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Reconfigurable Multi-Band Mixer for SDR System

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Abstract

A reconfigurable multi-band mixer for the SDR system is proposed. The proposed reconfigurable mixer is operated between 850 MHz～2 GHz, which includes all commercial mobile communication service. Because the varactor diodes are used to select a specific frequency and to adjust the impedance characteristic of the selected frequency band, the proposed reconfigurable mixer can be achieved to similar performance across all of the tuning range. In addition, the designed reconfigurable mixer is applicable for the SDR system since it has a single signal path for the multi-band signals and wide band tuning range.

Key words : Reconfigurable, SDR, Multi-Band, Cascode FET, Mixer.

Ⅰ. Introduction

In recent, the wireless communication service is developed rapidly and the number of wireless standards is increasing every year. To make this possible, a numerous number of different standards and technologies are used such as GSM, IS-95, W-CDMA, GPS, Bluetooth, and WLAN. To cope with all this, users don't want a collection of different handheld devices, but they want all services to be integrated into one portable device which can offer mobility and which can simultaneously handheld different services. In addition, multi-mode and multi-band circuits have recently gained a lot of interest since inserting a new standalone radio into a mobile handset for each emerging system is not feasible.

In order to build such a multi-standard adaptive transceiver, various solutions with single signal path and multi signal path exist. Most existing multi-standard wireless devices use separate signal paths for different standards[1],[2]. However, these methods increase the cost, power consumption and size of the radio frequency(RF) module. Clearly, a single path that can operate at two or more frequency bands would be preferable[3]~[5]. Therefore, a transceiver with reconfigurable building blocks where the performance and hence the power consumption can be scaled to the needs of the standard and operating mode, is much more desirable. This is the concept of a flexible or reconfigurable transceiver, which has gained considerable interest recently. If such reconfigurable front-end is controlled and reconfigured through digital programmable software, then this is called a soft-defined radio(SDR).

In this paper, the reconfigurable multi-band mixer with a single signal path and one local oscillator(LO) input is proposed. The multi-band characteristic of the mixer is achieved by adding tunable elements to the matching networks, which provides a very simple designed mixer structure. Then, the proposed mixer has more simple structure than conventional multi-band mixer with multi signal path by switching circuit or wideband path. The operating RF frequencies bands of the proposed mixer are from the 850 MHz band to the 2 GHz bands. Because the IF frequency is fixed at 50 MHz and the mixer is driven by the second harmonic of the LO signal, the LO frequencies bands are from 450 MHz to 1 GHz.

Ⅱ. Theoretical Background

2-1 Resistive Cascode FET Mixer

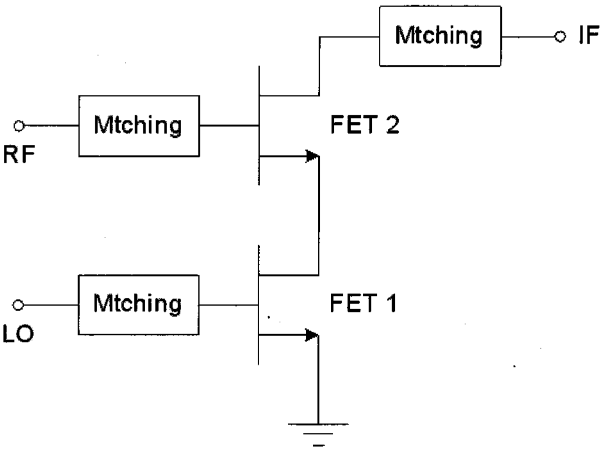

Fig. 1. Resistive cascode FET mixer.

