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Application Note

CRYSTAL SWITCHING METHODS FOR MC12060/MC12061 OSCILLATORS

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This report discusses methods of using diodes to select series resonant crystals electronically. Circuit designs suitable for use with crystal frequencies from 100 kHz to 20 MHz are developed with emphasis being placed on minimizing frequency pulling. Although developed for use with the MC12060 and MC12061 integrated circuit crystal oscillators, the techniques will, in general, be useful in any application where it is desired to electronically select one out of a group of crystals with a minimum of disturbance to the series resonant frequency of the selected crystal.

MOTOROLA Semiconductor Products Inc.

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INTRODUCTION

Crystal switching can be achieved electronically for the MC12060 and MC12061 crystal oscillator integrated circuits by utilizing diodes as RF switches. The switching is controlled by applying a forward bias to the diode associated with the desired crystal and applying a reverse bias to the remaining diodes related to the unselected crystals.

In addition to functioning with the MC12060/MC12061 IC's, the switching circuit designs described here can also be used in other applications where it is desired to electronically switch series-resonant crystals with a minimum of frequency pulling.

Advantages to this switching scheme include the following:

1. Eliminates the need to run high frequency signals through a mechanical switch;
2. Permits switching crystals from a remote position with a minimum of disturbance to the oscillator;
3. Minimizes RF radiation;
4. Adapts easily to electronic scanning methods;
5. Operates from a single polarity, low voltage supply (5.0 volts).

GENERAL

The MC12060 and MC12061 crystal oscillators are specified for operating frequency ranges of 100 kHz to 2.0 MHz, and 2.0 MHz to 20 MHz respectively. Their outputs consist of a single-ended TTL signal, plus complementary sine wave and ECL signals. The sine wave outputs are capable of driving an ac load of 50 ohms at 500 mVp-p (typical) when an external resistor is used to increase the current in the emitter follower output. The ECL and TTL outputs are capable of driving five and ten gate loads respectively.

Series resonant crystals connected between pins 5 and 6 are required for use with these oscillators. The total effective ac series resistance (crystal series resonance resistance plus any additional resistance contributed by switching components) between these pins must be less than 4 k ohms for the MC12060, and less than 155 ohms for the MC12061.

For additional information on these IC's, see the device data sheet and Engineering Bulletins EB-58 and EB-59.

Schematic diagrams for the MC12060 and MC12061 crystal switching circuits are given in Figures 1 and 2 respectively. The same basic technique is employed for each IC except that an additional diode-resistor pair (D6, R18 through D10, R22) is incorporated for the MC12060 to offset its greater sensitivity to ac loading.

The MPN3401 PIN diode and the MSD7000 PN junction diode are used to switch the crystals. The MSD7000 was selected for use with the MC12060 oscillator because of its low capacitance (1.5 pF max. for V_R = 0 volts). It is also an economical dual diode in the configuration needed for this circuit.

The MPN3401 is used with the MC12061 circuit because it offers a large off-to-on impedance ratio for low dc bias currents at frequencies within the range of the MC12061.

DC BIAS REQUIREMENTS

Forward bias for the desired crystal selecting diode (D1, D2, D3, D4, or D5) is applied by setting the five position switch. The bias current is primarily set by R17 and R2 (R4, R6, R8, and R10 have identical functions to R2 when they are switched-in). The four remaining sets of bias resistors, corresponding to the unselected crystals, add a smaller amount of current to the forward-biased diode. The total forward bias current, I_D, can be described by the formulas:

$$I_D = \frac{V - 2V_D}{R2 + \left\{R17 \,||\, \left(\frac{R3 + R4 + R19}{4}\right)\right\}} - \left(\frac{V_D}{R1}\right) \quad \text{(For MC12060);}$$

$$I_D = \frac{V - V_D}{R2 + \left\{R17 \,||\, \left(\frac{R3 + R4 + R13}{4}\right)\right\}} - \left(\frac{V_D}{R1}\right) \quad \text{(For MC12061).}$$

While one diode (or one diode pair in the case of Figure 1) is always forward biased, the remaining diodes are reverse biased to minimize their capacitance. This is accomplished with a single polarity supply by using pullup resistors (R12, R13, R14, R15, and R16) from the positive potential to each switch terminal. Therefore, the cathodes of the diodes corresponding to the unselected crystals are pulled up to approximately the supply voltage. Since one diode (or diode pair) is always selected, current is flowing through R17 continuously, causing a voltage drop. Therefore, the anodes of the unselected diodes will be negative with respect to their cathodes. When using a 5.0 volt supply, this reverse bias will be 1.6 volts for the MC12060 and 1.2 volts for the MC12061 crystal switching array.

