A low distortion two tone oscillator

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Introduction

Unlike the ultra-simple two tone oscillator I described in the September 2004 issue of *Amateur Radio* magazine which has a distortion of around 2.5% THD, this unit is of laboratory grade and features oscillators with a THD of around 0.05%. This specification not only allows gross operating defects such as instability, non-linearity, and overdrive to be observed on an oscilloscope, but also allows serious engineering measurements to be done on transmitters. Such tests include those for intermodulation distortion (IMD), and the typical published specifications of between -28 and -35 dB for an amateur transceiver/linear can be easily verified.

Output frequencies of 700 Hz and 1900 Hz are provided. These frequencies are not harmonically related, and are approximately equal distances in from either end of the audio pass band. Both frequencies are available individually for single tone testing, or in combination for two tone testing. The output levels of both test frequencies can be adjusted relative to each other, accommodating for variations in the transmitter audio response, and hence allowing perfect zero crossings to be obtained on the oscilloscope two tone test pattern. If you want 1 kHz spacing between the two tones (700/1700 Hz), all you have to change is two resistors.

How it works

The Wien Bridge circuit, which is used in the two sine wave generators in this instrument, can be broken into two halves. Looking at the 1900 Hz oscillator we can see that the first half, which provides positive feedback around the
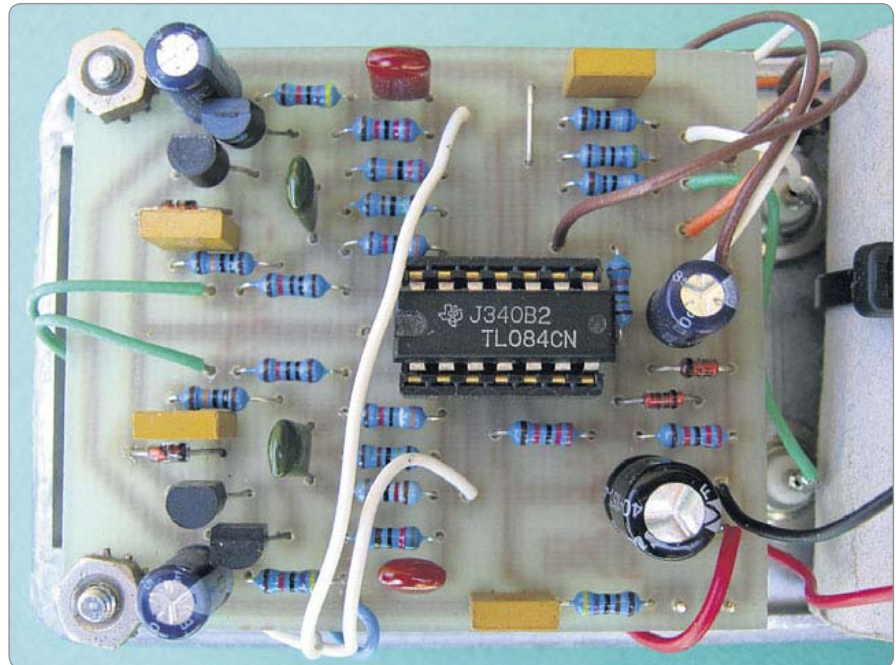

Photo 1: A view of the PCB.

amplifier, is formed from an upper section with a resistor and capacitor in series (R1, C1) and a lower section with a resistor and capacitor in parallel (R3, C2). This network is frequency selective and at the frequency of oscillation, provides a phase shift of zero between output and input of the amplifier.

In a normal realization of the oscillator, equal values of capacitors and resistors are used in each of these bridge sections, and a little circuit analysis will show that an amplifier gain of just three is necessary to maintain oscillation. This in turn means that when the amplitude of oscillation has settled, one third of the output amplitude appears at the non-inverting amplifier input and consequently this same large signal swing must appear at the inverting input too. To provide this signal level at the inverting input (negative feedback) means that the other half of the

Wien Bridge must have a resistance in the upper section (R2) of twice the value of the resistor in the lower section (R4 plus the drain source resistance of the FET). These large signal levels at the two amplifier inputs create distortion, because the transfer characteristics of the op amp inputs are not precisely linear over large voltage ranges, and neither is the drain source resistance of the FET exactly constant under varying voltage conditions. In this circuit, the FET is used as an output amplitude sensitive resistance which sets the negative feedback to precisely that required to maintain a stable amplitude of oscillation. It replaces the thermistor or low current tungsten filament lamp normally used for this function, as both of these components are now very difficult to obtain.

