

shows the average of the local error obtained by using the new profiles against regularisation factor α and for two different multiplication factors λ . For comparison, in the same graph we give the minimum local error obtained for the parabolic-like profile (with order $n = 4.6$), as well as the local error that has been obtained with order $n = 2$ [5]. As it is possible to see, the PML with the new profiles performs extremely well for all of the chosen regularisation factors, having for a certain multiplication factor ($\lambda = 0.55$), a performance even slightly better than the best obtained for just a particular order ($n = 4.6$) of the parabolic-like profile. The performance is therefore broadband with respect to the regularisation and the multiplication factors.

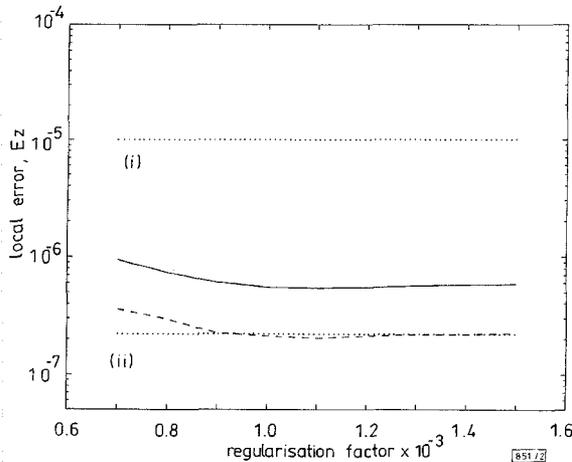


Fig. 2 Average of local error obtained by using new profiles against regularisation factor α and for two different multiplication factors λ

- (i) parab.-like, $n = 2.0$
- (ii) parab.-like, $n = 4.6$
- $\lambda = 1.0$
- - - $\lambda = 0.55$

Conclusions: An efficient approach to determine alternative profiles of the conductivities to be used for effective performances of the PML ABC for the FDTD code has been presented. It is shown that by using an inverse theory approach it is possible to design highly absorbing profiles of conductivities to be used for the PML layers. Further investigations in this area should be carried out with other characterisations of the PML error, leading to the possibility of an optimum design of the needed boundary conditions for any situation.

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References

- 1 BERENGER, J.P.: 'A perfectly matched layer for the absorption of electromagnetic waves', *J. Comp. Phys.*, 1994, **114**, pp. 185–200
- 2 KATZ, D.S., THIELE, E.T., and TAFLOVE, A.: 'Validation and extension to three dimensions of the Berenger PML absorbing boundary condition for FD-TD meshes', *IEEE Microw. Guided Wave Lett.*, 1994, **4**, pp. 268–270
- 3 WU, Z., and FANG, J.: 'Numerical implementation and performance of perfectly matched layer boundary condition for waveguide structures', *IEEE Trans. Microw. Theory Techniques*, 1995, **43**, pp. 2676–2683
- 4 DE MOERLOOSE, J., and STUCLY, M.A.: 'Reflection analysis of PML ABC's for low frequency applications', *IEEE Microw. Guided Wave Lett.*, 1996, **6**, pp. 177–179
- 5 LAZZI, G., and GANDHI, O.P.: 'On the optimal design of the PML absorbing boundary condition for the FDTD code', *IEEE Trans. Antennas Propag.*, 1997, (to be published)
- 6 MUR, G.: 'Absorbing boundary conditions for the finite-difference approximation of the time-domain electromagnetic field equations', *IEEE Trans. Electromag. Compat.*, 1981, **23**, pp. 377–382
- 7 BERNTSEN, S., and HORNSLETH, S.N.: 'Retarded time absorbing boundary conditions', *IEEE Trans. Antennas Propag.*, 1994, **42**, pp. 1059–1064
- 8 ZHDANOV, M.S., and KELLER, G.V.: 'The geoelectrical methods in geophysical exploration' (Elsevier, 1994)
- 9 MOORE, T.G., BLASHAK, J.G., TAFLOVE, A., and KRIEGSMANN, G.A.: 'Theory and applications of radiation boundary operators', *IEEE Trans. Antennas Propag.*, 1988, **36**, pp. 1797–1812