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In the usual cascade FET mixer, the LO power is injected into the FET 2 gate. The LO voltage at FET 2 gate swings the drain current, then the drain voltage of the FET 1 varies from the linear to the saturated current region with the LO cycle. The FET 1 works like a single-gate FET drain driven mixer. The non-linearity of the FET 1's transconductance is dominant mixing element. On the other hand, the LO power drives the FET 1 gate and the RF signal is injected into the FET 2 gate in the resistive cascade FET mixer. The drain voltage is kept at low-level, however the LO power swings I_{ds} and change of the transconductance. The FET 1 works as the gate driven(LO) mixer with the RF injected from drain port and the drain voltage is very low[6]. Linearity of mixers utilizing DC parameters of the FET can be compared to analyze the transconductances of the FET as function of V_{g1} and V_{g2}. They are calculated with extracted DC parameters of the single gate FET. Both g_{m1} that is the transconductance of the FET 1 and g_{m2} that is the transconductance of the FET 2 change with the LO cycle. From [6], the variation of the g_{m1} is large than one of g_{m2} with the same LO voltage variation. It means the former has a high conversion gain, however, the latter provides better linearity of the g_{m1} for the RF voltage.

2-2 Sub-harmonic Mixer

A sub-harmonic mixer has historically been implemented in millimeter-wave applications as a means of performing down-conversion of the received signal with a signal LO operating at a fraction of the frequency of the input signal. Several early direct-conversion receivers adapted the diode-based sub-harmonic mixers in order to minimize the conversion of the LO signal to dc[7].

Since a sub-harmonic mixer is driven by sub-harmonic components of the LO signal, the frequency of an injected LO signal is $(f_{RF}-f_{IF})/N$, where N is the order of sub-harmonic components of the LO signal. For a second-harmonic mixer, the conversion frequency is chosen as $f_{RF}-2f_{LO}$. Thus the LO frequency is half of that of a fundamental mixer and the frequency separation between RF and LO frequencies becomes $f_{IF}+f_{LO}$. This implies not only an improvement of the LO-to-RF isolation characteristic, but also lower LO noise and adequate LO power level for the mixer operation. Therefore, a sub-harmonic mixer can be used to improve the isolation characteristic of an unbalanced mixer[8].

It is possible to achieve sub-harmonic operation with a single-ended mixer. However, in such mixers the fundamental mixing response is usually greater than the second harmonic response and is a source of interfering signals and down converted LO noise. It is also an additional loss mechanism, because a large fraction of the RF input power is converted to the mixing frequencies near the LO and radiated from the LO port. Unless the IF frequency is unusually high, it is impossible to filter out this response without rejecting the LO frequency as well. Hence, single-ended sub-harmonic mixers are rarely used in low-noise receivers. They are sometimes used in systems where high conversion loss is tolerable and the ability to generate responses with a wide range of LO harmonics is necessary. Such mixers are called harmonic mixers, and their applications include frequency synthesizers and the input circuits of spectrum analyzers[9].

Ⅲ. Design of a Reconfigurable Multi-band Mixer

A reconfigurable multi-band mixer is designed by using a cascode FET structure and a schematic of the mixer is shown in Fig. 2. As the LO and the RF signals are injected into gate 1 and gate 2, respectively, the designed mixer operates as a resistive cascode FET mixer and has a good LO-RF isolation characteristic[6],[10].

The LO voltage at gate 1 swings the drain-source current I_{ds} of the cascode FET. Then the RF frequency is converted to a low intermediate frequency(IF) band signal in FET 1. The mixer has a low distortion characteristic with this condition because FET 1 acts as the gate-driven resistive FET mixer with the RF injected into the drain port. Moreover, the conversion gain of the designed mixer can be obtained since FET 2 is operated as a common gate amplifier for the converted signal.

In the designed mixer, the bias point of FET 2 is 3 V and 60 mA, while FET 1 operates in the pinch-off region. Thus, the bias current of the cascode FET is zero, and I_{ds} flows down only during the positive period of the LO signal because the drain currents are the same for both transistors. Therefore, the designed mixer has a very high-power efficiency and low-power consumption.

