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Realization of Voltage Controlled Oscillator using Different Active Building Blocks

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Abstract—*This paper presents a realization of voltage controlled oscillators (VCO's) using different active building blocks. The voltage controlled oscillators based on an independent control of the frequency of oscillation and condition of oscillation by replacing the grounded and floating resistors with voltage controlled resistors. The frequency of oscillation for realized VCO's is directly proportional to the control voltage. The active blocks considered in this paper are current Feedback Operational Amplifier (CFOA), Differential Voltage Current Conveyers (DVCC), Differential Difference Complementary Current Conveyers (DDCCC) and Current Differencing Buffered Amplifier (CDBA).The simulation results are obtained for various active blocks based VCO's in P-Spice software tool.*

1. INTRODUCTION

The voltage controlled oscillators (VCO's) are an important building blocks in instrumentation, electronic and communication systems. It has a number of important applications such as its use as a critical feedback element in phase locked loops [1], VCO's are used in frequency modulated transmitters [13], the production of electronic music and to generate tones in synthesizers.

Different Active Blocks have their own attributes. In past oscillators are synthesized where frequency of oscillation and condition of oscillation are uncoupled, that means we can change the frequency without affecting the condition of oscillation. If we replace passive resistors with Voltage Controlled Resistors in such type of oscillators, we can implement the Voltage Controlled Oscillators.

In past various voltage controlled oscillators have been realized. In [2] VCO is implemented by replacing frequency determining resistor in single Resistance Controlled Oscillator (SRCO) using OPAMP ,with FET based resistor, working in range below pinch off value. In [3] the same method is applied to convert CFOA based SRCO to VCO. These VCOs do not follow the linear tuning laws that is frequency do not vary linearly with control voltage.

However if two analog multipliers(AM) are used appropriately in the oscillator configuration, to enable independent control of the oscillation frequency through an external control voltage V_c applied as the common multiplicative input to both the multipliers, this technique may give rise to linear tuning law. Based upon this idea various VCOs have been proposed in past [4-6]. Another systematic method known as state variable approach of synthesizing Linear VCOs was introduced in [7].

Thus, the method given in this paper for realizing the VCO is easier comparative to the other known methods.

2. LINEAR VOLTAGE CONTROLLED RESISTANCE

The voltage controlled resistance (as given in [8]) is shown in Fig. 1.

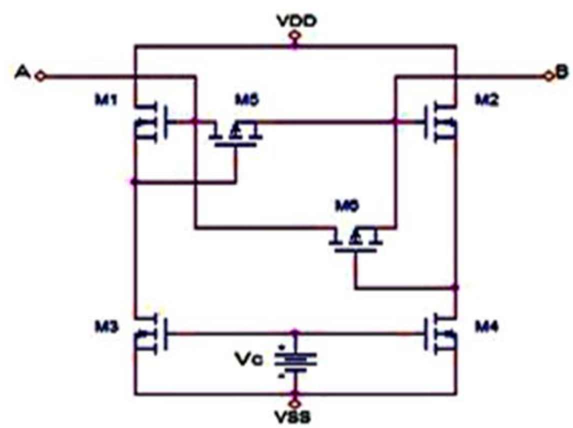


Fig. 1: CMOS Voltage Controlled Resistor.

In the circuit of Fig. 1 the first order nonlinearity of MOS is cancelled to implement linear voltage controlled resistor.

The drain current in triode region of p-MOS is given[15]

$$I_D = -\mu C_{ox}\frac{W}{L}\Big\{(V_G - V_B - V_{FB} - 2\varphi_F)(V_D - V_S) - \frac{1}{2}\left[(V_D - V_B)^2 - (V_S - V_B)^2\right] - \frac{2}{3}\gamma\left[(-V_D + V_B - 2\varphi_F)^{\frac{3}{2}} - (-V_S + V_B - 2\varphi_F)^{\frac{3}{2}}\right]\Big\} \quad (1)$$

Where V_G, V_S, V_D and V_B are the gate, source, drain and substrate voltages. W and L are gate width and length, μ is the effective mobility in the channel, C_{ox} is the oxide capacitance per unit area, V_{FB} is the flat band voltage, φ_F is the substrate Fermi potential and γ is body effect coefficient.

