Design of a sub-harmonic dual-gate FET mixer for IMT-2000 base-station

Jeongpyo Kim[1] and Jaehoon Choi[2]
[1] Department of Electrical and Computer Engineering, Hanyang University,
17 Haengdang-dong seongdong-Gu, Seoul, 133-791, korea
Tel. 82-2-2290-0376, Fax. 82-2-2293-0377
[2] Department of Electrical and Computer Engineering, Hanyang University,
17 Haengdang-dong seongdong-Gu, Seoul, 133-791, korea
e-mail : jprx@com.ne.kr, choijh@hanyang.ac.kr

Abstract : In this paper, a sub-harmonic dual-gate FET mixer for IMT-2000 base-station was designed by using single-gate FET cascode structure and driven by the second order harmonic component of LO signal. The dual-gate FET mixer has the characteristic of high conversion gain and good isolation between ports. Sub-harmonic mixing is frequently used to extend RF bandwidth for fixed LO frequency or to make LO frequency lower. Furthermore, the LO-to-RF isolation characteristic of a sub-harmonic mixer is better than that of a fundamental mixer because the frequency separation between the RF and LO frequency is large. As RF power is –30dBm and LO power is 0dBm, the designed mixer shows the –47.17dBm LO-to-RF leakage power level, 10dB conversion gain, -0.5dBm OIP3, -10.5dBm IIP3 and –1dBm 1dB gain compression point.

1. Introduction

The rapid growth of wireless communication services, such as wireless phone, GPS, WLAN, Bluetooth and so on, requires low-cost, simple structured and high-performance RF systems. A double balanced mixer is frequently used in mobile communication systems. Balanced mixers generally have better power-handling capabilities, and higher isolation characteristic between ports than unbalanced mixers. In addition, certain spurious responses, LO noise, and spurious signals can be rejected by balanced mixer scheme. Their disadvantages are the need for greater LO power to drive many nonlinear devices and the complicated structure due to the external devices, such as balun and many devices.

In this paper, the simple structured sub-harmonic dual-gate FET mixer was designed. The isolation between ports is improved by using dual-gate structure and driving the mixer with sub-harmonic component of the LO signal.

2. Theoretical Background

2.1 Dual-gate mixer

A dual-gate mixer has following advantages over single-gate mixer : the LO and RF signals can be applied to separate gates and the mixer has good LO-to-RF isolation because the capacitance between the tow gates is very low. Thus, it is often practical to use a single-device dual-gate FET mixer in applications where a balanced mixer would otherwise be needed

Dual-gate FETs are usually modeled as two single-gate FETs in series, as shown in figure 1. The I/V characteristics are found by applying two constraints : (1) the sum of the drain –to-source voltages of the individual devices must equal the drain voltage of the dual-gate device, and (2) the drain current must be the same in both devices.[1]

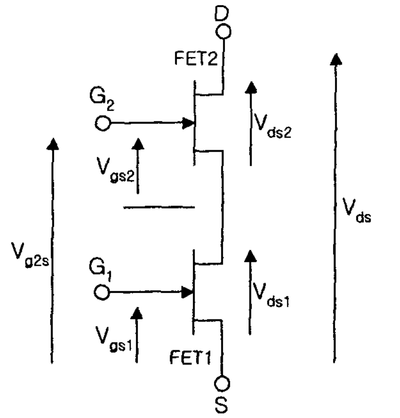


Fig 1. Dual gate FET modeled as two single-gate FETs an series

The RF and LO signals are injected into either one of the two gates. Usually, the LO signal is fed into gate2 and the RF signal is injected into gate1. In this case, the best mode of operation of a dual-gate FET mixer is one in which the LO drives the FET1 into and out of current saturation over LO cycle. In order for FET2 to control the transconductance of the FET1, the FET1 must be operated in its linear region. This occurs as the FET1's drain voltage is forced alternately low and high by the LO and the FET1's transconductance is pumped. Therefore, this provides frequency mixing in the FET1. The FET2 is operated in its saturation region and is in current saturation over most of the LO cycle. Thus, it operates simultaneously as a source-follower for the LO and a common-gate amplifier for the IF. The dual-gate FET mixer can get the high conversion gain from the low LO power.[1,2]

