VOL. 15, NO. 20, OCTOBER 2020 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

DESIGN AND SIMULATION OF SINGLE ENDED DOUBLE BALANCED RF GILBERT MIXERS

Rohit Vasu, Abdul Rajak and Shazia Hassan
Birla Institute of Technology and Science, Pilani, Dubai, United Arab Emirates
E-Mail: rohitvnambiar@gmail.com

ABSTRACT

The super heterodyne receiver is employed to receive signals at any frequency. A Mixer is an integral block of super heterodyning reception. It down converts the received signal at RF frequency to IF frequency. In this paper, a single ended double balanced Gilbert mixer is designed. This is matched internally to 60 ohms and is operated at a 900 MHz frequency, which is the band frequency of amateur radio (UHF) Spectrum. The circuit of this mixer is simulated and analyzed to find the conversion gains, spectral analysis of the input and output frequencies (IF & RF).

Keywords: gilbert mixer, frequency, IF, RF, signal, conversion, gains.

1. INTRODUCTION

The World has been witnessing 'change' constantly and is revolutionizing, rationalizing and replacing the ancient techniques with more efficient cost effective systems. The communicational revolution is no exception. It all sparked when Samuel Morse built the first ever telegraphic line for successful long-distance communication in 1843. Since then we have had various modulations and the first ever telephonic communication was introduced in 1876 by Alexander Graham Bell.

The early 19th century witnessed the first ever wireless communication which was made possible by Marconi [1][5]. And Claude Elwood Shannon came up with the first communication model. So over the years, the technology had taken great strides and in 1967[2], the Gilbert Cell concept was put forth, revolutionizing the frequency conversion techniques. The *Gilbert cell mixer* or the "Four Quadrant Multiplier" is a device designed to provide better quality output after heterodyning [3], i.e. when the signal is shifted from the specific frequency to a different modulated frequency that can be easily transmitted. The main reason for using the mixer circuits is for

a) Spectrum Sharing

b) Making the signal appropriate for transmission

c) Interference Resilience.

The presence of Gilbert mixers ensures better isolation and improved spectral and conversion gains. Due to the symmetrical circuit design, the RF noise signals can be removed from the IF signals [4]. Every adjacent quadrant matches and cancels the noise signals hence useful signal multiplication is obtained. This is the reason behind choosing the Gilbert mixer for commercial ICs [1] [5] [6] [7]. The central theme of this paper is to establish the characteristics of Gilbert mixers when matched at a particular frequency and compare their gain with the existing model.

2. MIXER PARAMETERS

A mixer has a few crucial characteristic specifications which are used for determining and categorizing the type and its usage, these include the following: Conversion Gain [8] [9], it is measured by computing the ratio of power or voltage at IF output to the power or voltage of RF input and it mostly lies in the close range between 4dB to 9dB. The conversion Gain of the Gilbert Mixer is described by the following equations

$$CG = \frac{V_{out}}{V_{in}} = \frac{2}{\pi} g_m R_{out}$$

$$g_m = \frac{1}{2} K \frac{4I_D / (K - 2V_{RF}^2)}{\sqrt{4I_D / (K - V_{RF}^2)}}$$

Wherein, g_m refers to the transconductance of the transistors M_3 and M_4 with M_1 *and* M_2 matched internally such that W and L parameters of the respective transistors are equal. $K = \mu_0 C_{OX} W_1 / L_1$ is a constant depends on the type of transistor used.

Noise Figure [11] [12] [13], this term indicates the loss in passive circuits that are caused due to the presence of other RF components. It is defined mathematically as the ratio of the SNR at the input (RF) to the SNR at the output (IF).

$$NF = \frac{(SNR)_{RF}}{(SNR)_{IF}}$$

Isolation [10] describes how much signal leakage will occur between the ports. Isolation of ports essentially shows the power leakage within the circuit which implies higher the isolation, better the performance due to lower power leakage. Since the LO signal power is large compared to the RF output power any leakage in the LO signal would weaken the overall mixer performance.

VOL. 15, NO. 20, OCTOBER 2020 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Linearity of a system expresses' the capability to predetermine the output power of the system for the confined inputs. Non-linear circuits can be categorized as (i) Harmonic distortion and (ii) intermodulation distortion. Harmonic distortions are caused when the input follows the sinusoidal curve or the harmonics produced in the multiple frequencies compared to the input frequency.