I_D is approximately linear with V_{DS}(V_{DS}=V_D-V_S)for small values of V_{DS} but these values are too small for various applications.The major nonlinerity comes with the square term in equation 1,these can be cancelled by setting

$$V_G = V_C + \frac{V_D+V_S}{2} \quad (2)$$

For this value of V_G equation 1 becomes as given below

$$I_D = -\mu C_{ox}\frac{W}{L}\left\{(V_C - V_{FB} - 2\varphi_F)V_{DS} - \frac{2}{3}\gamma\left[(-V_D + V_B - 2\varphi_F)^{\frac{3}{2}} - (-V_S + V_B - 2\varphi_F)^{\frac{3}{2}}\right]\right\} \quad (3)$$

Where V_T is the threshold voltage. For small values of γ (lighty doped substrate), I_D is approximately linear with V_{DS}, even for relatively larger values also. The required V_G (equation 2) can be obtained by the VCR(Fig. 1), if we consider the linear terms in taylor series expansion of equation 3 with respect to V_D and V_S ,it can be shown that the small signal resistance between A and B is.

$$R = \frac{1}{2\mu C_{ox}\frac{W}{L}(V_c - V_T)} \quad (4)$$

From the above expression we can see that the Resistance is inversely proportional to the applied voltage V_c. For proper linearity W/L of M_5 and M_6 should be matched.

The main advantage of the above VCR is that it can be used both in floating as well as in grounded form. To get the grounded resistor we simply ground one of the terminals.

From the Fig. we can see that resistance decreases almost linearly for a particular range of control voltage (V_c).Thus it may be used to convert a simple oscillator to a VCO.

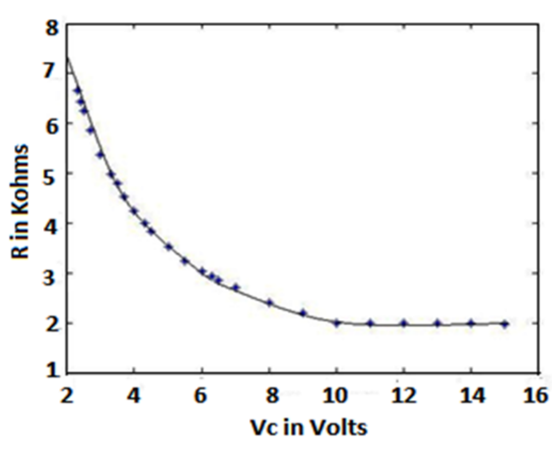


Fig. 2: Variation of R with V_c.

3. VOLTAGE CONTROLLED OSCILLATOR REALIZATION

3.1 VCO using CFOA

CFOA have attracted prominent attention in analog circuit design due to their two significant properties namely, the gain-bandwidth independence and very high slew rates together with their commercial availability as the self ICs from almost all leading IC manufactures. CFOA is four terminal building block and characterized by equation (5).

$$\begin{bmatrix} Iy \\ Vx \\ Iz \\ Vw \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} Vy \\ Ix \\ Vz \end{bmatrix} \quad (5)$$

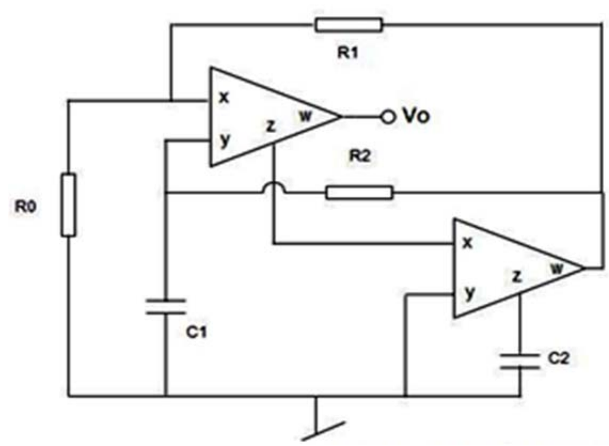


Fig. 3: CFOA based sinusoidal oscillator circuit

The CFOA based oscillator considered in this paper is shown in **Fig.** 3(as in [9]). The Condition of oscillation for **Fig.** 4 is obtained as shown below.

$$\frac{R_2}{R_1} = \frac{C_1}{C_2} \quad (6)$$

And, frequency of oscillation is obtained below.

$$f_o = \frac{1}{2\pi}\sqrt{\frac{1}{C_1C_2R_0R_2}} \quad (7)$$

Here, if we replace R_o, R_1 and R_2 with VCR then frequency of oscillation will be directly proportional to the control voltage V_c since all the resistors have same value as given in equation 4.

