3Pa3-5
Proceedings of Symposium on Ultrasonic Electronics, Vol. 33 (2012) pp. 351-352
13-15 November, 2012

Negative-resistance simulation in NMOS Colpitts crystal oscillators
NMOS コルピッツ水晶発振回路における負性抵抗算出法

Shigeyoshi Murase [1†], Yasuaki Watanabe [2]
(Nihon Dempa Kogyo , Grad. School of Sci. and Eng., Tokyo Metropolitan Univ.)
村瀬重善 [1†]，渡部泰明 [2] ([1] 日本電波工業, [2] 首都大学東京）

1. Abstract

Crystal oscillators have been widely used in wireless applications to provide a timing reference signal. It has recently become necessary to lower the power consumption and improve applications by designing low voltage driven oscillators [1].

Various methods for analyzing negative resistance have been proposed for Colpitts crystal oscillators that use BJT, CMOS and NMOS amplifiers[2-5].

A method for analyzing negative resistance for oscillators using NMOS (Negative-MOS) with its small signal level of negative resistance to steady the oscillation level is proposed in this paper. In particular, the gate current of NMOS has a lower power consumption that makes it almost negligible.

The input and output characteristics($V_{GS}-I_D$ characteristic) of NMOS circuits are formulated from the cutoff, saturation and triode regions. It is difficult to calculate each region because the boundary condition included in the equation of each region is different. Thus, the approximation of the operating characteristics can be derived from making a polynomial approximation of the input and output characteristics calculated by using the DC characteristic. The mutual conductance (g_m) and negative resistance can be calculated by numerically integrating the approximation.

2. Structure of NMOS oscillators

Figure 1 shows a Colpitts crystal oscillator with an NMOS of the modified equivalent model.

According to Fig. 1 the impedance Z_{in} can be derived and be represented using the following equation.

$$Z_{in}=R_G // Z_3 //(Z_1+Z_2+g_m\cdot Z_1\cdot Z_2)//\frac{(Z_1+Z_2+g_m\cdot Z_1\cdot Z_2)\cdot Z_3}{g_m\cdot Z_1\cdot R_D} \tag{1}$$

3. Derivation of g_m

The voltage between the gate and source $V_{GS}(t)$ can be represented by using the following equation

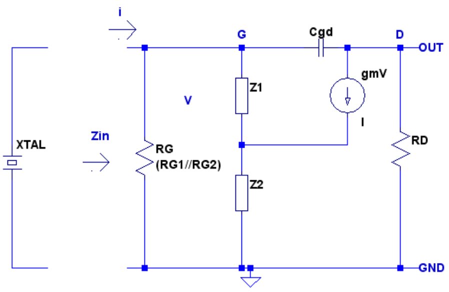

Fig. 1 Colpitts crystal oscillator with NMOS of modified high frequency equivalent model

$$V_{GS}(t)=V_{GS0}-Z_2\Delta I_D+V_{GSW}\sin\omega t \tag{2}$$

V_{GS0} is the voltage between the gate and source under a DC bias and ΔI_D is the increment from the bias current I_{D0}. V_{GSW} is the amplitude of the AC voltage between the gate and source.

The input and output characteristics can be calculated by substituting $V_{GS}(t)$ from 0 to V_{DD} for calculating $I_D(t)$. The result is derived from the polynomial of degree n, where n = 20, and then I_{D_app} can be derived by using the polynomial approximation.

$$I_{D\_app}(V_{GS})=a_0+a_1V_{GS}+a_2V_{GS}{}^2+a_3V_{GS}{}^3+\ldots a_{20}V_{GS}{}^{20} \tag{3}$$

Where, $a_0,a_1,a_2,a_3..a_{20}$ are the coefficients

Based on Eq. (3), when the operating point is $V_{GS}(t)=V_{GS0}$, the current (I_{D0}) will be derived using the following equation.

$$I_{D0}=I_{D\_app}(V_{GS0}) \tag{4}$$

The DC portion of the drain current I_{DC} and the fundamental frequency magnitude can be derived from Eq. (2) using a Fourier transform which are represented by using the following equations and the results can be calculated by using numerical integration

$$I_{dc}=\frac{1}{2\pi}\int_{-\pi}^{\pi}I_{D\_app}(V_{GS}(t))d\omega t \tag{5}$$

$$I_w = \frac{1}{\pi}\int_{-\pi}^{\pi} I_{D\_app}(V_{GS}(t))\sin\omega t d\omega t \tag{6}$$

ΔI_D can be derived from equation (4) and equation (4) and represent as below equation.

$$\Delta I_D = I_{dc} - I_{D0} \tag{7}$$

Substituting Eq. (5) for Eq. (2), and then perform a feedback, g_m can be represented by using the following equation.

$$gm = \frac{I_w}{V_{GSW}} \tag{8}$$

Here, g_m has been nonlinearly taken into account. Z_{in} can be calculated by substituting in this resulting g_m for Eq. (1). The real part of Z_{in} is the negative resistance.