Intermodulation distortions occur when more than one sinusoidal signals of close frequencies are present at the circuits input. The mixer's output contains signal at multiple frequencies.

3. MIXER DESIGN

The mixer configuration consists of two inputs and a single resulting output as shown in Figure-1. The carrier signal is mixed with either the RF signal or the IF signal depending on whether the mixer is up or down conversion design[14], the Local Oscillator input signal is given to aid the heterodyning process.

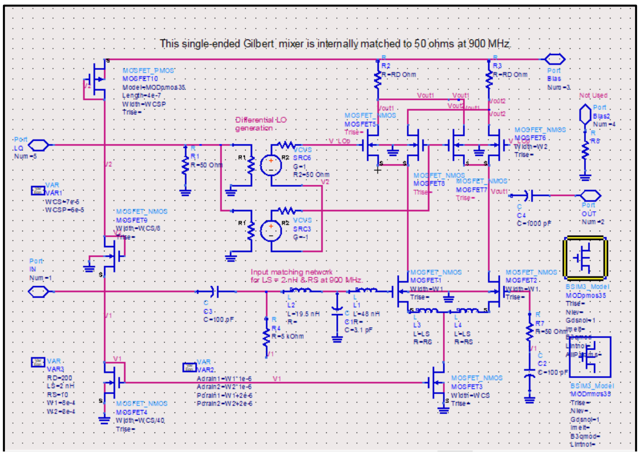

Figure-1. Single ended double balanced gilbert mixer design (operating at 900 MHz Frequency).

Let us consider two generalized input signals [15][16][17] 'a' and 'b'.

$$a = A\sin(\omega_1 t + \varphi_1)$$

$$b = B\sin(\omega_2 t + \varphi_2)$$

After the mixing process, the output signal would be the product of the two signals 'a' and 'b'

$$a.b = AB\sin(\omega_1 t + \varphi_1).\sin(\omega_2 t + \varphi_2)$$

$$= -\frac{AB}{2}\{(\cos((\omega_1 t + \varphi_1) + (\omega_2 t + \varphi_2)) - \cos((\omega_1 t + \varphi_1) - (\omega_2 t + \varphi_2))\}$$

$$= -\frac{AB}{2}\{(\cos((\omega_1 + \omega_2)t + (\varphi_1 + \varphi_2)) - (\cos((\omega_1 - \omega_2)t - (\varphi_1 - \varphi_2))\}$$

Sum frequency removed by filtering — Difference frequency which is I.F.

This implies that both the summation and the different components are present in the mixer's output [18].

In this work, a Gilbert mixer is designed for operation in the local communication range at 900 MHz - 1.5 GHz, A mixer by itself is not a complete design and its utility, performance and many other factors depend upon the circuit which is considered. Here the mixer is used in the up conversion and the down conversion of UHF signals which appears in the transmission and reception paths [19] respectively.

Table-1. Below, represents the Gilbert mixer set up, Box 3 represents the Local Oscillator signal generator and the Box 4 is the frequency selector.

RF (input) Frequency	IF (Output) Frequency for Down Conv.	IF (Output) Frequency for Up Conversion	LO Frequency
900.0 M	45.00 M	1.755 G	855.0 M
1.200 G	345.0 M	2.055 G	855.0 M
1.500 G	645.0 M	2.355 G	855.0 M

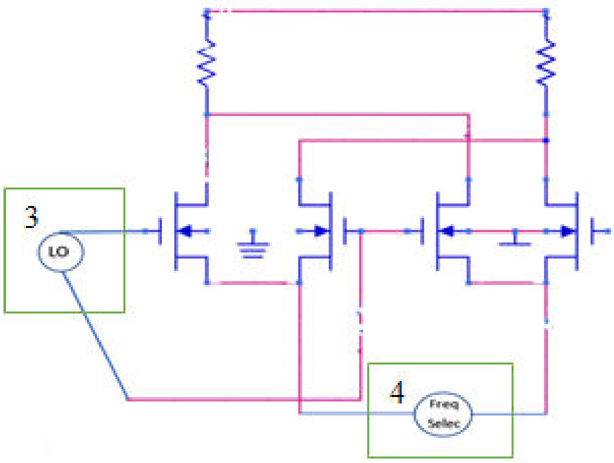

Figure-2. Gilbert mixer.