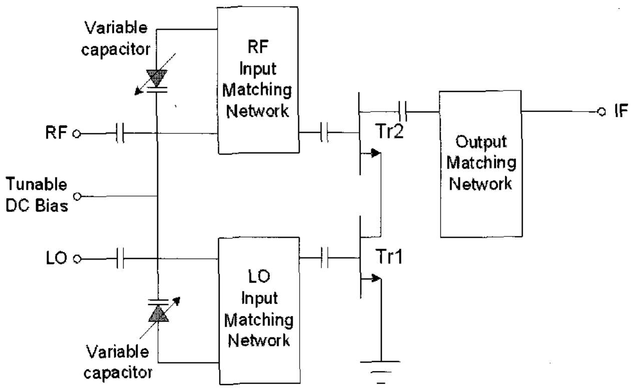


Fig. 2. Schematic of the proposed reconfigurable multi-band mixer.

In order to obtain multi-band characteristics, the variable capacitors are added to the input matching networks of the RF and LO ports. In general, the two elements matching networks of the series C and the shunt L are used at two input ports. There are two main reasons for this choice. The first is in-corporate a high pass filter characteristic into the matching circuit. Second, the series C and shunt L combination will match the entire range of the RF port impedances to 50 Ω. Most wireless communication bands are sufficiently narrow so that a single frequency approach to impedance matching is adequate. In this matching network, the shunt L plays the role of the resonant frequency shift, and thus the impedances are matched to 50 Ω near the region using the series C. Therefore, in order to obtain efficient multi-band characteristics, the variable capacitors are connected in parallel to the shunt L. If the impedances of the desired resonance frequencies are far from the center of the smith chart, the impedances can be modified by adjusting the series C, which is controlled by using a parallel variable capacitor.

The IF port impedance matching network should be a low pass filter to reflect the RF and LO power back into the mixer, while allowing the IF to pass through. The shunt C and series L combination is a very practical choice that will meet the low pass filter requirement while matching any IF impedances. The operating frequency of the IF port is fixed at 50 MHz. Therefore, the output matching network consists of the shunt C and series L without any variable capacitors. Agilent-ADS[11] is used for the simulation of the proposed mixer.

Ⅳ. Simulation Results

The proposed multi-band mixer is designed at three service bands, cellular(850 MHz), K-PCS(1.8 GHz) and W-CDMA(2 GHz) in order to confirm the multi-band characteristics shown in Table 1.

In the RF and LO ports, the matching network consists of the shunt L and series C, and two variable capacitors are added in parallel to the shunt and series locations. In the matching network, the resonant frequency is selected by adjusting the shunt elements. Therefore, the input resonant frequency is fixed by the shunt L and the frequency is adjusted by the added variable capacitance. The series elements are affected to the impedance matching. When the resonant frequency is shifted by the added shunt variable capacitance, the impedance characteristics at the resonant frequency may be different from that of the first resonant frequency. If the impedance characteristics are poor, the characteristics can be improved by adding in parallel a variable capacitance to series elements.

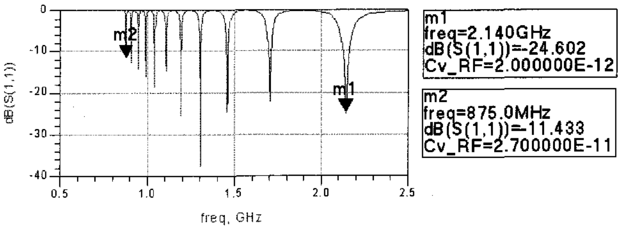
Table 1. Design frequencies.

	RF	LO	IF
Cellular	881.5 MHz (869~894)	465.75 MHz	50 MHz
K-PCS	1,855 MHz (1,840~1,870)	952.5 MHz	
W-CDMA	2,140 MHz (2,110~2,170)	1095 MHz	

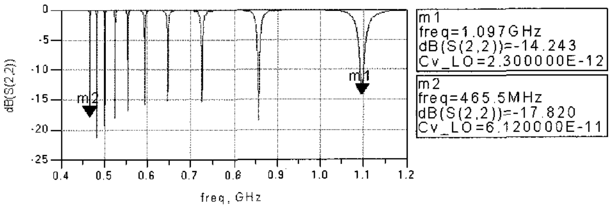
Fig. 3(a) shows the return loss characteristic by the variation of the capacitance of the added variable capacitor. As the capacitance, Cv_RF, increases from 2 pF to 27 pF, the resonant frequency moves from 2,140 MHz to 875 MHz. In order to match the impedance of each resonant frequency, the added series variable capacitor simultaneously increases.