4. Simulation results

Figures 2 and 3 represent the I_C and I_D characteristics and calculated approximation results when the supplied voltage is 5V.

A ripple occurs when the polynomial approximation based on the current characteristic of a BJT is sharp. Therefore, the approximation result is separated from the theoretic value. In contrast, the MOS results were basically consistent.

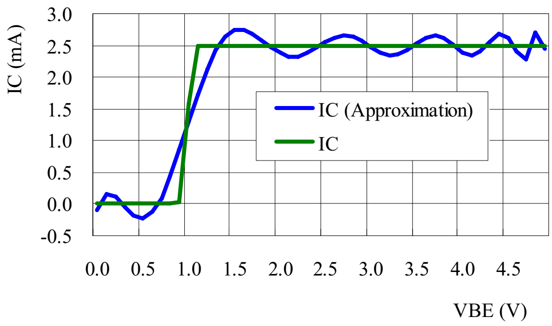

Fig. 2 $I_C - V_{BE}$ characteristics and approximation result of BJT

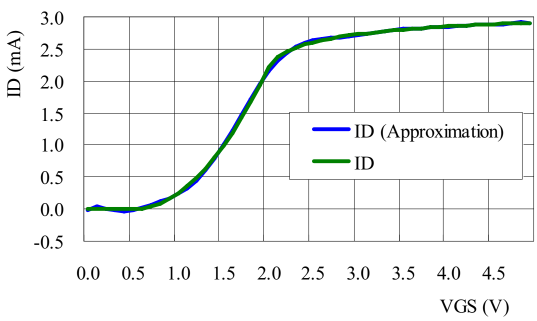

Fig. 3 $I_D - V_{GS}$ characteristics and approximation result of NMOS

I_w can be derived by substituting this approximation for Eq. (6). g_m can be calculated from Eq. (8). The negative resistance can be derived from by substituting the calculated g_m for Eq. (2). The negative resistance of BJT is much larger because the g_m of the BJT and CMOS are different.

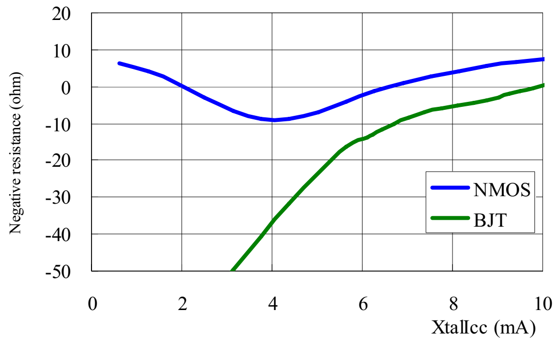

Fig. 4 Negative resistance characteristic of BJT and NMOS crystal oscillators

5. Conclusion

We analyzed the negative resistance of BJT and NMOS circuitry. The input and output characteristics of NMOS using a polynomial approximation are basically consistent.

The negative resistance of NMOS is smaller because the g_m is smaller, but it is obvious that the negative resistance calculation is simplistic based on the simulation. Our future work will be to compare these simulation results and the actual measurements taken from a NMOS oscillator.

References

[1]T.Kumazawa,N.takai "Low power-supply voltage equivalent MOSFET and its application. "ECT-02-81 2009.

[2]T.Adachi,M.Hirose and Y.Tsuzuki: "Computer Analysis of Colpitts Crystal Oscillator" Proc. of 39th Annual Frequency Control Symp. (1985) p. 178-182.

[3]T.Adachi,Y.Tuzuki"On Operating Characteristics and Design Considerartions Of Colpitts Crystal Oscillator Circuit"IEICE C-2 Vol J73-C-2 No3 p154-162(1990)

[4]Y.Tsuzuki , T.Adachi:"Formulation of Nonlinear Negative Resistance For Calculation of Start-Up Characteristics of Crystal Oscillators" Proc. Int. Frequency Control Symp. (1996) p. 710-713.

[5]Hanazawa,S.Koyama,Y,Watanabe,H.Sekimoto, "Approximate Analysis of Negative Resistance of a Quarts Oscillator with Frequency-Selective Function " IEICE . A-33(1996)