The Effect of Image Rejection Filter on Flatness of Microwave Terrestrial Receiver

Sok-Kyun Han · Byung-Ha Choi

Abstract

A flat conversion loss in microwave mixer is hard to achieve if integrating with an image rejection filter(IRF). This is due to the change of termination condition with respect to the LO and IF frequency at RF port where the filter has 50 ohm termination property only in the RF band. This paper describes a flatness maintenance in the down mixer concerning a diode matching condition as well as an electrical length of embedding line at RF port. The implemented single balance diode mixer is suitable for a 23 GHz European Terrestrial Radio. RF, LO and fixed IF frequency chosen in this paper are 21.2～22.4 GHz, 22.4～23.6 GHz and 1.2 GHz, respectively. The measured results show a conversion loss of 8.5 dB, flatness of 1.2 dB p-p, input P1dB of 7dBm, IIP3 of 15.42 dBm with nominal LO power level of 10dBm. The return loss of RF and LO port are less than －15 dB and －12 dB, respectively and IF port is less than －6 dB. LO/RF and LO/IF isolation are 18 dB and 50 dB, respectively. This approach would be a helpful reference for designing up/down converter possessing a filtering element.

Key words : Conversion Flatness, Mixer, Image Rejection.

Ⅰ. Introduction

From the early 1900s, the mixer has a very important role in radio system as a frequency conversion device in a transceiver. As the MMIC technique is enhanced for a use of higher frequency application, many of transceivers have been developed with a form of multi-functional single chip. These devices show very good performance in the aspect of conversion loss, IIP3, spurious level, LO isolation and P1dB over the octave band[1]~[4]. The design cost is, however, generally so high that hybrid design of mixer is sometimes more efficient in the system of which specifications are relatively not too strict to use an antiparallel diode pair.

When designing a receiver, image rejection filter is essential component because noise figure is strongly influenced by its image band rejection performance. The problem existing in designing a mixer with an image rejection filter is to maintain a conversion loss to be flattened. Although recent papers have shown that electrical phase between the filter and the mixer is a main cause to break flatness, embedding electrical phase is not a sole solution to maintain flatness in the receiver[5],[6].

Band pass filter for rejecting image frequency has 50 ohm of characteristic impedance within the RF band frequency merely. Generally, LO and IF band are far from the RF frequency band, so termination condition of RF port with respect to the LO and IF frequency cannot be maintained if inserting an IRF. This situation makes that un-terminated high power components at diode pair, usually LO harmonics, are reflected from the RF port and injected back into a mixer circuit. It causes levels of power for pumping diodes to fluctuate and results in variation with the converted IF signal. This paper introduces a proper matching condition for the diodes and optimum line length embedded between the IRF and RF port in the mixer in order to keep the flatness regardless of filter.

Ⅱ. The Effects of Filter on Flatness of Terrestrial Receiver

2-1 Analysis of Mixer Flatness Regarding IRF

Fig. 1 represents a receiver architecture for a 23 GHz point-to-point terrestrial communication radio link. The presented receiver is made up of WR42-to-microstrip transition, LNA, IRF, down conversion mixer, IF gain block and low pass filter. In the receiver design, IRF

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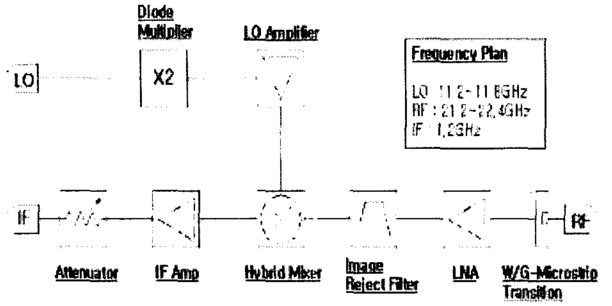

Fig. 1. Block diagram of 23 GHz point-to-point microwave receiver.

becomes considerable for an overall flatness of receiver. Non-frequency converting components, such as LNA, IF amplifier, and transition, would not be responsible for breaking a flatness when inserted into a module, but the connection of IRF and mixer would be the major problem on keeping an overall flatness of receiver. This is because a filter's termination characteristic maintains only within the RF band frequency and is broken at the LO and IF band.

