Design for the Low IF Resistive FET Mixer for the 4-Ch DBF Receiver

Jee-Won Ko[1] · Kyeong-Sik Min[1] · Hiroyuki ARAI[2]

Abstract

This paper describes the design for the resistive FET mixer with low IF for the 4-Ch DBF(Digital Beam Forming) receiver. This DBF receiver based on the direct conversion method is generally suitable for high-speed wireless mobile communications. A radio frequency(RF), a local oscillator(LO) and an intermediate frequency(IF) considered in this research are 2.09 GHz, 2.08 GHz and 10 MHz, respectively. This mixer is composed of band pass filter, a low pass filter and a DC bias circuit. Super low noise HJ FET of NE3210S01 is considered in design. The RF input power, LO input power and V_{GS} are used −10 dBm, 6 dBm and −0.4 V, respectively. In the 4-Ch resistive FET mixer, the measured IF and harmonic components of 10 MHz, 20 MHz and 2.087 GHz are about −19.2 dBm, −66 dBm and −48 dBm, respectively. The IF output power observed at each channel of 10 MHz is about −19.2 dBm and it is higher 28.8 dBm than the maximum harmonic component of 2.087 GHz. Each IF output spectrum of the 4-Ch is observed almost same value and it shows a good agreement with the prediction.

Key words : DBF, Receiver, Mixer, Direct Conversion, FET

Ⅰ. Introduction

In recent years, a high-speed wireless mobile communication technology is strongly required.

In general, super-heterodyne receiver is widely used for wireless communications. This method has low noise characteristics and excellent stability, but circuit size due to multi-IF ports is large and complex. On the other hand, direct conversion receiver offers significant reduction of circuit complexity due to the elimination of IF circuitry, including IF filters and IF mixers[1]. The received RF signal is converted directly to baseband.

Resistive FET mixers, due to its simple biasing requirements, are well suited for direct conversion applications. The resistive FET mixer only requires negative gate bias, with the LO applied to the gate, RF applied to the drain, and IF signal filtered from the drain[2]. Because there is no drain bias, problems regarding the separation of the baseband signal and DC bias voltage are eliminated.

In this paper, we design the band pass filter, DC bias circuit, low pass filter and low IF resistive FET mixer for the 4-Ch DBF receiver. Also, we present calculation and measurement results of each device and the 4-Ch resistive FET mixer[3].

Ⅱ. Direct Conversion Mixer

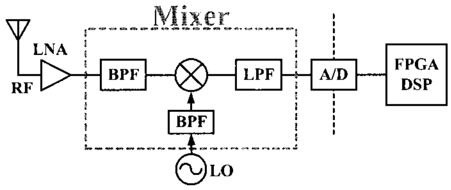

Fig. 1. Block diagram of DBF receiver.

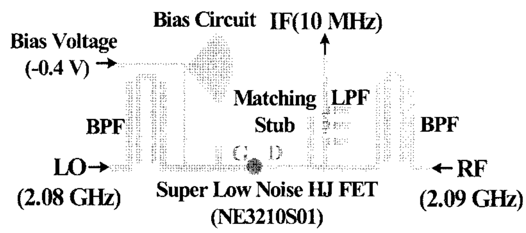

Fig. 2. Design model of the resistive FET mixer.

Fig. 1 shows the block diagram of DBF receiver[4]. This mixer shown in Fig. 1 is composed of band pass filter, a low pass filter, a DC bias circuit and mixer with super low noise HJ FET of NE3210S01[5].

Fig. 2 shows a design model of the resistive FET Mixer. The signals of LO and RF are supplied to the gate and drain of FET, respectively. The IF signal of 10 MHz is extracted from the drain by using the low pass filter.

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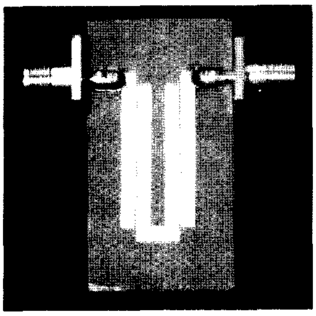


Fig. 3. Photograph of the fabricated band pass filter.

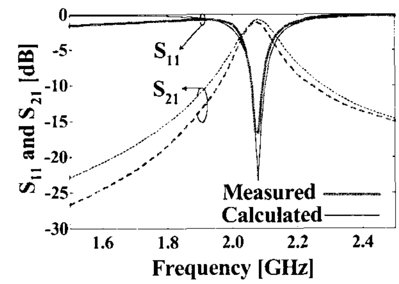


Fig. 4. S_{11} and S_{21} of the band pass filter.