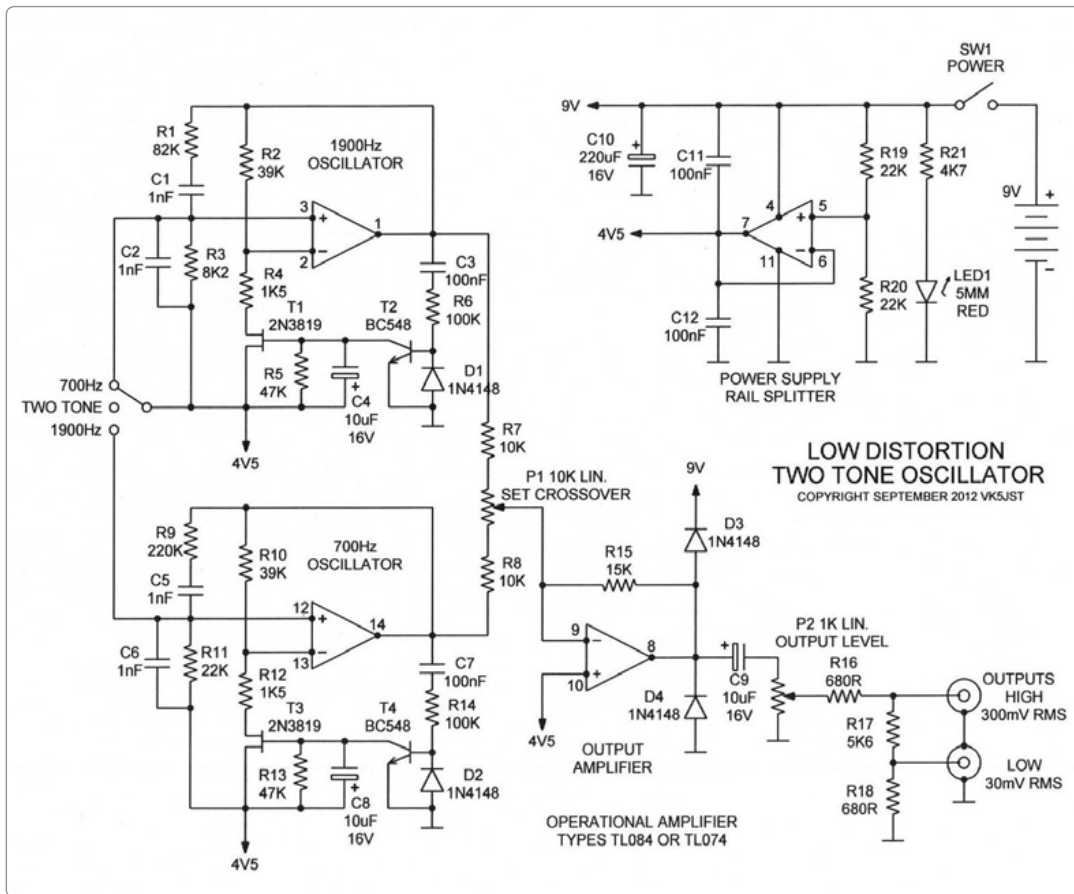The distortion created by the FET and op amp inputs is overcome

Figure 1: The circuit.

Text in figure includes labels such as:

R1 82K, C1 1nF, R2 39K, 1900Hz OSCILLATOR, C2 1nF, R3 8K2, R4 1K5, T1 2N3819, T2 BC548, R5 47K, C4 10uF 16V, D1 1N4148, C3 100nF, R6 100K, 700Hz TWO TONE 1900Hz, R9 220K, C5 1nF, R10 39K, 700Hz OSCILLATOR, C6 1nF, R11 22K, R12 1K5, T3 2N3819, T4 BC548, R13 47K, C8 10uF 16V, D2 1N4148, C7 100nF, R14 100K, R7 10K, P1 10K LIN. SET CROSSOVER, R8 10K, R15 15K, D3 1N4148, D4 1N4148, OUTPUT AMPLIFIER, C9 10uF 16V, P2 1K LIN. OUTPUT LEVEL, R16 680R, R17 5K6, R18 680R, OUTPUTS HIGH 300mV RMS, LOW 30mV RMS, SW1 POWER, 9V, C10 220uF 16V, C11 100nF, C12 100nF, R19 22K, R21 4K7, R20 22K, LED1 5MM RED, 9V, POWER SUPPLY RAIL SPLITTER, LOW DISTORTION TWO TONE OSCILLATOR, COPYRIGHT SEPTEMBER 2012 VK5JST, OPERATIONAL AMPLIFIER TYPES TL084 OR TL074, 4V5

