FREQUENCY TUNING LOOP FOR VCOS

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Abstract–For a Voltage Controlled Oscillator (VCO) the oscillating frequency is controlled by an external input. The relationship between the oscillating frequency and the input control voltage is, in most cases, expected to be linear and independent of parasitics, process parameters, temperature, and other non–idealitites. In this paper we introduce a frequency tuning circuit for VCOs so that the final relationship between oscillating frequency and input control voltage is fixed and independent of the previous mentioned non–idealities. This tuning loop is applied to an OTA–C sinusoidal VCO. Such an oscillator has an output frequency–input voltage relationship that depends on temperature, process parameters, and even amplitude of the oscillations. It is shown that by adding the tuning loop all these non–ideal dependences will be minimized.

I. INTRODUCTION

Voltage Controlled Oscillators are key components in many signal processing and communication systems [1–3], and are also used for the tuning of monolithic filters [4–9]. They also may be used for instrumentation applications [2]. In many cases it is necessary that the relationship between the actual oscillating frequency of the VCO and its input control voltage is very precise and does not change with temperature, process parameters or parasitics.

Consider a certain VCO (sinusoidal, triangular, or square wave,) that has an "uncontrolled" input voltage–output frequency characteristics. We will show that by adding the frequency tuning loop described in this paper the input voltage–output frequency relationship can be made very linear and completely independent of secondary parameters (temperature, amplitude, parasitics, and process parameters) within the tuning range of the original VCO.

The tuning loop proposed in this paper is valid for any type of VCO. We are going to verify its operation by applying it to an OTA–C sinusoidal VCO [10].

Sinusoidal OTA–C VCOs have a nonlinear input voltage–output frequency relationship that depends on process parameters, temperature, parasitic components and even amplitude of the oscillations. By adding the proposed tuning loop we will show that this relationship will become linear and independent of the previously mentioned parameters.

II. THE FREQUENCY TUNING LOOP

Figure 1 shows the basic structure of the frequency tuning loop [11,12].

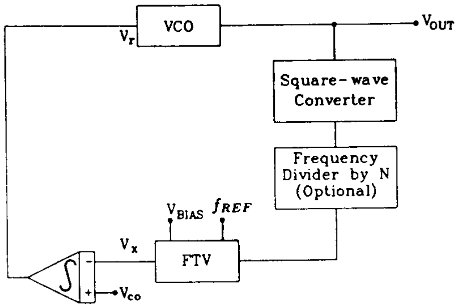

Fig. 1. Block Diagram of Frequency Control Loop.

The output of the oscillator (if not square) is converted to a square wave, divided by N (optional) and applied to a Frequency–to–Voltage (FTV) converter. Usually the maximum operating frequency of an oscillator is higher than the maximum possible frequency in a Frequency–to–Voltage Convertor. For this reason the inclusion of the frequency divider in Fig. 1 is many times mandatory.

As we will see in the next section, the FTV converter is a device such that if f_{in} is the frequency of its input signal, its output voltage will be given by

$$V_x = n\, V_{BIAS} \frac{f_{in}}{f_{REF}} \qquad (1)$$

Where n is a positive integer, V_{BIAS} is a reference voltage and f_{REF} the frequency of a reference square wave

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signal (like a crystal oscillator). If f is the output frequency of the VCO and a frequency divider is used with a rate N, then $f_{in} = f/N$. If β^{-1} is the time constant of the integrator, its output voltage will be given by:

$$\dot{V}_r = \beta(V_{co} - V_x) \qquad (2)$$

On the other hand, for a CMOS OTA–C sinusoidal oscillator we have [13],

$$f = \frac{1}{2\pi}\frac{g_m}{C} = \frac{K}{2\pi C}(V_r - V_{th}) \qquad (3)$$

where K and V_{th} are given by the topology and transistor geometries of the OTAs used as well as by the process parameters.

Solving equations (1), (2) and (3) yields,

$$\dot{f} = \frac{K\beta}{2\pi C}\left(V_{co} - V_{BIAS}\frac{nf}{Nf_{REF}}\right) \qquad (4)$$

which has a stable stationary point $\left(\frac{d\dot{f}}{df} < 0\right)$ characterized by

$$f = f_{REF}\frac{NV_{co}}{nV_{BIAS}} \qquad (5)$$

The relation between f (output frequency) and V_{co} (input voltage) is shown in Fig. 2. Note that it is linear and it depends only on f_{REF}, V_{BIAS}, n and N.

