120 and 60 GHz Monolithic InP-based HEMT Diode Sub-harmonic Mixer

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ABSTRACT

Monolithic sub-harmonic mixers are designed using two circuit topologies for RF frequencies at 60 and 120 GHz. They are fabricated on a 3-mil thick InP substrate using 0.1 μm pseudomorphic InAlAs/InGaAs HEMT process. On-wafer measurements from 110 to 120 GHz at an IF of 7.8 GHz show a minimum conversion loss of 14.3 dB with 8.2 dBm of a sub-harmonic LO drive. This is the first demonstration of a monolithic HEMT diode sub-harmonic mixer at 120 GHz. The 60 GHz sub-harmonic mixer achieves a minimum conversion loss of less than 12 dB at an LO drive of 13 dBm. The conversion loss dependence on LO drive power and RF frequency are presented. Results indicate that within the band of interest at 120 GHz the mixer performance remains admirable even when LO drive is as little as 5.3 dBm.

INTRODUCTION

High frequency receiver functions such as mixing is very important for military and commercial appilcations. To date monolithic HEMT mixers have demonstrated their capabilities of providing low conversion loss and reasonably low noise figure due to their superior high frequency characteristics [1][2]. For the state-of-the-art performance including a maximum oscillation frequency (f_{max}) of 455 GHz [3] and low power requirement, an InAlAs/InGaAs heterostructure is an appropriate choice for HEMT realization [4]. This paper explores sub-harmonic mixer designs at RF frequencies at 60 and 120 GHz using 0.1 μm gate length, 3-mil thick InP process. The mixers utilize a pair of anti-podal HEMT diodes and simple matchings in microstrip line environment. On-wafer testing data indicate that the mixer has a wide-band low conversion loss (about 15 dB) performance, and it requires low LO drive power (minimum at 5.3 dBm) for RF operation at 120 GHz. For 60 GHz downconversion similar designs achieve conversion loss less than 12 dB with a 13 dBm LO drive at 23 GHz.

CIRCUIT DESIGN

The 120 GHz sub-harmonic mixers are designed to downconvert an RF signal of 112 to 120 GHz to an IF of 4 to 12 GHz by mixing it with the 2nd harmonic of a 62 GHz LO signal. The 60 GHz sub-harmonic mixers downconvert an RF signal of 50 to 58 GHz to an IF of 4 to 12 GHz with a 23 GHz LO drive. Two circuit topologies of the sub-harmonic mixers are presented. Circuit schematics are shown in Fig. 1 and 2 for each design respectively. A pair of anti-podal HEMT diodes, each having two gate fingers of 0.1 μm gate length and total periphery 20 μm, are used as the mixing elements. Diode model parameters were obtained through on-wafer measurement and curve fitting. The first design as shown in Fig. 1 utilizes quarter-wavelength open-stub and short-stub at each end of

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the diodes pair to achieve good isolation between LO and RF ports. LO port matching is done by conventional microstrip-lines reactive matching techniques while RF port matching is obtained with a two-section edge-coupled line filters. IF signal is tapped through a low pass network and is connected to one end of the diodes opposite to the dc-shorted end. The second design utilizes a simpler topology where LO, RF and IF matching networks are connected to a common end of the diodes as shown in Fig. 2, avoiding design complexicities and risk as compared with the first design. All passive matching structures were electromagntically simulated by Sonnet EM-software. The chip layouts for the 120 GHz sub-harmonic mixers are shown in Fig. 3 and 4 respectively for these two designs. Both chips have a common size of 1.7 mm by 2 mm. Chip layouts for the 60 GHz sub-harmonic mixers with similar circuit topologies as those of 120 GHz ones are given in Fig. 5 and 6 . Both chips have a size of 1.7 mm by 1.75 mm.

MEASURED PERFORMANCE

On wafer measurements of the sub-harmonic mixers were performed. For the 120 GHz sub-harmonic mixers conversion losses were measured as a function of the LO input power. RF and LO signal frequencies were fixed at 113 GHz and 60.4 GHz respectively. The IF signal of the mixer at 7.8 GHz was measured on a Tek-

