A Compact 60GHz Sub-Harmonically Pumped Mixer MMIC Integrated with an Image Rejection Filter

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Abstract — **In this paper we present a sub-harmonically pumped image-rejection mixer MMIC for antenna-integrated modules in the 60GHz-band. The mixer MMIC consists of a mixing part and a filter part. The filter has two λ/2 microstrip resonators and has a mutual-inductive coupling and a capacitive one between its input and output ports, which results in transmission zeros near the pass band. In the mixing part an electrical short circuit for an LO signal is provide by the filter characteristics at an LO frequency instead of a conventional λ/4-open-stub. The fabricated image-rejection mixer MMIC, of which size is only 1.0mm x 1.5mm, shows a conversion loss of 11~13dB and an image rejection ratio of more than 30dB in a pass-band of 60~61.1GHz when an LO frequency is 29.5GHz.**

I. INTRODUCTION

Recently many millimeter-wave system applications such as wireless LANs, wireless IEEE1394 and millimeter-wave video transmission system have been proposed [1-3]. In order to make these applications succeed especially in consumer markets, developing compact and low-cost RF modules is indispensable.

In millimeter-wave communication systems using heterodyne scheme, there have been mainly two approaches to realize image rejection characteristics so far. One is using an external filter such as wave-guide or dielectric filters [4,5], and the other is balanced configuration of two mixer elements to cancel undesired signals [6-8]. The former approach, however, results in larger module size and adds up assembling cost, while the latter usually needs an external IF hybrid and the bandwidth is limited by its performance. Therefore the integration of a filter and a mixer on a chip is very attractive if its performance satisfies the system specification and the chip size is comparatively small.

This work presents the design and measurement results of a sub-harmonically pumped mixer with an image-rejection filter on a GaAs chip, which is intended to be used as up- or down-converters for antenna-integrated millimeter-wave modules. The designed and fabricated mixer has several features. Firstly even harmonic signals are canceled in the mixer because it consists of anti-parallel diode pair (APDP). Secondly the filter has fairly steep rejection performance considering it is built on a GaAs substrate. And lastly total chip size is very small as a result of the novel filter configuration and the design of the mixer circuit utilizing the filter performance.

II. CONCEPT OF MILLIMETER-WAVE ANTENNA INTEGRATED MODULES

Fig.1 shows the concept of antenna-integrated millimeter-wave modules we have proposed [9]. There are MMICs or HICs on one side and printed patch-antennas on the other side of a ceramic substrate. RF circuits and an antenna feed line are connected by electromagnetic coupling through a slot.

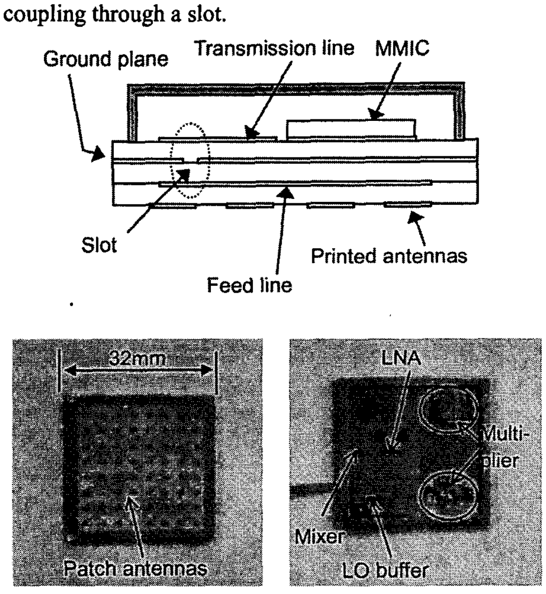

Fig. 1. Concept of antenna-integrated millimeter-wave modules.

In this module, since a wide band of more than 1GHz is to be up/down-converted by a fixed local signal, not only securing bandwidth but also rejecting undesired signals have to be considered carefully.

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Table 1 shows our target frequency specification of the image rejection mixer.