In the next Section we will give the implementation details of the FTV converter, which is the key component of the frequency tuning loop.

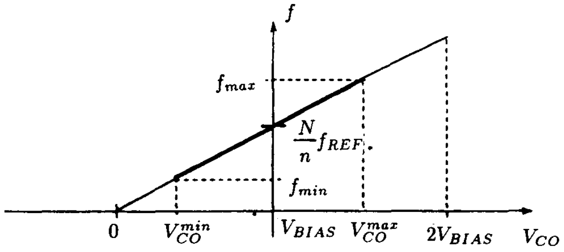

Fig. 2. Frequency vs control voltage relationship for V_{co} with frequency tuning loop.

III. The FTV Converter

Consider the circuit of Fig. 3. It contains a monostable that produces a pulse of duration $t_o = \frac{1}{2f_{REF}}$. During this pulse, capacitor C is charged by a current $g_o\,(2nV_{BIAS} - V_x)$. The rest of the time it is discharged by g_oV_x. The waveform that results at the capacitor $u(t)$ is shown in Fig. 4. For each cycle of $u(t)$, $V_x(t)$ is the peak value of $u(t)$ of the previous cycle. Two consecutive peak values are related by

$$V_x(t+nT) = V_x(t) - \frac{g_o}{C}V_x(NT - t_o) + \frac{g_o}{C}(2nV_{BIAS} - V_x)t_o \qquad (6)$$

where $T = 1/f$. If f is constant and the FTV converter reaches its steady state, then $V_x(t + NT) = V_x(t)$, i.e.,

$$V_x = V_{BIAS}\frac{nf}{Nf_{REF}} \qquad (7)$$

A stability condition for the steady state can be obtained by writing (6) in the Z–domain and making the poles to be inside the unity circle. The resulting condition is [12],

$$f > \frac{Ng_o}{2C} \qquad (8)$$

A convenient IC implementation for this FTV converter is shown in Fig. 5. To improve the time response, the switch of Fig. 3 has been replaced by a differential pair and current mirrors. The current sources are implemented with linearized OTAs.

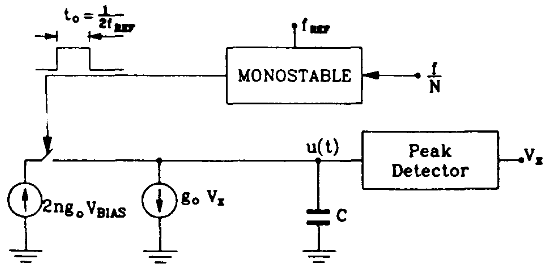

Fig. 3. Frequency–to–Voltage Converter

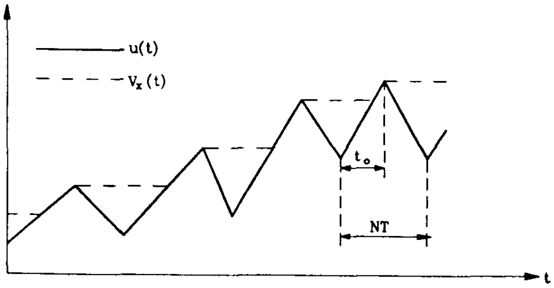

Fig. 4. Time waveforms of $u(f)$ inside the FTV Converter, and of $V_X(t)$, its output.

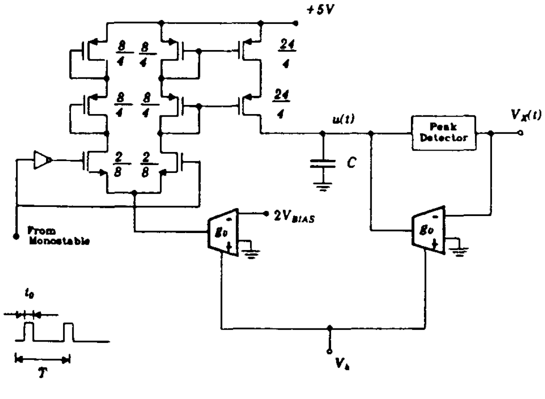

Fig. 5. CMOS Circuit Implementation of FTV Converter

The monostable has to provide a pulse of duration $t_o = 1/2f_{REF}$. Such a circuit is shown in Fig. 6. The duration of the output pulse t_o is given by the time it takes to charge capacitor C_1 from $0V$ to V_{REF} by the current I_{REF}. V_{REF} is given by the voltage to which C_2 is charged, starting at $0V$ by a current I_{REF} during a time $t_o = 1/2f_{REF}$. Therefore, if the two circuits enclosed by broken lines in Fig. 6 are perfectly matched, the duration of the monostable output pulse will be $t_o = 1/2f_{REF}$, independent of I_{REF} and $C_1 = C_2 = C$. If there is a mismatch between the two circuits the width of the monostable output pulse will not be equal to half the period of reference signal f_{REF}. However, besides this, the operation and characteristics of the tuning loop still remain basically invariant.

