GAIN AND NOISE ANALYSİS OF ZERO IF SECOND HARMONIC MIXER

Osman Palamutçuoğulları

e-mail: opal@ehb.itu.edu.tr

Mehmet Kayhan

e-mail: : kayhanm@itu.edu.tr

Istanbul Technical University, Faculty of Electric-Electronics Engineering, Division of Electronics and Communication Maslak,34469 Istanbul, TURKEY

ABSTRACT

This paper presents the design and noise analysis of a second harmonically pumped MOSFET RF Mixer with zero-IF for HyperLan applications. Since, it provides a considerable amount of LO phase noise reduction which is the most important problem in the design of front-ends with zero-IF, this type of mixing attracts its use in many applications. The half frequency operation not only simplifies the design of LO circuits but, also the required LO power levels are more readily available. Apart from that, operation of LO at half frequency simplifies the realization of band selection filters which are situated right after the antenna. Almost the total suppression of the LO leakage through the antenna is the other imported advantage which is provided by this type of mixing. BSIM3 Ver 3.1 model of IBM 0.18μm 7RF MOSFET process is used in the simulation and the simulated results are compared with the theoretical findings.

I. INTRODUCTION

1st Harmonic MOSFET Mixers have so far been used in many applications and particularly, the switched mode single balanced forms are the most widely used types [1]. Beyond this, double-balanced mixer (Gilbert Cell) is another widely used type of MOSFET mixers which suppress both LO and RF signals at the IF port. Conversion gains which can be obtained from these mixers are approximately at the level of 4dB for single balanced type and 6dB for double balanced type. OFDM type modulation is used in the Hyperlan applications. Because of the both phase and amplitude change which are taking place in this type modulation, phase noise is a very important criterion in mixer circuit designs for Hyperlan applications. For this reason the LO signal which is the most significant source of phase noise in mixers is restricted to have a very tight design standards. Therefore, special precautions must be taken in the LO design process [2]. Even though the conversion gain in 1st Harmonic mixing is higher than the 2nd harmonic pumping the noise of LO directly transferred to IF band in the former type. It is mandatory for the LO signal which is used in this type of mixer to have a phase noise characteristics determined by the strict standards. In second harmonic mixing however, transfer of LO noise band will be completely circumvented if the products of 1st harmonic mixing totally disposed (Figure-1). This feature is being known for many years [3], [4] and the conversion gains of this type of mixers are lower [3], [5]. Therefore, suppression of the 1st Harmonic mixing products causes a decrease in the conversion gain difference between second and first harmonic pumping types [6], [7].

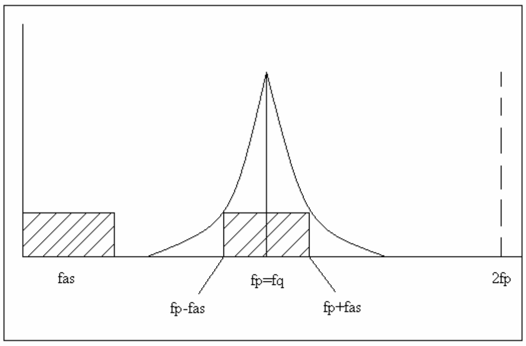


Figure-1. Pump signal phase noise

In the diode mixers, suppression of 1st harmonic mixing products is easily provided by using an anti-parallel diode pair [3]. In MOSFET mixers however, suppression is provided by applying RF signal in the same phase and LO signal in 180 degree out of phase to the matched MOSFETs [4]. The principle of this type driving has shown in Figure-2.

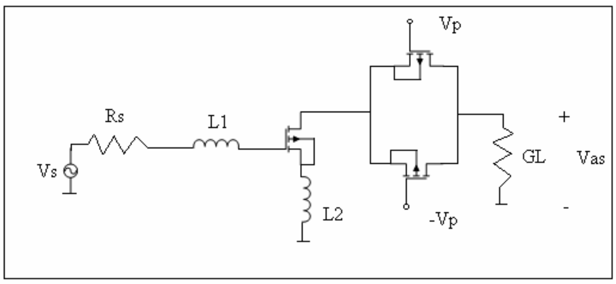


Figure-2. MOSFET Mixer with 2nd Harmonic Pumping

II. MIXER ANALYSIS AND GAIN OPTIMIZATION

Under the assumption of MOSFET's transfer curve is in square characteristics and pump signal is purely sinusoidal, change of pump current will be as shown in Figure-3.
By the reason of periodically changing the current the transconductance of the MOSFET will also be changed periodically and the Fourier expansion of the transconductance variation can be written as follows;