2.2 Harmonic mixer

A sub-harmonic mixer has historically been implemented in millimeter-wave application as a mean of performing down-conversion of the received signal with an LO operating at a fraction of the frequency of input signal. Several early direct conversion receivers were adapting diode-based sub-harmonic mixers as a mean to minimize the conversion of the LO signal to dc. Recently, they have been implemented by utilizing silicon bipolar technology for lower frequency applications using PWM technique.[3]

Usually, the mixing frequency is chosen to be $f_{RF} - f_{LO}$ in the down-conversion. The unbalanced mixers are simple structured with poor LO-to-RF isolation characteristic. Thus, couplers or filters are required to improve the LO-to-RF isolation characteristic of unbalanced mixers. For the harmonic filter, since the output frequency is $f_{RF} - f_{2LO}$, the frequency separation between RF and LO becomes $f_{IF} + f_{LO}$. This implies not only improvement of the LO-to-RF isolation characteristic but also lower LO noise and adequate LO power level for the mixer operation.[4]

3. Design of a sub-harmonic mixer

The LO-to-RF isolation characteristic of a dual-gate FET mixer is better than that of a single-gate mixer, but worse than that of a double-balanced mixer. In this paper, the sub-harmonic dual-gate FET mixer was designed by using single-gate FET cascode structure and driven by the second order harmonic component of LO signal, as shown figure 2. Here, two ATF-54143 are used to construct dual-gate FET.

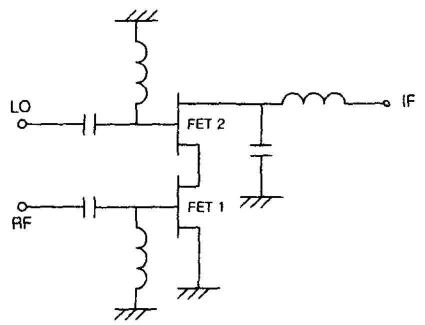
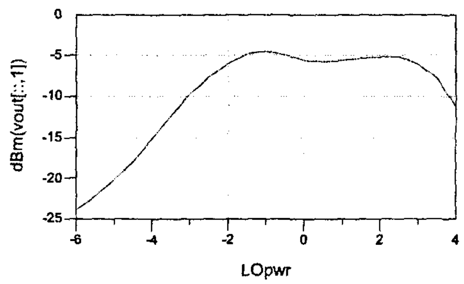
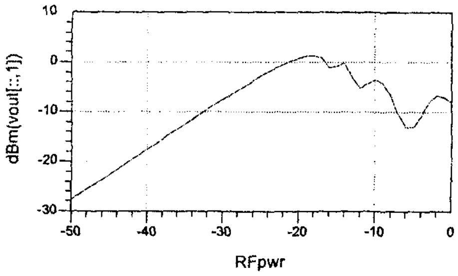


Fig 2. Designed dual-gate FET mixer

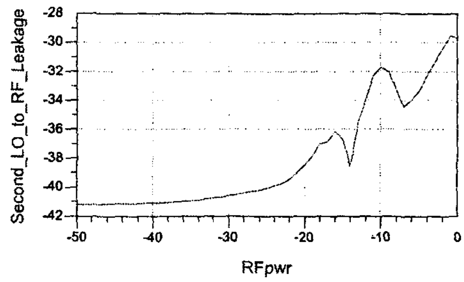
The characteristic of designed mixer is shown in figure 3.



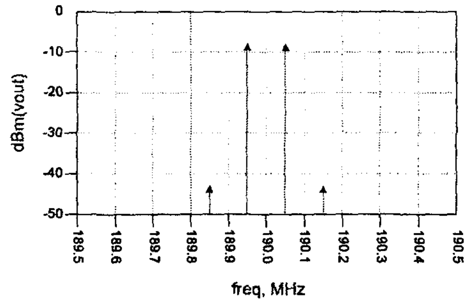
(a) IF output power vs. Lo power



(b) IF output power vs. RF power



(c) Leakage power vs. RF power



(d) IP3 characteristic

Fig 3. Characteristic of the designed mixer

As designed mixer was driven by -2.5dBm LO power level, 1dB gain compression point was about 0dBm with conversion gain of 22.4dB, as shown in Fig 3.(b). LO-to-RF leakage power level was lower than -40dBm, as illustrated in Fig3.(c). OIP3 was 9.5dBm, as shown in Fig3.(d) and IIP3 was -12.9dBm. The performance characteristics of the fundamental and sub-harmonic mixers are compared in Table 1.