This double balanced symmetric circuit layout is designed using a combination of MOSFET [11], Local Oscillators, Inductors, resistors, and capacitors.

ARPN Journal of Engineering and Applied Sciences

Figure-2 shows the Mixing part of the circuit. Figure-3 shows the Local Oscillatory circuit and Figure-4 shows the IF Generator.

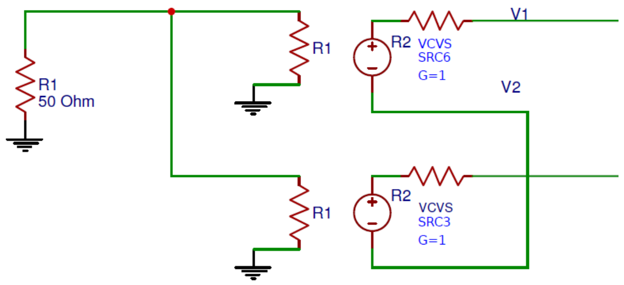

Figure-3. Local oscillator circuit.

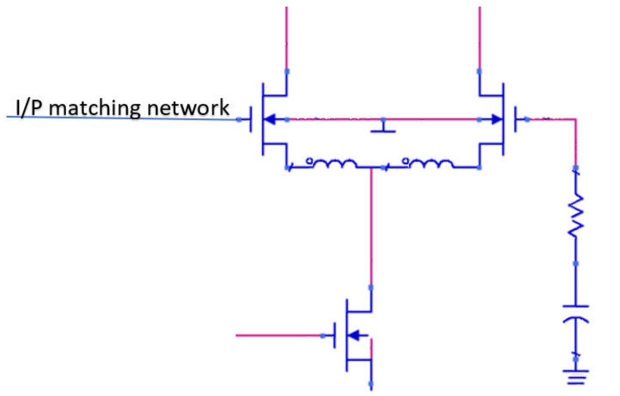

Figure-4. Frequency selector.

The Mixer design consists of two differential transistor pairs, one input signal is used to control the bias current and the other input signal is used to drive the base electrode. So, every time the switch changes its location, the current changes direction and mixes with the Local Oscillator signal through the load resistors and thus voltage output is obtained from the input current. The differential output from the mixer is the multiplied version of the two input signals[20][21][22]. The current element (I_{ss}) helps in maintaining the linearity and the stability of the circuit.

4. RESULTS

The above designed Gilbert mixer was simulated and the following results were obtained from the simulation.

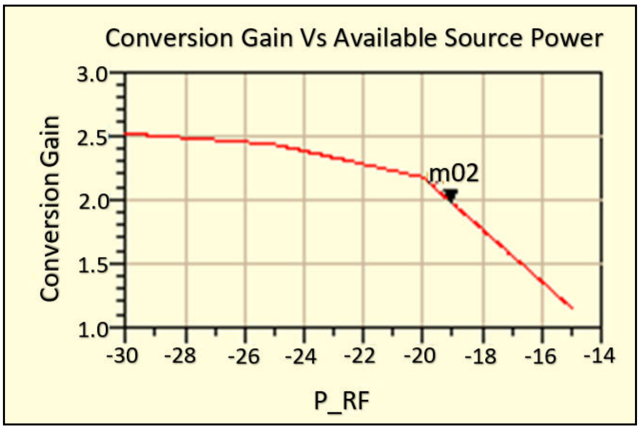

Figure-5a. Conversion gain vs available source power.

Figure-5a & Figure-5b shows the actual output power when compared with the ideal small signal case. The receiving power increases beyond 20dB of the available RF power. The "compression" input power of 20 dB is showed in the conversion gain versus.

Figure-6a, indicates the IF power available when the mixer is at down conversion, decreases after 18dB IF power output. In Figure-6b, the mixer acts as up conversion mixer with the conversion gain region ranging from {-2.4 to -2.6} and the corresponding power consumption ranges from {-32 to -23}, after -23dBm there is a steady drop in Power (IF) and it is noticed in Figure-6a that the steady gain is observed when the RF power is between -30dBm to -25 dBm after which the gain begins to drop which indicates the active region of the mixer is in this range. The mixing and conversion of RF to IF and vice-versa.The gain compression increases rapidly towards the -15dB RF power which indicated the mixer circuit is no longer in an active region and its dissipating power (other electromagnetic signal distortions, etc.) this is a significant signal Phenomenon.