ADDITIONAL CONSIDERATIONS

A sufficient amount of forward current through the diode selecting the desired crystal is required to insure a low value for diode resistance R_D (see Figure 3). This is important for two reasons:

1. To minimize the effects of diode capacity on the crystal's natural series resonant frequency.
2. To minimize the total effective external resistance between pins 5 and 6 of the integrated circuit.

From Figure 3 it is apparent that as R_D is made smaller, X_S is decreased and C_S is increased. A large value for

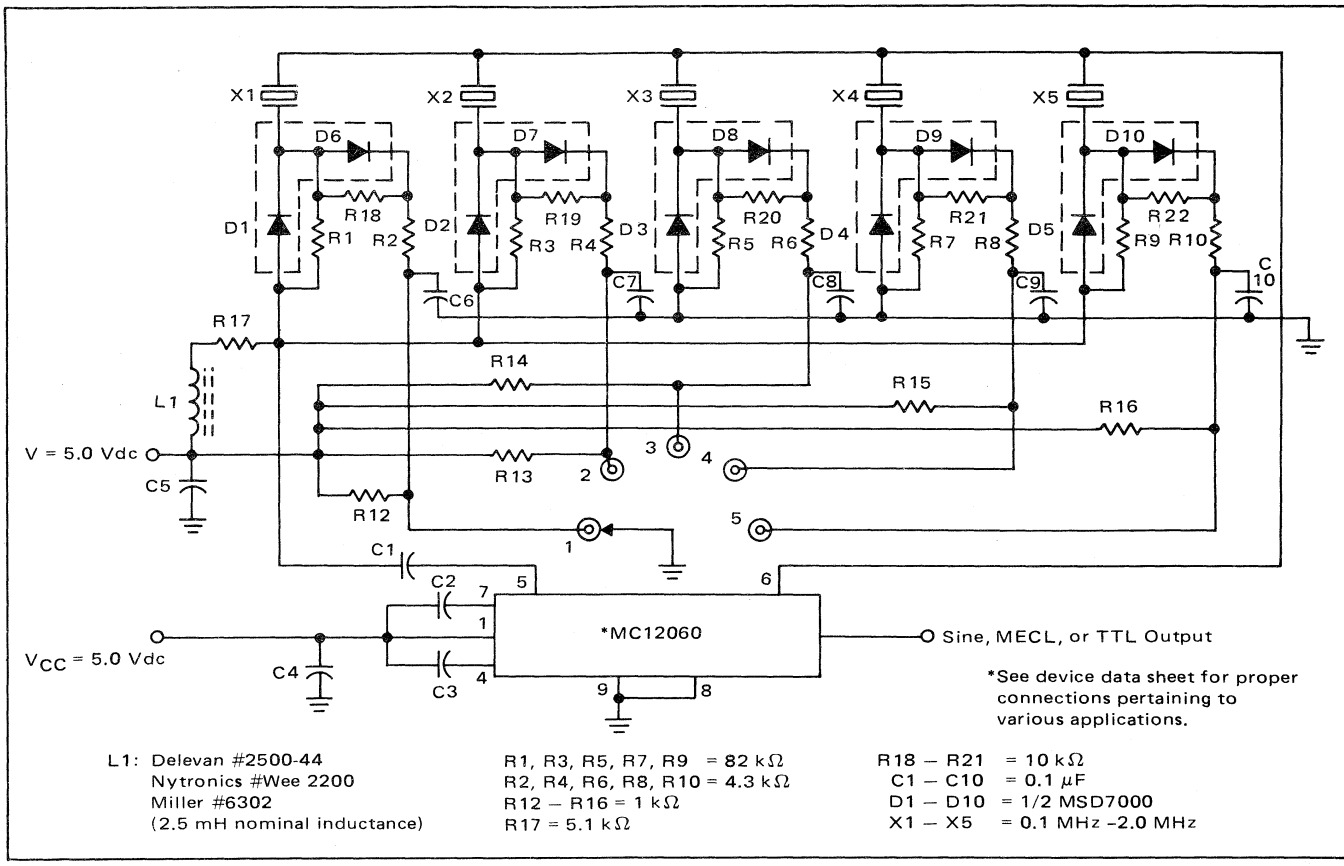

FIGURE 1 – Schematic Diagram of Crystal Switching for the MC12060

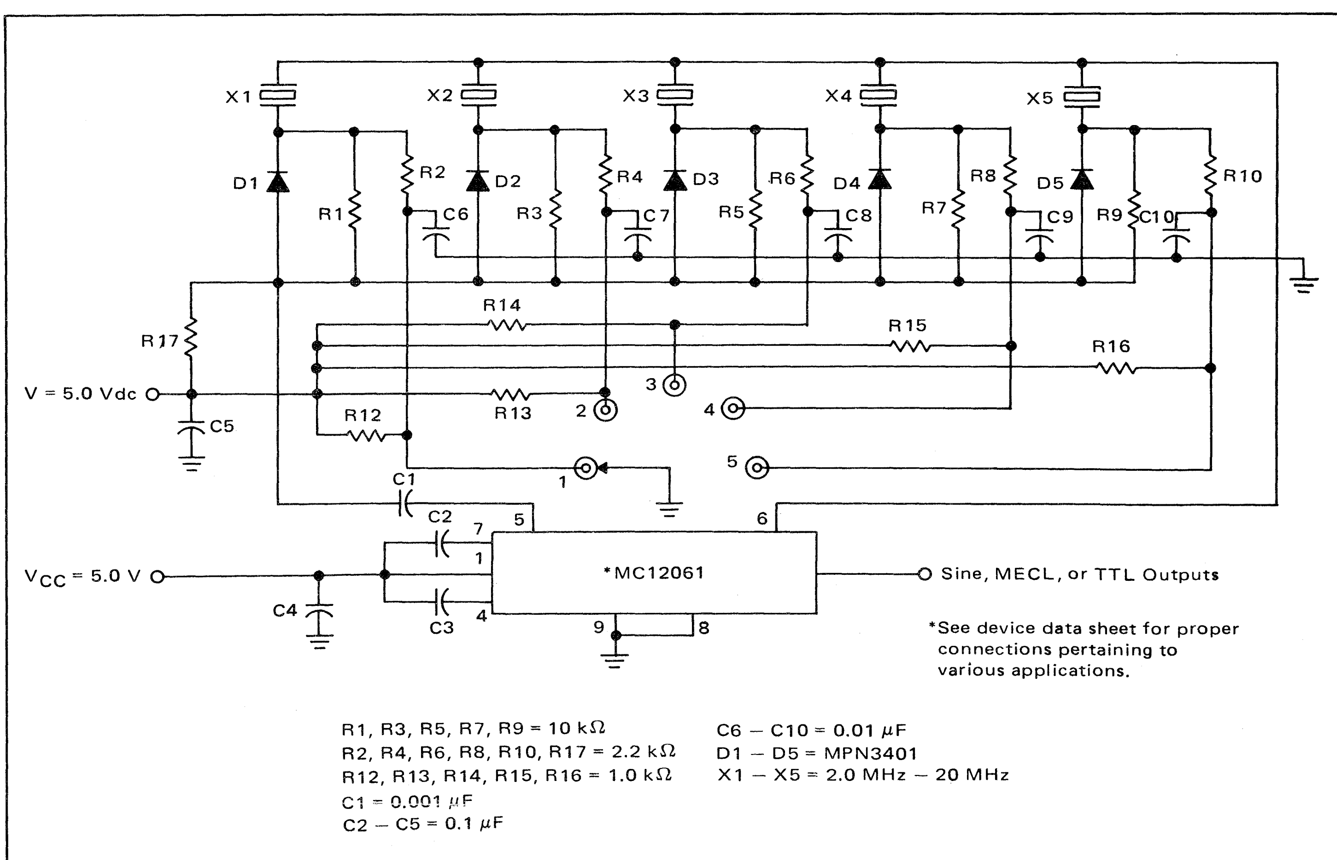

FIGURE 2 – Schematic Diagram of Crystal Switching for the MC12061

Loading and therefore frequency pulling will be greater for higher frequency crystals and will increase as the total number of crystals to be switched is increased. However, by using the switching techniques shown in Figures 1 and 2, any frequency pulling in addition to that for a single crystal connected directly to pins 5 and 6 (i.e. pulling caused by the ICs alone) is negligible below approximately 1 MHz for the MC12060 and 15 MHz for the MC12061. Measurements of this additional pulling are summarized in Table I. Typical frequency pulling values attributable to the ICs themselves are given in Table II. In this case the devices are operating with a single crystal connected directly to pins 5 and 6 with no crystal switching circuits. The Table