DRA with Rat-race Hybrid Fed pHEMT Differential LNA for X-band Receiver Front-end Application

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***Abstract*—In this paper, a novel balanced amplifier antenna has been proposed for X-band. The antenna module consists of a microstrip fed ground slot excited cylindrical dielectric resonator (CDR). The unbalanced antenna output is converted into balanced outputs by a 180 degree rat-race hybrid which feed a differential low noise amplifier (LNA) consisting of two cascade stages. A marchand balun type biasing arrangement is employed for the differential LNA to increase common mode rejection ratio (CMRR). The differential LNA provides peak differential gain of 30 dB, CMRR of 16.8 dB and 12.6% 3 dB FBW. The insertion gain of the hybrid fed LNA is about 21 dB, 3 dB FBW is 8.4% and overall noise figure of the system is about 4 dB. The CDRA has peak gain of 5.47 dBi. The proposed design is suitable for modern receiver front-end applications requiring balanced outputs.**

Keywords—Balun; dielectric resonator antenna; differential amplifier; low noise amplifier; rat-race hybrid.

I. Introduction

Modern antennas are rapidly growing in population which has integrated amplifiers for enhancing the transmitted or received power. The low noise amplifiers are integrated to the singular or array antennas, and the whole module can be used for the receiver front-end. Several amplifier antennas have been reported so far. A broadband differential low noise amplifier integrated antenna array has been proposed [1] which can be used for radio astronomy. Differential LNAs are suitable where balanced outputs are necessary. A 60 GHz balance antenna integrated with low noise amplifier is reported in [2]. The amplifier antennas are also suitable for MIMO applications as proposed in [3].

In this work an integrated amplifier antenna has been proposed which works at X-band. The circuit is designed using hybrid MIC approach. A high gain cylindrical DRA output is fed to a 180 degree two section rat-race hybrid which converts unbalanced antenna output into two balanced outputs and they are used to feed a pHEMT differential amplifier. Each side of the differential amplifier comprises of two cascade stages to increase the gain. The differential amplifier has moderate noise figure and provides very high gain. The proposed design is suitable for modern receivers working in X-band. The structure is simulated in Ansoft HFSS and Keysight ADS.

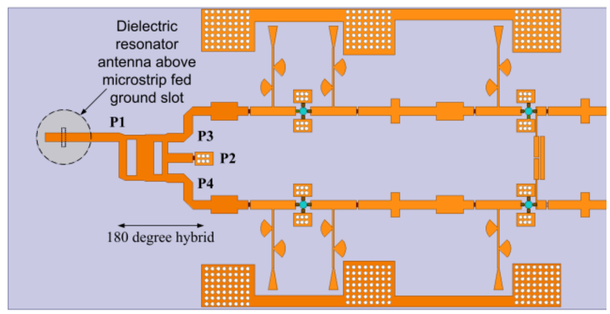

Fig. 1: Layout of the amplifier antenna.

II. Amplifier Antenna Design

A. Cylindrical Dielectric Resonator Antenna

The antenna module shown in Fig. 1 is a cylindrical dielectric resonator (RT/Duroid 6010, dielectric constant 10.2, loss tangent 0.0023) of height 2.57 mm and radius 7.4 mm excited in $HE_{11\delta}$ mode by a microstrip fed ground slot. The antenna is kept on the opposite side of the amplifier to diminish the effect of radiation on the active amplifier section. The antenna operates in X-band.

B. Rat-race hybrid

The layout of the rat-race hybrid is shown in Fig. 2. The unbalanced antenna output is fed to a 180 degree rat-race hybrid at P1, provides two balanced outputs (P3 and P4). The rat-race hybrid structure consists of two sections and hence provides wider bandwidth. A similar structure has been proposed in [4]. Characteristic impedances in Ohms are $\{Z_1,Z_2,Z_3,Z_4,Z_5\}=\{66,57,30,53,74\}$. P2 is isolated port and it is matched terminated by a lumped 50 Ohm chip resistor.

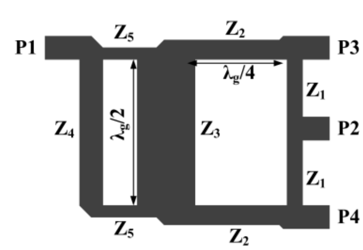

Fig. 2: Layout of the two section rat-race hybrid.