When designed fundamental mixer was driven by -6.6dBm LO power level,LO -to-RF leakage power becomes -18dBm. So LO-to-RF isolation characteristic of the fundamental mixer was 11.4dB. The designed sub-harmonic mixer was driven by -2.5dBm LO power level and -40.6dBm LO-to-RF leakage power was obtained. So LO-to-RF isolation characteristic of the sub-harmonic mixer was 38.1dB. Therefore, the isolation characteristic of the sub-harmonic mixer is 22.6dB higher than that of the fundamental mixer.

Table 1. Characteristics of the fundamental and sub-harmonic mixers

	Fundamental	Second harmonic
RF Frequency	1950MHz	1950MHZ
LO Frequency	1760MHz	880MHz
RF Power	-30dBm	-30dBm
LO Power	-6.6dBm	-2.5dBm
Conversion Gain	21.5dB	22.4dB
Noise Figure	7dB	8.9dB
OIP3	5.3dBm	9.5dBm
IIP3	-16.2dBm	-12.9dBm
P_{-1dB}	0dBm	0dBm
LO-to-RF Leakage Power	-18dBm	-40.6dBm

Table 2. Measurement result of the designed mixer

RF frequency (MHz)	1950 (1920 ~ 1980)
LO frequency (MHz)	880 (865 ~ 895)
IF frequency (MHz)	190 (RF – 2LO)
RF power (dBm)	-30
LO power (dBm)	0
IF power (dBm)	-20 (RF–2LO=190MHz) -48 (RF–LO=1070MHz)
Conversion gain (dB)	10
OIP3 (dBm)	-0.5
IIP3 (dBm)	-10.5
P_{-1dB} (dBm)	-1
RF-to-IF Leakage (dBm)	-54.34
LO-to-IF Leakage (dBm)	-28(LO=880MHz) -50.5(2LO=1760MHz)
LO-to-RF Leakage (dBm)	-19.5(LO=880MHz) -47.17(2LO=1760MHz)

4. Experimental Results

Fig. 4 shows the photograph of the sub-harmonic dual-gate FET mixer.

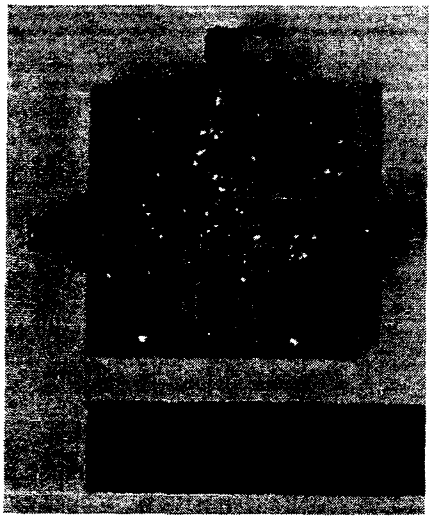
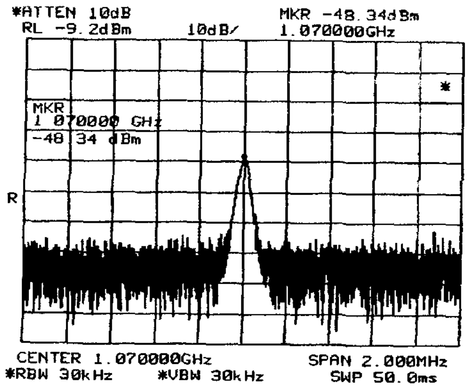


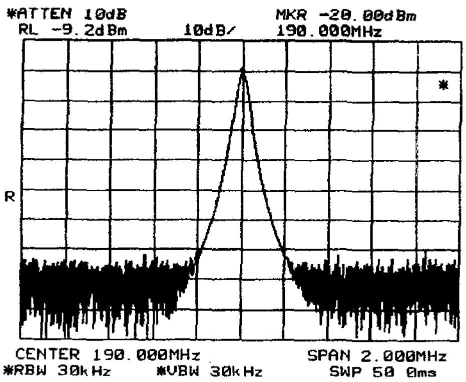
Fig. 4. Photograph of the sub-harmonic dual-gate FET mixer

As RF power level was –30dBm and LO power level was 0dBm, the designed mixer had characteristics of the –47.17dBm LO-to-RF leakage power level, 10dB conversion gain, -0.5dBm OIP3, -10.5dBm IIP3, and –1dBm 1dB gain compression point. The measurement results of the designed mixer are shown in table 2. Although conversion gain and OIP3 characteristics in table 2 are worse than that in table 1, IIP3 and LO-to-RF leakage power characteristics are better than those in the table 1.