$$f_0 \propto (V_c - V_T) \quad (8)$$

and the condition of oscillation will become.

$$C_1 = C_2 \quad (9)$$

3.2 VCO Using DDCCC

DDCCC characteristic equation is given below

$$\begin{bmatrix} Vx \\ Iy1 \\ Iy2 \\ Iy3 \\ Iz1 \\ Iz2 \end{bmatrix} = \begin{bmatrix} 0 & 1 & -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} Ix \\ Vy1 \\ Vy2 \\ Vy3 \\ Vz1 \\ Vz2 \end{bmatrix} \quad (10)$$

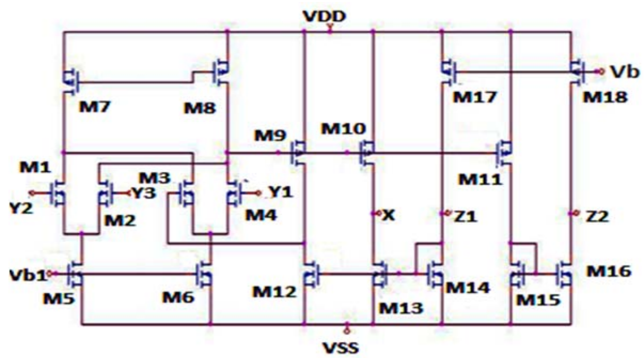


Fig. 4: DDCCC CMOS implementation

The Oscillator circuit using DDCC is given below (as in[10]).It is a current mode oscillator.

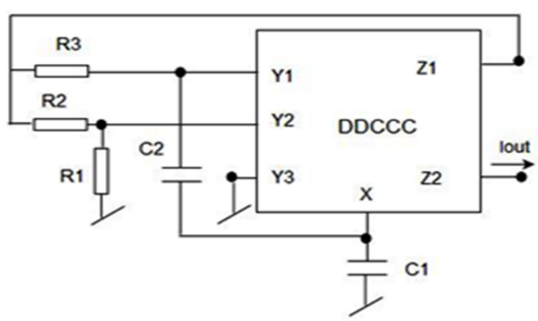


Fig. 5: DDCCC based sinusoidal oscillator.

Here Condition of Oscillation is:

$$\mathbf{2R_1C_2 = R_2C_1} \quad (11)$$

If we replace VCR in place of R_1, R_2 and R_3 then condition becomes

$$2C_2 = C_1 \quad (12)$$

And Frequency of Oscillation is:

$$f_o = \frac{1}{2\pi}\sqrt{\frac{1}{R_1R_3C_1C_2}} \quad (13)$$

The above oscillator is synthesized using genetic algorithm [14].Genetic algorithms are a class of algorithm inspired by natural evolution. The main advantage of genetic algorithm is that it is fast, design of oscillator using two active blocks and it does not impose any topological restrictions on oscillator circuit and explore the whole possible outcomes.

The above oscillator has many advantages such as minimum component count and canonicity. The realization required two capacitors and one active block.

3.3 VCO USING DVCC

DVCC is the extension to the second generation current conveyer (CCII). CCII has a disadvantage that only one of the input terminal has high input impedance (Y-terminal), thus it is less efficient in handling the differential signals. DVCC has an advantage that it can handle differential signals efficiently.

The characteristic equations are given below as

$$\begin{bmatrix} Vx \\ Iy1 \\ Iy2 \\ Iz1 \\ Iz2 \end{bmatrix} = \begin{bmatrix} 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} Ix \\ Vy1 \\ Vy2 \\ Vz1 \\ Vz2 \end{bmatrix} \quad (14)$$

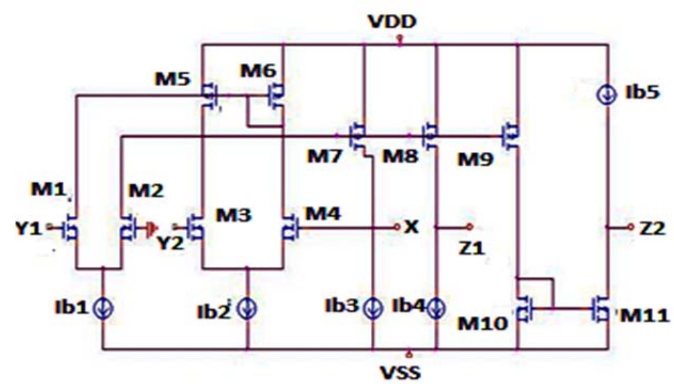


Fig. 6: CMOS implementation of DVCC.