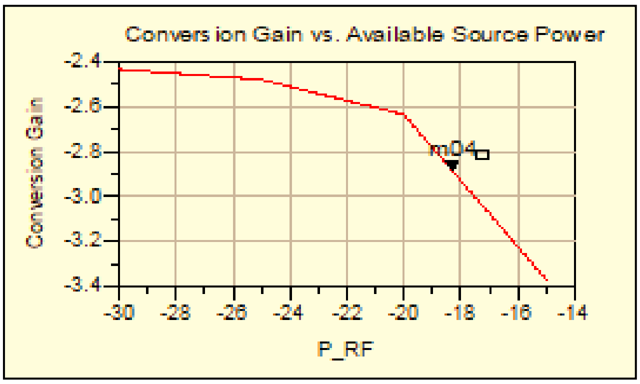

Figure-5b. Conversion gain vs available source power.

VOL. 15, NO. 20, OCTOBER 2020 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

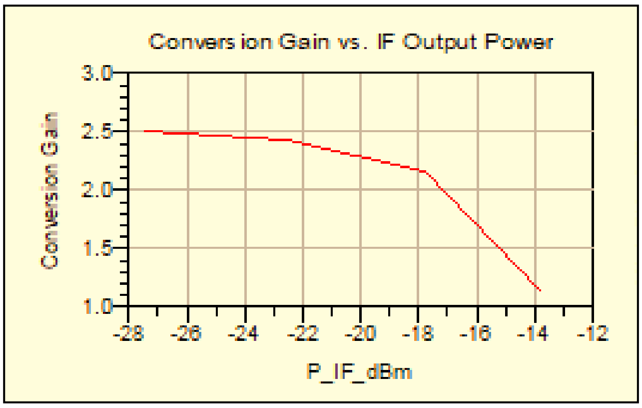

Figure-6a. Down conversion gain vs. if output power.

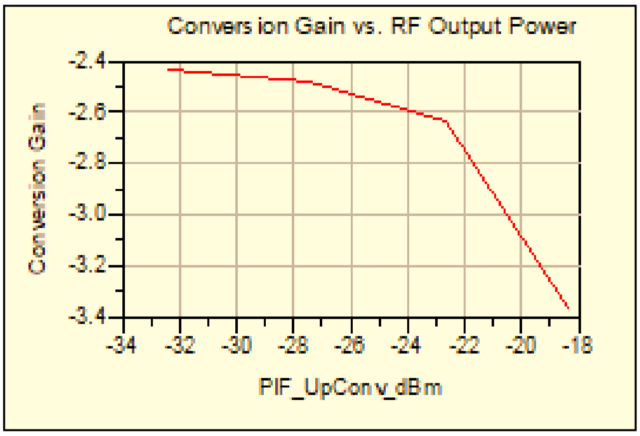

Figure-6b. Up conversion gain vs IF output power.

Figures 7a & 7b the output power (in dBm) is delivered to the load for the gains. Figure-7a shows the results obtained for the up conversion and how the mixer would have behaved if there were no losses and no compression and 7b shows the similar mixer behavior for down conversion.

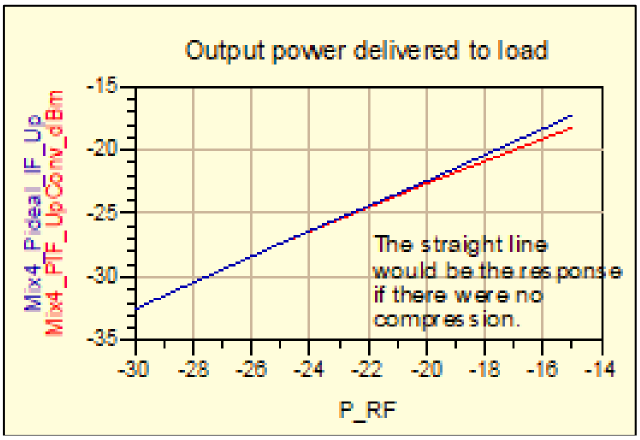

Figure-7a. Output power delivered to the load.