II values have been taken as a reference in establishing the pulling (noted in Table I) caused by the switching networks. When using the crystal switching circuits, complete pulling from the crystal's series resonant frequency is obtained by algebraically adding the respective values in Tables I and II. For example, absolute crystal pulling for the five crystal switching system when selecting the nominal 1.0 MHz crystal is approximately -0.0040 + 0.0031 = -0.0009 percent. Similarly, absolute pulling for the 8.0 MHz crystal becomes -0.004 +0.0001 = -0.0039 percent. Pulling effects of the switching circuits when selecting the 0.2 MHz crystal offset pulling caused by the IC to give approximately zero absolute crystal pull.

When desirable, a trim capacitor can be added in series with the crystals and adjusted to pull the oscillator up in frequency.

Several options are possible to reduce ac loading for both the MC12060 and MC12061 crystal switching circuits. Using a higher voltage supply for the bias networks will allow larger values of bias resistors to be used at the same diode current, resulting in reduced loading. Also, RF decoupling chokes may be added between resistors R2, R4, R6, R8, and R10 and capacitors C6 through C10. Where frequency pulling is not as critical, L1 in Figure 1 may be eliminated. These options are left to the discretion of the user.

TABLE I — Typical Frequency Pull In Percent Attributable to Crystal Switching Networks

Device	MC12060					MC12061			