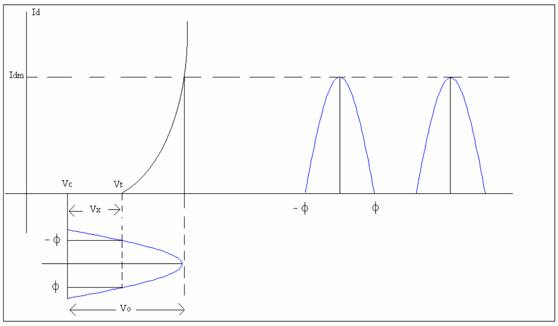


Figure-3. Pump current change drived by sinusoidal voltage

$$g(t) = g_0 + 2\sum_{n=1}^{\infty} g_n \cos n\omega_p t \qquad (1)$$

Here; "n" and ω_p show the harmonic number and the angular frequency of pump (local oscillator) signal, respectively. For 2nd harmonic pumping the values of n for our concern are 0 (direct component) and 2. If MOSFETs are assumed of having conductances that change periodically with time and only the RF signal voltage component is allowed to be presented at the input port (pump and all other harmonics are shorted) and only the IF (Base Band) voltage component is allowed to be presented at output port (with RF, LO and all other harmonics are shorted), mixer circuit could than be modelled as in Figure-4 (Y Mixer).

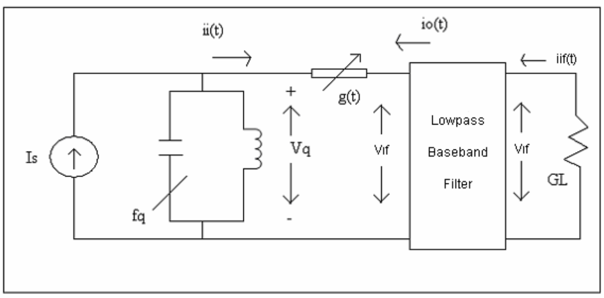


Figure-4. Y Mixer Model

If the input port is resonated at the signal frequency the following equations should be provided for the impedance matching at this port.

$$g_{mi}\frac{L_2}{C_{gs}} = R_S \quad \text{and} \quad \omega_q^2 = 1/(L_1 + L_2)C_{gs} \qquad (2)$$

Here; ω_q is the signal frequency, g_{mi} and C_{gs} are the transconductance and gate-source capacitance of the input MOSFET, respectively. Consequently, by an adequate choose of L_2 and L_1 values, resonance and impedance matching can be provided simultaneously at the input port. In such a case current source in Figure-4 will be considered as MOSFET's drain current source and it's value can be calculated as below;

$$I_0 = Q_i g_{mi} V_S \qquad (3)$$

Here; $Q_i = 1/2\omega_q C_{gs} R_S$ is the quality factor of input circuit. Conversion gain of Y Mixer in Figure-4 can be calculated by using (3) within the voltage-current matrix relationship of the circuit as below;

$$CG = 4R_S G_L \left(\frac{V_{if}}{V_S}\right)^2 = 4R_S G_L \left(\frac{g_2 g_{mi} Q_i}{g_0(g_0 + G_L) - g_2^2}\right)^2 \qquad (4)$$

Here g_0 and g_2 are the coefficients of mean value and second harmonic component of transconductance whose Fourier expansion is given in (3). It can be seen that, relationship (4) can be optimised according to G_L. Results of calculations show that load conductance that optimises (4) can be written in the form below in terms of two coefficents g_0 and g_2;

$$G_{L0} = g_0^2\left[1 - \left(\frac{g_2}{g_0}\right)^2\right] \qquad (5)$$

The conversion gain will be maximized when $G_L = G_{L0}$ used in (4). Having done this the maximum conversion gain can be found as;

$$CG_O = \frac{R_S g_{mi}^2 Q_i^2 (g_2/g_0)^2}{g_0\left[1-(g_2/g_0)^2\right]} \qquad (6)$$

Here; it can be seen that, the flow-angle Φ of the pump current in Figure-2 that maximises the (g_2/g_0) ratio will also maximises the conversion gain. For the sinusoidal voltage drive which shown in Figure-3, MOSFET's transconductance coefficients can easily be be calculated.