Ⅲ. Design for Devices

3-1 Band Pass Filter

Fig. 3 shows the photograph of the fabricated hairpin band pass filter. The hairpin band pass filter is formed with transmission line resonators which are approximately 1/2 wavelength long and are coupled externally by gaps between the line edges[6]. This band pass filter removes the harmonic signals and the inflow of DC current. The size of the fabricated band pass filter is 21.5 mm×27.1 mm.

Fig. 4 shows the reflection and transmission coefficients for the calculated and measured results of band pass filter. The measured reflection and transmission coefficients are about −17 dB and −1 dB at 2.08 GHz, respectively. These results show a fine agreement with the calculated ones. Bandwidth of −10 dB below is about 30 MHz from 2.065 GHz to 2.095 GHz.

3-2 DC Bias Circuit

Fig. 5 shows the photograph of the fabricated DC bias circuit with approximately 1/4 wavelength of open radial stub. This DC bias circuit is used to supply the direct current and to remove the alternating current from LO signal. Since radius of open stub of bias circuit is smaller than 1/4 wavelength, open radial stub compared with general strip line stub is profitable in miniaturization and integration of device. The size of the fabricated DC bias circuit is 41.0 mm×38.8 mm.

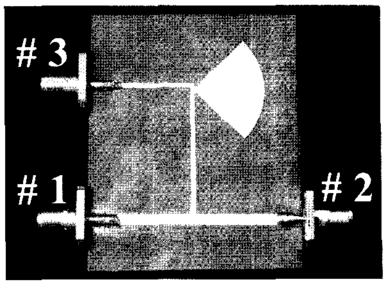


Fig. 5. Photograph of the fabricated DC bias circuit.

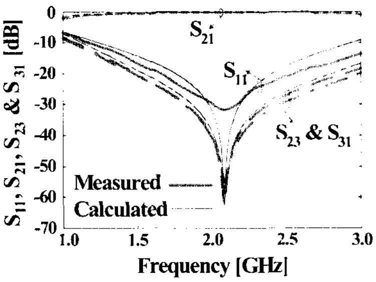


Fig. 6. S_{11}, S_{21}, S_{23} and S_{31} of the bias circuit.

Fig. 6 shows the characteristics of S_{11}, S_{21}, S_{23} and S_{31} for the calculated and measured results of DC bias circuit. The measured S_{11}, S_{21}, S_{23} and S_{31} are about −32 dB, −0.16 dB, −55 dB and −62 dB at 2.08 GHz, respectively. These results show a fine agreement with the calculated ones. Especially, the isolation characteristics of S_{23} and S_{31} show the broad bandwidth of 1.5 GHz at −20 dB below.

3-3 Low Pass Filter

Fig. 7 shows the photograph of the fabricated low pass filter composed of chip inductor, chip capacitor and microstrip line. Low pass filter is used to remove the harmonic components except IF frequency band of 10 MHz. As shown in Fig. 7, K-type low pass filter consisting of lumped elements is generally used, their values of L and C are calculated by Eq. (1).

$$L=\frac{Z_0}{\pi f_c}, \quad C=\frac{1}{2\pi Z_0 f_c} \tag{1}$$

where f_c is a cutoff frequency of the low pass filter and Z_0 is a characteristic impedance.

Lumped elements are considered for compact size and simple fabrication of circuit. The size of the fabricated low pass filter

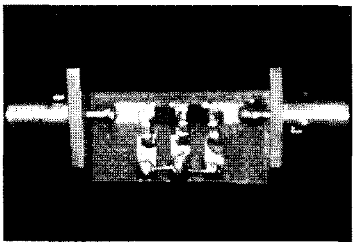


Fig. 7. Photograph of the fabricated low pass filter.

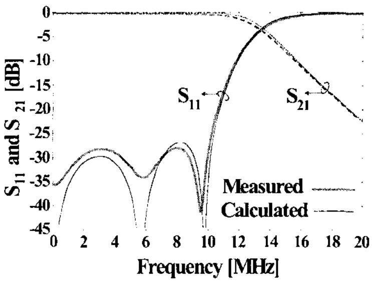


Fig. 8. S_{11} and S_{21} of the low pass filter.

is 20.6 mm×9.2 mm.

