The Design of a Sub-Harmonic Dual-Gate FET Mixer

Jeongpyo Kim[1] · Hyok Lee[1] · Jaehoon Choi[2]

Abstract

In this paper, a sub-harmonic dual-gate FET mixer is suggested to improve the isolation characteristic between LO and RF ports of an unbalanced mixer. The mixer was designed by using single-gate FET cascode structure and driven by the second harmonic component of LO signal. A dual-gate FET mixer has good isolation characteristic since RF and LO signals are injected into gate1 and gate2, respectively. In addition, the isolation characteristic of a sub-harmonic mixer is better than that of a fundamental mixer due to the large frequency separation between the LO and RF frequencies. As RF power was −30 dBm and LO power was 0 dBm, the designed mixer yielded the −47.17 dBm LO-to-RF leakage power level, 10 dB conversion gain, −2.5 dBm OIP3, −12.5 dBm IIP3 and −1 dBm 1 dB gain compression point. Since the LO-to-RF leakage power level of the designed mixer is as good as that of a double-balanced mixer, the sub-harmonic dual-gate FET mixer can be utilized instead.

Key words : Dual-gate FET Mixer, Sub-harmonic Mixer, LO-to-RF Isolation.

Ⅰ. Introduction

The rapid growth of wireless communication services, such as mobile phone, GPS, WLAN, Bluetooth and so on, requires lowcost, simple structured and high-performance RF systems. Furthermore, since various communication systems are operated simultaneously, intersystem interference need to be kept as low as possible. Power amplifier(PA) output and local oscillator(LO) leakage signals are important interference sources because their power level is much higher than that of a desired signal. Interference by PA output can be overcome by filtering a received signal with good linearity. Interference by LO leakage can be overcome not only by high linearity and powerful filtering of a received signal but also by reducing LO leakage power level in a down conversion mixer.

The isolation between LO and RF ports of a mixer is important because LO-to-RF feed-through results in LO signal leaking through an antenna. If a down conversion mixer is in a different package from a LNA, the amount of allowable LO-to-RF feed-through depends on the reverse isolation of a LNA and a stop band attenuation of RF and image rejection filters at LO frequency. On the other hand, if a LNA and a mixer are packaged together, the LO signal can feed-through to RF input port of a LNA, by passing the RF filter and LNA[1].

A double balanced mixer is frequently used in a mobile communication system. It generally has better power-handling capability and higher isolation characteristic between ports than those of an unbalanced mixer. In addition, certain spurious responses, LO noise, and spurious signals can be rejected by balanced mixer scheme. However, it requires high LO power to drive many nonlinear devices and has complicated structure due to many nonlinear and external devices. On the other hand, an unbalanced mixer has very simple structure because of having single nonlinear device. In addition, the mixer has good conversion gain and noise figure characteristics. However, this type of a mixer has poor isolation characteristic between ports. Thus, band pass filters or hybrids are required in order to improve the isolation characteristic[2].

In this paper, a simple structured sub-harmonic dual-gate FET mixer was introduced. The mixer was designed by using dual-gate FET structure. In order to improve the port-to-port isolation, the designed mixer was driven by the second order harmonic component of the LO signal.

Ⅱ. Theoretical Background

2-1 Dual-Gate FET Mixer

A dual-Gate FET mixer has two gates and LO and

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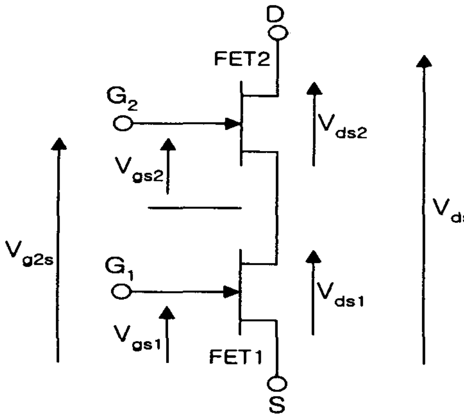


Fig. 1. Dual gate FET modeled as two single-gate FETs in series.