Fig. 5 shows IF output power levels. f_{RF}–f_{LO}(1070MHz) component power level was –48dBm and f_{RF}–f_{2LO}(190MHz) component power level was –20dBm. Therefore, it is easy that unwanted f_{RF}–f_{LO} component output is separated from required f_{RF}–f_{2LO} component output.



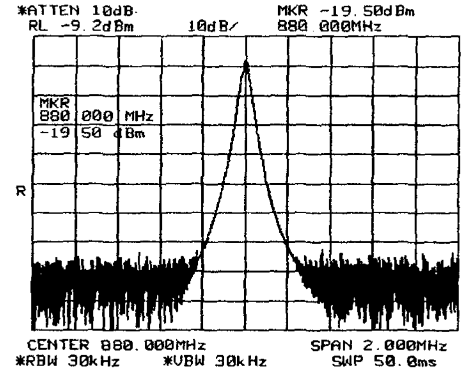
(a) $f_{RF} - f_{LO}$ (1070MHz) component



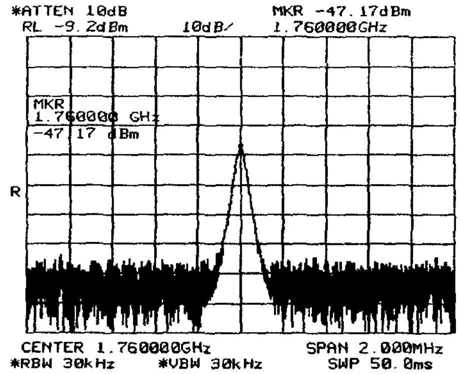
(b) $f_{RF} - f_{2LO}$ (190MHz) component

Fig. 5. IF output power

Fig. 6 shows LO-to-RF leakage characteristic. In LO signal's RF and IF ports leakage characteristics, the leakage power levels of the second harmonic components of LO signal were very low and the designed mixer has very good isolation characteristics between ports. However the leakage power level of the fundamental components were not low enough. This signals can be rejected by RF filter or IF filter in the receiver.



(a) Fundamental component leakage characteristic



(b) Second-harmonic component leakage characteristic

Fig. 6. LO-to-RF leakage characteristic

Fig. 7 shows measured IP3 characteristics. The fundamental output power level was –18dBm and the 3rd power level was –53dBm. Therefore, OIP3 characteristic is –0.5dBm and IIP3 is –10.5dBm.

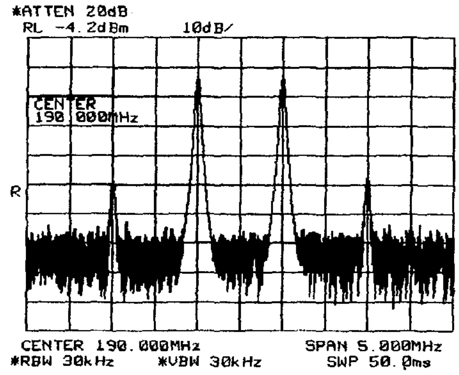


Fig. 7 IP3 characteristic

5. Conclusion

In this paper, in order to improve the LO-to-RF isolation of the down-conversion mixer, the sub-harmonic dual-gate FET mixer was designed by using single-gate cascode structure and driven by the second order harmonic component of LO signal. As RF power was -30dBm and LO power was 0dBm, the designed mixer had characteristics of the –47.17dBm LO-to-RF leakage power level, 10dB conversion gain, -0.5dBm OIP3, -10.5dBm IIP3 and –1dBm 1dB gain compression point. Because the LO-to-RF leakage power level of the designed sub-harmonic mixer is as good as that of double-balanced mixer, sub-harmonic dual-gate FET mixer can be used instead.

Reference

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