Step by step design of a lock

Introduction

This paper outlines the step by step design of a lock in amplifier based micro-ohmmeter. This is very useful in measuring small resistances without applying large currents. And find its usefulness in tracing short circuits on printed boards containing sensitive components.

The Audio Micro Ohm Meter uses synchronous detection to measure low value resistances. The circuit provides a variable frequency audio tone to indicate the resistance under test. Such a tone is invaluable when troubleshooting shorted tracks on multi-layer circuit boards because it is easier and quicker to observe 1.

The source generates a 1KHz, 250mV peak square wave carrier signal that is injected into the unknown resistance, the resulting voltage across the resistor is amplified by the instrumentation amplifier. The phase reversing switch then rectifies the complementary square wave input, the rectified output is not all smooth so a low pass filter is needed. A Voltage controlled is then used to measure and indicate low value resistances such as track resistances on printed circuit boards. To provide a convenient indication, we want a ‘ display’ that has high resolution (like a digital display) but is easy to read (like analogue meter) and that preferably doesn’t even need to be looked at, so we can concentrate on the probes. To trace short circuits, the one thing we don’t really need is high accuracy, since we are generally moving the probes 1. A muting detector then comes in to compare the control voltage with reference voltage.

The Proteus ISIS software is used for the simulation of the circuit while a printed circuit board was used for the verification of the circuit. Resistor selection, analysis of waveforms , sensitivity and linearity of the device to supply voltage and possible improvements of the device were discussed.

Excitation Oscillator

One of the most useful ICs ever made is the 8-pin 555 timer and it is used in many projects. It can be used to build many circuits by just adding a few external components.

NE555 is a popular version and it is suitable in most cases where a ‘ 555 timer’ is specified. Some low power types of the 555 are made, for instance the ICM7555, but can only be used when specified (to increase battery life) because their maximum output current of about 20mA (with a 9V supply) is too low for many standard 555 circuits. The ICM7555 has the same pin arrangement as a standard 555. The circuit symbol for a 555 is a box with the pins arranged to suit the circuit diagram: for example 555 pin 8 at the top for the +Vs supply, 555 pin 3 output on the right. Usually just the pin numbers are used and they are not labeled with their function.

Standard 555 ICs create a significant ‘ glitch’ on the supply when their output changes state. This is not a problem in small circuits with no other ICs, but in a complex circuit a smoothing capacitor can be connected across the +Vs and 0V supply near the 555 . The 555 timer operates in different modes. The astable mode suits our design criteria. An astable circuit produces a ‘ square wave’, this is a digital waveform with sharp transitions between low (0V) and high (+5Vs). It is possible that the durations of the low and high states may be different. The circuit is called an astable because it is not stable in any state: the output is continually changing between ‘ low’ and ‘ high’. Our circuit needs a square waveform output of 4KHz, for this to be obtained an appropriate resistor value can be estimated by calculation to obtain the needed signal to drive the circuit

Duty cycle

The duty cycle of an astable circuit is the proportion of the complete cycle for which the output is high (the mark time). It is usually given as a percentage. The duty cycle of our circuit can be determined using Time period. The timeperiod (T) of the square wave is the time for one complete cycle, but it is usually better to consider frequency (f) which is the number of cycles per second 2. The time period can be split into two parts:

T = Tm + Ts 5

Mark time (output high): Tm = 0. 7 × (R1 + R2) × C1

Space time (output low): Ts = 0. 7 × R2 × C1 we can determine our R2 using

C3= 10nF, R1= 1k and f= 4kHz we calculate our R2 as

Tm = 0. 7 X (1K + 33K) X 10 X 10^-9

= 238 µs

While Space-time represents low output, Ts= 0. 7 × R2 × C1

Ts = 0. 7 X (1K) X 10 X 10^-9

= 0. 7 µs

T = Tm + Ts = 238 + 0. 7 = 238. 7 µs

Duty cycle = = 99. 7%

The Quadrature Divider

A quadrature divider, comprises a plurality of flip-flops, it includes at least two flip-flop, the flip-flops are interoperably coupled in series to produce a set dividing ratio 7. Each of the flip-flops includes two differential inputs I, two differential outputs O, and two differential clock inputs C, the outputs O, of one flip-flop is connected to the inputs I, of the next flip-flop, the outputs O, of the last flip-flop is connected inversely to the inputs I, of the first flip-flop, the flip-flops are clocked at their clock inputs C with differential clock signals in a consecutive manner which, for each flip-flop, are individually selected from quadrature clock input signals, 0, 90, 180, and 270, the quadrature divider is an even number divide-by-n circuit comprising a number of 2n flip-flops and providing a number of 4n output signals having 4n equidistant phases. 9