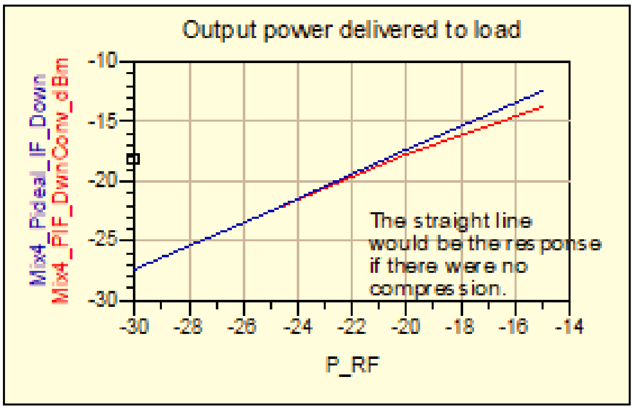

Figure-7b. Output power delivered to the load (active region).

Figure-8a shows the results obtained when the mixer is run in the active region and it was observed the steady declinein the gain characteristics of the mixer towards the other part of the spectrum exceeding 900Mhz. In Figure-8b, it was noted in the isolation curves and here the isolations appear to be higher than 100, which is not feasible in the real world as there will be losses, as the circuit gets unbalanced after an extent.

It is observed that for an input frequency of 900.0 MHz and LO Frequency of 855.0 MHz, when a load impedance (Z load) is 200.0 is given, the RF and IFvoltages were calculated to be 0.034/-5.334 and 0.316/0.0 respectively. So, an output Voltage of 0.081/-82.3 is observed for a down conversion gain of 2.172 dB at 45.00Mhz and an output Voltage of 0.047/-1.733 is observed for an up-conversion gain of -2.635 at 1.76 GHz (Output Frequency).

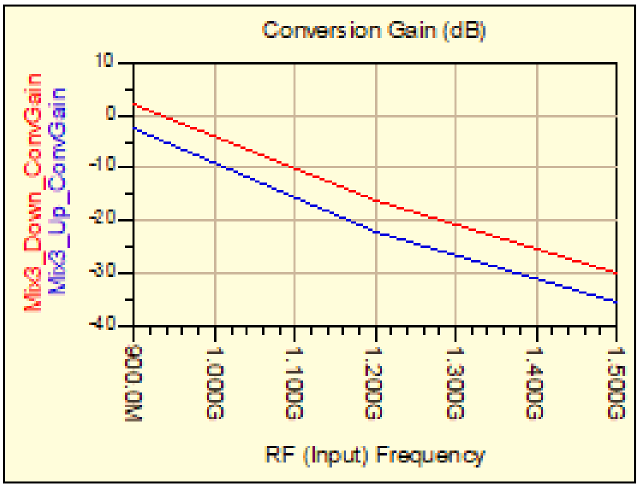

Figure-8a. Conversion gain vs RF input frequency for mixer in active region.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

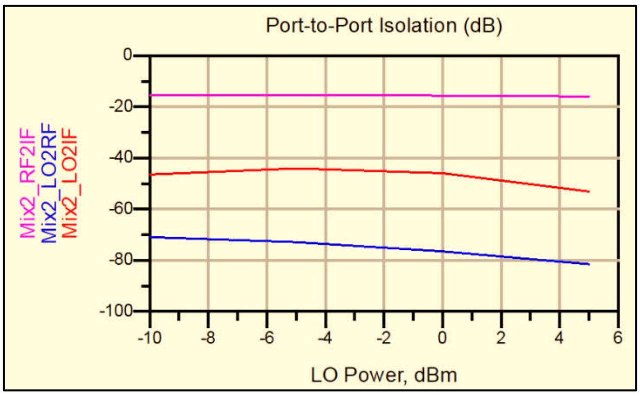

Figure-8b. Port to port isolation for different signal mixing.

