Wide-Band Balanced Active HEMT Mixer

Andrey S. Yanev, Bogdan N. Todorov, and Vancety Z. Ranev

***Abstract*—The design and characteristics of a balanced active high electron-mobility transistor (HEMT) mixer operating in the 4.5–10-GHz frequency band are described in this paper. It consists of two parts implemented as independent hybrid circuits, namely, an microwave part fabricated by using a uniplanar technology and comprising a 180° hybrid ring coupler, HEMTs, and input–output matching circuits, and a low-frequency part consisting of an L–C balun and a low-pass filter built of discrete elements. The design of the microwave part of the mixer ensures a high degree of isolation between the signal and local-oscillator (LO) inputs within a wide frequency band at low IF. The measurements show a conversion gain of 5–7 dB, noise figure of 5–7.5 dB, and isolation between the signal and LO ports greater than 20 dB within the 4.5–10-GHz range.**

***Index Terms*—Balanced mixer, balun, hybrid ring coupler, uniplanar technology.**

I. Introduction

In recent years, the MESFET and high electron-mobility transistor (HEMT) have been the object of extensive studies in what concerns their application as nonlinear elements in the design of efficient microwave mixers and multipliers. These devices exhibit a number of advantages in comparison with their diode counterparts, such as easy integration with other transistor devices on the same chip and the possibility for amplification of the converted signal. Among the various modes of operation of transistor mixers, most of the research has focused on the resistive-type mixer [1]–[3], which has conversion loss comparable with that of the diode mixer, but with superior intermodulation characteristics.

The active-type transistor mixer offers another alternative to the diode mixer. The studies devoted to these mixers have demonstrated their capability of providing conversion gain and a noise figure lower in comparison with the resistive transistor mixers [4], [5]. The main problem arising in their design is providing a high degree of isolation between the signal and local-oscillator (LO) inputs, particularly when operating in a wide frequency band and at low IF.

The aim of this paper is to design and investigate a balanced active HEMT mixer characterized by an easy-to-implement structure and a high RF/LO isolation (>20 dB) in the 4.5–10-GHz frequency band, without making use of filtering circuits.

II. Mixer Structure and Design

Fig. 1 presents the schematic diagram of the transistor mixer considered. To achieve high decoupling between the signal and LO inputs in a wide frequency range, we chose a balanced mixer configuration and implemented it by means of two separate hybrid circuits: a microwave one and a low-frequency (LF) one, which could be studied and adjusted independently. The microwave part is fabricated entirely using a uniplanar technology and consists of a 180° hybrid ring, HEMT's, and input and output matching circuits. The LF circuit, built of discrete elements and comprising an L–C balun and a low-pass filter (LPF), performs the summation of the IF signals from the two arms of the microwave part.

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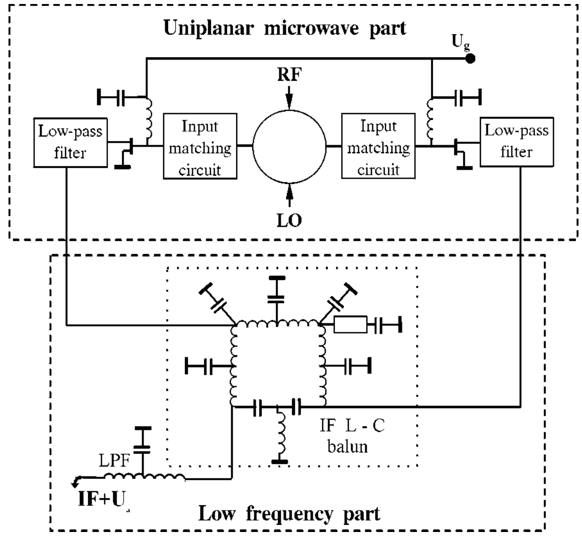

Fig. 1. Schematic diagram of the mixer.