In the LO port, the resonant frequency shifts from 1097 MHz to 465.5 MHz as the capacitance, Cv_LO, increase from 2.3 pF to 61.3 pF. Although the series variable capacitance is not added, the mixer matches the impedance well in the LO port, as shown in Fig. 3(b). In the mixer simulation, the designed mixer is driven by the 0 dBm LO signal and −40 dBm RF signal is incident on the RF port of the mixer.

In the first test band, since Cv_RF is 27 pF and Cv_LO is 61.2 pF, two matching networks are matched to 881.5 MHz, f_{RF1}, and 465.75 MHz, f_{LO1}, respectively. In the second, the designed mixer is operated in the K-PCS band and then Cv_RF and Cv_LO are replaced with 3.4 pF and 5.4 pF, respectively. The impedance matching network of RF port is matched to 1,885 MHz, f_{RF2}, and that of the LO port selects the resonant frequency



(a) RF port



(b) LO port

Fig. 3. Resonant frequency variances.

Table 2. Simulated results of the designed mixer.

Band	Parameters	Values
Cellular	Gain (dB)	−2.869
	1st LO-RF (dBm)	−65.869
	2nd LO-RF (dBm)	−38.024
	1st LO-IF (dBm)	−74.421
	2nd LO-IF (dBm)	−78.227
	RF-IF (dBm)	−112.471
	IIP3 (dBm)	−2.254
	Noise (dB)	15.059
K-PCS	Gain (dB)	3.446
	1st LO-RF (dBm)	−56.279
	2nd LO-RF (dBm)	−24.437
	1st LO-IF (dBm)	−69.175
	2nd LO-IF (dBm)	−105.765
	RF-IF (dBm)	−101.292
	IIP3 (dBm)	−8.318
	Noise (dB)	5.737
W-CDMA	Gain (dBm)	2.97
	1st LO-RF (dBm)	−48.003
	2nd LO-RF (dBm)	−16.673
	1st LO-IF (dBm)	−72.272
	2nd LO-IF (dBm)	−80.574
	RF-IF (dBm)	−98.460
	IIP3 (dBm)	−5.507
	Noise (dB)	9.482

of 952.5 MHz, f_{LO2}. Finally, when Cv_RF is 2 pF and Cv_LO is 2.3 pF, two matching networks are matched to 2,140 MHz, f_{RF3}, and 1,095 MHz, f_{LO3}, respectively. Two signals of the f_{RFn} and f_{LOn} in each test band are inserted to two gates of the proposed mixer and mixed; hence the wanted signal component, $2f_{LOn}-f_{RFn}$, is output at the drain port.

The simulation results of the designed reconfigurable multi-band mixer are shown in Table 2.

Ⅴ. Measurement Results

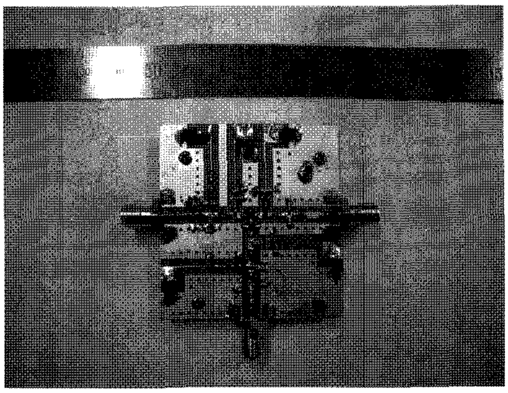
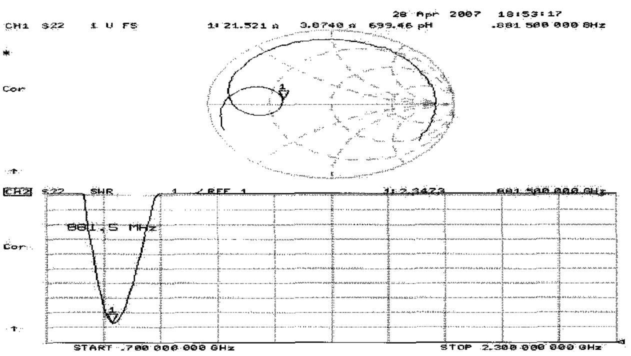


Fig. 4. Fabricated reconfigurable multi-band mixer.