Nominal crystal frequency (MHz)	0.1	0.2	0.5	1.0	2.0	2.5	8.0	13.4	20.0
One crystal (connected directly to pins 5 and 6)	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Two crystal switching system	*	+0.0005	+0.0006	+0.0035	-0.004	+0.0008	+0.0013	+0.0004	-0.005
Five crystal switching system	*	+0.0005	+0.0006	+0.0031	-0.018	+0.0008	+0.0001	-0.0006	-0.023

*Less than one Hertz pull, measurement limited to resolution of test equipment.

TABLE II — Typical Frequency Pull In Percent For ICs Only

Device	MC12060					MC12061			
Nominal crystal frequency (MHz)	0.1	0.2	0.5	1.0	2.0	2.5	8.0	13.4	20.0
Pull in percent	*	-0.0005	-0.0012	-0.0040	-0.03	-0.0002	-0.004	-0.01	-0.05

*Less than one Hertz pull, measurement limited to resolution of test equipment.

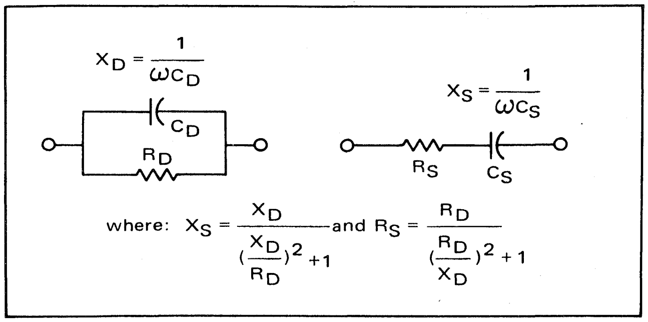

FIGURE 3 — Diode Equivalent Circuits

C_S relative to the crystal's equivalent series capacitance is required to satisfy item 1.

The impedance of the MSD7000 diode with 0.45 mA of bias current has a typical value of $115\underline{/-3^{\circ}}$ = 114.6-j6 ohms at 100 kHz and $115\underline{/-8^{\circ}}$ = 113.8-j16 ohms at 2 MHz; resulting C_S values are respectively 0.265 μF and 0.005 μF. Since typical series resonant crystals in this frequency range exhibit equivalent series capacitance values, C_X, ranging from 0.024 pF to 0.012 pF, item 1 is satisfied. Also, since the equivalent series resistance of the diode is much less than the maximum effective resistance specification (4 k ohms) for the MC12060, item 2 is satisfied.