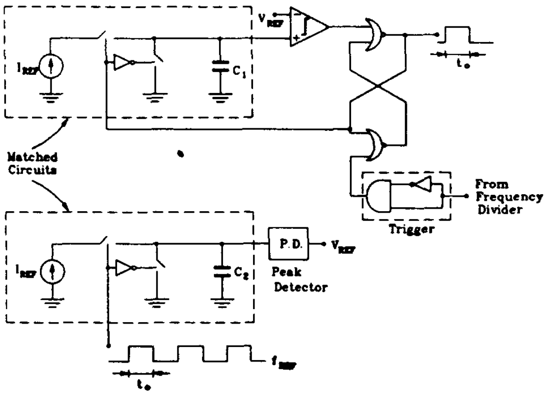

Fig. 6. Block Diagram of Monostable with Output Pulse Width Controlled by an External Square Wave Signal of Precise Frequency.

IV. EXPERIMENTAL RESULTS

In order to test the proposed frequency tuning loop strategy we used a sinusoidal OTA-C oscillator [10,12]. Its frequency dependence is shown in Fig. 7. Note that the relationship between output frequency and input voltage (Bias Voltage) is nonlinear and changes with the amplitude of the oscillations.

A discrete frequency tuning loop was implemented around the previous CMOS OTA-C oscillator. Since the output frequency goes over 13MHz, a fast comparator (CM710C) was used to convert the sinusoid to a square wave signal. For the monostable a conventional 555 timer was used. In this case, the width of its output pulse is not controlled by an external frequency reference, but by a precise RC constant. Also, since this circuit has very bad time response (propagation times are around $100ns$ the output of the oscillator had to be divided by 32. The resulting output frequency-input voltage relationship of the VCO with frequency tuning loop is shown in Fig. 8. This characteristic is the same for different values of the oscillating amplitudes, for different temperatures and for different IC chips. At this time we do not have available a complete IC prototype to quantify the degree of linearity, which is highly dependent on the implementation.

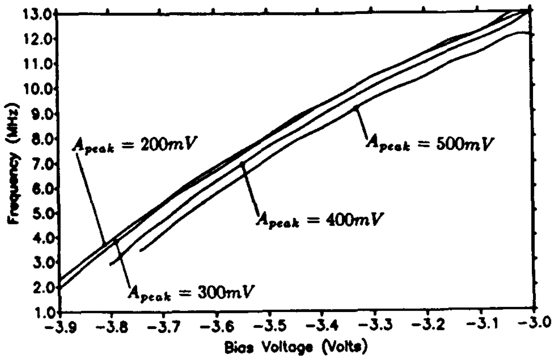

Fig. 7. Frequency vs Bias Voltage for sinusoidal OTA-C Oscillator without frequency tuning loop.

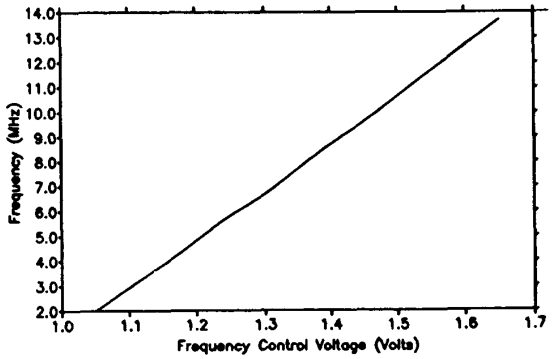

Fig. 8. Measured Oscillation Frequency vs Frequency Control Voltage of VCO with Frequency Tuning Loop.

V. CONCLUSIONS

A frequency tuning loop for VCOs is presented that compensates for temperature, process parameters, amplitude, and parasitics influence in the original output frequency-input voltage relationship. This tuning loop can be applied to any type of VCO. Its viability has been demonstrated, by applying it to a sinusoidal OTA-C VCO. The tuning loop was constructed using a breadboard prototype, but it can be integrated together with the oscillator in the same IC die [14].

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