In our case the quadrature divider receives the square waveform signal from excitation oscillator as its clock signal . Figure 4 and 5 of the appendix show the pictorial representation of the quadrature divider as obtained from the circuit simulation and the oscilloscope graphic display. There are four output signals from the quadrature divider and they each have amplitude of about 5V but frequency of 1 KHz. This shows that the quadrature divider effectively divides the clock frequency into four amongst the equidistant phases.

Attenuator

An attenuator is a circuit that allows a known source of power to be reduced by a known factor usually expressed in decibels. The main advantage of an attenuator is that it is made from non-inductive resistors and therefore able to change a source or load, which might be reactive, into a resistive one that is know. The power reduction is achieved by the attenuator without introducing distortion.

The attenuator used in our circuit is a pi type It is used to attenuate the 0 and 180 degrees antiphase 5V signal form the quadrature divider to 250mV at 1KHz. In order to get this value we need to select R5 in this attenuator circuit. Using Thevenin’s theorem.

RTH = R5// (R3 + R4) where RTH = 100 ohms, R3 = 1K1ohms and R4 = 1K1 ohms.

R5 = = 104. 76 ohms.

The best resistor to this to this value is a110 ohms resistor.

So R5 = 110 ohms.

figure 6 of the Appendix shows the graphical output of the attenuator with amplitude of about 250mV and frequency of 1 KHz. The attenuator’s gain in decibels is obtained by finding the ratio of the voltage corresponding to a known factor. Using the formula:

, where R1 = 1100 ohms and the Z = 100, K = = 1. 2

The value of attenuation, A in dB is obtained using K = 10 (“ A” / 20)

1. 2 = 10 (“ A” / 20)

A = 20 log 1. 2 = 1. 584 dB

Instrumentation Amplifier

An instrumentation amplifier is a variation of differential amplifier with input buffers that eliminates the need for input impedance matching making the amplifier suitable for use in measurement 5. It is a differential op-amp circuit providing high input impedances with the pleasure of gain adjustment through the adjustment of a single resistor. Instrumentation amplifier has very low DC offset, low drift, low noise, very high open-loop gain, very high common-mode rejection ratio, and very high input impedances. The instrumentation amplifier used in this circuit affected its accuracy and stability. The attenuated signal is applied across a resistor with very small resistance. The voltage drop across the resistor is small and needs to be amplified. The instrumentation amplifier does this, it composes of three op-amps arranged so that there is one op-amp to buffer each input signal and one to produce the desired output with adequate impedance matching for the function. 3

The gain of the instrumentation amplifier circuit used for this micro-ohmmeter design is known to be 60 dB. Using the formula below then,

Av = where AV = 60 dB, R = 10 k,

60 =, R9 = = 338. 98 Ω

The best resistor to this value is 340 Ω and it controls the gain of the instrumentation amplifier.

The negative feedback of U3: A makes the voltage at pin 2 of U3: A to be equal to Voltage across R8. while, the voltage at pin 6 of U3: B is held to a value equal to Voltage across R14. This establishes a voltage drop across R9 equivalent to the voltage difference between V1 and V2 and subsequently a current through R9 and since no current is drawn by the feedback loops of the two input op-amps , the same amount of current through R9 must be going through R10 and R12 resistors above and below it. This produces a voltage drop between points A and B equal to

V

The ordinary differential amplifier part of the circuit then amplifies this voltage drop by a gain of 1. The post- differential amplifier circuit, with gain = R19 / R15 and differential input resistance = 2*R15. The two amplifiers on the left are the buffers. With R9 = Rgain removed (open circuited), they are simple unity gain buffers; the circuit will work in that state, with gain simply equal to R19 / R15 and high input impedance because of the buffers. The buffer gain is increased by putting resistors between the buffer inverting inputs and ground to shunt away some of the negative feedback; however, the single resistor Rgain between the two inverting inputs is a much more elegant method: it increases the differential-mode gain of the buffer pair while leaving the common-mode gain equal to 1. This increases the common-mode rejection ratio (CMRR) of the circuit and enables the buffers to handle much larger common-mode signals without clipping than would be the case if they were separate and had the same gain. Another benefit of the method is that it boosts the gain using a single resistor rather than a pair, thus avoiding a resistor-matching problem.