TABLE I
Frequency specification of image rejection mixer

Band	Frequency	Target
IF band	1.0~2.1GHz	-
LO	29.5GHz	Input power < 10dBm
Pass band at RF	60.0~ 61.1GHz	Conversion gain > -13dB
2 x f_{LO}	59GHz	Leak at RF port < -40dBm (Up-conv.)
Rejection (Image) Band	56.9~ 58.0GHz	Conversion gain < -36dB (Image rejection > 23dBc)

III. Design Approach and Measurement Results

A. Filter

Fig.2 illustrates the equivalent circuit of the filter [10,11]. It has only two resonators which are capacitively coupled with each other, and it has also a mutual-inductive coupling and a capacitive coupling between its input and output ports. These two couplings create rejection poles near the pass band and this leads to steep rejection performance in spite of the wide pass-band. We realized this configuration by using microstrip lines on 70μm-thick GaAs substrate.

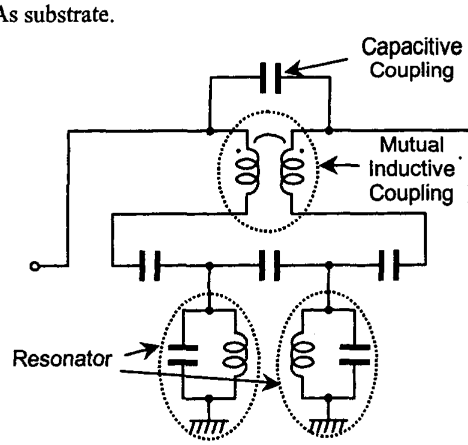

Fig. 2. Equivalent circuit of the filter.

Fig.3 shows a photograph of the fabricated sample of the filter. The metal thickness is 10μm and minimum line and space is 20μm, which enables the steep rejection characteristics and is difficult for other technologies like PCB. We used commercial moment method simulator IE3D to optimize the geometrical parameters. In order to enhance the mutual-inductive coupling between its input and output ports by maximizing the current, the coupling location is designed to be approximately λ/4 away from the microstip line open end.

The test chip size is 1.0mm x 1.0mm and the net filter area is only 0.37mm x 0.48mm.

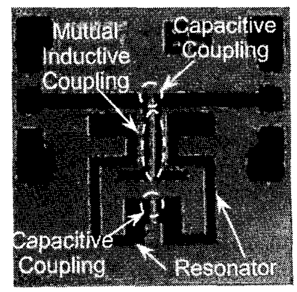

Fig. 3. Photograph of the filter test sample. The chip size is 1.0 mm x 1.0 mm.

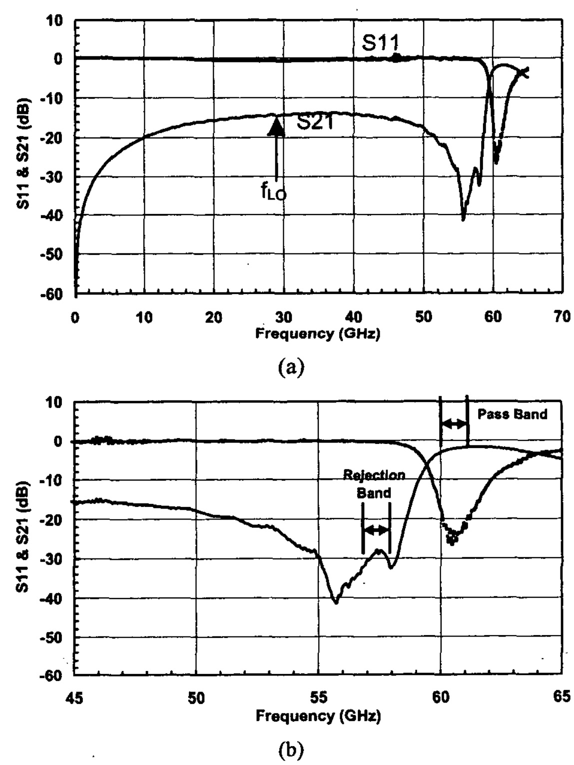

Fig. 4. Frequency response of the fabricated filter in (a) a wide span and (b) a narrow span graph.