Fig. 2 represents a construction of mixer integrated with IRF. A embedding length of Le means an electrical phase between the RF port of mixer and IRF. Generally, a embedding Le is helpful for adjusting the broken flatness of mixer sometimes. Fig. 3 represents

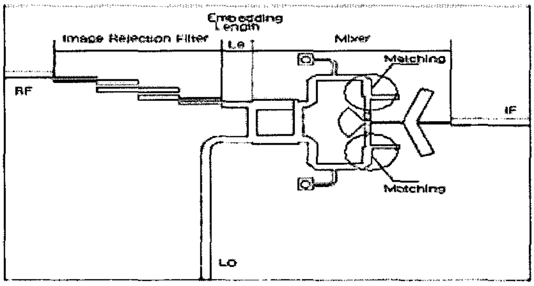

Fig. 2. Construction of mixer integrated with IRF.

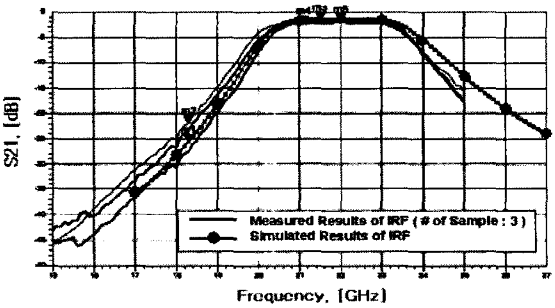

Fig. 3. Simulated and measured response of IRF.

an insertion loss indicating image rejection under 20 dBc, and LO is not terminated. Regarding LO/RF isolation among functions of IRF, the more rejection of LO leads the less LO power at the RF port. Also, rejection of LO causes to break LO termination condition so that degrades LO-to-RF isolation. In this paper, signal bandwidth and IF frequency are 1.2 GHz. Low frequency region of LO is suppressed as same amounts at high edge of image band. Thus, LO-to-RF isolation of integrated mixer is degraded comparing to mixer only case. Fig. 4 shows a flatness response to the mixer with and without IRF designed. When matching of diode is designed for RF band dominantly, a flatness performance of mixer cannot be compensated with the embedding length of Le solely. This is because the reflected LO power flows on the circuits and makes pumping power level at the diode junction fluctuated. If the design is completed to minimize LO reflection power at the diode junction, mixer's flatness can be maintained with a certain embedding length of Le. Thus, the key point to eliminate an effect of IRF on flatness of mixer is how we can minimize the reflected LO harmonics. Additionally, a consideration on LO buffer amplifier is needed. As the impedance of an IRF changes a matching conditions of LO and IF port, insertion of buffer amplifier on the LO port of mixer causes mismatching to the RF and IF port. Thus, the impedance of LO buffer amplifier should be considered with IRF simultaneously, and DC block circuit is utilized for compensating the effect of LO amplifier in this paper.

2-2 Design of Single Balance Diode Mixer with IRF

Specifications of single balanced diode mixer are extracted through the budget analysis of a down converter for a terrestrial radio as shown in Table 1.

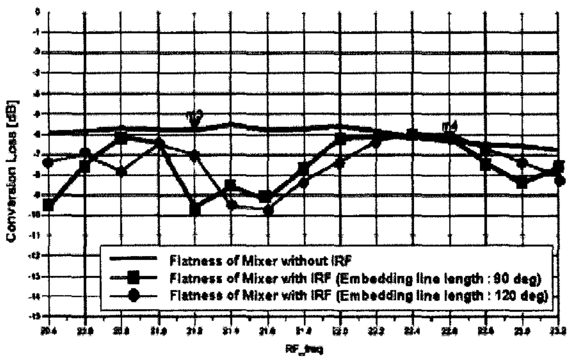

Fig. 4. The effect of IRF on flatness of microwave mixer.

Table 1. Specifications and measured results of integrated mixer.

Parameters	Specifications	Results
RF frequency	21.2～22.4 GHz	21.2～22.4 GHz
LO frequency	22.4～23.6 GHz	22.4～23.6 GHz
IF frequency	1.2±0.05 GHz	1.2±0.05 GHz
LO power level	10 dBm nom.	10 ±2 dBm
Conversion loss	10 dB nom.	8.5 dB nom.
Flatness	±1 dB	±0.6 dB
IIP3	12 dBm min.	15.42 dBm min.
P1dB(in)	5 dBm min.	7 dBm min.
N.F.	10 dB nom.	9 dB nom.
Image rejection	15 dB nom.	20 dB min.
LO/RF isolation	15 dB min.	18 dB min.
LO/IF isolation	20 dB min.	50 dB min.
RF/IF isolation	40 dB min.	40 dB min.
VSWR @RF port	−10 dB max.	−15 dB max.
VSWR @LO port	−10 dB max.	−12 dB max.
VSWR @ IF port	−10 dB max.	−6 dB max.