Fig. 8 shows the reflection and transmission coefficients for the calculated and measured results of the low pass filter. The measured transmission and reflection coefficients are −0.1 dB and −28 dB below at the 10 MHz band, respectively. These results show fine agreement with the calculated ones.

Ⅳ. 1-Ch Resistive FET Mixer

Fig. 9 shows the photograph of the fabricated resistive FET mixer constructed on 0.7874 mm thick microstrip substrate(ε_r =2.5). HJ FET of NE3210S01 is used as the FET with super low noise. DC bias is applied for using 1/4 wavelength of open radial stub. The RF, the LO frequency and the IF are corresponding to 2.09 GHz, 2.08 GHz and 10 MHz, respectively. The size of the fabricated resistive FET mixer is 96.5 mm×38.6 mm.

Fig. 10 (a) and (b) show the IF spectrum of the fabricated resistive FET mixer. When the RF input power, the LO input power and V_{GS} voltage are −10 dBm, 6 dBm and −0.4 V, respectively, the calculated IF signal at 10 MHz is −16.4 dBm and harmonic components of 20 MHz, 2.09 GHz and 4.17 GHz are −70.9 dBm, −133.0 dBm and −116.0 dBm, respectively. The measured IF signal at 10 MHz is −18.6 dBm and harmonic components of 20 MHz and 2.087 GHz are −67.3 dBm and −47.5 dBm, respectively. Even though a little difference between the calculated and measured results due to the loss of

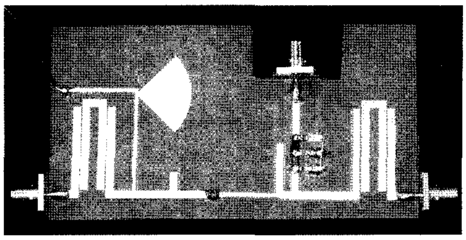
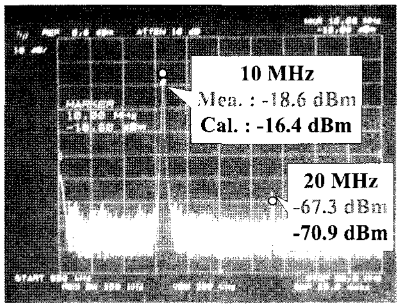
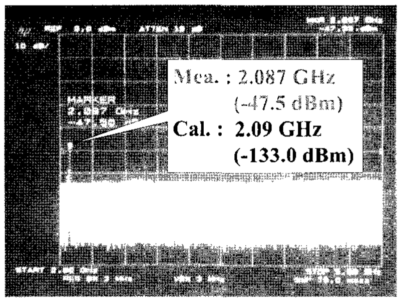


Fig. 9. Photograph of the fabricated resistive FET mixer.



(a) IF & harmonic components



(b) Harmonic components of high frequency

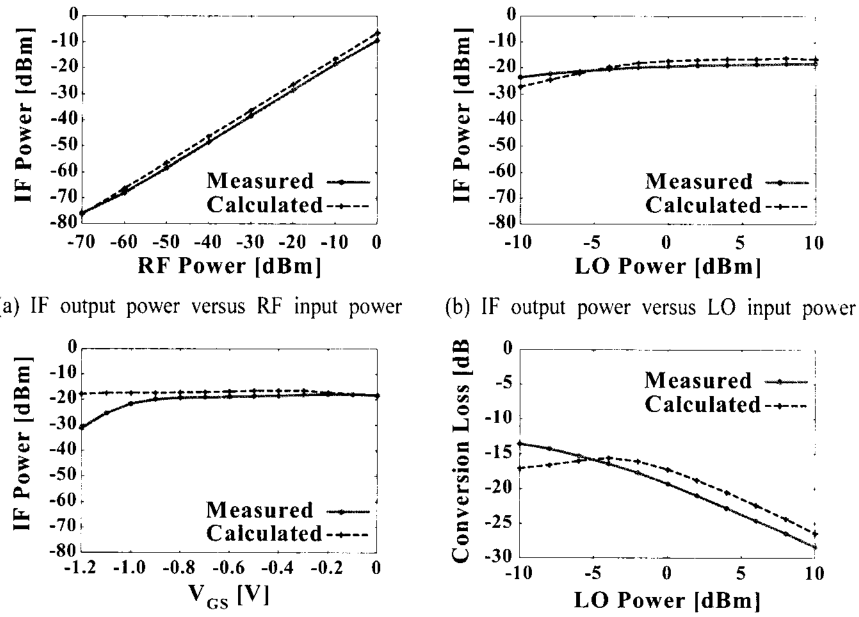
Fig. 10. IF spectrum of the resistive FET mixer.

the transmission line observes, these results show reasonable value. The measured harmonic components level between 10 MHz and 20 MHz is obtained about 48.7 dBm difference. And the IF output power of 10 MHz is higher 28.9 dBm than the maximum harmonic component of 2.087 GHz.