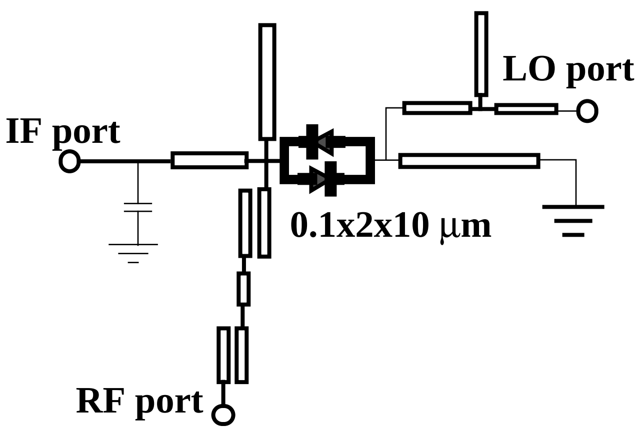

Figure 1 Circuit schematic of the first design for the sub-harmonic mixer

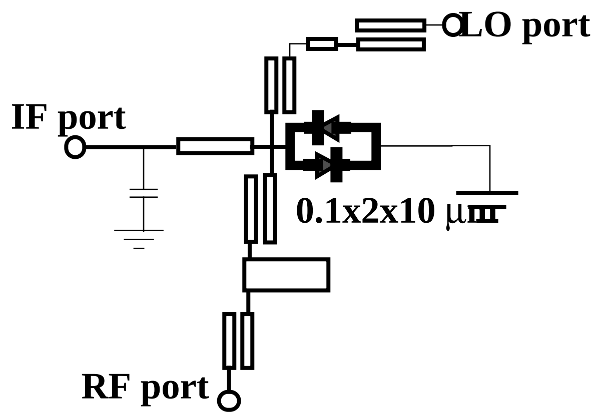

Figure 2 Circuit schematic of the second design for the sub-harmonic mixer.

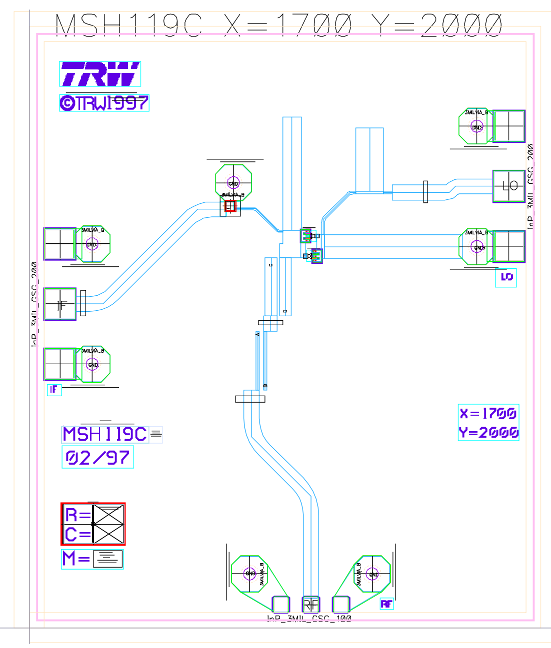

Figure 3 120 GHz sub-harmonic mixer chip layout of the first design corresponding to circuit schematic in Fig. 1.

tronix spectrum analyzer and the conversion losses were plotted in Fig. 7 (a). Both designs achieved a conversion loss of about 15 dB even with an LO drive power as little as 5.3 dBm (or 3.4 mW). As shown in Fig. 7 (b), the RF frequency responses were also measured from 110 to 120 GHz with a constant LO drive of 8.2 dBm (or 6.7mW) at 60.4 GHz. It is found that within the band from 112 to 118 GHz the 1st design had

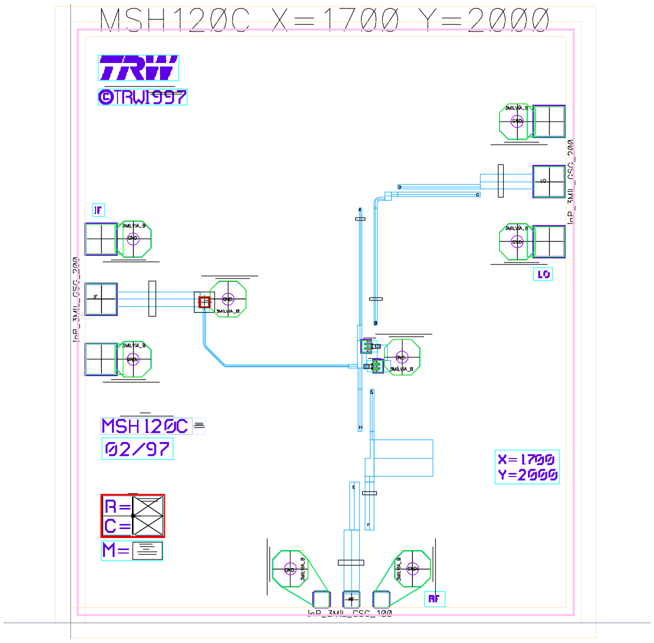

Figure 4 120 GHz sub-harmonic mixer chip layout of the first design corresponding to circuit schematic in Fig. 1.