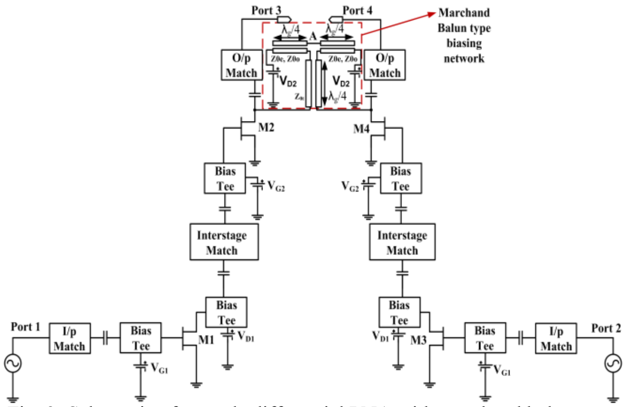

Fig. 3: Schematic of cascade differential LNA with marchand balun type biasing network.

C. *Differential amplifier*

The differential amplifier as shown in Fig. 3 consists of two cascaded common source stages in each balanced arm. Four identical pseudomorphic HEMTs (NE3210S01) have been used for the design. Interstage matching is used between the cascade stages. The upper common source stage drain bias is provided by a marchand balun type biasing network as in [5], which improves the CMRR.

III. SIMULATION RESULT

The whole structure is designed with RT/Duroid 5880 substrate with dielectric constant 2.2, loss tangent 0.0009 and substrate height 0.787 mm. The simulated response of the magnitude and phase differences of the hybrid is shown in Fig. 4. It is evident that the two outputs (P3 and P4) provide almost equal insertion loss and 180 degree phase shift between them when fed at P1. The differential amplifier is simulated to find single ended S-parameters S^{std}. The mixed mode S-parameters S^{mm} [6] are calculated from (1).

$$S^{mm} = MS^{std}M^{-1} \tag{1}$$

Where conversion matrix $M = \dfrac{1}{\sqrt{2}}\begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{bmatrix}$

The *CMRR* is given by (2) in terms of S^{std}.16.8 dB *CMRR* has been achieved. Differential gain S_{dd21} is about 30 dB.

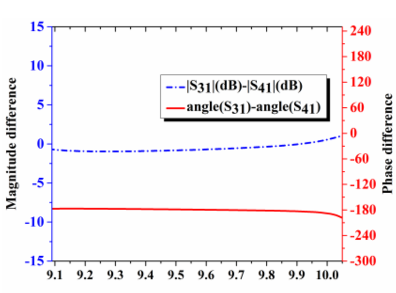

Fig. 4: Magnitude and phase difference of hybrid outputs.

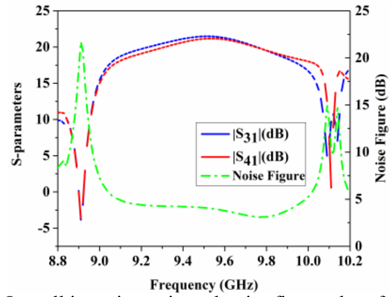

Fig. 5: Overall insertion gain and noise figure plot of the rat-race hybrid fed differential LNA.

$$CMRR = \frac{S_{dd21}}{S_{cc21}} = \frac{S_{31} - S_{32} - S_{41} + S_{42}}{S_{31} + S_{32} + S_{41} + S_{42}} \tag{2}$$

The overall gain and noise figure (with 3 dB hybrid insertion loss) of the rat-race fed amplifier module is shown in Fig. 5. The S_{11} and 3D radiation pattern of the CDRA is shown in Fig. 6 at 9.5 GHz. The gain of the antenna is 5.47 dBi and 10 dB return loss bandwidth is 13.4% (8.88-10.16 GHz).

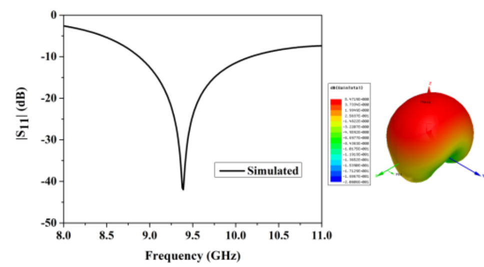

Fig. 6: Simulated S_{11} and 3D radiation pattern (9.5 GHz).

IV. CONCLUSION

The amplifier antenna proposed here has high gain and moderate bandwidth. It may act as receiver front-end element in GPS, WiFi, RFID etc. The differential outputs can be fed by quadrature hybrid to mixer of direct conversion receivers.

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