The calculated and measured results of the 1-Ch resistive FET mixer at 10 MHz are shown in Fig. 11 (a)~(d).

Fig. 11 (a) shows the IF output power versus RF input power of the 1-Ch resistive FET mixer. The IF output power with respect to the RF input power shows the linear characteristics. The measured IF power is observed a good agreement with the calculated one.

Fig. 11 (b) and (c) show the IF output power versus LO input power and V_{GS} of the 1-Ch resistive FET mixer, respectively. A little difference between the calculated and the measured IF



(a) IF output power versus RF input power (b) IF output power versus LO input power

(c) IF output power versus V_{GS} (d) Conversion loss versus LO input power

Fig. 11. Calculated and measured results of the 1-Ch resistive FET mixer.

output power depends on the loss of microstrip line. This level difference observed in Fig. 11 (b) and (c) is appeared the measured IF output power level at 10 MHz as shown in Fig. 10 (a). Variation of the IF output power level is almost dependent upon RF power variation compared with LO power and V_{GS}.

Fig. 11 (d) shows the conversion loss versus LO input power of the 1-Ch resistive FET mixer. When the LO input power is increase, the measured conversion loss is decrease. From the above results, when the RF input power and V_{GS} are constant, the conversion loss can be controlled by LO power. Two data of Fig. 11 (d) show a similar trend with respect to the LO power and the measured conversion loss at 6 dBm is about −24.6 dB.

V. 4-Ch Resistive FET Mixer

5-1 Structure

Fig. 12 shows the structure of the 4-Ch resistive FET mixer. The signals supplied the RF and the LO input terminal are 2.09 GHz and 2.08 GHz, respectively. The LO signal is supplied to four mixers by 5-port power divider. In order to obtain the IF signal of 10 MHz at each port, the RF signal and the LO signal are mixed each other at the mixer.

5-2 5-port Power Divider

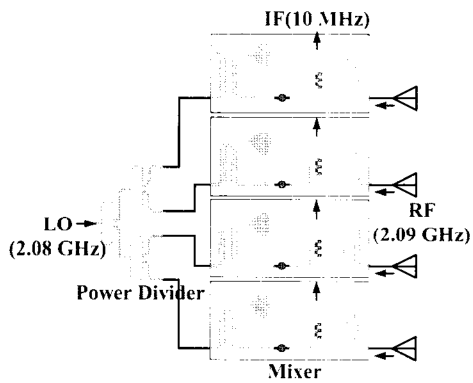


Fig. 12. Structure of the 4-Ch resistive FET mixer.

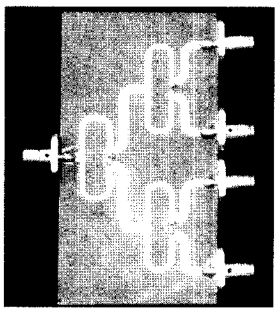
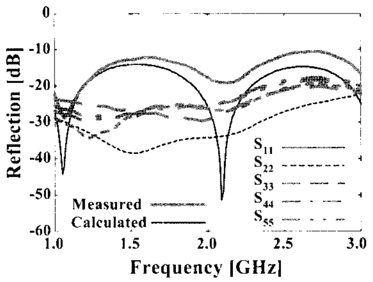
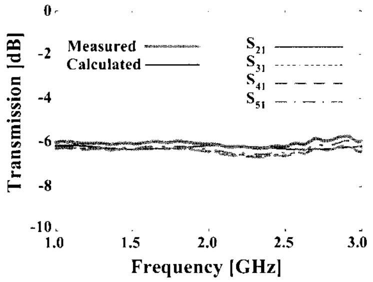


Fig. 13. Photograph of the fabricated 5-port power divider.