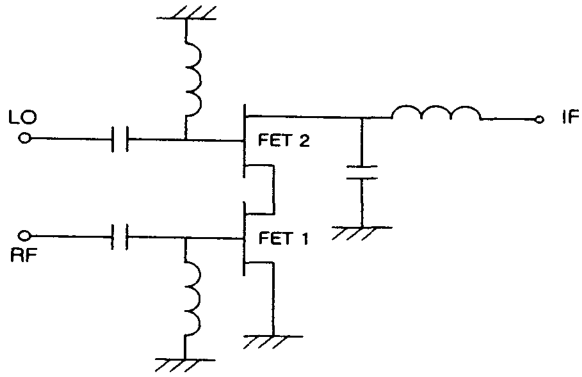


Fig. 2. Schematic diagram of a designed sub-harmonic dual-gate FET mixer.

RF signals are injected into each gate, separately. Therefore, a dual-gate FET mixer has better LO-to-RF isolation characteristic than a single-gate mixer. It is very practical to use a single-device dual-gate FET mixer in applications where a balanced mixer would otherwise be needed.

A dual-gate FET is usually modeled as two single-gate FETs in series, as shown in Fig. 1.

The best operating mode 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 this case, frequencies are mixed in FET1 and FET2 operates simultaneously as a source-follower for the LO and a common-gate amplifier for the IF. The dual-gate FET mixer can produce the high conversion gain in spite of the low LO power[2],[3].

2-2 Sub-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 single LO operating at a fraction of the frequency of input signal. Several early direct conversion receivers were adapting diode-based sub-harmonic mixers 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[4].

The conversion frequency is usually chosen as $f_{RF}-f_{LO}$ in the down-conversion, where f_{RF} is RF signal frequency and f_{LO} is LO signal frequency. For a sub-harmonic mixer, the convertsion frequency is chosen as $f_{RF}-2f_{LO}$. Therefore, the LO frequency of a sub-harmonic mixer is a half of that of a fundamental mixer. Therefore, the frequency separation between RF and LO frequencies becomes $f_{RF}+f_{LO}$. 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[5]. Thus, a sub-harmonic mixer can be used to improve the isolation characteristic of an unbalanced mixer.

Ⅲ. Mixer Design and Simulation Results

In general, a double balanced mixer has about 50 dB LO-to-RF isolation characteristic and is driven by 7~17 dBm LO power level. On the other hand, a dual-gate FET mixer has about 20 dB LO-to-RF isolation characteristic and is driven by −10~0 dBm LO power level. Therefore, a double balanced mixer has −33~−43 dBm LO-to-RF leakage power level and a dual-gate FET mixer has −20~−30 dBm. In order to use dual-gate FET mixers instead of double-balanced mixers, the isolation characteristic of dual-gate FET mixers needs to be improved.

A dual-gate FET can be used to design a sub-harmonic mixer. In a dual-gate FET mixer scheme, RF signal is injected into gate 1 and LO signal is injected into gate 2. Since a sub-harmonic mixer is driven by sub-harmonic components of LO, the frequency of LO signal is $(f_{RF}-f_{IF})/N$, where N is the order of sub-harmonic components of LO signal. For this operation, the bias point of a dual-gate FET needs to be adjusted to optimize the mixing operation.

In this paper, a sub-harmonic dual-gate FET mixer was designed to improve the isolation characteristic of a dual-gate FET mixer. The designed mixer had single-gate FET cascode structure and was driven by the second harmonic component of the LO signal to improve LO-to-RF leakage characteristic, as shown in Fig. 2.

Since RF frequency band for IMT-2000 is 1920~1980 MHz and IF frequency is selected 190 MHz, a fundamental dual-gate FET mixer has 1730~1790 MHz LO frequency band and the sub-harmonic dual-gate FET mixer has 865~895 MHz LO frequency band. The two designed mixers were biased at Vds = 3 V, Ids = 60 mA and Agilent-ADS[6] was used for simulation.