Miniature MMIC star double balanced mixer using lumped dual balun

Hwann-Kao Chiou, Yu-Ru Juang and Hao-Hsiung Lin

Indexing terms: MMIC, Mixers (circuits), Baluns

The authors present the design and performance of a very compact MMIC star mixer. The mixer is composed of four diodes and two lumped dual baluns which are realised using two high-lowpass out-of-phase power splitters in parallel. The MMIC star mixer shows wide bandwidth, high P1dB, high third order intercept (IP3) point and high port-to-port isolations both in the applications of up and down converter. The chip size of this star mixer is much smaller than those of the conventional mixers. To the best of the authors' knowledge, it is the smallest size ever reported for passive mixer operated at S-band.

Introduction: The star double balanced mixer (DBM) is an excessively complex version of DBMs. The advantage of star mixers over the traditional ring DBMs is mainly on their low IF parasitic inductance which enables a much wider IF bandwidth to be achievable. In star mixers, the IF signal is direct coupled, which allows the applications on phase detection or direct baseband conversion. Furthermore, the circuit size can be greatly reduced because the IF diplexing filter and external DC return path are no longer needed. So far, very few studies regarded star mixers [1–3] because they need a complicated dual balun structure, which is much more difficult on circuit realisation than the conventional single balun. Previous star mixers were designed using hybrid-based implementations. Their distributed balun utilised either vertical or horizontal couple stripe-lines to form a Marchand balun. Consequently, these mixers become bulky or nonplanar, and cannot be adopted in MMIC processes. In comparison to these hybrid star mixers, very few MMIC star mixers have been presented. A Ka-band MMIC star mixer with excellent performances using a coplanar Marchand-like balun was first reported by Maas *et al.* [4]. However, even in the Ka-band, the chip size is $2.4 \times 2.8 \text{ mm}^2$, still too large for commercial applications. In addition, the distributed baluns would become an impractical way to realise the balun in star mixers in the lower frequency range. In this Letter, an S-band MMIC star mixer using a lumped dual balun is first proposed. With the chip dimension significantly reduced to $0.8 \times 0.8 \text{ mm}^2$, the mixer still has all the feasibilities that the conventional star mixer has. It would certainly find wide applications in the low microwave band.

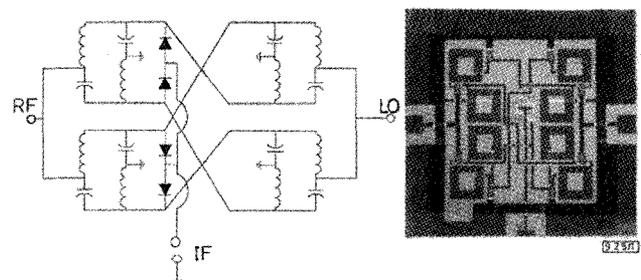


Fig. 1 Circuit schematic diagram and photograph of lumped high-lowpass star mixer

Dual balun and mixer design: The schematic diagram and photograph of the star mixer are shown in Fig. 1. The star DBM consists of two RF/LO dual baluns and four diodes located between the baluns. The IF signal is taken from the centre of diodes. The key component of the star mixer, the dual balun, is realised with two parallel out-of-phase power splitters. Each splitter is composed of a highpass filter and a lowpass filter connected in parallel. The baluns serve both phase shift and power distribution purposes. An ideal dual balun acts like an impedance transformer, the phase difference between its two output ports is 180°, and the power distributed to them are equal. The impedance of the dual balun Z_t is given simply as

$$Z_t = (Z_o \times Z_d)^{1/2} \quad (1)$$

where Z_o and Z_d are characteristic and diode impedance, respectively. In our design, the filter with order two built only one inductor, and one capacitor is chosen for the minimal use in lumped elements. The relations between the Z_t and the values of the L and C is illustrated in the following equation:

$$L = Z_t / (2\pi f) \quad C = 1 / (Z_t \times 2\pi f) \quad (2)$$

where f is the centre frequency of the balun. The insertion loss of this dual balun outputs are equal only at the centre frequency and the amplitude balances degrade outside the centre frequency. This drawback can be improved by using higher order filter topology. However, it will pay the penalty of extra lumped elements. The N-implanted diode with size $4 \times 25 \mu\text{m}$ is chosen to fabricate the star diode quad. Each diode has a series resistance $\sim 9 \Omega$ and a junction capacitance of $\sim 0.23 \text{pF}$. This corresponds to an f_j of 77 GHz. With this diode impedance, the dual balun is realised with a 50Ω system. The star diode quad can be driven by the available LO power level from 15 to 21 dBm. After performing the impedance matching, eight 5 nH inductors, eight 0.5 pF capacitors, and four diodes are connected to form a complete star mixer circuit. The chip size is only $0.8 \times 0.8 \text{mm}^2$, compared with the traditional single or double balanced mixers, the size is several times smaller.

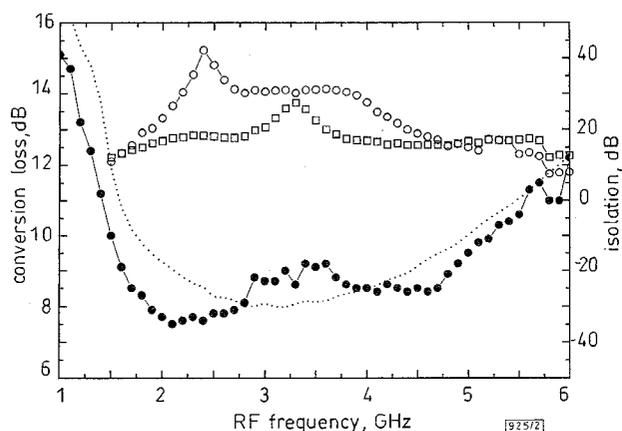


Fig. 2 Conversion loss and isolations of star mixer operated as a down-converter

Fixed IF = 100 MHz, LO power = 17 dBm

- LO/IF isolation
- LO/Rf isolation
- measured CL
- simulated CL

Results: Fig. 2 shows the performance of the star mixer operated as a downconverter. The single sideband conversion loss of the mixer is typically 8.5 dB. The bandwidth of the conversion loss $< 10 \text{dB}$ is from 1.5 to 5.2 GHz, which is better than the conventional lumped hybrid DBMs which have only 30% bandwidth. Because the lumped balun structure can be analysed very accurately, the measured results are in good agreement with the predicted data. When the RF is fixed at 2.4 GHz, at ISM band frequency, the IF bandwidth is up to 750 MHz. The LO/Rf and LO/IF isolations are over 15 dB from 1.6 to 5.0 GHz. Fig. 3 shows the upconversion loss of the same star mixer measured at a fixed RF frequency of 2.4 GHz. As can be seen, the typical conversion loss is 8 dB. The IF bandwidth is up to 1000 MHz. The LO/Rf isolation is $> 20 \text{dB}$. Because of its excellent up or down conversion

efficiency, this circuit is suitable to be used in Doppler transceiver system or used as a high frequency phase detector. Fig. 4 shows the IF output power and its third order product against RF input power. The 1 dB compression and third order intercept points are as high as 13 and 23.5 dBm, respectively. This result is comparable to the resistive FET mixers which have the highest IP3 performance among the mixers.