The ideal common-mode gain of an instrumentation amplifier is zero. The common-mode gain of the instrumentation amplifier used in this design is near zero because of the equally numbered resistors and by the matched common-mode gains of the two buffer op-amps of the instrumentation amplifier. To obtain a closely matched resistors is difficult, as is optimizing the common mode performance of the input op-amps. All resistors are of equal value for this instrumentation amplifier except for R9. This method has the advantage of possessing extremely high input impedances on the input voltage across R= 39 because they connect straight into the non-inverting inputs of their respective op-amps and adjustable gain that can be set by a single resistor. The lowest gain possible is obtained from the above circuit with R9 completely open (infinite resistance), and that gain value is 1.

The output of the instrumentation amplifier is an anti-phase square wave signal from the that connects to the phase shift detector for further modification.

Lock-In Amplifier

A lock-inamplifier otherwise known as a phase-sensitive detector is a type of amplifier that can extract a signal with a known carrier wave from extremely noisy environment. It is a homodyne with a very low pass filter making it very narrow band. Lock-in amplifiers utilizes mixing, via a frequency mixer, to convert the signal’s amplitude and phase to a DC—in fact a time-varying low-frequency—voltage signal. It is often used to measure phase shift, even when the signals are of a high value and of high signal-to-noise ratio, and do not need any other improvement. To obtain signal at low signal-to-noise ratios, it is necessary that a strong, undiluted reference signal is made available at the same frequency as the signal to be measured.

Phase Difference

Two oscillators that have the same frequency and different phases that is, a phase difference, the oscillators are said to be out of phase with each other. The amount by which such oscillators are out of step with each other can be expressed in radians from 0 to 2π or in degrees from 0° to 360°, If the phase difference is 180 degrees (π radians), then the two oscillators are said to be in antiphase. If two interacting waves meet at a point where they are in antiphase, then destructive interference will occur. It is common for waves of electromagnetic (light, RF), acoustic (sound) or other energy to become superposed in their transmission medium. When that happens, the phase difference determines whether they reinforce or weaken each other. Complete cancellation is possible for waves with equal amplitudes.

Phase compensation

This is the correction of phase error (i. e., the difference between the actually needed phase and the obtained phase). To obtain stability in an operational amplifier a phase compensation is required. To keep a phase margin in the phase compensation a capacitor/RC network is usually used . A phase compensator works by subtracting out an amount of phase shift from a signal which is equal to the amount of phase shift added by switching some additional amplifier stages into the amplification signal path.

Low-Pass Filter

A low-pass filter is a filter that passes low-frequency signals but attenuates (reduces the amplitude of) signals with frequencies higher than the cutoff frequency. An ideal low-pass filter completely eliminates all frequencies above the cutoff frequency while passing those below unchanged: its frequency response is a rectangular function, and is a brick-wall filter 8. If we need to get rid of an interfering signal in order to get a lot of attenuation, several RC filters can be cascaded. Unfortunately, the impedance of one RC section affects the next. What this means is that the transition between the pass and stop bands will not be sharp. A sharp transition helps reduce the interfering signal without causing degradation to the desired signals. In this case, the Sallen-Key active filter can do the job well. This circuit uses a 2-pole filter. Cascading a number of stages can give a steep attenuation transition with a very sharp knee. This cut-off frequency aids in selecting the R20 and R22 resistor values to be used in the low pass filter design to average noise in the DC signal 6.

The required Q for the butterworth filter = 1. 414. The op-amp stage is a unity gain follower when R20 = R22. if C9 and C10 are equal, then the Q = 1. 5858 for Butterworth response.

Using convenient near values gain of 1. 56 in the formula,

R20 = R22 = Q / (4·π·fo·C9) where, fo = cut-off frequency = 4Hz, C9 = C10 = 0. 1µF

R20 =

R20 = 310. 31kΩ

The nearest standard resistor value to this calcualted resistor value is 330k

Voltage Controlled Oscillator

A voltage-controlled oscillator is an oscillator whose frequency is determined by a control voltage. As the control voltage causes the frequency to rise slowly until it hits a maximum and then falls back to the starting frequency. The first op-amp is an integrator(U7: A). A voltage divider puts the + input at half the control voltage. The op-amp attempts to keep its – input at the same voltage, which requires a current flow across the 100k to ensure that its voltage drop is half the control voltage.