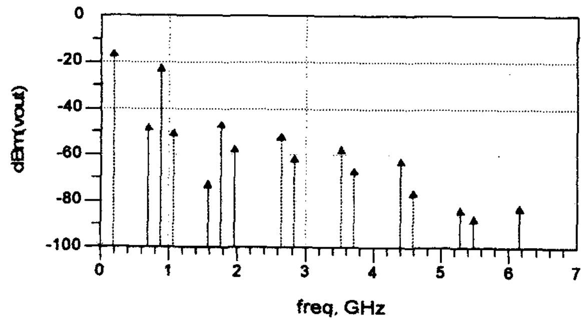
The performance characteristics of a designed fundamental mixer and the sub-harmonic mixer are compared in Table 1.

As the designed sub-harmonic mixer was driven by 0 dBm LO power level, 1 dB gain compression point was about − 1.9 dBm with conversion gain of 14.8 dB, as shown in Fig. 3. (b). LO-to-RF leakage power level was lower than − 24.6 dBm, as illustrated in Fig. 3(c). It had 29.4 dB IMD, − 1.5 dBm OIP3 and − 15.3 dBm IIP3, as shown in Fig. 3. (d).

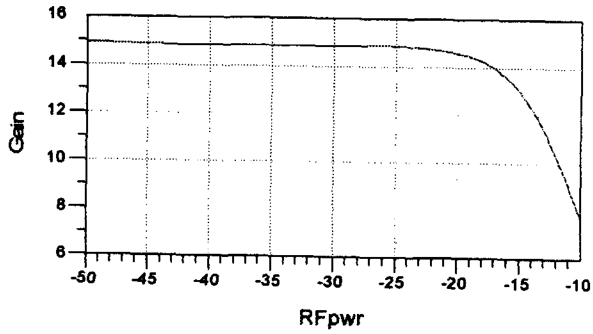
When the designed fundamental mixer was driven by − 3.5 dBm LO power level, LO-to-RF leakage power became − 18 dBm and LO-to-RF isolation characteristic was 14.5 dB. When the designed sub-harmonic mixer was driven by 0 dBm LO power level, − 24.6 dBm LO-to-RF leakage power was obtained and LO-to-RF isolation characteristic of the sub-harmonic mixer was 24.6 dB. Therefore, the LO-to-RF leakage power level of the sub-harmonic mixer is 6.6 dB lower than that of the fundamental mixer. This implies that

Table 1. Simulation results of the fundamental and sub-harmonic dual-gate FET mixers.

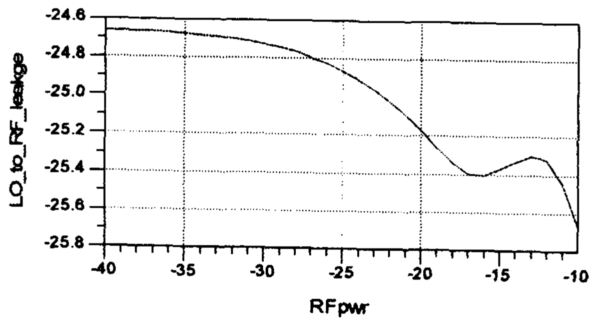
	Fundamental	Sub-harmonic
RF Frequency	1950 MHz	1950 MHz
LO Frequency	1760 MHz	880 MHz
RF Power	− 30 dBm	− 30 dBm
LO Power	− 3.5 dBm	0 dBm
Conversion Gain	20.7 dB	14.8 dB
Noise Figure	7 dB	8.9 dB
OIP3	4.9 dBm	− 1.5 dBm
IIP3	− 12.6 dBm	− 15.3 dBm
P-1dB	2.7 dBm	− 1.9 dBm
Lo-to-RF Isolation	14.5 dB	24.24 dB(LO) 24.6 dB(2LO)



