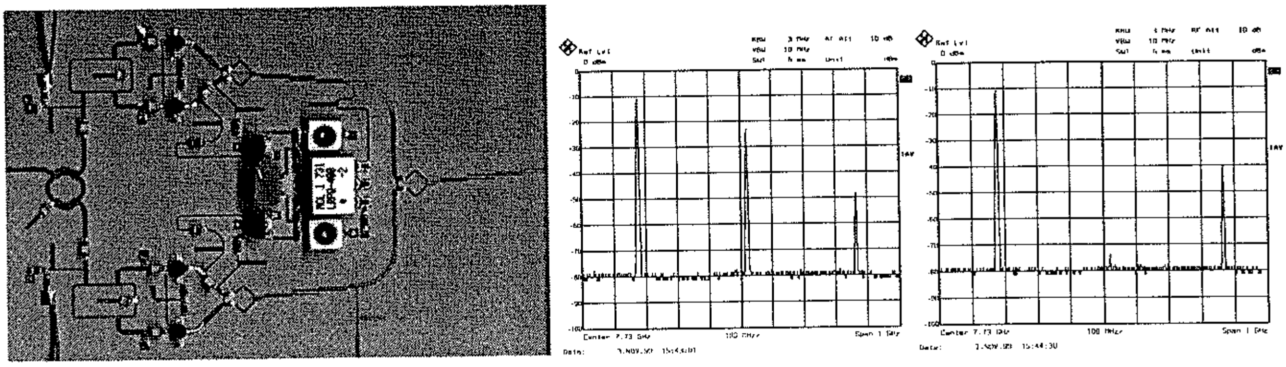

Fig. 9 Resistive HEMT image reject upconverter, second approach, with and without adjustment of LOL.

f_{LO} [GHz]	P_{RF} [dBm]	US [dBc]	LOL [dBm]	IMD_3 [dBc]	OIP3 [dBm]	Vd1 [V]	Id1 [mA]	Vd2 [V]	Id2 [mA]
7.45	-5.1	-25	< -60	-53	21	-1.2	-0.11	4.0	0.64
7.65	-5.8	-17	< -60	-52	20	0.8	0.05	3.9	0.62
7.85	-4.6	-20	< -60	-48	19	1.3	0.14	1.3	0.13
8.05	-4.7	-22	< -60	-45	18	-0.8	-0.05	-0.6	-0.01

Table 3 Performance of the 7 GHz resistive HEMT image reject upconverter, second approach.

Conclusion

In this paper it has been demonstrated how well-known designs of passive transistor mixers can obtain improved suppression of the LO-leakage through biasing. The unbalance in a 7 GHz resistive HEMT image reject upconverter was compensated by diverging the gate voltages on the four transistors. This approach is, however, limited by tight tolerances and lack of robustness. By adding four PIN-diodes to the circuit, the LO suppression became much more robust and could be regulated by only two control-voltages.

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