The Oscillator using DVCC (as in[11]) is given below

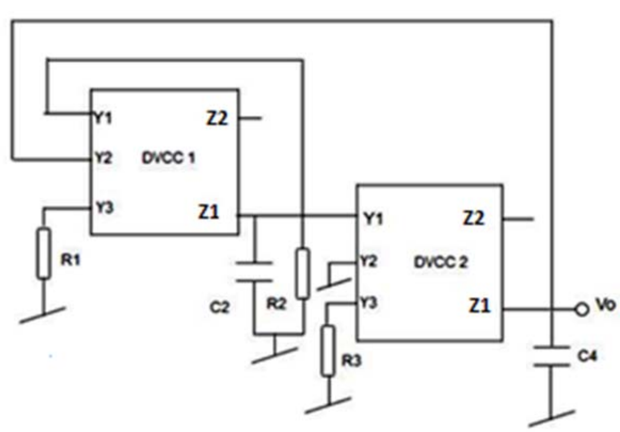


Fig. 7. DVCC based sinusoidal oscillator.

The given oscillator have many advantages such as the oscillation frequency has small active and passive sensitivities, it has all the grounded capacitors ,which is advatageous in integrated circuit manufacturing point of view,it has all the grounded resistors which has advantage for electronic tuning applications.

Frequency of oscillation is:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{C_2 C_4 R_1 R_3}} \qquad (15)$$

The condition of oscillation is:

$$R_2 = R_1 \qquad (16)$$

If we apply VCR in place of R_1,R_2 and R_3 condition of oscillation do not disturb for any value of V_c.

3.5 VCO USING CDBA

CDBA has various advantages. It is suitable for monolithic implementation with bipolar and CMOS technologies. Moreover it operates in current mode as well as in voltage mode. Hence, it has large dynamic range and quite wide bandwidth. CDBA can be implemented using two commercially available CFOAs i.e. AD844. Another advantage of CDBA oscillator is that it does not consist of input parasitic capacitance since its input terminals are internally grounded.

$$\begin{bmatrix} Iz \\ Vw \\ Vp \\ Vn \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} Vz \\ Iw \\ Ip \\ In \end{bmatrix} \qquad (17)$$

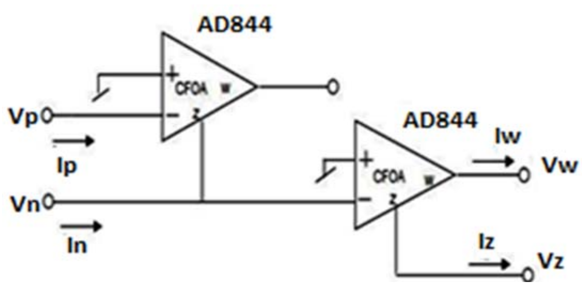


Fig. 8: Implementation of CDBA using commercially available CFOA.

CDBA oscillator is given (as in[12])

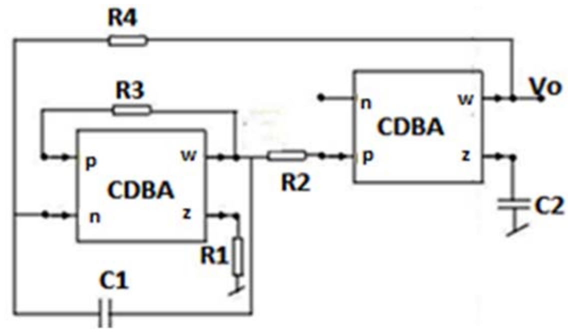


Fig. 9: CDBA based sinusoidal oscillator.

Condition of oscillation is:

$$R_1 \leq R_3 \qquad (18)$$

Frequency of oscillation is:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{C_1\, C_2 R_2 R_4}} \qquad (19)$$

Here we will use VCR in place of R_2 and R_4 and fix R_1 and R_3 such that the condition of oscillation of equation 18 is satisfied.

The main advantage of CDBA based oscillator as compared to CFOA and CCII arises from behavior of the input terminals. In CFOA and CCII there exist internal parasitic capacitances. Whereas the input capacitances do not exist in CDBA case because of the input terminals are internally grounded.