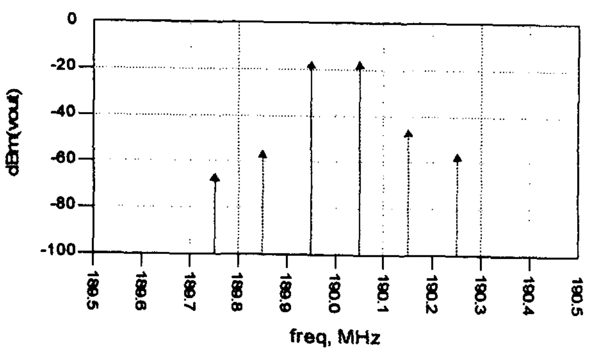
(a) IF output power vs. frequency



(b) Conversion Gain vs. RF power



(c) LO Leakage power vs. RF power



(d) IMD characteristic

Fig. 3. Simulation characteristic of the designed mixer.

the isolation characteristic of the sub-harmonic mixer is 10.1 dB higher than that of the fundamental mixer. However, the sub-harmonic mixer had poorer conversion gain and IP3 characteristics than those of the fundamental mixer. In general, a sub-harmonic mixer requires higher LO power level and has poorer conversion gain characteristic than a fundamental mixer [5],[7]. The conversion gain and IP3 characteristics of the designed sub-harmonic mixer need to be improved further. The characteristic of the designed mixer is illustrated in Fig. 3.

Ⅳ. Measurement Results

Fig. 4 shows the photograph of the manufactured sub-harmonic dual-gate FET mixer. Two ATF-54143s were used to construct a dual-gate FET and the mixer was fabricated on RO4350b($\varepsilon_r = 3.48$, $h = 30$ *mil*) substrate. 8753ES network analyzer, 8563E spectrum analyzer, and E4436B signal generator of the Agilent Technologies were used to measure the characteristics of the manufactured mixer. The manufactured mixer was operated at Vds = 3 V and Ids = 60 mA.

As RF power level was −30 dBm and LO power level was 0 dBm, the designed mixer had characteristics of −47.17 dBm LO-to-RF leakage power level, 10 dB

Table 2. Measurement result of the designed sub-harmonic dual-gate FET mixer.

Parameter	This paper	Commercially available mixers	
		passive[8]	active[9]
RF frequency(MHz)	1950(1920～1980)	NA	
LO frequency(MHz)	880(865～895)	NA	
IF frequency(MHz)	190(RF-2LO)	NA	
RF power(dBm)	− 30	NA	
LO power(dBm)	0	7～19	− 5
IF power(dBm)	− 20(RF-2LO=190 MHz) − 48(RF-LO=1070 MHz)	NA	
Conversion gain(dB)	10	− 7～ − 6	9
OIP3(dBm)	− 0.5	21～38	3
IIP3(dBm)	− 10.5	NA	
P_{-1dB}(dBm)	− 1	10～24	− 8
RF-to-IF Leakage (dBm)	− 54.34	NA	
LO-to-IF Leakage (dBm)	− 28(LO=880 MHz) − 50.5(2LO=1760 MHz)	− 19～ − 12	− 39
LO-to-RF Leakage (dBm)	− 19.5(LO=880 MHz) − 47.17(2LO=1760 MHz)	29～ − 21	− 23

