Intrinsic Performance of Dual-Gate FET Dual-Band Distributed Mixers with Composite Right/Left-Handed Transmission Lines

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Abstract

Composite Right/Left-Handed Transmission Lines (CRLH-TLs) have been recently used to design active distributed mixers with new performance like, for instance, dual-band frequency response. However, these circuits present a poor local oscillator to radiofrequency isolation and require an external coupler to inject both signals into the mixer, as conventional ones also do. These draw-backs can be removed by using dual-gate FETs instead of single-gate ones. In this contribution the intrinsic performance of dual-band distributed mixers based on dual-gate FETs is assessed by simulating a simplified mixer model.

1. Introduction

Active distributed circuits are based on transmission lines actively coupled by means of active devices like, for instance, FETs. Their frequency response, i.e. their performance, is governed by the phase constants of those transmission lines. If CRLH-TLs are used instead of conventional (Right-Handed, RH) ones, new possible designs emerge. This basic idea has been used to proposed novel distributed amplifiers and mixers based on CRLH-TLs [1-3].

In the case of mixers, a proper design with CRLH-TLs allows, for instance, two pass-bands (dual-band mixer) that are extracted through different physical ports (diplexer) [3]. Unfortunately, active distributed mixers based on two transmission lines require an external coupler to combine radiofrequency (RF) and local oscillator (LO) signals, which results, in general, in an increased circuit size and a poor LO-RF isolation. This drawback, which is also present in conventional (RH-TLs) distributed mixers [4], can be removed by increasing the number of coupled transmission lines (three) and coupling them by means of dual-gate FETs [5].

In this contribution, such a solution is applied to improve the LO-RF isolation in dual-band active distributed mixer designs based on CRLH-TLs. A preliminary assessment of its performance is carried out using a very simple model for both the transmission lines and the active devices (dual-gate FETs). Simulated results suggest that it is possible to keep the desired dual-band/diplexer behaviour whilst significantly improving the LO-RF isolation and avoiding the need of any external coupler.

2. Conversion gains in active distributed mixers

The intrinsic frequency response of active distributed mixers can be easily analyzed by means of a simplified continuous, lossless and unilateral model of the actively coupled transmission lines [3]. The two possible conversion gains, defined for the so-called forward and reverse ports, are given by [3]:

$$G_{fwd} = \frac{(|g_{mc}|l)^2 Z_{0g}(\omega_{RF}) Z_{0d}(\omega_{IF})}{4} sinc^2\left(\left(\Delta\beta_g(\omega_{IF}) - \beta_d(\omega_{IF})\right) l/2\right) \qquad (1)$$

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$$G_{rev} = \frac{(|g_{mc}|l)^2 Z_{0g}(\omega_{RF}) Z_{0d}(\omega_{IF})}{4} sinc^2\left(\left(\Delta\beta_g(\omega_{IF}) + \beta_d(\omega_{IF})\right) l/2\right) \quad (2)$$

where g_{mc} is the conversion gain per unit length, Z_{0g} and Z_{0d}, the characteristic impedances of the so-called gate and drain lines, and β_d the drain line phase constant. The parameter $\Delta\beta_g$ depends exclusively on the gate line phase constant and is given by:

$$\Delta\beta_g = \begin{cases} \beta_g(\omega_{RF}) - \beta_g(\omega_{LO}) = \beta_g(\omega_{LO} + \omega_{IF}) - \beta_g(\omega_{OL});\ \ \omega_{LO} > \omega_{IF} \\ \beta_g(\omega_{LO}) - \beta_g(\omega_{RF}) = \beta_g(\omega_{OL}) - \beta_g(\omega_{LO} - \omega_{IF});\ \ \omega_{LO} < \omega_{IF} \end{cases} \quad (3)$$

These equations clearly show that it is possible to obtain novel functionalities, like, for instance, a dual-band frequency response [3], by properly engineering the phase constant of the lines. CRLH-TLs, among others, provide interesting choices for this dispersion engineering.

3. Dual-gate FET distributed mixers

The intrinsic performance of dual-gate FET distributed mixers can be analyzed in a similar way using three transmission lines (Fig. 1). Two of them, the so-called gate$_1$ and gate$_2$ lines are uncoupled, while the third line (drain line) is unilaterally coupled to the others.

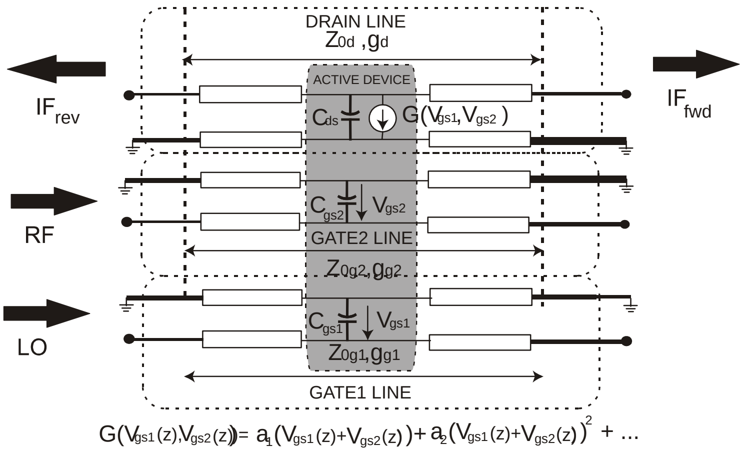

Fig. 1: Dual-gate FET distributed mixer (incremental circuit model).

