A Users Guide to COPS™ Oscillator Operation

National Semiconductor
Application Note 326
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The following discussion is an overview of the COPS oscillator circuits meant to give the reader a working knowledge of the circuits. Although the descriptions are very general and light on detail; a background in complex frequency analysis is necessary. For additional information the references cited should be consulted as well as the many works on oscillator theory.

There are 2 basic circuits from which all of the COPS oscillator options are provided. (See option lists in individual data sheets.) The first and simplest in description is the astable one shot of *Figure 1* which gives us our RC oscillator option. A1 and A2 are inverters with A1 possessing a Schmitt trigger input. T1 is a large N channel enhancement MOS FET. Operation with the external R-C shown is as follows. Assuming C is initially discharged the CKI pin is low forcing T1 off. As C charges through R the trigger point of A1 is eventually reached at which time T1 is turned on discharging C and beginning a new cycle. Although almost any combination of R-C could be chosen, we would ideally like to have as short a discharge time as possible thereby eliminating the high variability in T1 drain current from device to device as a timing factor. For this reason R is chosen very large and C very small. This choice also leads to minimum R-C power dissipation. For the CKI Schmitt trigger clock input option the T1 MOS FET is merely mask disabled from the oscillator circuit.

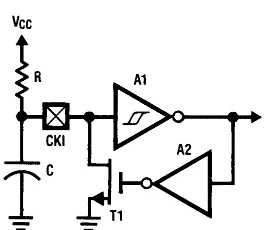

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FIGURE 1. R-C Oscillator

The second oscillator circuit is the classic phase shift oscillator depicted in *Figure 2*. Found not only on COPS but on most other microprocessor circuits it is the simplest oscillator in terms of component complexity but the most difficult to analyze.

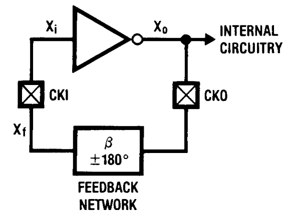

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FIGURE 2. Phase Shift Oscillator

The conditions under which the circuit will oscillate are described by the Barkhausen Criterion which states that oscillation will occur at the frequency for which the total loop phase shift from x_i to x_f is 0° or a multiple of 360° (i. e., x_f is identical to x_i). In addition the total loop gain must be $>$ 1 to insure self propagation. The inverting amplifier shown between x_i and x_o provides 180° of phase shift thus leaving the feedback network to supply the other ±180°. The feedback network can be comprised of active or passive components but highly effective oscillators are possible using only passive reactive components and the general configuration of *Figure 3*.

If you work out the feedback loop equations for *Figure 3* it can be shown that in order to achieve ±180° phase shift:

$$X1 + X2 + X3 = 0 \quad (1)$$

X1 and X2 must both be inductors or capacitors (2)

therefore X3 is inductive if X1 is capacitive and vice versa

if X1 and X2 are capacitors it is a Colpitts Oscillator

X1 and X2 are inductors it is a Hartley Oscillator

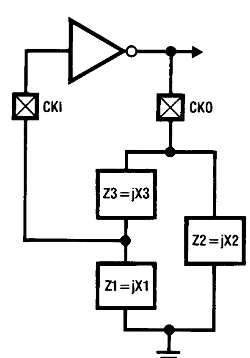

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FIGURE 3. Typical Feedback Configuration

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The Colpitts configuration is commonly shown in microprocessor oscillator circuits (*Figure 5*) with the inductive X3 replaced by a crystal for reasons we shall soon see. The equivalent electrical model of a crystal is shown in *Figure 4b* and a plot of its Reactance versus Frequency shown in *Figure 4c*. R-L-C represent the electro-mechanical properties of the crystal and C_o the electrode capacitance. There are 2 important points on the reactance curve labeled f_a and f_b.

At $f_a = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$

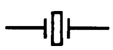
the crystal is at series resonance with L and C canceling each other out leaving only a nonreactive R for 0 phase shift. This mode of operation is important in oscillator circuits where a non-inverting amplifier is used and 0° phase shift must be preserved.

At $f_b = \frac{1}{2\pi}\sqrt{\frac{1}{LC} + \frac{1}{LC_C}}$

which is just a little higher than f_a the crystal is at parallel resonance and appears very inductive or capacitive. Note that the cyrstal will only appear inductive between f_a and f_b and that it becomes highly inductive very quickly. In addition f_b is only a fraction of a percent higher than f_a. Therefore the only time that the crystal will satisfy the $X3 = -(X1 + X2)$ condition in the Colpitts configuration of *Figure 5* is when the circuit is oscillating between f_a and f_b. The exact frequency will be the one which gives an inductive reactance large enough to cancel out:

$$X1 + X2 = \frac{1}{\omega C1} + \frac{1}{\omega C2} = \frac{1}{\omega}\left[\frac{1}{C1} + \frac{1}{C2}\right] = \frac{1}{2\pi f}\left[\frac{1}{C_L}\right]$$

Therefore by varying C1 or C2 we can trim slightly the oscillator frequency.