The design is focused to have robust performances regarding the flatness as well as satisfying input P1 dB above 5 dBm and IIP3 above 15 dBm nominally when IRF is integrated with mixer simultaneously.

The matching network is designed for obtaining a better matching performance in LO frequency band rather than in RF band as shown in Fig. 5. LO pumping power is set by simulating flip chip diode of DMK2790 satisfying input P1 dB specification. RF choke for terminating an induced DC power is made up of a higher impedance line of quarter-wave length at RF and LO frequency band with via hole so as to make "open" characteristic on intersection. Radial stub at the junction of diode pair rejects LO power and enhances LO/IF and RF/IF isolations. Low pass filter is designed to suppress LO's fundamental frequency additionally.

Two mixers are developed with same specifications except the effect of IRF. Fig. 6 shows simulated flatness of a conversion loss in diode mixer. A rectangular dot represents the response of mixer without IRF and circular dot is the response of mixer with IRF. The presented results are extracted when embedding

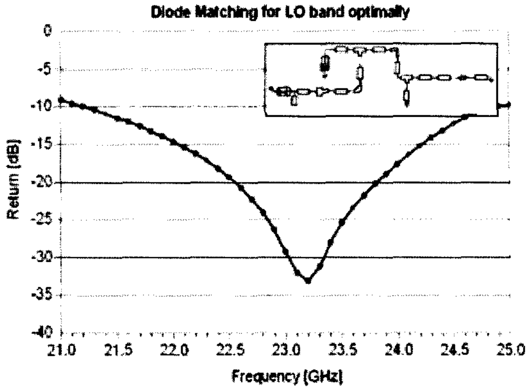

Fig. 5. Diode matching for LO band and RF band.

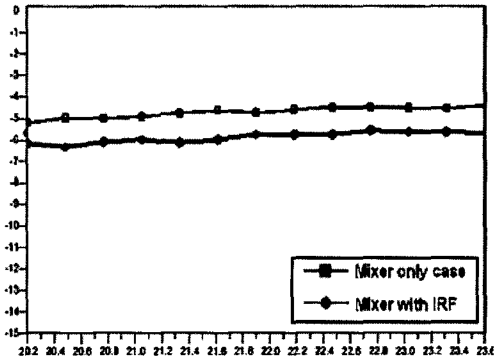

Fig. 6. Simulated conversion loss of mixer only and integrated mixer.

length between IRF and RF port of mixer is 50 mil and matching is performed as shown in Fig. 5. Other lengths cause fluctuation of LO pumping power and degrade flatness performance. The flatness of mixer is maintained regardless IRF and conversion loss is increased as much as insertion loss of IRF. Fig. 7 shows simulation result of optimum LO power in mixer. It reveals that conversion loss is saturated above 8 dBm injection. Other parameters of VSWR, isolation, IIP3 and etc. are simulated to satisfy given specifications.

Ⅲ. Verification

Fig. 8 shows a test bench for measuring the fabricated mixer. HP83650A is utilized as a RF sweeping source and HP83630B is used as a LO sweeping source.

A loss of cable and connector is compensated with a power meter. Since a IF is fixed at 1.2 GHz, output

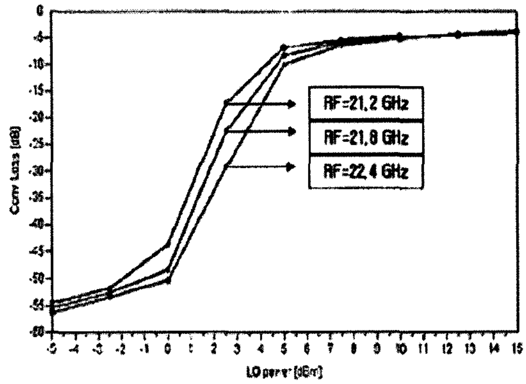

Fig. 7. Conversion loss vs. LO power in mixer without IRF.