4. SIMULATION RESULTS

PSPICE simulation of the circuits is done. The CMOS implementation of the devices are shown in Fig. 4 and 6.The level 3 MOSFET parameters obtained through MOSIS for 1.2μm CMOS process have been used for DDCCC implementation(Fig. 4). The DC bias voltages are chosen as $V_{b1} = -2.458$V and V_b=1.485V. The DC supply voltages are $\pm$3.3V. The W/L ratios are shown in table1.

Table 1: Aspect Ratios for MOSFET's in Fig. 4.

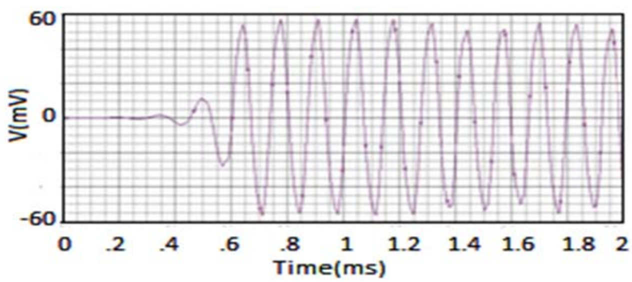
MOS Transistor	W/L(μm/μm)
M1,M2,M3,M4	7.2/4.8
M7,M8	39.6/4.8
M9,M10,M11,M17,M18	111.6/3.6
M5,M6,M12,M13,M14,M15,M16	144/4.8

For DVCC structure as shown in Fig. 6 device model parameters are taken from TMSC 0.35μm CMOS process through MOSIS. The DC supply voltage are $\pm$2.5V.All the bias currents are 60μA.The W/L ratios is shown in table 2.

Table 2: Aspect Ratios for MOSFET's in Fig. 6.

MOS Transistor	W/L(µm/µm)
M1,M2,M3,M4	7.2/4.8
M5,M6	200/10
M7,M8,M9	20/1
M10.M11	10/1

In CFOA oscillator (Fig. 3) the DC supply voltages are taken $\pm15\mathrm{V}$ and $\mathrm{C}_1 = 1\mathrm{nF}$ and $\mathrm{C}_2 = 0.98\mathrm{nF}$, if we apply VCR (Fig. 1) the sinusoidal outputs for V_c is shown in Fig. 13.



***f*₀=10.4KHz**

Fig. 10: CFOA VCO output for V_c=8V.

From the Fig. 11, we can see that frequency vary linearly with V_c for some range.

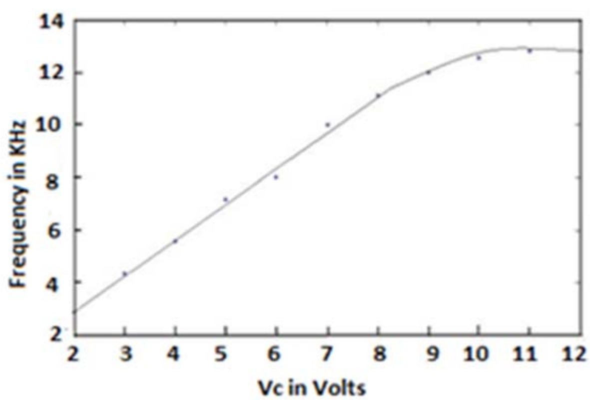
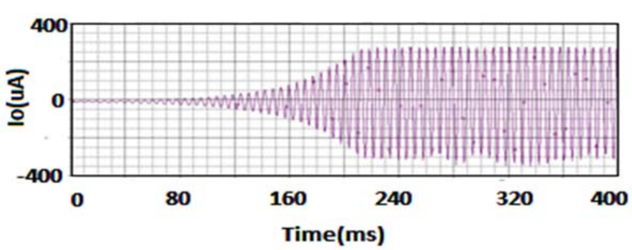


Fig. 11: Variation of frequency with V_c in CFOA VCO

Now we have applied VCR in DDCCC based oscillator (Fig. 5), the output for C_1=2pF and C_2=1pF is shown in Fig. 12.



f_0=1.7KHz

Fig. 12: DDCCC VCO output for V_c=4V.