It can be shown that forward and reverse conversion gains can be computed by equations (1) and (2), but now $\Delta\beta_g$ is given by:

$$\Delta\beta_g = \begin{cases} \beta_{g2}(\omega_{RF}) - \beta_{g1}(\omega_{LO}) \\ \beta_{g1}(\omega_{LO}) - \beta_{g2}(\omega_{RF}) \end{cases} \quad (4)$$

since, in the 3-line structure, the LO phase depends on the gate$_1$ phase constant, whilst the RF phase depends on the gate$_2$ phase constant. An important conclusion that can be extracted by comparing equations (3) and (4) is that the dual-gate FET distributed mixer can replicate any response of the single-gate FET version by simply designing the gate lines to have the same dispersion diagram, i.e. $\beta_{g1}(\omega)= \beta_{g2}(\omega)$. The advantage of the dual-gate FET mixer is now evident: ideally, it provides perfect LO-RF isolation; practically, the LO-RF isolation can be made very high.

4. Discussion and simulations

A dual-gate FET dual-band distributed mixer has been designed to replicate the single-gate FET mixer described in [3].

The structure of the unit cell of the dual-gate FET distributed mixer is depicted in Fig 2a, where the increase in complexity is evident. The simulated frequency response of the 5-stage mixer is shown in

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Fig. 2b, where the dual-band performance and the diplexer functionality of the mixer are clearly visible. Nevertheless, the dual-gate FET mixer provides some additional degrees of freedom. Note, for instance, that in order to replicate a given performance of the single-gate FET mixer it is not necessary to have β_{g1} equal to β_{g2} at all frequencies. It will suffice if $\beta_{g1}(\omega_{LO}) = \beta_{g2}(\omega_{LO})$ (and equal to $\beta_g(\omega_{LO})$ of the replicated single-gate FET design). Therefore, the same mixer frequency response can be achieved regardless of the dispersion diagram of $gate_1$ line. An alternative implementation, using a conventional (RH) transmission line in $gate_1$ line, is illustrated in Fig. 2c and provides exactly the same response as that shown in Fig. 2b.

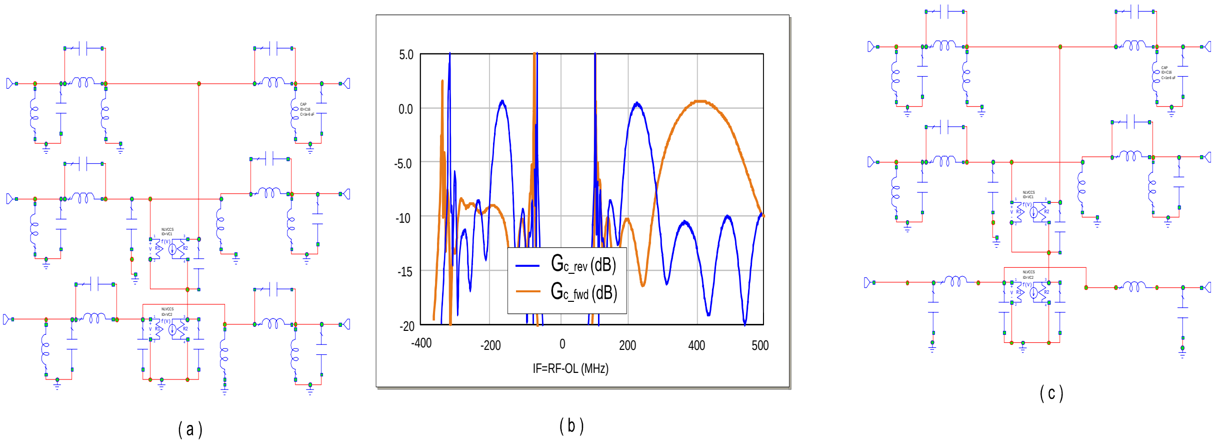

Fig. 2: Dual-gate FET distributed mixer: (a) unit cell with 3 CRLH-TLs; (b) Simulated forward and reverse conversion gains; (c) unit cell with 2 CRLH-TLs and 1 RH-TL ($gate_1$ line).

4. Conclusion

Dual-gate FETs can be used in conjunction with CRLH-TLs to design active distributed mixers with novel functionalities and improved LO-RF isolation. In this contribution, a preliminary analysis of these novel mixers has been performed using a simplified, continuous, unilateral and lossless model. The main conclusion is that any single-gate FET design can be replicated with dual-gate devices by just designing both gate lines as to have the same frequency behavior. Nevertheless, the new degrees of freedom make other choices possible and open the way to alternative designs that deserve further research.

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