Fig.4 demonstrates the frequency response of the fabricated filter in a wide span and a narrow span graph. There are two transmission zeros at 55~58GHz. The insertion loss is 1.9~3.0dB and the return loss is greater than 20dB in a pass band of 60.0~61.1GHz while the insertion loss is more than 29dB in a rejection band of 56.9~58.0GHz.

B. Design of Image rejection mixer

In the design of a sub-harmonically pumped mixer which consists of an APDP, an open stub of $\lambda/4$ at LO frequency has been generally used to provide ground for an LO signal and to pass RF signals. However, the open stub is about 1mm long at 30GHz and occupies pretty large area. Therefore, we utilized filter performance to create a virtual short circuit for an LO signal instead of the open stub to reduce the chip size. Fig.5 illustrates the configuration of the designed image rejection mixer.

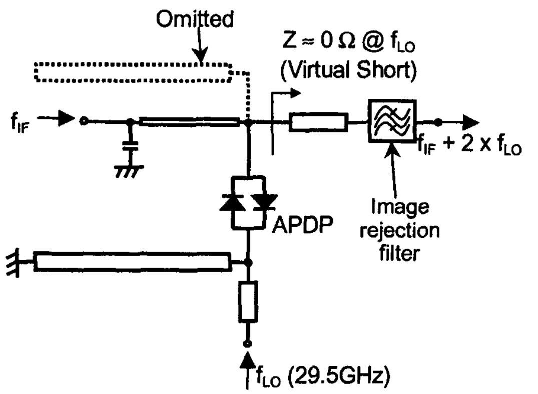

Fig. 5. Schematic of sub-harmonically pumped image rejection mixer with an APDP.

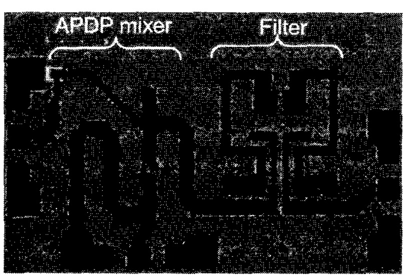

Fig. 6. Chip photograph of the sub-harmonically pumped image rejection mixer. (1.0 x 1.5mm)

A mixer circuit and a filter are connected through a transmission line of 50Ω, of which length is determined so that the impedance becomes virtually 0Ω at LO frequency at a contact point of the transmission line to the mixer circuit. We used harmonic balance simulator Serenade 8.5 to simulate the non-linear characteristics of the mixer and IE3D to optimize the geometry of passive elements such as a transmission line, a short stub, and a via-hole.

The diode layer consists of 700nm-thick n-GaAs ($3.0\times10^{16}cm^{-3}$), 20nm-thick n^+-InGaP ($3.0\times10^{18}cm^{-3}$), and 500nm-thick n^+-GaAs ($5.0\times10^{18}cm^{-3}$) on a GaAs substrate. The material of Schottky electrode is Ti/Pt/Au, of which contact area is 5.4μm x 7.2μm.

Fig. 6 shows the photograph of the fabricated image rejection mixer. The chip size is 1.0mm x 1.5mm and the thickness of the GaAs substrate is 70μm.

C. Performance of down-conversion

Fig.7 demonstrates the conversion gain as a function of an LO power when the mixer is used as a down-converter. RF is fixed to 60.5GHz and the input level is -10dBm. The saturation can be seen at an LO power of 6dBm.

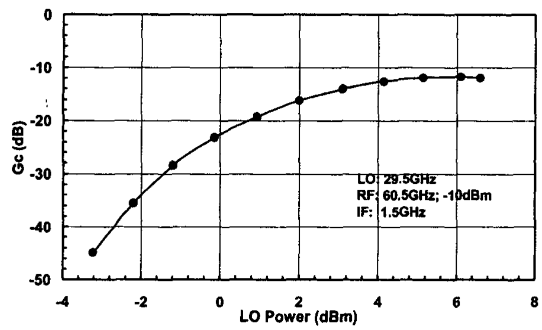

Fig. 7. LO Power sweep characteristics for down-conversion.