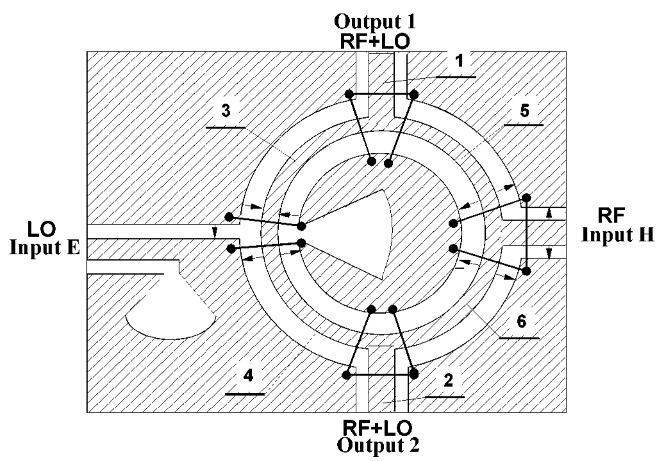

Fig. 2. Structure of the 180° hybrid ring.

The uniplanar 180° hybrid ring (Fig. 2), proposed and investigated by us, is the component, which determines, to a large extent, the wide-band performance of the mixer. The T-junction, which consists of a slot line and two coplanar lines 3 and 4, acts as a phase inverter. When the lengths of the ring's arms are equal, the signals from the H and the E inputs propagate in output arms 1 and 2 in-phase and out-of-phase, respectively, so that the opposite arms H, E and 1, 2 are perfectly decoupled in an unlimited frequency range. The device's wide-band performance is determined solely by its amplitude characteristics, which depend on the matching of the hybrid's inputs and outputs. In [6], the 180° slot-line ring coupler is simulated similar to its microstrip counterpart using an equivalent circuit that represents the phase inverter as a parallel connection of three slotlines. The experimentally measured losses of the out-of-phase power division significantly differ from those calculated from the equivalent circuit in the 2–4-GHz range. When calculating and optimizing hybrid ring characteristics, we used the equivalent circuit shown in Fig. 3. It differs from that used in [6] and [7] by the fact that the phase inverter (slot line—coplanar lines 3, 4) is represented as an in-series T-junction, modeled by means of the ideal impedance transformers $T2$, $T3$, and $T4$. The transformation ratios N are related to the impedance at the transformer input $(Z\mathrm{in})$ and output

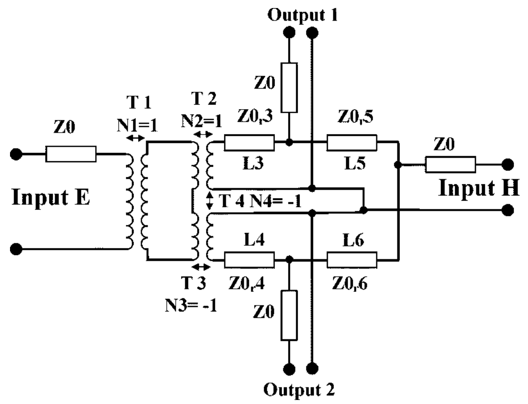

Fig. 3. Equivalent circuit of the 180° hybrid ring.

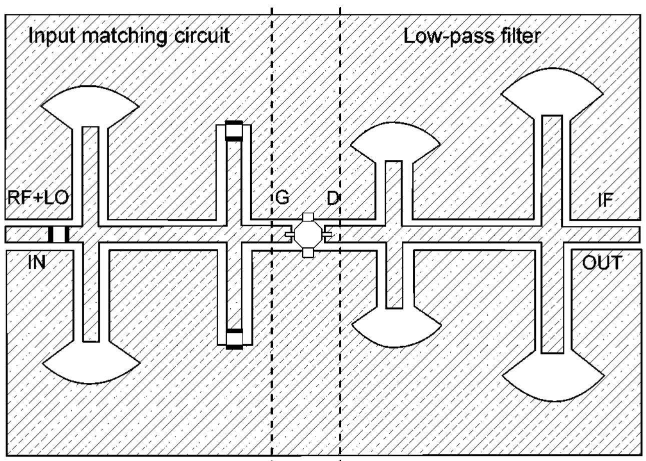

Fig. 4. Structure of the balanced mixer arms.

(Zout), as $N = (Z\text{in}/Z\text{out})^{1/2}$. The minus signs before the transformation ratio $N3$ and $N4$ indicate that the signals are inverted. The equivalent circuit allows one to use it to study the hybrid ring with the help of existing standard programs for analysis of microwave circuits.

The single-frequency analysis shows that the E and H inputs are perfectly matched when the following relations hold true:

$$L3-6=\lambda g/4 \quad Z0r3,4=Z0/\sqrt{2} \quad Z0r5,6=Z0\sqrt{2} \qquad (1)$$

where λg is the guide wavelength in the coplanar ring, $Z0 = 50\ \Omega$ is the impedance of the input and output lines, and $Z0r3-6$ is the impedance of the ring's coplanar lines.