When the MOSFET at the bottom is on, the current from the 200k goes through the MOSFET. Since the 100k resistor has the same voltage drop as the 100k but half the resistance, it must have twice as much current flowing through it. The additional current comes from the capacitor, charging it, so the first op-amp must provide a steadily rising output voltage to source this current. When the MOSFET at the bottom is off, the current from the 200k goes through the capacitor, discharging it, so a steadily falling output voltage is needed from the first op-amp. The result of the operation of this integrator circuit is a triangular waveform confirmed by figure 13 of the appendix.

The capacitance of the capacitor in our circuit is determined thus:

The second op-amp is a Schmitt trigger. It takes the triangle wave as input. When the input voltage rises above the threshold of 3. 33 V, it outputs 5 V and the threshold voltage falls to 1. 67 V. When the input voltage falls below that, the output goes to 0 V and the threshold moves back up. The output is a square wave. It’s connected to the MOSFET, causing the integrator to raise or lower its output voltage as needed 4. Figure 14 shows the graphical representation of this circuit .

The variation of the supply voltage from 3V to 9V while observing the output signal frequency obtains the sensitivity of the overall voltage- controlled oscillator circuit to supply voltage. From the test observation, the VCO produced no output signal at 3Vand beyond 6. 2V. The below table shows the values obtained for the during the sensitivity test of the voltage-controlled oscillator.

Using the power supply sensitivity formula

Sensitivity

Percentage change in frequency =

Percentage change in power supply voltage =

Between 5V to 6V, the percentage change in power supply voltage = = 20%

While the percentage change in frequency is = 3. 575%

VCO sensitivity to this supply voltage variation = = 17. 875 %

Between 4V to 5V, the percentage change in power supply voltage = = 25%

While the percentage change in frequency is = 12. 21%

VCO sensitivity to this supply voltage variation = = 48. 84%

The inference from the above calculation shows that the sensitivity of this lock-in amplifier based micro-ohmmeter to power supply voltage increases with reducing supply voltage.

The tuning range of the VCO refers to the range of oscillation frequencies

Two important parameters in VCO design are linearity and sweep range. Linearity correlates the change in frequency or the VCO output to the change in the control voltage. The sweep range is the range of possible frequencies produced by VCO control voltage.

The linearity

Muting Detector Circuit

The filtered output from the phase sensitive detector is a control voltage which, with Zero input (short circuited probes) is about Vg volts . It goes more positive with increasing signal level. With maximum input(open circuited probes) the voltage will saturate near the positive supply rail. This would result in a loud high pitched tone from the oscillator, which is not what we want.

We want the it to be mute when the probes are disconnected and to do this another operational amplifier is brought in to compare the control voltage with a reference voltage. Whenever the control voltage goes higher than the reference, the output will go negative. This allows a small current to be drawn through D1 and R25, which will keep the oscillator transistor switched off, stopping oscillation.

The output voltage of an AM synchronous detector is compared with a reference potential level by a voltage comparator. A muting device connected with the output of the detector is controlled by a control circuit connected with the comparator. Through this control circuit, the detector output is immediately muted when the detector output level falls below the reference potential level, and the muting of the detector output is removed after a predetermined retardation when the detector output level exceeds the reference potential level.

References

1 Bateson, S. January 2010, Electronic Signal Conditioning Labs, Teesside University, Middlesbrough

2 Hewes, J, (17. 02. 2010), 555 Timer, http://www. kpsec. freeuk. com/555timer. htm#astable

3 Instrumentation amplifier, (14. 02. 2010) http://en. wikipedia. org/wiki/Instrumentation_amplifier

4 Java, (19. 01. 2001), Voltage controlled oscillator, http://www. falstad. com/circuit/e-vco. html 13022010

5 Kuphaldt, T, (12. 02. 2010), Differentiator and Integrator Circuits, http://www. allaboutcircuits. com/vol_3/chpt_8/10. html

6 Low pass filter, (14. 02. 2010) http://en. wikipedia. org/wiki/Low-pass_filter

7 Quadrature Divider, (17. 02. 2010), http://www. patentstorm. us/patents/7425850/claims. html

8 Sallen-key low-pass filter (13. 02. 2010), http://www. ecircuitcentezr. com/Circuits/opsalkey1/opsalkey1. htm

9 Widerin, P, (13. 02. 2010), Quadrature Divider, http://www. freshpatents. com/Quadrature-divider-dt20070111ptan20070009077. php