For the MC12061 circuit, the diode forward bias current is 1.15 mA. This current is sufficient to keep the series impedance of the MPN3401 PIN diode low. At 2 MHz the impedance is nominally $22\underline{/-28^{\circ}}$ = 19.4-j10 ohms and at 20 MHz $3.3\underline{/-37^{\circ}}$ = 2.6-j1.98 ohms. The resulting C_S values in this case are 0.008 μF and 0.004 μF. Typical series resonant crystals in this frequency range exhibit equivalent C_X capacity values of 0.012 pF to 0.003 pF and the maximum series resistance specification for the MC12061 is 155 ohms. Again, the requirements of both items 1 and 2 above are met.

DECOUPLING UNSELECTED CRYSTALS

Isolating unselected crystals is very important from the standpoint of minimizing frequency pull of the selected crystal, and insuring that the oscillator will lock on a new crystal frequency when switched from a previous one.

The objective for decoupling unselected crystals is to place a high impedance in series with them. The MSD7000 typically has 0.72 pF of shunt capacitance C_D (refer to Figure 3) at V_R = 1.6 volts, and the MPN3401 typically 0.75 pF at 1.2 volts of reverse bias. Since R_D is extremely large for the reverse bias condition, the resulting diode R_S resistance will not be exceptionally large and C_S will approximately equal C_D. This series capacitance is 30 to 300 times greater than typical values of equivalent crystal series resonant capacitance (C_X). Therefore, the total series equivalent capacitance ($C_T = \frac{C_S C_X}{C_S + C_X}$) decreases by only 3.2% to 0.33% respectively. This, combined with a low value for R_S, maintains considerable coupling between the unselected crystal (s) and the oscillator. Thus, the oscillator may remain at the previous crystal frequency, or operate at some random frequency.

To reduce this problem, a shunt resistor (R_1, R_3, R_5, R_7, R_9) is added to each switching diode (D_1, D_2, D_3, D_4, D_5) in Figures 1 and 2. This shunt resistor establishes a new and lower value for R_D in Figure 3, which results in a new R_S value - much greater than the maximum allowable effective resistance specification for the MC12060/MC12061.

Worst-case coupling effects occur at 2 MHz for the MC12060 and 20 MHz for the MC12061. Referring to Figure 3: assume C_D is equal to 1 pF; this gives

$$X_D = \frac{1}{2\pi f C_D} = 79.5 \text{ k ohms at 2 MHz, and 7.95 k ohms at}$$

20 MHz. To maximize the series equivalent resistor (R_S), the parallel resistor R_D is made equal to the reactance X_D at the highest operating frequency. For the MC12060, the vlaues of R_D = X_D = 79.5 k ohms give R_S = X_S = 39.7 k ohms. Since R_S is now much greater than 4 k ohms, the unselected crystals will be virtually isolated from the oscillator. This isolation will become greater with a decrease in frequency.

Using the same formulas to determine the required R_D and to calculate R_S and X_S at 20 MHz for the MC12061 results in R_D = X_D = 7.95 k ohms, giving a new value of R_S = X_S = 3.97 k ohms. This value of R_S is much greater than 155 ohms, the maximum effective resistance specification for the MC12061. Therefore, the oscillator will now have sufficient isolation from the unselected crystals to prevent erratic performance.

The values used for R1, R3, R5, R7 and R9 are 82 k ohms, and 10 k ohms for Figures 1 and 2 respectively.

OSCILLATOR AC LOADING

Oscillator ac loading must be minimized to reduce frequency pulling and sine wave distortion. For the circuits shown in Figures 1 and 2 the ac loading is primarily attributable to the biasing networks for the five diodes (D1-D5). All bias elements contribute to an effective ac load, regardless of which crystal position is selected. This occurs because the RF signal is coupled through the parallel capacitance (C_o) of the unselected crystals.

Due to a greater sensitivity to ac loading of the MC12060, additional elements are used in the switching networks for this device. An RF choke, L1, is incorporated to minimize the loading effects of the common bias resistor, R17. In addition, a modified approach is used to bias diodes D1 through D5. The networks (D6, R18) through (D10, R22) are added to minimize ac loading and, at the same time, supply sufficient forward current with a 5-volt supply. One diode (D1-D5) in the MSD7000 dual diode package is used to switch the crystal and the second diode (D6-D10) is used for reducing ac loading. R18 through R22 are essential to supply a small amount of current for reverse bias of diodes D1-D5 corresponding to the unselected crystals.

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