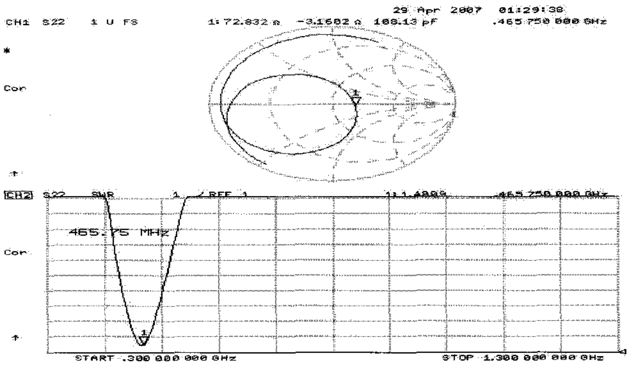
Fig. 4 shows a photograph of the fabricated reconfigurable multi-band mixer. Two ATF-54143s are used to construct a cascode FET, and the mixer is fabricated on an FR-4(ε_r=4.4 and h=0.8 mm) substrate. Because the designed mixer is operated by using the resistive cascode FET properties, LO and RF matching networks are located at the prestage of the gate 1 and gate 2, respectively. The varactor diodes are added into matching networks in order to cover the target service bands of 850 MHz~2 GHz.

The resonant frequency is more strongly affected by the shunt elements than the series elements. On the other hand, the impedance characteristic is better compensated by the series elements than the shunt. Therefore, the varactor diodes with sufficient wide capacitance range must be added to the shunt element of the matching network. In an RF port matching network, the shunt varactor diode, Cv_RF1, is added to the shunt element that consists of a KDV241E and a KDV650E[12], which are connect in series to achieve the required capacitance. The KDV240E[12] is used for the series varactor diode, Cv_RF2. The two added varactor diodes, Cv_RF1 and Cv_RF2, are simultaneously controlled to select a specific resonant frequency with a DC bias voltage, V_{Cv_RF}, of 0 V to 4.4 V. In the LO port matching network, the shunt varactor diode, Cv_LO1, is constructed by connecting the KDV650E and 100 pF in series. The series varactor diode, Cv_LO2, is used by the KDV240E in the RF port matching network. Two added varactor diodes, Cv_LO1 and Cv_LO2 are also simultaneously controlled to select the wanted resonant frequency by a DC bias voltage, V_{Cv_LO}, of 0 V to 6 V.

When V_{Cv_RF} and V_{Cv_LO} are zero, RF and LO matching networks are matched to 881.5 MHz and 465.75 MHz for the cellular service band, respectively, as shown in Fig. 5. For the K-PCS service band, V_{Cv_RF}=2.4 V and V_{Cv_LO}=2.7 V and each matching network is matched to 1,855 MHz and 952.5 MHz, respectively, as shown in Fig. 6. When V_{Cv_RF}=4.4 V and V_{Cv_LO}=6.0 V, each matching network is matched to 2,140 MHz and 1,095 MHz for the W-CDMA service band, respectively, as shown in Fig. 7.