The reflection coefficient and the VSWR (Voltage Standing Wave Ratio, determines the efficiency of power transmission from the source) were also calculated looking into the RF (input) Port: for 900 MHz Frequency and with reference impedance of 56.47 -j11.47 the reflection coefficient (Rho) was found to be 0.12/-54.42 and the VSWR was found to be 1.28. Looking into the LO Port for a frequency of 855 MHZ and Reference impedance of 50.00+j0.0, the coefficient rho is 0.00/0.00 and the VSWR = 1.00 this is because the local oscillator doesn't carry any information by itself (input side). Looking into the IF (Output) port at the down-conversion frequency of 45MHz and for Ref Impedance the Rho is found to be 0.60/-3.30 and VSWR = 3.95 and similarly, while looking into the IF (Output) port at the up-conversion frequency of 1.76GHzand with reference impedance of 19.64-j50.30 the Rho was found to be 0.68/-85.28 with VSWR = 5.33.

5. MATHEMATICAL ANALYSIS

The Gain of this single ended double balanced Gilbert mixer can be derived as follows:

I_1 = Current through M_4
I_2 = Current through M_3
I_3 = Current through M_5
I_4 = Current through M_6
S(t) = Switching function of the mixer
$I_{DC} = I_{bias}$
$I_2 - I_1 = I_{DC} + (I_{RF}\cos\omega_{RF}t).S(t)$
$I_3 - I_4 = I_{DC} - (I_{RF}\cos\omega_{RF}t).S(t)$
$I_{01} = I_2 + I_4$
$I_{02} = I_1 + I_3$
$I_{OD} = I_{02} - I_{01}$

$$= (I_2 + I_4) - (I_1 + I_3)$$
$$= (I_2 - I_1) + (I_4 - I_3)$$
$$= (I_2 + I_4) - (I_1 + I_3)$$
$$= (I_{DC} + I_1\cos\omega_{RF}t)S(t) + (I_{DC} - I_{IF}\cos\omega_{RF}t)S(t)$$
$$= (2I_{RF}\cos\omega_{RF}t)S(t)$$

S(t) is a switching function given by $\frac{2}{\pi}$

$$= \frac{4I_{RF}}{\pi}\{\sin(\omega_{LO} + \omega_{RF})t + \sin(\omega_{LO} - \omega_{RF})t + \frac{1}{3}\sin(3\omega_{LO} - \omega_{RF})t + \frac{1}{3}\sin(3\omega_{LO} + \omega_{RF})t \ldots)$$

By taking the amplitude the equation of the Gain of the mixer boils down to

$$G_C = \frac{\frac{4I_{RF}}{\pi}(R_L)}{2V_{RF}}$$

$$= gmR_L(\frac{2}{\pi}) = \frac{V_o(t)}{V_{RF}(t)}$$

For Gilbert Cells the degeneration resistor or inductor can be represented as

$$\frac{V_o(t)}{V_{RF}(t)} = \frac{2}{\pi}(\frac{R_L}{R_S + 1/gm})$$

From the above equations the mixer is proportional and depends on (g_m) Trans conductance value and the Tuning resistive loadR_L.

6. CONCLUSIONS

A mixer circuit is designed to desired results in its linearity gain and noise figures and the topology in which it's used decide the value of the component. This Gilbert Mixer is designed for the communication spectrum of *900MHz* and the following results show that this mixer can be effectively used in the communication system for transmitting better quality output after extraction of the signal back from mixing. This mixer has a better compression gain as it can withstand higher transconductance, in terms of linearity, there is a better control over the harmonics and the input frequencies are suppressed better due to the Double differential architectural design. This design also provides a better isolation but due to the increase in the use of the transistors the Noise Figures (NF) and the power consumption will also be significant due to the non-ideal switching

REFERENCES

[1] Razavi Behzad. 1997. Design Considerations for Direct Conversion Receivers DCR. IEEE Transactions on Circuits and Systems-Il, Analog and Digital Signal Processing. 44: 428-435.

[2] Parsinen, J. Jalisa, J. Ryan, L. Listening, k. Kivakas and K. Helony. 2000. Circuit Solutions WCDMA Direct Conversion Receiver. IEEE Norsig 2000, Kolmar den, Sweden, June 13-15.

[3] 1986. High frequency noise measurement on FETs with small amplitudes by ABID A on electronic devices. ED-33, November.

[4] 2001. Effect of offset on bipolar integrated circuit mixer equal-order distortion by Cofing D Conditions. IEEE Trans. Microwave Theory Tech.49: 23-30.

[5] Prokis JG, Digital Communications, Mc Graw Hill, New York, 905 pages, 19 is 4.