to a very large degree in this design by using a most uncommon version of the Wien Bridge. In this variant, the capacitors and resistors in the frequency selective part of the bridge are in the ratio 10:1, which causes the resistors in the negative feedback section to be in the ratio 20:1. This in turn means the amplifier gain required for steady state oscillation is 21, and also means that the signal swings at the two amplifier inputs are much reduced, relative to the normal oscillator design. It is these low amplitudes of input voltage which give this design its excellent low distortion characteristics, and typically harmonics are at least 65 dB down on the amplitude of the fundamental sine wave (<0.05% THD). This is difficult to measure, and initial attempts using the FFT feature on a Rigol DS1052 digital oscilloscope were disappointing. No matter what was done with instrument settings or the circuit

design, the displayed harmonics were never more than 43 dB below fundamental. Given the oscillator design, this figure could not have been correct, and the distortion was later measured using a HP spectrum analyser, with -65 to -70 dB figures being obtained.

At switch on, the *gate* source voltage of the FET is zero, and so its drain-source resistance is typically around 180-200 Ω. The gain of the amplifier is thus around 24, {(39k + 1k5 +200)/(1k5 +200)} and so oscillation starts to build up. When the amplitude reaches about 1.0 volt peak to peak, D1 and the base emitter junction of T2 turn on, causing collector current pulses to flow through C4 and R5. These components have a large time constant which reduces these current pulses to a smooth DC voltage at the FET gate. Note that both the diode and transistor turn on at around 500 millivolts, not the usual 600 millivolts for a

silicon junction, due to the minute currents being used. As the amplitude of oscillation increases, this smoothed DC voltage takes the gate of the FET negative with respect to source, increasing the drain-source resistance, and consequently also increasing negative feedback. When the drain-source resistance reaches 450 Ω, the gain of the amplifier is lowered to exactly 21, and so this process rapidly stabilizes the level of oscillation. Due to the large voltage gain of T2, it takes very little extra voltage swing at the base of T2 to cause very large changes in DC voltage at the gate of the FET and so oscillation settles to a level of one volt peak to peak and this is largely independent of the huge spreads which occur in the FET characteristics.

Both oscillators work identically producing one volt p-p of about 700 Hz and 1900 Hz at their outputs. For single tone testing, either oscillator can be turned off by shorting the lower part of the frequency selective arm of the Wien Bridge. The two oscillator outputs are current summed at the virtual earth existing at the inverting input of the output amplifier, via R7, R8, and P1. P1 allows the amplitude of one sine wave to be varied relative to the other, allowing the perfect test patterns mentioned earlier in this article to be obtained. The sum of the two voltages appears at the output of this amplifier, which has both high and low level variable outputs with a 600 Ω impedance level. The low level output is

suitable for direct injection into the microphone input of a transceiver. The amplifier output is protected by D3 and D4, which prevent the output being dragged above the positive supply or below ground by external signals.

The last section of the circuit is simply a rail splitter, which turns the nine volt battery into a balanced dual supply of 2 @ 4.5 V DC for the other three op amps in the chip.

Construction notes

The component overlay drawing details everything required to assemble this piece of test gear correctly. Note that to prevent RF feedback during testing, the unit should be built in a metal box.
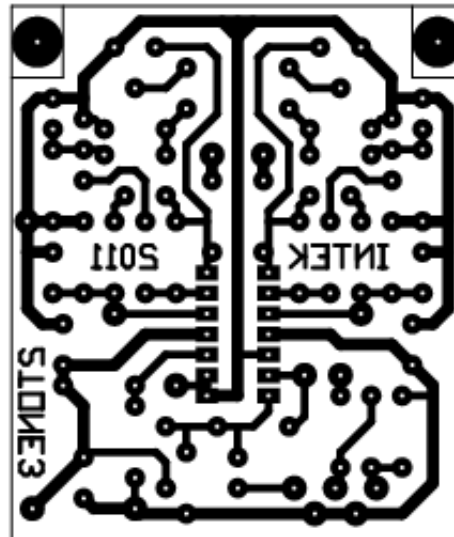
Figure 3: The PCB. NOTE: Exact size is 2.20 x 2.60 inches (55.88 mm x 66.04 mm)

For this same reason, any connections between this test oscillator and transmitter should be made using well screened coaxial cable.