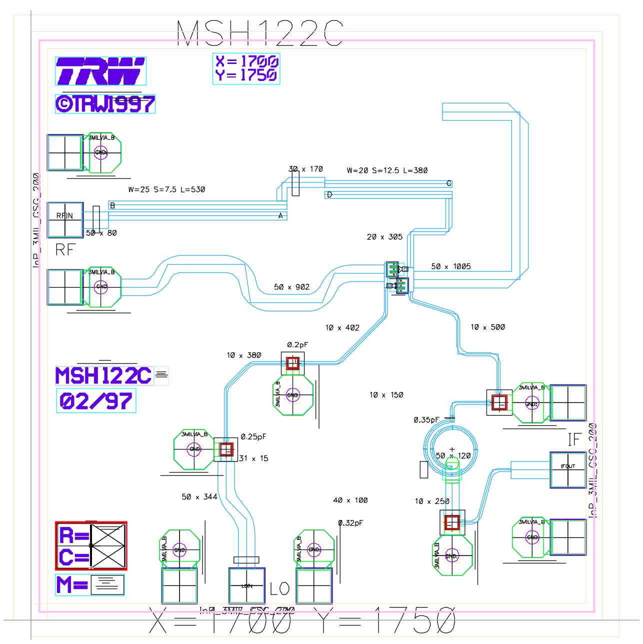

Figure 5 60 GHz sub-harmonic mixer chip layout of the first design corresponding to circuit schematic in Fig. 1. except the IF port low pass network.

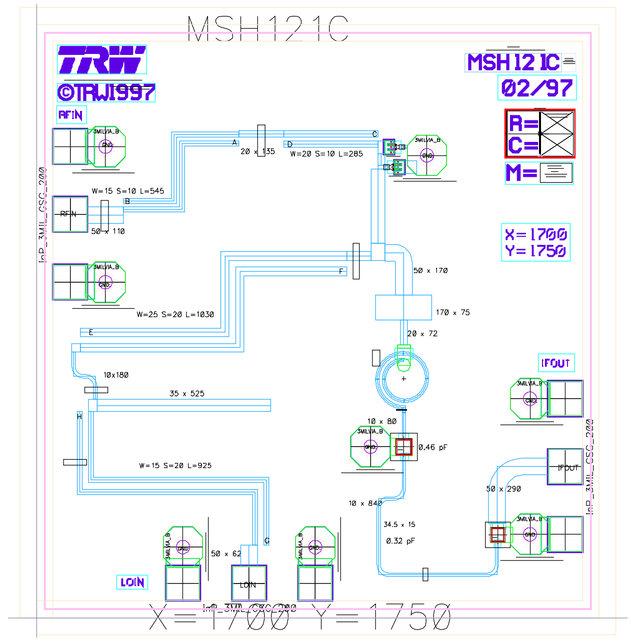

Figure 6 60 GHz sub-harmonic mixer chip layout of the second design corresponding to circuit schematic in Fig. 2. except the IF port low pass network.

a flatter frequency response whereas the conversion loss ranges within 15 to 17 dB. For the 60 GHz sub-harmonic mixers conversion loss measurements were made as a function of RF frequencies from 50 to 57 GHz where a 23 GHz LO drive is fixed at 13 dBm. As indicated in Figure 8, sub-harmonic mixers designed by the second topology (Fig. 2) achieved a conversion loss less than 12 dB across the RF band while the first design topology (Fig. 1) maintained a conversion loss less than 15 dB within the band of interest.

CONCLUSION

Two circuit topologies were utilized for the design of monolithic sub-harmonic mixers at RF frequencies of 120 and 60 GHz based on the 3-mil InP-based HEMT process. On-wafer measurement results showed that the sub-harmonic mixers achieved conversion losses less than 17 dB within the RF band from 110 to 120 GHz even with a small LO drive power of 5.3 dBm at 60.4 GHz. At the RF band from 50 to 57 GHz a minimum conversion loss less than 12 dB with a 23 GHz LO drive at 13 dBm was achieved. The

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success of high frequency, low power sub-harmonic mixing functions at 120 and 60 GHz will provide a vehicle for extending the useful spectrum of microwave technology for commercial and military applications.

