

## SINGLE TRANSISTOR CRYSTAL OSCILLATOR CIRCUITS

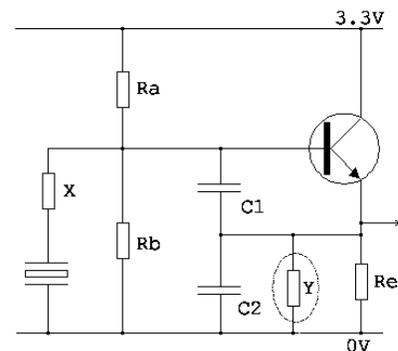
The majority of modern crystal oscillator circuits fall into one of two design categories, the Colpitts / Clapp oscillator and the Pierce oscillator. There are other types of single transistor oscillators ( Hartley and Butler for example ), but their usefulness and application is beyond the scope of this discussion.

For an electronic circuit to oscillate there are two criteria which must be satisfied. It must contain an amplifier with sufficient gain to overcome the losses of the feedback network (quartz crystal in this case) and the phase shift around the whole circuit is  $0^\circ$  or some integer multiple of  $360^\circ$ . To design a crystal oscillator the above has to be true but there are a myriad of other considerations including crystal power dissipation, unwanted mode suppression, crystal loading (the actual impedance the crystal sees once oscillation has started) and the introduction of a non-linearity in the gain to limit the oscillation build-up.

Consider the apparently simple circuit of the Colpitts / Clapp oscillator in Fig. 1. Without the correct simulation tools it is not immediately obvious this circuit has Negative Resistance at the frequency of oscillation (necessary to overcome the crystals Equivalent Series Resistance), an initial gain in excess of one (to allow oscillator start-up) which drops to unity once the oscillation starts, and is then subsequently stabilised by either the voltage limiting on the transistor's base emitter junction, or transistor collector current starvation.

For AT cut crystals this circuit, with careful choice of the component values, can be made to oscillate from about 1MHz to above 200MHz with complete control over the crystal drive level and crystal loading impedance. For a stable low noise oscillator the choice of transistor is critical. Ideally it will be a high frequency, low noise transistor with low internal capacitances (an Ft of ~1 to 5 GHz is recommended). For medium / high frequency oscillators try a BFS17 or BFR92. For low frequency oscillators the 2N2369A or BSV52 work well. It is not recommended to use a BC107 type transistor.

**Fig. 1**



The component marked X is a reactance (capacitor and / or inductor) to match the oscillator load capacitance to that of the selected crystal (series, 20pF, 30pF etc.)

The component marked Y is for overtone crystals only. It is usually an inductor in series with a capacitor. Its purpose is to make C2 look inductive at the frequencies you want to suppress but still look capacitive at the selected working overtone frequency.

The Colpitts and Clapp oscillators are variants of the same design. In Fig 1 the Colpitts variant does not use component X to adjust the frequency, instead relying solely on the tapped tank C1 and C2. The addition of the series component X turns the Colpitts oscillator into a Clapp oscillator. The Clapp variant is preferred as changing the values / ratio of C1 and C2 will change the oscillators characteristics and may adversely affect the oscillator.

Fig 2 is a table of typical starting values at various frequencies to make a working oscillator using a BFS17 transistor. The crystal load capacitance has been chosen to be approximately 20pF and the crystal power dissipation has been chosen to be approximately 100µW. All the values will require optimising to suit the actual selected crystal, the chosen transistor and the required oscillator performance (phase noise, short term stability, output voltage level, crystal drive level, crystal load impedance etc.)

**Fig.2**

Freq MHz	ESR Ω	C0 pF	Ra kΩ	Rb kΩ	Re kΩ	C1 pF	C2 pF	X	NegR Ω	Gain	Vout Vpk/pk
1	100	4.0	8.2	12	1.3	680	1200	22pF	730	6	0.6
5	50	3.5	8.2	12	1.3	150	330	27pF	450	7	0.5
10	20	3.0	8.2	12	1.3	120	270	27pF	180	7	0.4
50	10	2.5	8.2	12	1.3	27	68	330pF	100	8	0.4
100	10	2.0	8.2	12	1.3	18	39	47nH	60	6	0.3
150	10	1.5	8.2	12	1.3	12	27	47nH	50	5	0.3

Freq, ESR, C0 are functions of the chosen crystal.

Ra, Rb, Re, C1, C2, X are the chosen circuit values.

NegR, Gain are the initial conditions the crystal sees before oscillation starts.