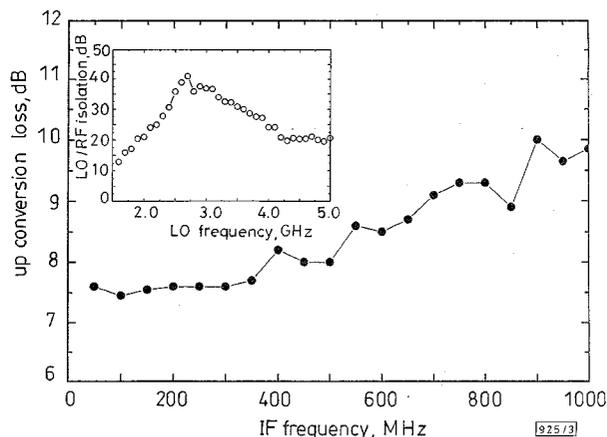


Fig. 3 Conversion loss and LO/Rf of the star mixer operated as up-converter

LO power = 17.0 dBm

Fixed RF = 2.4 GHz lowside LO

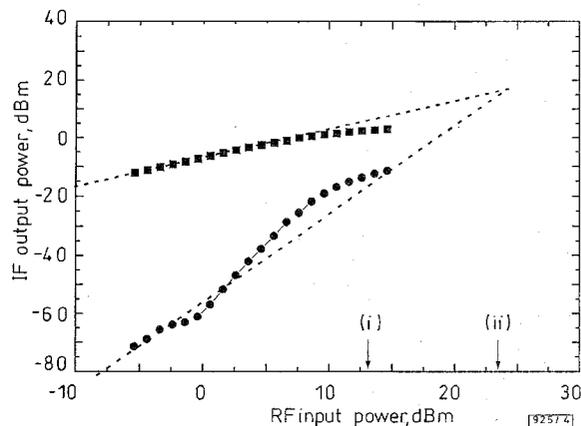


Fig. 4 First order and third order IF power outputs against RF input power, with mixer operated as downconverter

- RF1 = 2.4 GHz, RF2 = 2.403 GHz
- LO = 2.3 GHz, LO power = 17 dBm
- (i) P1 dB = 13 dBm
- (ii) IP3 point = 23.5 dBm
- single tone
- two tones

Conclusions: A new planar star DBM suitable both in MIC and MMIC fabrication has been presented. The MMIC star mixer exhibits the wideband, high isolation, P1 dB and IP3 characteristics. The most promising feature is its compact size that allows the circuit to be processed with high yield and low cost. For its simple geometry, small size and easy fabrication, the star mixer will consequently become a high performance and low cost component and find wide applications in low microwave band such as a wireless communication system.

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References

- 1 MOUW, R.B.: 'A broadband hybrid junction and application to the star mixer', *IEEE Trans. Microw. Theory Technol.*, 1968, **16**, pp. 911
- 2 HALLFORD, R.B.: 'A designer's guide to planar mixer baluns', *Microw.*, 1979, **18**, (12), pp. 52
- 3 MAAS, S.A.: 'Microwave mixers' (Artech House, Norwood, MA, 1992), 2nd edn.
- 4 MAAS, S.A., and CHANG, K.W.: 'A broadband, planar, doubly-balanced monolithic Ka-band diode mixer', *IEEE Trans. Microw. Theory Technol.*, 1993, **41**, pp. 2330-2335

Integrated push-push frequency doubling active microstrip transponder

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Indexing terms: Transponders, Microwave devices

A new compact frequency doubling active transponder using a push-push technique is presented. Two outputs in anti-phase from the receiving patch antenna are amplified nonlinearly using MMICs and combined in phase suppressing the fundamental and enhancing the second harmonic. The doubled signal is then transmitted from a second patch antenna with a measured conversion gain of 6dB.

Introduction: A transponder is a circuit which radiates a signal when an input signal from an external transmitter is detected. In this configuration, the output signal from the transponder may be at a different frequency than the received signal. There are many applications for transponders [1] which include communication systems and contactless RF identification in road vehicle tolling [2].

An efficient frequency doubling effect can be achieved from two nonlinear devices connected in a push-push configuration [3]. The inputs of the two identical nonlinear devices are 180° out of phase with each other at fundamental frequency and the output power is combined in phase. The fundamental and odd harmonics cancel each other while the even harmonics add together. This technique has been utilised in a transponder by Linden *et al.* [4], where two transistors were used as active devices. The input signal was detected by an antenna which was passed through a phase shift circuit to provide an appropriate phase shift. In the new configuration described in this Letter, the required 180° phase shift is derived from the patch itself, removing the need for an additional phase shift circuit, therefore reducing the overall size of the transponder and losses in the phase shift circuit.

The new transponder circuit consists of a receiving active frequency doubling microstrip antenna and a transmitting passive microstrip antenna. The receiving active antenna itself consists of a 10GHz half wavelength patch antenna and two identical MMIC amplifiers which provided the required nonlinearity and conversion gain. The doubled signal is radiated out by a microstrip antenna that resonates at 20GHz.