* NA : not available

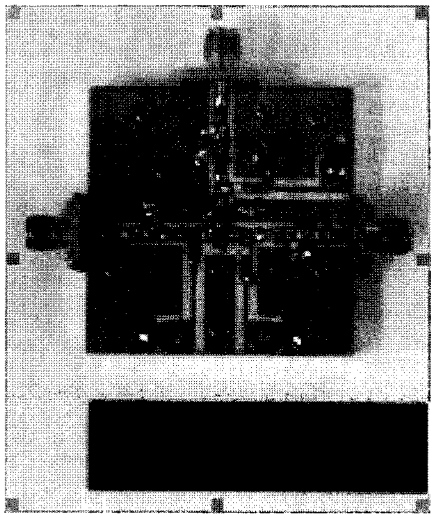
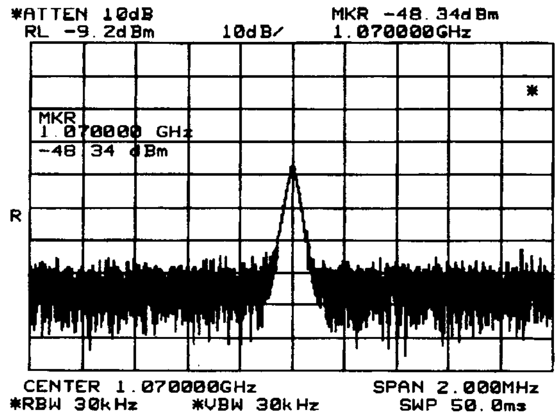
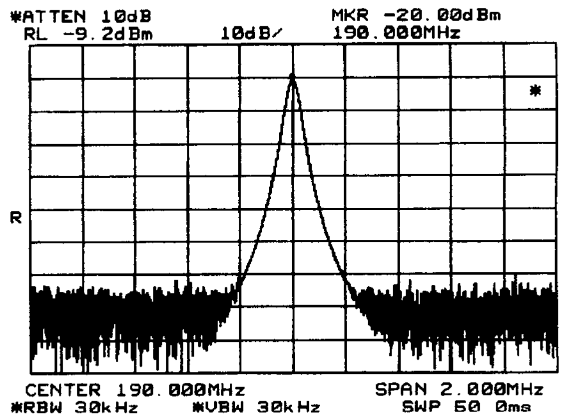


Fig. 4. Photograph of the sub-harmonic dual-gate FET mixer.



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



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

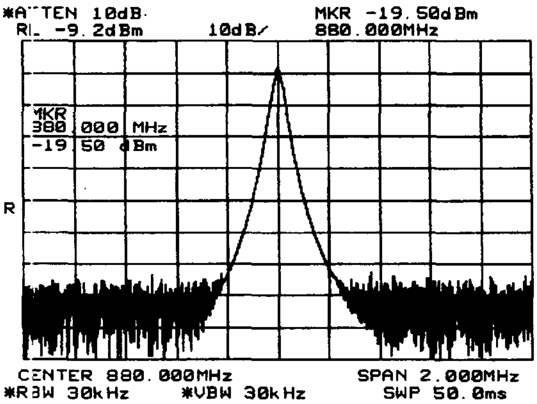
Fig. 5. IF output power.

conversion gain, −2.5 dBm OIP3, −12.5 dBm IIP3, and −1 dBm 1 dB gain compression point. The measured characteristics of the designed mixer are summarized in Table 2.

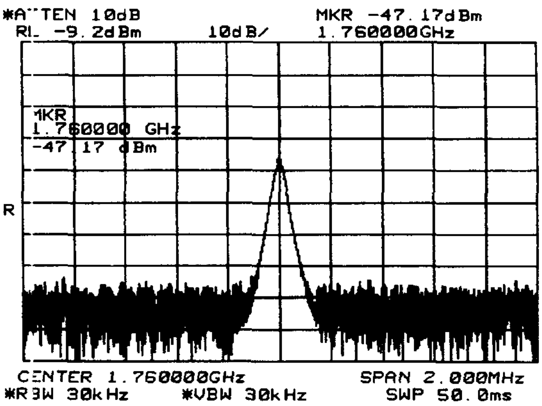
Since the designed mixer was simulated under the ideal condition, conversion gain in Table 1 is 4.8 dB higher than that in Table 2. However, measured convert-sion gain is comparable to that of commercially available one.

Fig. 5 shows measured IF output power levels. Power levels of $f_{RF}-f_{LO}$(1070 MHz) component and $f_{RF}-2f_{LO}$(190 MHz) component are −48 dBm and −20 dBm, respectively. Therefore, it is easy to separate unwanted $f_{RF}-f_{LO}$ component from required $f_{RF}-2f_{LO}$ component.

