

## EMITTER COUPLED HARMONIC CIRCUIT

Appendix B was originally published [21] in RF Design, Mar. 1987 0. With permission, Cardiff Publishing Co.

The Emitter coupled harmonic circuit has the best short term stability of any harmonic circuit tested by the author to date. Originally described by Driscoll [22], the circuit has been simplified and improved by eliminating a transistor stage and a transformer, and adding an RC phase lag network. The basic schematic of the improved Emitter coupled harmonic circuit is shown in Fig. B.1. It uses only one transistor, and operates at frequencies up to 100 MHz. The oscillator's output is a clean sine wave.

The crystal is connected as the transistor's emitter load impedance, and controls the oscillation frequency by controlling the transistor's gain and phase shift. The circuit's very good short term frequency stability comes from the high capacitance load shunted across the crystal by the transistor's emitter output, which keeps the crystal's in-circuit Q high. The large capacitive loading on the crystal means the resistive loading losses that reduce in-circuit Q will be low. In addition, the crystal has direct emitter control of the transistor's gain. This is almost an optimum crystal oscillator circuit—the crystal is located at the lowest power point in the circuit (minimum crystal heating), and the output signal is taken at the highest amplitude point in the circuit (maximum signal/noise ratio and minimum external amplification).

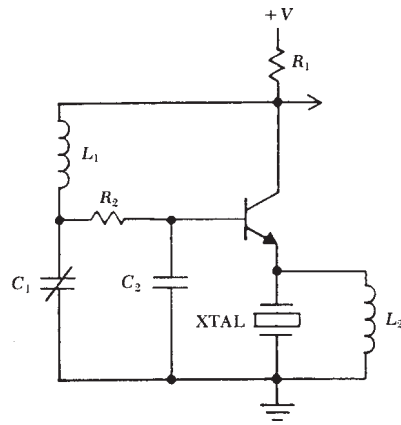


Figure B. 1. Basic circuit of Emitter coupled harmonic oscillator.

### B.1. HOW IT OPERATES

The basic circuit is shown in Fig. B. 1. It has positive feedback and oscillates at a frequency of  $0^\circ$  (or  $360^\circ$ ) phase shift, presuming the loop gain is greater than one. The  $L_1C_1$  network normally operates just above resonance, and provides about  $120^\circ$  of phase lag. The  $R_2C_2$  network provides an additional phase lag of about  $60^\circ$ . The transistor provides  $180^\circ$  of phase reversal, giving a total of  $0^\circ$  (or  $360^\circ$ ) around the circuit's feedback loop.

The inductor  $L_2$  can be any value larger ( $2X - 20X$ ) than what will resonate with the crystal's terminal-to-terminal capacitance  $C_o$ . The purpose of  $L_2$  in the circuit is not understood, but the circuit will not oscillate if  $L_2$  is equal to or less than this resonance value. The circuit also will not oscillate if a resistor is substituted for inductor  $L_2$ .

In practice, the crystal's internal impedance, which is lowest at series resonance, controls the transistor gain. It can also vary the normal  $180^\circ$  phase shift through the transistor stage by  $\pm 50^\circ$ . The crystal uses these gain and phase shift mechanisms to control the oscillation frequency.

### B.2. TYPICAL CIRCUITS

A typical circuit at 20 MHz is shown in Fig. B.2. The crystal, which has an internal series resistance  $R_s$  of 14 ohms, oscillates at a third harmonic. The diode clamp  $D_1 - D_2$  limits the oscillation amplitude, to avoid overdriving the crystal. The transistor operates continuously in a linear mode over a

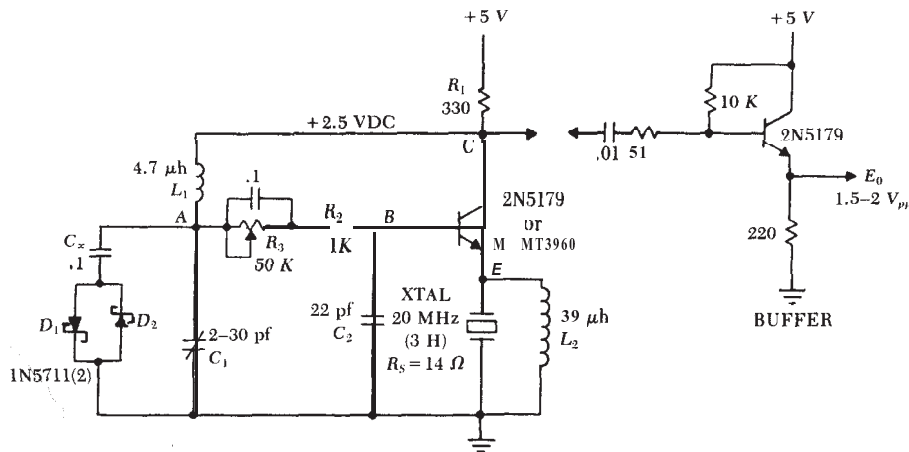


Figure B.2. Emitter coupled harmonic circuit at 20 MHz.

complete cycle of oscillation, and reflects a reasonably constant load across the crystal at all instants of time. Fig. B.3 shows the oscillation waveforms at various points in the circuit. The calculated gain and phase characteristics for the oscillator's entire closed loop in Fig. B.2 are shown in Fig. B.4. Note the steep phase change with frequency, an indication of good frequency stability.

The circuit values in Fig. B.2 are derived as follows. The transistor's gain is proportional to the ratio of the collector's load impedance to the emitter's load impedance. At the crystal's series resonant frequency, the gain is approximated by the ratio  $R_1/R_s$ , where  $R_1$  is the collector's load resistance and  $R_s$  is the crystal's internal resistance.  $R_s$  is fixed by the crystal and the operating frequency.  $R_1$  is selected as a ratio to  $R_s$  so as to provide enough gain for the circuit to oscillate.  $L_1$  is selected to have a high shunt impedance with respect to  $R_1$  and still resonate at or just below the oscillation frequency with a reasonable-sized variable capacitor  $C_1$ .  $R_2$  is selected to provide a relatively high load resistance to  $C_1$ .

The capacitive impedance of  $C_2$  is reflected across the crystal by the transistor's emitter, multiplied by the transistor's current gain  $H_{FE}$ . To provide a low impedance load and high Q for the crystal,  $C_2$  should be as large as possible, consistent with  $R_2C_2$  providing a large phase lag without too much gain loss.  $R_3$  controls the transistor's DC current, which is conveniently adjusted to set the transistor's DC collector voltage at half the power supply voltage. At low frequencies, the 2N5179 transistor in Fig. B.2 is a good selection. At 50 MHz and above, the higher gain of the MMT3960 is needed.