A Users Guide to COPS™ Oscillator Operation

National Semiconductor
Application Note 326
Jim Murashige
April 1983

A Users Guide to COPS Oscillator Operation

AN-326

TL/DD/5139

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

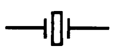
the crystal is at series resonance with L and C canceling each other out leaving only a nonreactive R for 0 phase shift. This mode of operation is important in oscillator circuits where a non-inverting amplifier is used and 0° phase shift must be preserved.

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:

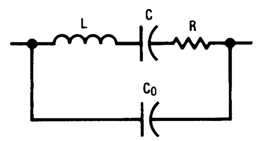
$$X1 + X2 = \frac{1}{\omega C1} + \frac{1}{\omega C2} = \frac{1}{\omega}\left[\frac{1}{C1} + \frac{1}{C2}\right] = \frac{1}{2\pi f}\left[\frac{1}{C_L}\right]$$

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



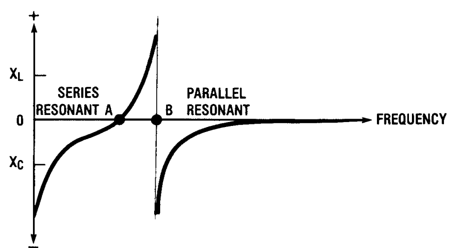
TL/DD/5139-4

a. Circuit Symbol



TL/DD/5139-5

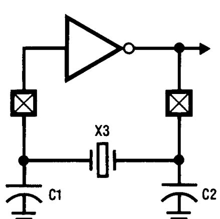
b. Electrical Equivalent



TL/DD/5139-6

c. Reactance Versus Frequency

FIGURE 4. Quartz Crystal

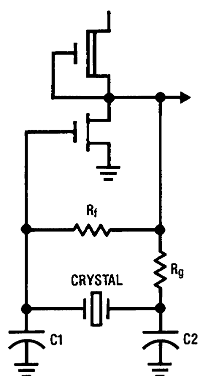


TL/DD/5139-7

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.

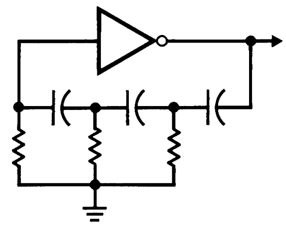


TL/DD/5139-8

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°

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



TL/DD/5139-9

FIGURE 7. R-C Phase Shift Oscillator

REFERENCES

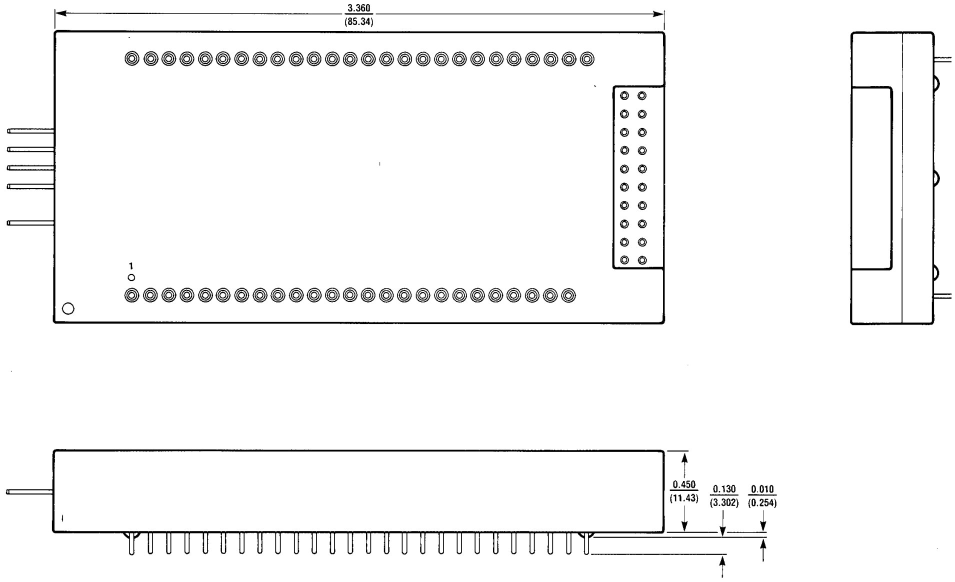
1. Crystal/INS8048 Oscillator, AN-296, March 1982, National Semiconductor

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



TL/DD/5139-10

National Semiconductor Corporation
1111 West Bardin Road
Arlington, TX 76017
Tel: 1(800) 272-9959
Fax: 1(800) 737-7018

National Semiconductor Europe
Fax: (+49) 0-180-530 85 86
Email: cnjwge@tevm2.nsc.com
Deutsch Tel: (+49) 0-180-530 85 85
English Tel: (+49) 0-180-532 78 32
Français Tel: (+49) 0-180-532 93 58
Italiano Tel: (+49) 0-180-534 16 80

National Semiconductor Hong Kong Ltd.
13th Floor, Straight Block,
Ocean Centre, 5 Canton Rd.
Tsimshatsui, Kowloon
Hong Kong
Tel: (852) 2737-1600
Fax: (852) 2736-9960

National Semiconductor Japan Ltd.
Tel: 81-043-299-2309
Fax: 81-043-299-2408