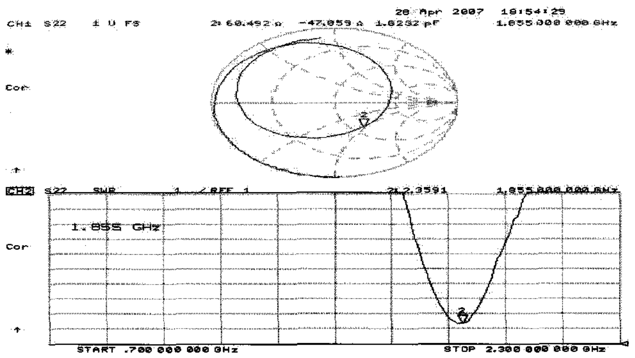


(a) RF

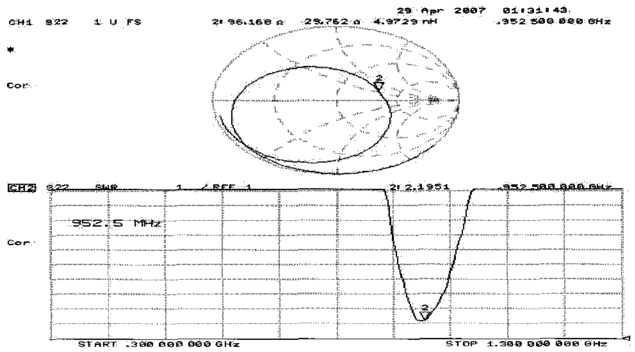


(b) LO ports

Fig. 5. Return loss characteristics in the cellular band.

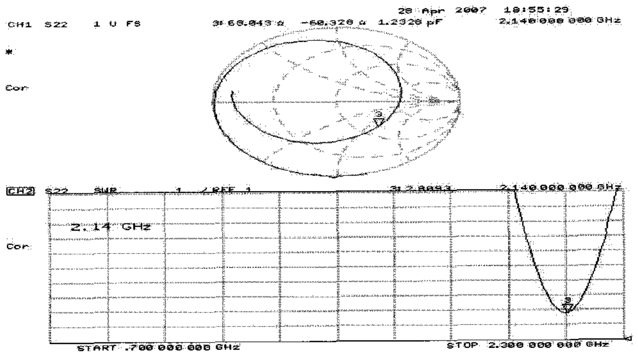


(a) RF

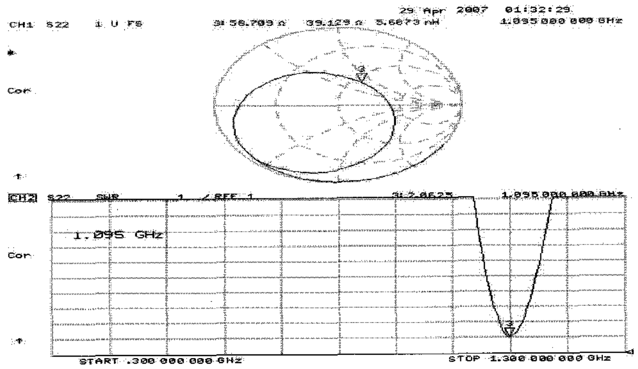


(b) LO ports

Fig. 6. Return loss characteristics in the K-PCS band.



(a) RF



(b) LO ports

Fig. 7. Return loss characteristics in the W-CDMA band.

The measured characteristics of the designed reconfigurable multi-band mixer are summarized in Table 3 and are similar to simulated results shown in Table 2 without LO-IF and RF-IF isolations.

Table 3. Measured results of the designed mixer.

Band	Parameters	Values
Cellular	Gain (dB)	−2.7
	1st LO-RF (dBm)	−74.22
	2nd LO-RF (dBm)	−45.66
	1st LO-IF (dBm)	−44.26
	2nd LO-IF (dBm)	−75.52
	RF-IF (dBm)	−89.13
	IIP3 (dBm)	−0.25
K-PCS	Gain (dB)	3.17
	1st LO-RF (dBm)	−55.47
	2nd LO-RF (dBm)	−35.83
	1st LO-IF (dBm)	−64.75
	2nd LO-IF (dBm)	−55.25
	RF-IF (dBm)	−87.27
	IIP3 (dBm)	−1.22
W-CDMA	Gain (dBm)	3.39
	1st LO-RF (dBm)	−54.33
	2nd LO-RF (dBm)	−29.67
	1st LO-IF (dBm)	−61.75
	2nd LO-IF (dBm)	−48.39
	RF-IF (dBm)	−87.55
	IIP3 (dBm)	1.74

Ⅵ. Conclusion

A reconfigurable multi-band mixer is designed by using a resistive cascade FET scheme. Therefore, the designed mixer has good linearity and conversion gain. Although the mixer has a conversion loss instead of a conversion gain in the lowest band, the loss is much lower than that of commercial passive mixers. In addition, because the RF signal and the LO signal are injected into separated gates and the mixer is driven by the 2^{nd} harmonic of the LO signal, the LO-RF isolation characteristic of the mixer is good.