Vout is the expected pk / pk voltage at the transistor's emitter once oscillation has stabilised.

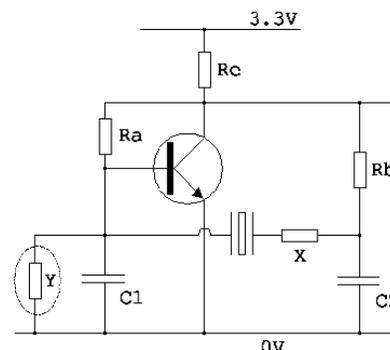
The output from the Colpitts / Clapp oscillator is normally taken from the transistor's emitter, the lowest impedance point in the circuit. Great care must be exercised in how this point is loaded so as not to reflect back into the oscillator loop and adversely affect the oscillators performance. The waveform on the transistor emitter is not sinusoidal but rather a small rounded 'square wave' of typically 0.3V / 1V pk/pk and 15% / 30% duty cycle. This is because the circulating sinusoidal oscillator current is flowing around the Crystal, X, C1, C2 loop with the transistor just supplying a 'blip' of current every cycle to make up for the resistive losses in the Crystal, X, C1, C2 loop.

It is not recommended to take the voltage form the base of the transistor or from across the crystal as these are high impedance points in a very high Q circuit. Small changes in the loading circuit will have large (and possibly catastrophic) effects on the oscillators performance.

The Pierce oscillator in Fig 3. is similar to the Colpitts / Clapp oscillator in Fig 1 except the crystal cannot be referenced to ground. It to can oscillate from about 1MHz to above 200MHz with AT cut crystals but has the added advantage of being easier to use for the much lower frequency (32kHz) tuning fork type crystals.

Fig 4 is a table of typical starting values at various frequencies to make a working oscillator. As with the Colpitts / Clapp oscillator the crystal load capacitance has been chosen to be approximately 20pF

**Fig. 3**



and the crystal power dissipation has been chosen to be approximately 100µW. Again all the values will require optimising to suit the actual selected crystal, the chosen transistor and the required oscillator performance. The function of components X and Y are as per the Colpitts / Clapp oscillator.

**Fig.4**

Freq	ESR	C0	Ra	Rc	Rb	C1	C2	X	NegR	Gain	Vout
MHz	Ω	pF	kΩ	kΩ	Ω	pF	pF		Ω		Vpk/pk
1	100	4.0	27	1.3	180	680	2000	22pF	490	6	0.9
5	50	3.5	27	1.3	180	150	560	24pF	290	7	0.9
10	20	3.0	27	1.3	180	150	470	27pF	100	6	0.9
50	10	2.5	27	1.3	180	47	120	39pF	40	5	0.8
100	10	2.0	27	1.3	180	18	47	22nH	40	5	0.8
150	10	1.5	27	1.3	180	10	22	47nH	40	5	0.8

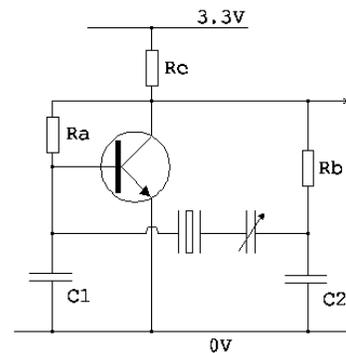
Freq, ESR, C0 are functions of the chosen crystal.  
Ra, Rb, Rc, C1, C2, X are the chosen circuit values.  
NegR, Gain are the initial conditions the crystal sees before oscillation starts.  
Vout is the expected pk / pk voltage at the transistor's emitter once oscillation has stabilised.

For the Pierce oscillator the output is normally taken from the transistor collector but the loading constraints and waveform shape is still as per the Colpitts / Clapp oscillator.

Should the oscillator require tuning then this is achieved by varying the reactive load seen by the crystal. In the above two designs (Fig 1 & Fig 3) the reactive load is approximately C1, C2 and X in series. Capacitors C1 and C2 play a major part in setting the initial gain, negative resistance and crystal drive level so should only be used to adjust the oscillator frequency if their effect is fully understood and acceptable.

A better choice for tuning is to use reactance X. This reactance doesn't need to be a single component, it can be a combination of Capacitors, Inductors and Resistors providing they give the required total reactance at the frequency of interest. For mechanical tuning, part of reactance X could be a variable capacitor, as shown in Fig 5, or for voltage tuning it could be a Varactor Diode, as shown in Fig 6.

**Fig. 5**



**Fig. 6**