The values of $L3-6$, $Z0r\,3,4$, and $Z0r5,6$, obtained from (1), and the equivalent circuit in Fig. 3 were used in the SCOMPACT program for wide-band simulation of in-phase and out-of-phase power division. This yielded a signal-division coefficient of less than 4 dB in the 4–12-GHz frequency range. The return loss is typically greater than 13 dB for both the E and H inputs and decreases to 9 dB at the ends of the frequency band.

Fig. 4 illustrates the structure of one of the two identical balanced mixer's arms. The input signal, and the LO signal from outputs 1,2 of the hybrid ring, are fed to the transistors gates through a five-element matching circuit, designed as bandpass filter. The latter, implemented by coplanar lines and a chip capacitor, transforms 50-Ω output impedance of the hybrid ring to the optimum gate impedance (10–15 Ω), providing maximal conversion gain in the frequency band considered (4.5–10 GHz). It also suppresses the propagation of the IF

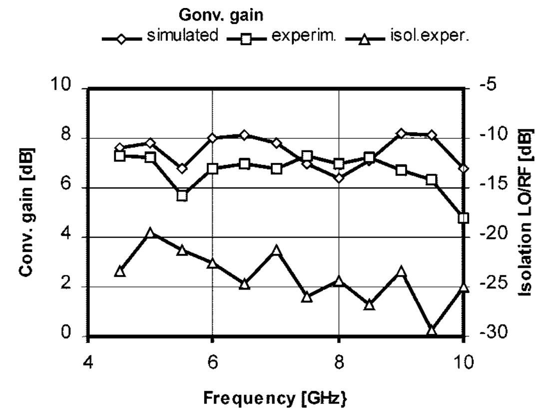

Fig. 5. Conversion gain and RF/LO isolation versus frequency.

signal (0.5 GHz) toward the hybrid ring. The LPF, consisting of in series and open parallel sections of coplanar lines, provides a suitable reactive load for the high-frequency products present at the transistor's drains and suppresses their propagation toward the IF output.

The IF signals from the two arms of the microwave part, 180° out of phase are summed by the IF L–C balun (Fig. 1). The balun is calculated to provide minimum insertion loss and out-of-phase balance in 200-MHz bandwidth, centered at 500 MHz. A three-element LPF filter added to the balun output performs additional high-frequency signal rejection.

Having measured the dc parameters and S-parameters of the transistor (ATF-36077), we extracted the parameters of the modified Materka nonlinear model supported within Compact Scout; together with the equivalent circuits of the structure's linear circuits, we used them to carry out a nonlinear simulation by means of the harmonic-balance technique. Bearing in mind that the hybrid ring is characterized by a high degree of isolation between the signal and LO inputs, we optimized the mixer's characteristics with respect to the conversion gain. With this aim, we applied the technique of matching the transistors gates. The results demonstrate that, in this case, one can increase the gain by about 2–3 dB as compared with connecting the transistors directly to the 50-Ω transmission lines. We also studied the influence of the gate voltage on the gain at constant LO power ($P_{\text{LO}} = 5$ dBm) and found the optimal voltage to be −0.7 V. During the optimization, we paid special attention to the synthesis of suitable circuits, ensuring stable operation of the transistors and eliminating self-oscillations. With this purpose, we also monitored the reflection coefficient at the signal and LO input, as well as the active part of the transistor's impedance.

III. Theoretical and Experimental Results

The microwave part of the mixer was implemented as a hybrid circuit on a 1.27-mm-thick RT/Duroid 6010.8 substrate. The 180° hybrid ring was built and tested independently in the 4–12-GHz range. The measurement show insertion loss less than 4.5 dB and return loss greater than 9 dB within the entire frequency band. The experimental values achieved agree well with the simulation results. The amplitude and phase balance between output ports 1 and 2 are within 0.3 dB and 2°, respectively. The isolation between the E and H input ports exceeds 27 dB, which is much less than calculated value because technological errors in the manufacturing process and parasitic port-to-port leakage.

The LF part was fabricated on the same substrate and investigated separately. Insertion loss of less than 0.5 dB in 400–600-MHz frequency band and more than 35-dB suppression of the LO and RF signals at the out-of-phase output was measured.