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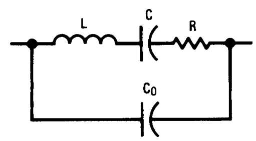
a. Circuit Symbol



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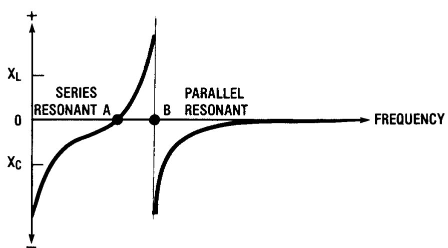
b. Electrical Equivalent



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c. Reactance Versus Frequency
FIGURE 4. Quartz Crystal

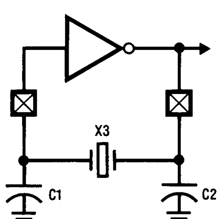

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FIGURE 5. Colpitts Oscillator

The Q of a circuit is often bounced around in comparing different circuits and can be viewed graphically here as the slope of the reactance curve between f_a and f_b. Obviously the steeper the curve the smaller the variation in f necessary to restore the Barkhausen Phase Shift Criterion. In addition a lower Q (more R) means that the reactance curve won't peak as high at f_b, necessitating a smaller $X1 + X2$. When selecting crystals the user should be aware that the frequency stamped on the cans are for either parallel or series resonance, which, although very close, may matter significantly in the particular application.

An actual MOS circuit implementation of *Figure 5* is shown in *Figure 6*. It consists of a MOS inverter with depletion load and the crystal π network just presented. External to the COPS chips are the R_f and R_g resistors. R_f provides bias to the MOS inverter gate $V_g = V_o$. Since the gate draws no current R_f can be very large (MΩ) and should be, since we do not wish it to interact with the crystal network. R_g increases the output resistance of the inverter and keeps the crystal from being over driven.

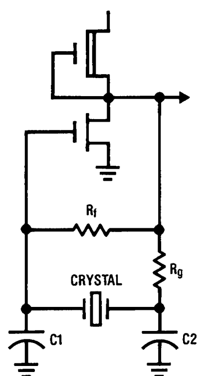

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FIGURE 6. MOS Oscillator

Of course the feedback network doesn't have to have the configuration of *Figure 3* and can be anything so long as the Barkhausen Phase Shift Criterion is satisfied. One popular configuration is shown in *Figure 7* where the phase shift will be 180°

$$\text{at } f = \frac{1}{(2\pi RC\sqrt{6})}$$

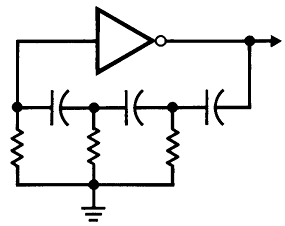

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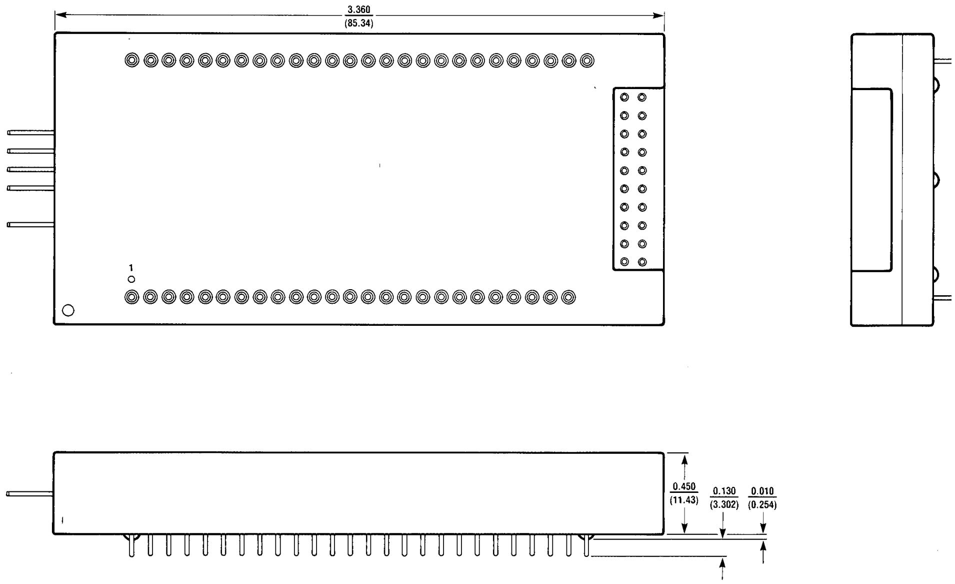
FIGURE 7. R-C Phase Shift Oscillator

REFERENCES

1. Crystal/INS8048 Oscillator, AN-296, March 1982, National Semiconductor
2. Oscillator Characteristics of COPS Microcontrollers, CN-5, Feb. 1981, National Semiconductor
3. Integrated Electronics, Chapter 14, Millman and Halkias 1972
4. Handbook of Electronics Calculations, Chapter 9, Kaufman and Seidman 1979
5. 1982 COPS Microcontroller Databook, National Semiconductor



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