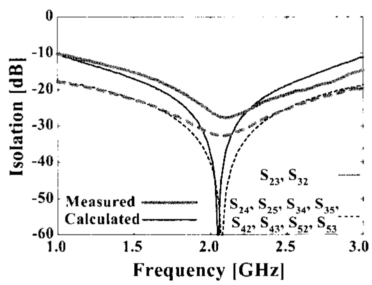
Fig. 13 shows the photograph of the fabricated 5-port power divider. The size of the fabricated 5-port power divider is 40.4 mm × 67.5 mm.



(a) Reflection coefficients



(b) Transmission coefficients



(c) Isolation coefficients

Fig. 14. Calculated and measured results of the 5-port power divider.

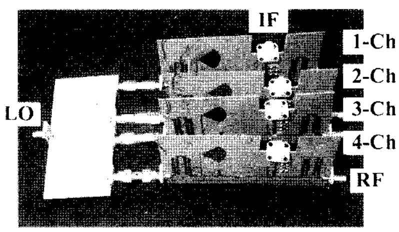
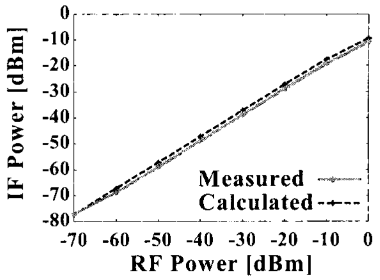
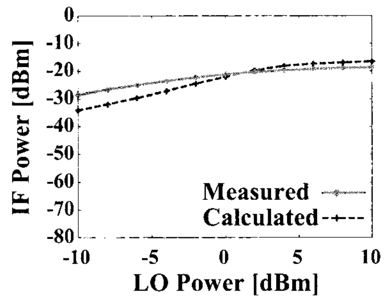


Fig. 15. Photograph of the fabricated 4-Ch resistive FET mixer.

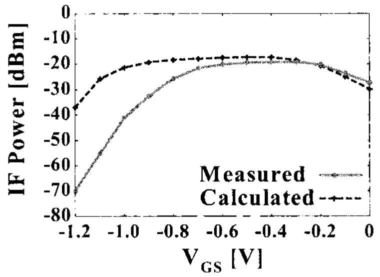
The calculated and measured of 5-port power divider are shown in Fig. 14. In the measured reflection coefficients, bandwidth with −10 dB below is broad and it is observed about −19 dB at design frequency. Transmission coefficients of 5-port power divider are observed about −6 dB and it agrees with prediction. The measured reflection, transmission and isolation



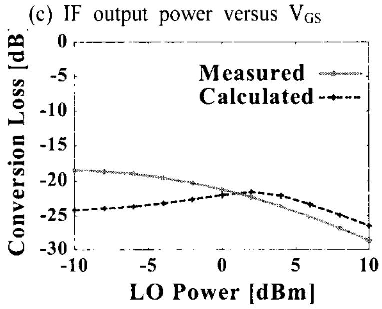
(a) IF output power versus RF input power



(b) IF output power versus LO input power



(c) IF output power versus V_{GS}



(d) Conversion loss versus LO input power

Fig. 16. Calculated and measured results of the 4-Ch resistive FET mixer.

coefficients of 2.08 GHz as shown in Fig. 14 (a), (b) and (c) are about −19 dB, −6 dB and −28 dB, respectively.

5-3 The Experimental Results

Fig. 15 shows the photograph of the fabricated 4-Ch resistive FET mixer with 5-port power divider.

The calculated and measured IF output power and conversion loss results of the 4-Ch resistive FET mixer at 10 MHz are presented in Fig. 16. These values present the average one measured by each channel with respect to the 4-Ch mixer. When the LO input power and V_{GS} are constantly given 6 dBm and −0.4 V, respectively, the IF output power is controlled by the RF input power as shown in Fig. 11.

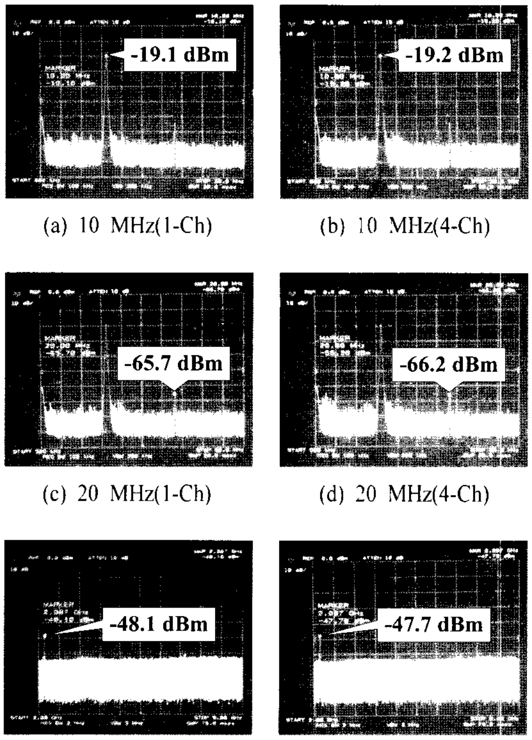
Fig. 16 (a) shows the IF output power versus the RF input power of 4-Ch resistive FET mixer.