The varactor diodes are added to the RF/LO matching network which are used to select a specific service frequency band. Because the resonant frequency and the impedance characteristics are simultaneously controlled, the tuning range of the mixer is enhanced and the performance of the mixer in each operated band is similar. Moreover, since the mixer has a single signal path for the multi-band signals and a wide band tuning range, the designed reconfigurable mixer is applicable for the SDR system.

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References

[1] Adiseno, M. Ismail, and H. Olsson, "A wideband RF front-end for multi-band multi-standard high-linearity low-IF wireless receiver", *IEEE Journal of Solid-State Circuits*, vol. 37, no. 9, pp. 1162-1168, Sep. 2002.

[2] R. Magoon, A. Molnar, J. Zachan, G. Hatcher, and W. Rhee, "A single-chip quad-band(850/900/1,800/1,900 MHz) direct conversion GSM/GPRS RF transceiver with integrated VCOs and fractional-N synthesizer", *IEEE Journal of Solid-State Circuits*, vol. 37, no. 12, pp. 1710-1720, Dec. 2002.

[3] R. Mukhopadhyay, Y. Park, P. Pen, N. Srirattana, J. Lee, C. Lee, S. Nuttinck, A. Joseph, J. D. Cressler, and J. Laskar, "Resonfigurable RFICs in Si-based technologies for a compact intelligent RF front-end", *IEEE Transactions on Microwave Theory and Techniques*, vol. 53, no. 1, pp. 81-93, Jan. 2005.

[4] A. Liscidini, M. Brandolini, D. Sanzogni, and R. Castello, "A 0.13 μm CMOS front-end for DCS1800/UMTS/802.11b-g with multiband positive feedbank low-noise amplifier", *IEEE Journal of Solid-State Circuits*, vol. 41, no. 4, pp. 981-989, Apr. 2006.

[5] M. Kawashima, T. Nakagawa, H. Hayashi, K. Nishikawa, and K. Araki, "A 0.9-2.6 GHz broadband RF front-end chip-set with a direct conversion architecture", *IEICE Transactions on Communications*, vol. E85-B, no. 12, pp. 2732-2740, Dec. 2002.

[6] M. Nakayama, K. Horiguchi, K. Yamamoto, Y. Yoshii, S. Sugiyama, N. Suematsu, and T. Takagi, "A 1.9 GHz single-chip RF front-end GaAs MMIC with low-distortion cascode FET mixer", *IEICE Transactions on Electrons*, vol. E82-C, no. 5, pp. 717-723, May 1999.

[7] E. L. Kollberg, *Microwave and Millimeter-wave Mixers*, IEEE press, Newyork, 1984.

[8] J. Kim, J. Choi, "Design of a subharmonic cascode FET mixer for an IMT-2000 base station", *Microwave and Optical Technology Letters*, vol. 39, no. 6, pp. 515-518, Dec. 2003.

[9] S. A. Maas, *Microwave Mixers*, 2nd, Artech house, Inc. Norwood, MA, 1993.

[10] J. Kim, J. Choi, "Design of a resistive cascode FET direct-conversion mixer with zero bias current", *Microwave and Optical Technology Letters*, vol. 42, no. 6, pp. 516-518, Sep. 2004.

[11] Advanced Design System, Agilent Technologies, 2004.

[12] http://www.kec.co.kr.

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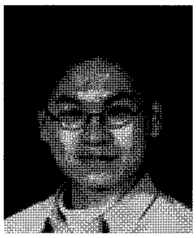

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