Instead of batteries, the two tone generator can be run from a mains powered supply such as a 'wall wart', but this supply should be carefully selected for low output noise and ripple. Output voltages from 9 to 15 V DC (or even higher) are fine. Some additional RF supply bypassing where the power supply enters the metal case will probably be necessary if you go this way.

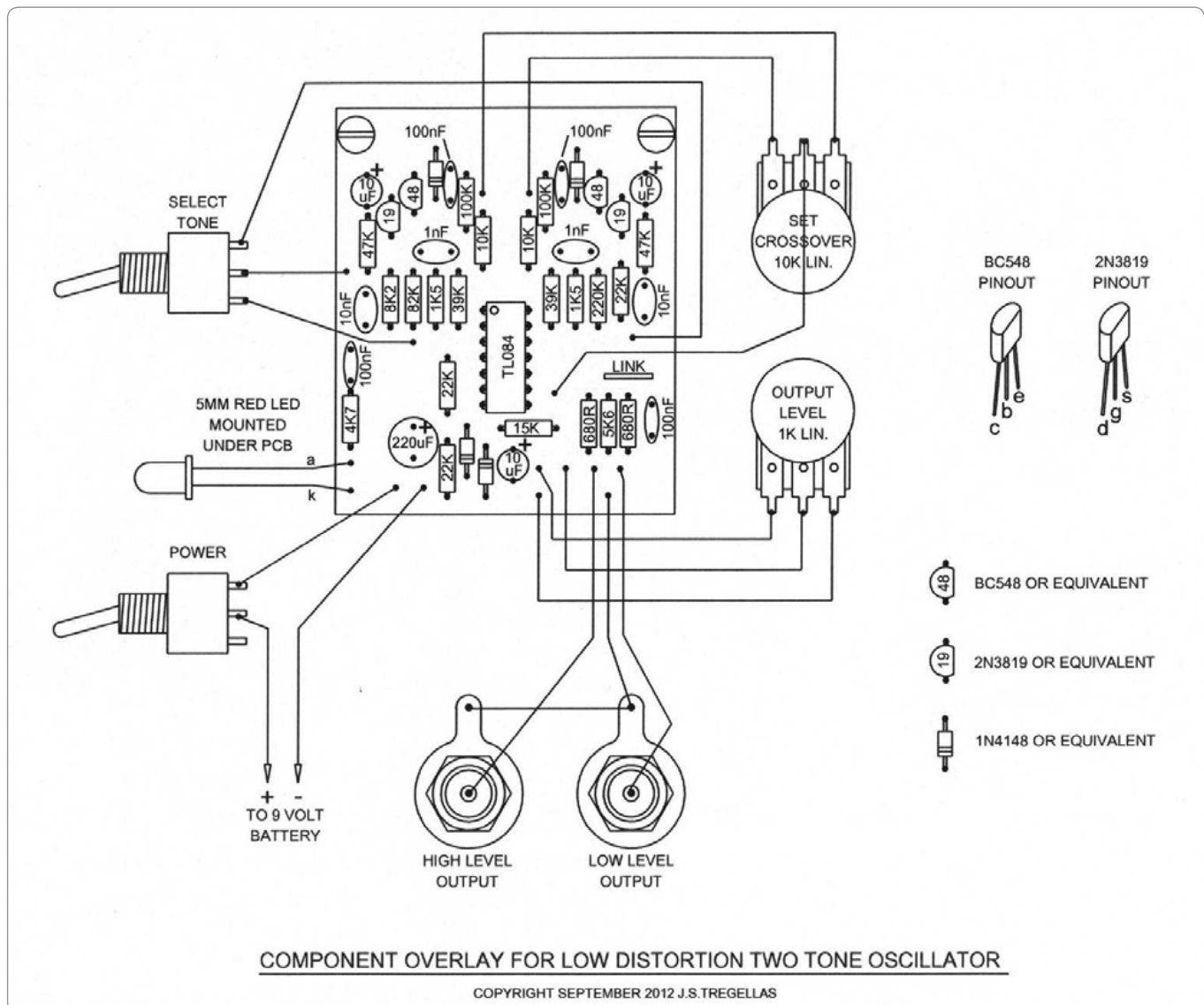Various semiconductors can be used to construct this project.