Fig. 6 shows LO-to-RF leakage characteristic. It reveals that the leakage power level of the second harmonic component of LO signal is very low and the designed mixer has very good isolation characteristic between ports. However, the leakage power level of the fundamental component is not low enough. This signals can be rejected by RF filter or IF filter in the receiver.



(a) Fundamental component leakage



(b) Second-harmonic component leakage

Fig. 6. LO-to-RF leakage characteristic.

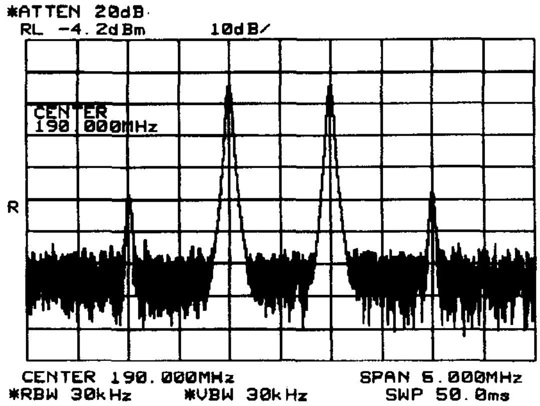


Fig. 7. IMD characteristic.

Fig. 7. shows measured IMD characteristic. The fundamental output power level is −18 dBm and the 3rd power level is −53 dBm. Therefore, the designed mixer had 35dBc IMD, −2.5 dBm OIP3 and −12.5 dBm IIP3.

V. Conclusion

In this paper, the sub-harmonic dual-gate FET mixer having good LO-to-RF isolation characteristic was designed by using single-gate FET cascode structure. It was driven by the second order harmonic component of LO signal. As RF power was −30 dBm and LO power was 0 dBm, the designed mixer yielded −47.17 dBm LO-to-RF leakage power level, 10 dB conversion gain, −2.5 dBm OIP3, −12.5 dBm IIP3 and −1 dBm 1 dB gain compression point. Because the LO-to-RF leakage power level of the designed sub-harmonic mixer is as good as that of a double-balanced mixer, the sub-harmonic dual-gate FET mixer can be used instead. However, in order to be utilized in real system, the linearity characteristic of the designed mixer needs to be improved further.

References

[1] K. L. Fong, R. G. Meyer, "Monolithic RF active mixer design", *IEEE Transactions on Circuits and System-II: Analog and Digital Signal Processing*, vol. 46, no. 3, pp. 231-239, Mar. 1999.

[2] S. A. Maas, *Microwave Mixer*, Artech House, Norwood, 1993.

[3] C. Tsirons, R. Meierer and R. stahlmann, "Dual-

gate MESFET mixers," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-32, no. 3, pp. 248-255, Mar. 1984.

[4] S. Liwei, C. J. Jonathan and E. L. Lawrence, "A widebandwidth Si/SiGe HBT direct conversion subharmonic mixer/down-converter", *IEEE J. Solid-State Circuits*, vol. 35, no. 9, pp. 1329-1337, Sep. 2000.

[5] A. C. A. Dias, D. Consonni and M. A. Luqueze, "High isolation sub-harmonic mixer", *Microwave and Optoelectronics Conference, 1999. SBMO / IEEE MTT-S IMOC '99. Inter-national*, vol. 2, pp. 378-381, 1999.

[6] *Agilent-Advanced Design System 2001*, Agilent Technologies, 2001.

[7] D. Neuf, "Fundamental vs. Harmonic Mixing : Some System Amplitude Ripple Considerations", *Microwave Journal*, pp. 181-184, Nov. 1984.

[8] *RF/IF Designer's Guide*, Mini-Circuits, pp. 62-89, 2001.

[9] http://www.semiconductor.agilent.com, model :IAM-91563.

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