Fig. 16 (b) and (c) show the IF output power versus the LO input power and V_{GS} of the 4-Ch resistive FET mixer. A similar phenomina observed in the 1-Ch mixer appears in the 4-Ch mixer. We know that variation of the IF output power level with respect to the LO input power and V_{GS} is very small compared with contribution of the RF input power.

Fig. 16 (d) shows the conversion loss versus the LO input power of the 4-Ch resistive FET mixer. When the RF input power is −10 dBm constant and the LO input power is changed to obtain the IF output signal of 10 MHz, the conversion loss appears and it is calculated by difference between the IF output power with respect to the given LO input power. For example, when the LO input power is 6 dBm in Fig. 16 (b), the measured IF output power is about −19.2 dBm and the conversion loss is −25.2 dB. The IF output power level observed each channel is almost same and it means performance of the fabricated 4-Ch mixer is excellent.

Fig. 17 shows the measured IF spectrums of the 1-Ch and 4-Ch resistive FET mixer. Fig. 17 (a), (c) and (e) show the measured IF spectrum of 10 MHz, 20 MHz and 2.087 GHz for the 1-Ch mixer, respectively. Also, Fig. 17 (b), (d) and (f) show ones for frequencies with the 4-Ch mixer. In the 1-Ch mixer, the measured IF spectrum values including harmonic components of 10 MHz, 20 MHz and 2.087 GHz are −19.1 dBm, −65.7 dBm and −48.1 dBm, respectively. In the same manner at the 4-Ch mixer, the measured ones of 10 MHz, 20 MHz and 2.087 GHz are −19.2 dBm, −66.2 dBm and −47.7 dBm, respectively. The characteristics of the 4-Ch mixer compared with ones of the 1-Ch mixer show a good agreement. It means each channel in the 4-Ch mixer has the same performance.

Table 1 represents the comparison between calculation and experiment of the IF spectrum power for the 4-Ch mixer. When the RF input power, LO input power and V_{GS} are −10 dBm, 6 dBm and −0.4 V, respectively, the measured IF spectrum power at 10 MHz, 20 MHz and 2.087 GHz are about −19.2 dBm, −66 dBm and −48 dBm, respectively. The measured IF output power at 10 MHz is higher 28.8 dBm than the maximum harmonic component of 2.087 GHz. Each IF output power in the 4-Ch mixer is observed almost same value.



(a) 10 MHz(1-Ch) (b) 10 MHz(4-Ch)
(c) 20 MHz(1-Ch) (d) 20 MHz(4-Ch)
(e) 2.087 GHz(1-Ch) (f) 2.087 GHz(4-Ch)

Fig. 17. IF spectrum of the 1-Ch and 4-Ch resistive FET mixer.

Table 1. The comparison between calculation and experiment of the IF spectrum power for the 4-Ch mixer.

	Calculation [dBm]	Experiment [dBm]			
		1-Ch	2-Ch	3-Ch	4-Ch
10 MHz	−17.3	−19.1	−19.2	−19.2	−19.2
20 MHz	−67.8	−65.7	−65.7	−66.2	−66.2
2.087 GHz	−132.0	−48.1	−47.9	−48.1	−47.7

Ⅵ. Conclusion

This paper presents a design for the 4-Ch low IF resistive FET mixer. The characteristics of hairpin band pass filter , DC bias circuit, low pass filter and 5-port power divider are designed and measured. Performance of the 1-Ch and 4-Ch mixer composed of above mentioned devices is compared and discussed. When the RF input power, the LO input power and V_{GS} in the 4-Ch mixer are −10 dBm, 6 dBm and −0.4 V, respectively, the IF output power measured at 10 MHz is −19.2 dBm and it is higher 28.8 dBm than the maximum harmonic component observed at 2.087 GHz. The measured IF output power per each channel of the 4-Ch mixer is observed almost same value and it shows a good agreement with prediction.

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