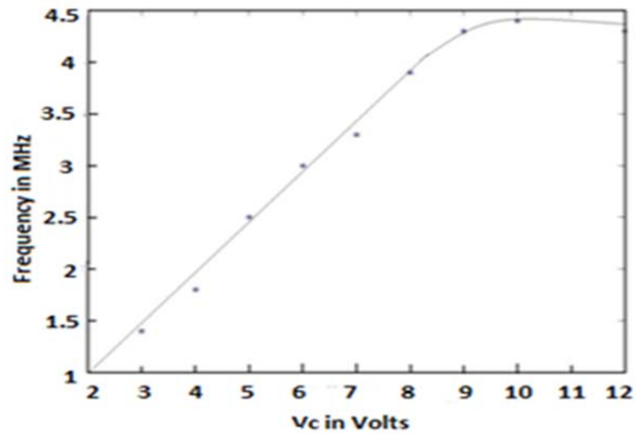
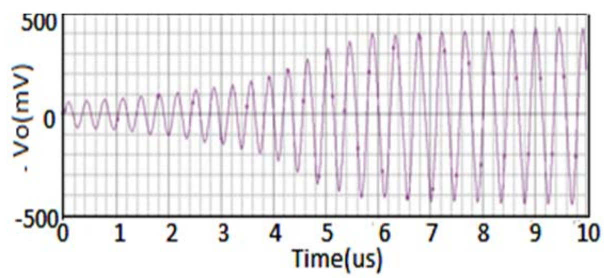


Fig. 13: Variation of frequency with V_c in DDCCC VCO

If we apply VCR in DVCC oscillator (Fig. 7) output is shown in Fig. 14.Here component values are C_2=C_4=10pF.



f_0=1.8MHz

Fig. 14: DVCC VCO output for V_c=4V.

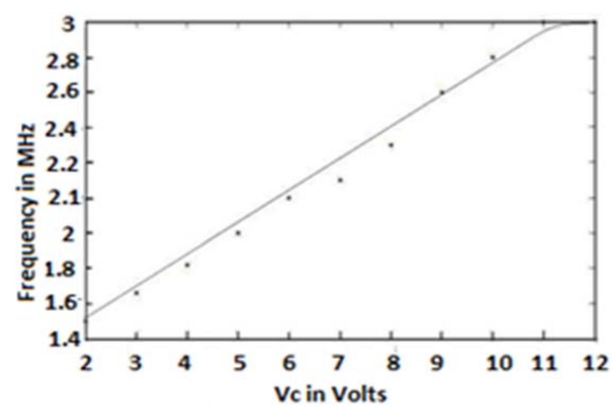
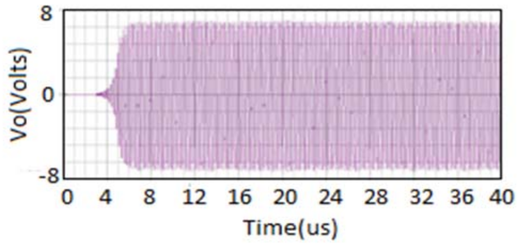


Fig. 15: Variation of frequency with V_c in DVCC VCO

The VCR technique is applied in CDBA oscillator of Fig. 9 and the output is shown in Fig. 16.Here the component values as R_1=5k, R_3=4k and C_1=C_2=100pF.



f_0=3.12MHz

Fig. 16: CDBA VCO output for V_c=8V.

Variation of frequency with V_c in CDBA VCO is shown

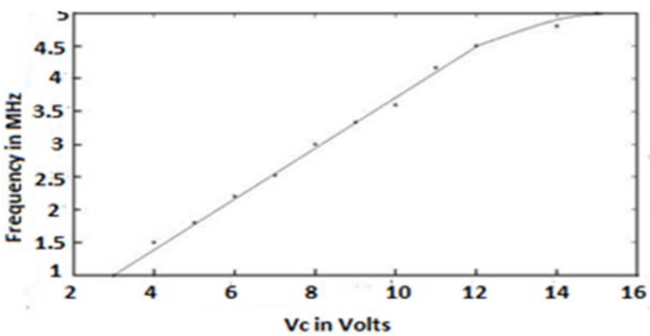


Fig. 17: Variation of frequency with V_c in CDBA VCO

5. CONCLUSION REMARKS

In this paper, we have converted a simple oscillator into a Voltage Controlled Oscillator by using CMOS Voltage Controlled Resistor (VCR) in place of passive resistors such that the condition of oscillation does not get disturbed. If we are using CMOS based active device than another advantage that we can get by using CMOS VCR is the implementation of fully integrated analogue MOS circuits.

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