Since MOSFETs operate in saturation, drain current, gate-source voltage change relationship will be as below;

$$i_D = K_N (v_{GS} - V_T)^2 \qquad (7)$$

Here; K_N : is the MOSFET's structural parameter as $[A/V\ ]$ and V_T shows the threshold voltage. Flow angle for the pump drive voltage with V_O amplitude and V_C bias voltage can be calculated as follows;

$$\Phi = \cos^{-1}\frac{V_T - V_C}{V_O} = \cos^{-1}\frac{V_X}{V_O} \qquad (8)$$

For the voltage driving shown in Figure-3, the change of transconductance of a single MOSFET in a single period can be stated as below;

$$\begin{aligned} g(t) &= 2K_N V_O [\cos\omega_p t - \cos\Phi] & -\Phi \le \omega_p t \le \Phi \quad (9)\\ g(t) &= 0 & \Phi < \omega_p t < 2\pi - \Phi \end{aligned}$$

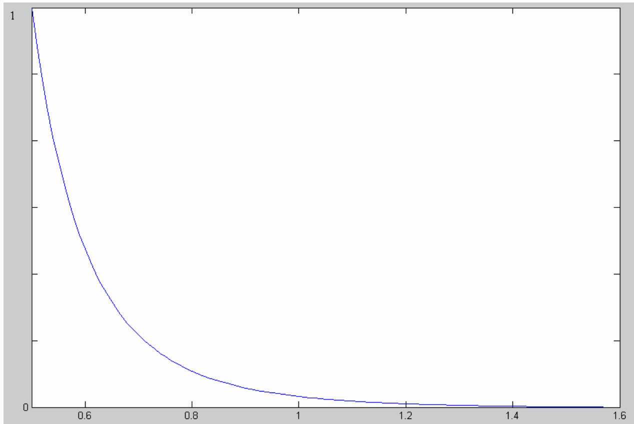
Then, the Fourier coefficients for a single MOSFET can be calculated as below;

$$\begin{aligned} g_0^1 &= 2K_N \frac{V_O}{\pi}[\sin\Phi - \Phi\cos\Phi] \\ g_1^1 &= K_N \frac{V_O}{\pi}\left[\Phi - \frac{1}{2}\sin 2\Phi\right] \qquad (10)\\ g_2^1 &= K_N \frac{V_O}{3\pi}\sin\Phi[1 - \cos 2\Phi] \end{aligned}$$

In the case of driving MOSFETs with a 180^0 out of phase those coefficients for the paired structure will be, $g_0 = 2g_0^1, g_2 = 2g_2^1$ and $g_1 = 0$. It is obvious that 1^{st} harmonic components are suppressed. By using these results (g_2 / g_0) ratio can be obtained as follows;

$$(g_2 / g_0) = \frac{\sin\Phi(1 - \cos 2\Phi)}{6(\sin\Phi - \Phi\cos\Phi)} \qquad (11)$$

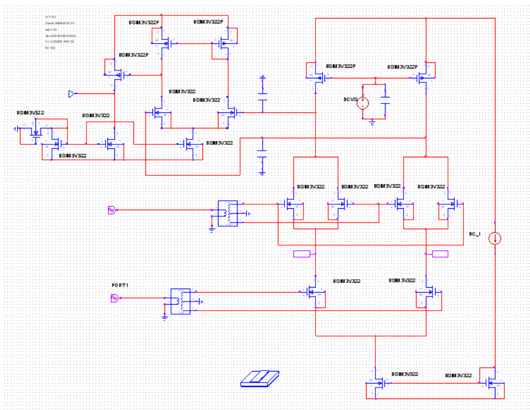
Figure-5 shows the change of (g_2 / g_0) ratio by the flow angle Φ. It can be seen that, for $\Phi = 0$ the ratio above takes it's maximum and as the angle rises, value of the ratio decreases. But, the value of $\Phi = 0^0$ shifts the current value to zero and load conductance approaches to infinitive. The optimum value of flow angle Φ so the optimum value of gain will be determined by the least load conductance that can be connected to drain. As it will be shown in the simulation results, for the values of $K_N = 7{,}4 10^{-3}$ (A/V^2) and $V_T = 0{,}33V$ of the selected transistor, the value of the flow-angle is found as $\Phi = 44{,}2^0$ for the selected load conductance value of $G_L \cong 1{,}7mS\,(R_L \cong 600\Omega)$. Then, the corresponding bias voltages and the amplitude of the LO are found as $V_X = 2.15$, $V_C = -1{,}82$, $V_O \cong 3$ V.