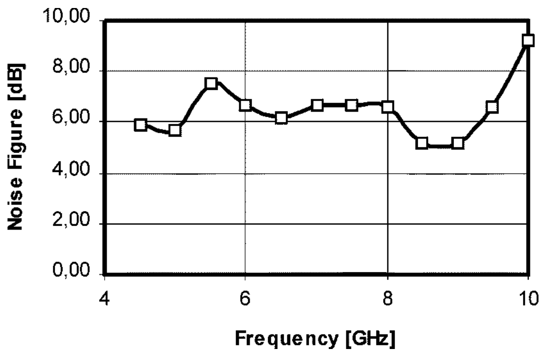

Fig. 6. Noise figure versus frequency.

The entire mixer circuit was tested with respect to the conversion gain, RF/LO isolation, noise figure, and saturation power. The dependencies of the conversion gain and the isolation between the RF and LO inputs on the frequency are shown in Fig. 5. The measurements were carried out at a transistor gate voltage of -0.6 V, a value yielding optimal characteristics at LO power of 5 dBm without using additional circuit adjustment. As one can see, we have obtained gain in the 5–7-dB range from 4.5–10 GHz with conversion down to an IF of 0.5 GHz, which agrees well with the simulation results (7–8 dB). Our experiments also show that the conversion gain is weakly sensitive to varying the LO power from 3 to 5 dBm. Setting the LO power to 3 dBm leads to a drop of gain by about 1 dB. The isolation measured between the signal and LO inputs is from 20 to 30 dB, which is 5–7 dB less than the calculated values. This is obviously due to the difference in the impedance of the transistor gates. The noise figure, shown in Fig. 6, is typically 5–7.5 dB and reaches 9 dB in the upper end of the band; it closely follows the behavior of the conversion gain. The values achieved for the noise figure are comparable with those typical for diode mixers in a wide-band mode of operation in the frequency range considered. The 1-dB compression point at the output was found to be 0 dBm.

IV. Conclusion

In this paper, we have developed and investigated a novel type of balanced active HEMT mixer in a wide-band mode of operation. The mixer is characterized by good isolation between the RF and LO ports without the use of filtering elements, conversion gain, and noise figure comparable to that of Schottky diode mixers. Input and output matching circuits are designed in order to obtain optimal conversion gain and noise figure. The conversion gain and noise figure values are typically in the 5–7- and 5–7.5-dB ranges, respectively, within the 4.5–10-GHz frequency band. The microwave part of the mixer is easy to implement which, together with the overall characteristics of the device, makes it suitable for many applications in the centimeter and millimeter ranges.

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Circular Cylindrical Waveguide Filled with Uniaxial Anisotropic Media—Electromagnetic Fields and Dyadic Green's Functions

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***Abstract*—Electromagnetic fields in a circular cylindrical conducting waveguide filled with uniaxial anisotropic media are formulated in this paper by using Fourier transformations. These fields are obtained as a superposition of the TE (or ordinary) and TM (or extraordinary) modes satisfying, respectively, different characteristic equations. Lastly, the dyadic Green's function is derived using the Ohm–Rayleigh method and represented by vector wave functions expansion.**

I. Introduction

Over the past several decades, considerable attention has been paid to the interaction between electromagnetic waves and anisotropic materials [1]–[3]. As is well known, an anisotropic medium is characterized by its permittivity tensor $\overline{\boldsymbol{\epsilon}}$ and permeability tensor $\overline{\boldsymbol{\mu}}$ [1], of which the form depends on the kind of anisotropy.

In analysis of anisotropic media, a couple of methods have been widely applied [2]–[9]. The Fourier transform relates the physical quantities in the spatial and spectral domains [2]–[6]. As an assistant, the method of angular spectrum expansion provides a way of coordinates transformation [4], [6]. The TE/TM decomposition method was used to solve electromagnetic problems involving a certain class of boundaries and media that basically separate TE- and TM-mode fields [7]–[9]. The dyadic Green's function (DGF) technique [10] is a powerful analytic method for solving boundary-value problems. Its applications in anisotropic media have already been well explored [11], [12].

In this paper, attention is paid to the analysis of the electromagnetic fields in circular cylindrical conducting waveguides filled with electrically uniaxial anisotropic media and the DGF. In obtaining the DGF, the main tasks are to find the vector wave eigenfunctions by which the electromagnetic fields can be expanded completely and then to determine the coefficients of eigenfunctions expansion. The conventional

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