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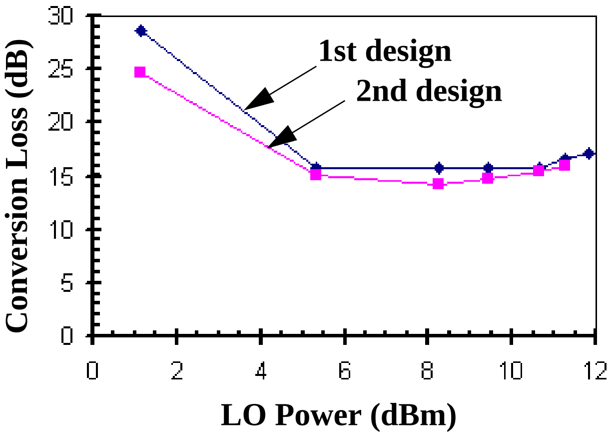
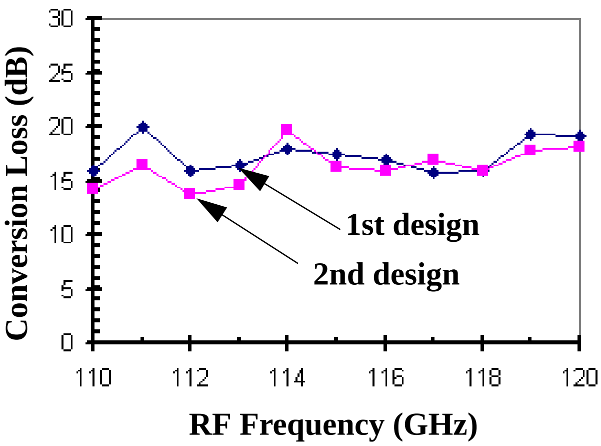


(a)



(b)

Figure 7 (a) Conversion losses of the 120 GHz sub-harmonic mixers (the 1st and the 2nd design) were measured against different LO input powers. RF and LO frequencies were fixed at 113 and 60.4 GHz respectively.
(b) Conversion losses of the 120 GHz sub-harmonic mixers (the 1st and the 2nd design) were measured for different RF frequencies from 110 to 120 GHz. The LO signal was fixed at 60.4 GHz with a power of 8.2 dBm (or 6.7 mW).

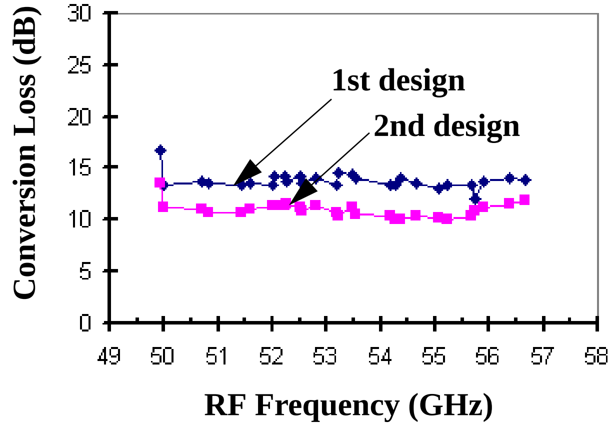


Figure 8 Conversion losses of the 60 GHz sub-harmonic mixers (the 1st and the 2nd design) were measured as a function RF frequencies from 50 to 57 GHz where LO signal frequency was fixed at 23 GHz with a power of 13 dBm

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REFERENCES

[1] S. A. Maas, “Design and performance of a 45-GHz HEMT mixer,” *IEEE Trans. Microwave Theory Tech.*, vol. MTT-34, no. 7, pp. 799-803, July 1986..

[2] P.D. Chow, D. Garske, J. Velebir, E. Hsieh, Y.C. Ngan and H.C. Yen, “Design and performance of a 94 GHz HEMT mixer,” *1989 IEEE MTT-S Int. Microwave Symp. Dig.*, June 1989, pp. 731-734.

[3] P. Ho, M.Y. Kao, P.C. Chao, K.H.G. Duh, J.M. Ballingall, S.T. Allen, A.J. Tessmer and P.M. Smith, “Extremely high gain 0.15 µm gate-length InAlAs/InGaAs/InP HEMT’s,” *IEE Electron Lett.*, vol. 27, pp. 325-327, 1990.

[4] Y. Kwon, D. Pavlidis, P. Marsh, G. Ng and T.L. Brock, “Experimental characteristics and performance analysis of monolithic InP-based HEMT mixers at W-band,” *IEEE Trans. Microwave Theory and Techniques*, vol. 41, no. 1, pp. 1-8, January 1993.