Fig.8 shows frequency response of the fabricated mixer for down-conversion. LO frequency is fixed to 29.5GHz, and its drive level is 6dBm. An IF band of 1.0~2.1GHz corresponds to an RF pass band of 60.0~61.1GHz and a rejection band of 56.9~58.0GHz. The conversion loss is 11~13dB, and an image rejection ratio is more than 30dB in the pass band.

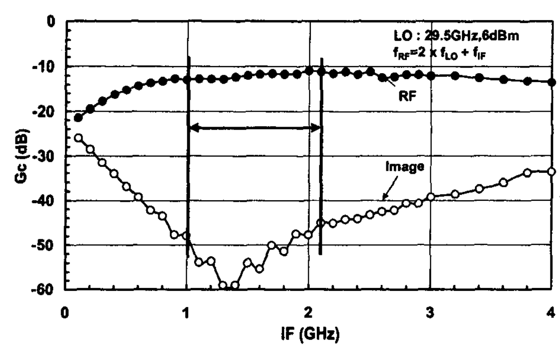

Fig. 8. Frequency response for down-conversion.

D. Performance of up-conversion

Fig.9 shows frequency response of the fabricated mixer for up-conversion. LO frequency is fixed to 29.5GHz, and its drive level is 6dBm. The frequency response for up-conversion shows the almost same tendency as that for down-conversion. The conversion loss of upper side band is 11~13dB in the IF band, and the rejection ratio of lower side band is greater than 30dB.

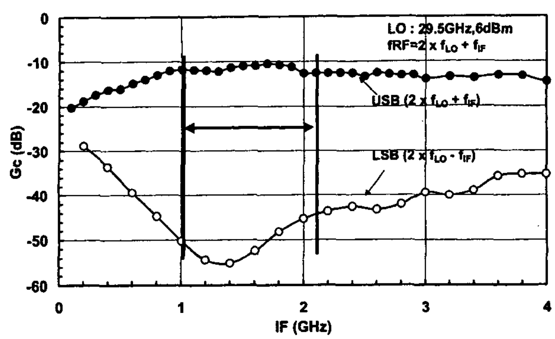

Fig. 9. Frequency response for up-conversion.

Fig.10 demonstrates the input and output characteristics. LO frequency is fixed to 29.5GHz, and its drive level is 10dBm. An IF of 1.5GHz yields an upper side band of 60.5GHz and a lower side band of 57.5GHz. The saturation level of upper side band is -8dBm, while the 2nd harmonic level of LO (59GHz) and the output level of LSB are less than -50dBm.

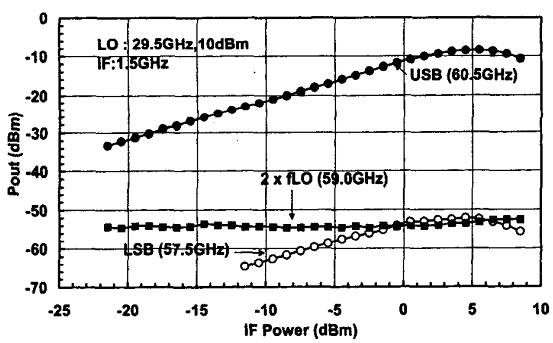

Fig. 10. Input and output characteristics for up-conversion.

IV. Conclusions

We described a compact sub-harmonically pumped image-rejection mixer MMIC for antenna-integrated millimeter-wave module in the 60GHz-band. The filter has two λ/2 microstrip resonators and has a mutual-inductive coupling and a capacitive one between its input and output ports, which results in transmission zeros near the pass band. An electrical short circuit for an LO signal is provide by the filter characteristics at an LO frequency instead of a conventional λ/4-open-stub in the APDP mixer. The fabricated image-rejection mixer MMIC, of which size is only 1.0mm x 1.5mm, shows a conversion loss of 11~13dB and an image rejection ratio of more than 30dB in a pass-band of 60.0~61.1GHz when an LO frequency is 29.5GHz. The rejection ratio of 2nd harmonic level of an LO signal relative to an RF output level is greater than 40dB at an IF input level of 0dBm for up-conversion. This MMIC design technique is effective in realizing further multifunctional MMICs such as one-chip transmitters and receivers for many applications in the millimeter-wave band.

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