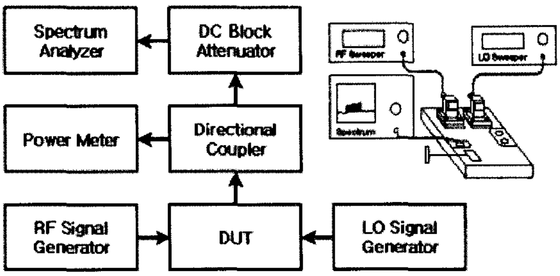

Fig. 8. Test bench for diode mixer.

power is measured with calibrated HP 8565E spectrum analyzer. The measured results of flatness of mixer with and without IRF are presented in Fig. 9. In case of mixer with IRF, the response of flatness is almost the same as the mixer without IRF, considering an insertion loss of filter. The flatness maintenance is the same with making a minimum LO power at the RF port by matching to LO frequency band carefully and deciding a proper embedding phase. The measured result of conversion loss regarding LO power is also well coincident with simulated one as shown in Fig. 10, Fig 11 and

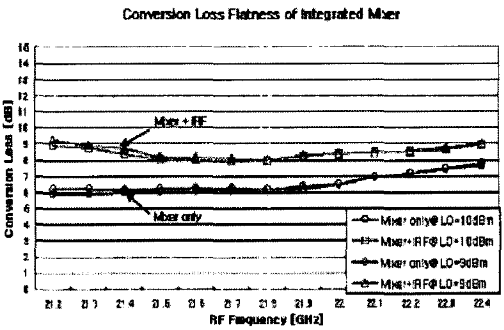

Fig. 9. Measured conversion loss of mixer only and integrated mixer.

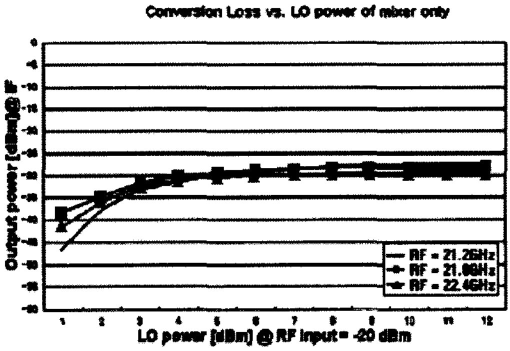

Fig. 10. Conversion loss regarding LO power (Mixer without IRF).

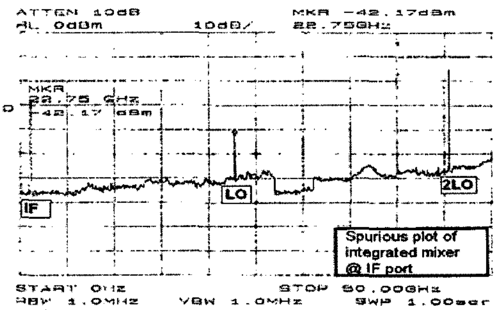

Fig. 11. Spurious response of mixer with IRF.

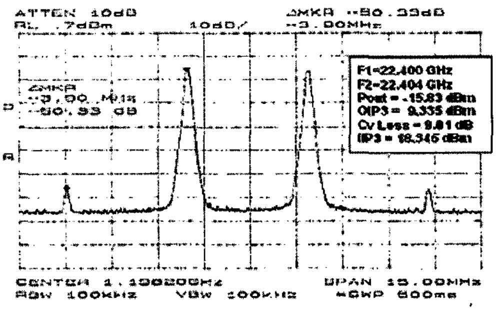

Fig. 12. Measured IIP3 of mixer with IRF at 22.4 GHz under LO=10 dBm.

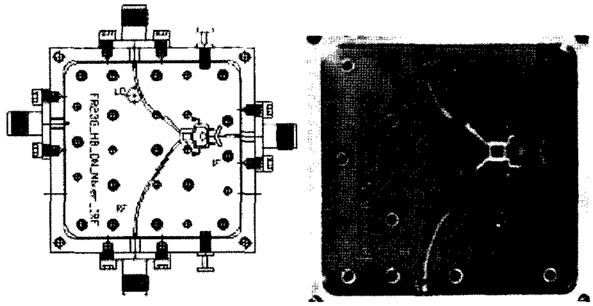

Fig. 13. Assembled picture of mixer with IRF.

Fig. 12 present the measured spurious plot and IIP3 of mixer with IRF. LO suppression is almost 50 dB at IF port. Frequency variation of IIP3 is under 2 dB, and minimum IIP3 is measured with a value of 15.42 dBm at the frequency of 21.2 GHz. Fig. 13 is the assembled picture of single balance diode mixer with IRF.

Ⅳ. Conclusion

Since almost all the receivers have IRF and mixer elements simultaneously, degradation of flatness should be carefully considered when integrating with IRF. Through this paper, the fact that a desirable flatness can be obtained by minimizing LO power reflection from the single balance diode pair and adjusting the proper embedding line length between IRF and RF port of mixer is presented. In the matter of connecting with LO components such as LO driving amplifier and frequency multiplier, it is similar situation with IRF because LO amplifier would have its own bandwidth. This paper is expected to be helpful guide to design a mixer integrated in the common receiver.

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