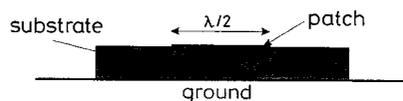


Fig. 1 E-field in half wavelength microstrip antenna

Circuit: The electric field in a half wavelength microstrip antenna is as shown in Fig. 1. The fields at any two opposite points equidistant from the middle of patch are equal in magnitude and opposite in phase (i.e. 180° out of phase). Two outputs from a half wavelength patch antenna, resonant at 10GHz, are taken. The outputs are of equal magnitude and in anti-phase to each other, which eliminates the need for a half wavelength microstrip line to give the same effect [3]. The antenna is connected to two identical MMIC amplifiers via quarter wavelength impedance transformers. The in-house designed two stage MMIC low noise

amplifiers (LNAs) are biased in nonlinear mode to generate high second harmonics. The outputs of both amplifiers are combined together by connecting to the same microstrip line. The second harmonic power at 20GHz is transmitted out by a half wavelength microstrip antenna which resonates at 20GHz. The antennas are oriented in such a way that the E fields of the received (10GHz) and transmitted (20GHz) signals are orthogonal for high isolation between them. The circuit is built on a 0.508mm substrate with a dielectric constant of 2.33. The layout diagram of the new transponder is shown in Fig. 2.

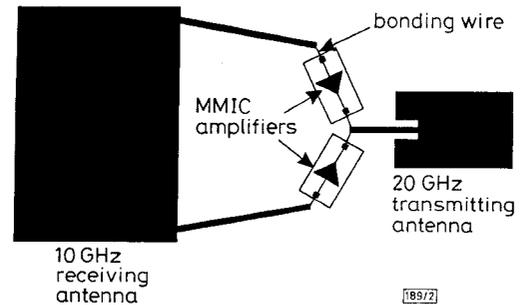


Fig. 2 Layout diagram of new compact transponder with MMIC amplifiers

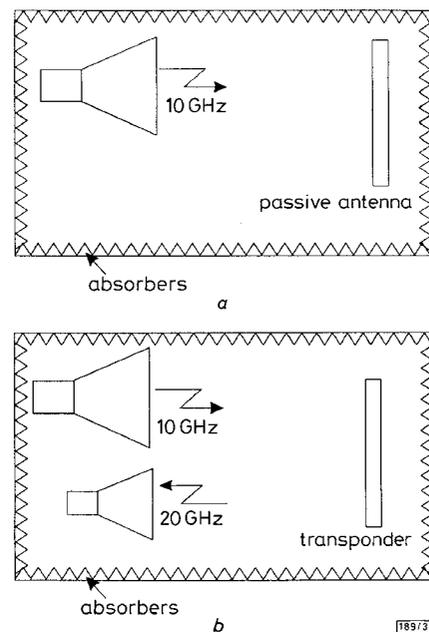


Fig. 3 Technique used to measure effective power received by transponder and conversion gain measurement technique

a Technique used to measure effective power
b Conversion gain measurement technique

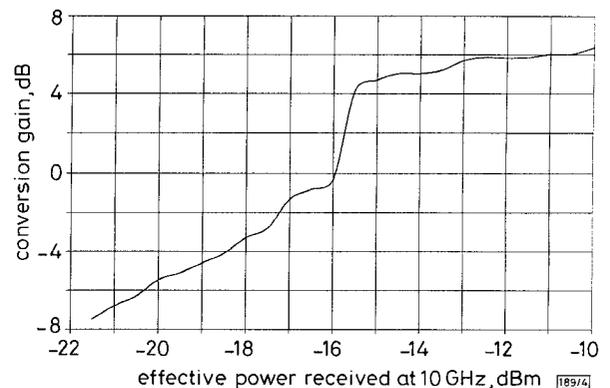


Fig. 4 Measured conversion gain of transponder

Results: The effective power received by the transponder at 10GHz was measured by a passive side fed patch antenna which has the same gain as the antenna in the transponder circuit as shown in Fig. 3a. The power necessary to achieve this level was