COMPONENT OVERLAY FOR LOW DISTORTION TWO TONE OSCILLATOR

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Figure 2: The overlay.
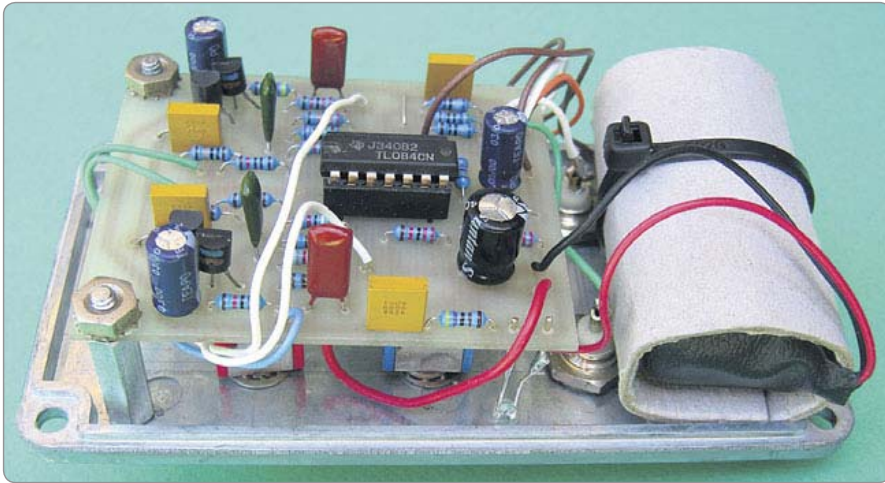
Photo 2: Inside the unit.

Photo 3: The finished unit.

The quad op amp can be a TL074 or TL084. Do not use type LM324, which has some unhappy habits. The NPN transistors can be any TO92 package which happens to be handy, and the FETs used should be of the Process 50 type, that is a 2N3819, 2N5485, MPF102 or similar. The PCB has been laid out for Process 50 FETS with the gate terminal in the middle, and one of the great things about these FETS is that they are closely electrically symmetrical. The drain and source are interchangeable, although the manufacturer does not say this, and with the gate in the middle, you simply can't put them in backwards. The 2N3819 which I used has this pin-out but both of the other types have their gate at one end, and so you will have to do a bit of package twisting and lead insulation if you use these alternatives.

The design provides oscillator output voltages fixed to within +/-15% for FETS at either end of the huge characteristic spreads. There is sufficient adjustment range provided in the SET CROSSOVER pot to cancel out these tolerances, but if you want to do a really good job, then short gate and source together and measure the drain source resistance with ohms feature on your DVM. I checked out 100 odd 2N3819s from various manufacturers, and with Vgs=0, Rds varied between 112 and 269 with the peak of the distribution being at 183 . Select a couple of FETS with drain source resistances within 10% and the two oscillators will behave virtually identically.

Good testing.

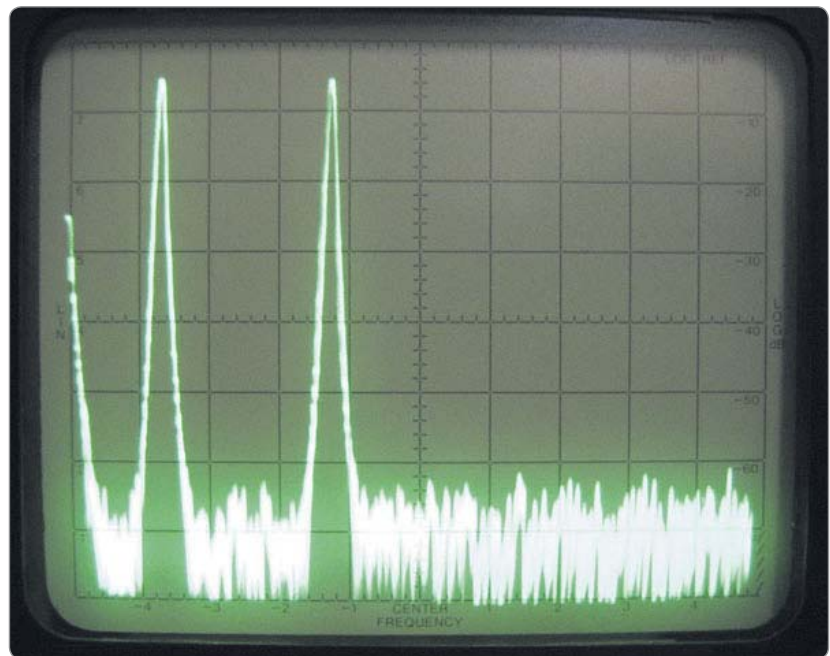Photo 4: The output spectrum of the two tone oscillator.