[6] J. Ouvre. Electronic des cyanoux analogics" edition Dunode, pp. 33-339, 19 uv.

[7] T. Chauchen, M. Sawan. 2001. A5GHz CMOS RF Mixer at 0.1 am CMOS Technology. IEEE CCECE 2003, Montreal, May 2003. [Ena] d. Lenaearts, j. Van der Tang, Cicero s. Vouchers, circuit design for RF transceivers, KLUUER Educational Publishers. pp. 122-128.

[8] C.F Au-Yeung and K. K. M. Cheng. 2003. CMOS Mixer Linearization by Low Frequency Signal Injection Method. IEEE MIT-S International Microwave Symposium Digest. 1: 9-5-98.

[9] Hung-Che Wei, Ro-min Weng, Chih-lung Hsiaoand Kun-yi Lin. 2004. 1.5 V2.4 GHz CMOS Mixer with High Linearity. 2007 IEEE Asia-Pacific Conference Circuits and Systems. 4-10.

[10] Kumar Munusamy and Zubaida Yusoff. 2006. A highly linear CMOS down conversion double balanced mixer. ICSE 2007 Proc. 2006, Kuala Lumpur, Malaysia. pp. 985-990.

[11] Goo-Young Jung, Jae-hoon Shin, Tae-uol Yoon. 2007. A low noise I_JWB cmos mixer using current bleeding and resonant inductor techniques. Wiley Interscience Journal. 79: 159. 5.

[12] T. K. Johansen, J. Wijker, and V. Kroeger. 2006. Conversion Matrix Analysis CGB HBT Gilbert Cell Mixer. INMIC, 1-1-1-1890, ROM.

[13] T. K. Johansen, J. Wijker, and V. Kroeger. 2005. Analysis and Design of 3-R Wide-Band SiGe HBT Active Mixers. IEEE Transactions on Microwave Theory and Technology. 53, No. 7.

[14] Nichols, K.P. And gardeners, J.G.E. 2006. Ultrapad drip mixers for digital microfluidics using self-propelled water droplets. In: Microts 2006 Conference, 5-9 November 2006, Tokyo, Japan. pp. 582-584.

[15] RF, RFIC, Microwave theory design Gilbert mixer design tutorial J P Silver.

[16] V. Widowskovic, J. Van der Tang, a. Leuvenberg and A.H.M.A. Van Rormund. 2005. A Low Voltage Fold-switching mixer in 0.18-gm CMOS. IEEE Journal of Solid-State Circuits. 40(6): 1259-1264.

[17] c. Harman, M. Tybout and H. Kaler. 2004. 2.0V 1.4MW. 2.5GHz connection based on transformer Mixer with +2.4dB gain and -2.8dBm llP3 in 0.1311m CMOS. IEEE Radio Frequency Integrated Circuit (RFIC) Symposium. pp. 35-38.

[18] E. a. M. Klumperink, SM Louvamma, G.J.M. Veenuck and B.A. Nauta. 2004. CMOS switched Transconverter Mixer. IEEE Journal of Solid-State Circuits. 39(8): 1231-1240.

[19] C. Yes. Tan. 2003. A High Performance Low-Power CMOS Double-Balanced IQ for Down-Conversion Mixer 2.45-GHz ISM Band Application. IEEE Radio Frequency Integrated Circuit (RFIC) Symposium.pp. 45-60.

[20] M. F. Huang, c. J. Ku and S.Y. Lee. 2006. A 5.25-GHz CMOS Folding-Cascode Even for Harmonic Mixer Low-voltage applications. IEEE Transactions on Microwave Theory and Technology. 542(Part 1): 660-669.

[21] K. Liang, H. why. Chang and Y.J. Chan. 2007. A 0.5-7.5 GHz Ultra Low Voltage Using Low Power Mixer Bulk-lnisation method by 0.18-gm CMOS technology. IEEE Microwave and Wireless Components Paper. 17(7): 531-533.

[22] S. Zhou P. Ma, L. Zhang, P.. Zampardi, J. Lee, Y.S. Chang, M. F. Chang. 2001. 1.8 V RF AGC and Mixer Novel Four-Terminal implemented with HBT (FHBT). Digest of Papers, 2001 Radio Frequency Integrated Circuit (RFIC) Symposium, pp. 241-244, Phoenix, Arizona.