Figure–5. Change of (g_2 / g_0) vs. Φ

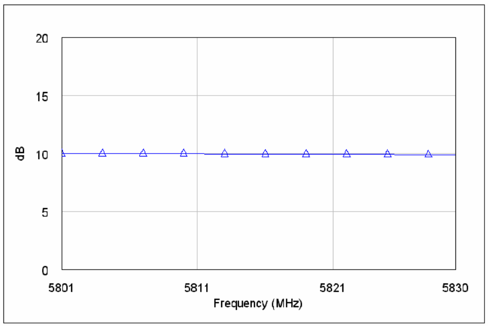
The parameters of the driving current source MOS are found to be as; $g_{mi} = 7{,}4mS$, $C_{gs} = 44{,}4fF$ and for $R_S = 50\Omega$ the value of quality factor can be calculated as $Q_i = 6{,}18$. By substituting this value into (6) the maximum conversion gain can be found as $CG_O \cong 4 \equiv 6dB$. This value is much higher than the values obtained by the diode mixers [1]. But, it is lower than the values obtained by the fundamentally pumped active mixers [2],[3]. As it is obvious that the maximum acquarible gain dependent mainly on load conductance. After adding P-MOS transistors instead of resistors circuit gain rises to 10dB. These results and circuit schematic are seen below.

III. SIMULATION RESULTS



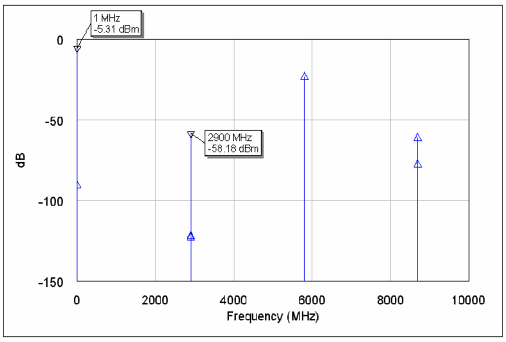
Figure–6. Schematic of the mixer with resistive load which is used in the simulations

Figure.6 shows the mixer schematic used in simulations. With this circuit below result are obtained. For example Figure.7 shows the conversion gain of mixer in dB in the bandwith used.



Figure–7. Mixer conversion gain vs. frequency

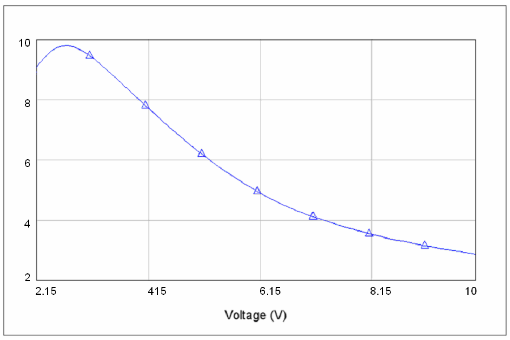
Figure.8 shows the spectrum of mixer output. As it can be seen that oscillator signal and second harmonic component at the output adequately suppressed.



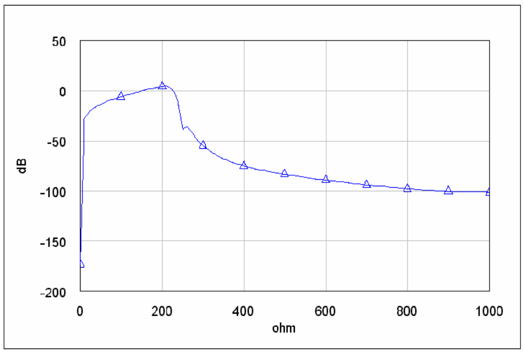
Figure–8. Frequency spectrum at mixer output

Figure.9 shows the relation between conversion gain and oscillator voltage. Oscillator voltage is directly related to flow angle Φ. Figure shows that for an optimum flow angle Φ, gain is maximised.

In Figure.10 mixer gain and load conductance relationship can be seen. In theoretical calculations it has been showed that for an optimum load conductance the gain value is maximised. Also simulation results confirm that thesis.



Figure–9. Mixer conversion gain vs. pump voltage



Figure–10. Mixer conversion gain vs. load resistance

IV. CONCLUSION

It can be seen that the obtained gain from the simulation results are somewhat lower than the expected values from calculations. However simulation results are in parallel with theoretical calculations.

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