Drift-free Induction Balance Metal Detector

Induction Balance (IB) metal detectors with concentric search heads are very popular as they have a high sensitivity and allow you to pinpoint the detected object. The simplest such instruments are based on a low-frequency RF oscillator tied to transmit coil(s), a pickup coil feeding the RF pre-amplifier, a peak detector, DC amplifier and an audio amplifier.

The problem with this approach is that the RF oscillator must be very stable or the instrument must be continuously adjusted. Also, thermal drift of the signal diodes used in the peak detector can affect their operation.

This design overcomes both problems by using a ceramic resonator to stabilise the RF oscillator and by employing pulsating DC current in the transmit coils, eliminating the need for a peak detector to rectify the received signal.

It can sense a coin at a distance of around 200mm and a larger object (400mm in diameter) 700mm away in free air. It is equipped with a discriminator section that can be set to non-ferrous (Mode 1) or ferrous (Mode 2) detection with a momentary press of the mode selector pushbutton.

The detector is built around a 4060B oscillator and a frequency divider (IC1), a TL064 quad op amp (IC2) and two gates of a 4066B quad bilateral switch (IC3). An ATmega8 microcontroller with a 16x2 alphanumeric LCD module and a series of LEDs is used to indicate the detector status.

IC1 forms the primary oscillator. Its frequency is set to 455kHz by ceramic resonator X1, which is accompanied by two 220pF load capacitors. Output pin 4 of IC1 (O5) provides a frequency which is 1/64th of the oscillator, which in this case is 7.1kHz.

This signal is then fed to control pin 13 of bilateral analog switch IC3a, causing it to dump the 5V charge across the 100nF capacitor at pin 1 through transmit coils L1 and L2 about 7,100 times per second.

These DC pulses cause a pulsating magnetic field around transmit coil L1 and bucking coil L2, which are wound in opposite directions and connected in series.

Under no-target conditions, their induced magnetic fields cancel each other out and so nothing is picked up by receive coil L3. But when a metallic object is inside the magnetic field, the balance of these magnetic fields is affected, resulting in a voltage appearing across L3. This is fed to a differential amplifier based around op amp IC2c and appears as an output signal at its pin 8.

The two 330nF capacitors in series across L3 (effectively, a single 165nF capacitor) cause it to be resonant at the expected signal frequency, rejecting external interference and maximising signal pick-up. The differential amplifier has a gain of around 94 times (220kΩ ÷ 4.7kΩ × 2).

The signal from IC1 which controls when the pulses are applied to the transmit coils is also fed to both inputs (pins 5 & 6) of op amp IC2b. However, the signal to non-inverting input pin 5 is delayed by an RC low-pass filter with a time constant of 2.2kΩ x 4.7nF = 10µs.

That causes output pin 7 of IC2b to go high a short time after output O5 of IC1 goes high (ie, when the pulse is applied to the transmit coils) and it stays high for a short time after output O5 goes low again.

This signal is used to control another analog switch, IC3b, which gates the output of differential amplifier IC2c so that it's only fed to the following amplifier stage, IC2d, during this window period. This preserves the polarity of the received DC voltage pulses and is necessary for the micro to provide the ferrous/non-ferrous metal discrimination function.

IC2d further amplifies the resulting signal by a factor of 48 and also provides some low-pass filtering due to the 33nF capacitor across its feedback resistor. The signal then passes to sensitivity adjustment potentiometer VR1 and another low-pass filter. The resulting DC signal then goes to analog input ADC5 (pin 28) of micro IC4.

IC4 converts this analog signal into a number, then displays the received voltage at right-hand side of the top line on the LCD, reading 0-5V DC. When a metal object is detected, the micro also uses the change in DC voltage to light up one of ten LEDs, LED1-LED10, giving an indication of the size and closeness of the metal object with LED1 indicating the weakest signal and LED10 the strongest.

The micro also drives its PWM output at PB1 (pin 15) to produce an AC waveform which is fed to an RC low-pass filter and thence to a 4046 voltage-controlled oscillator, IC5. Depending on the PWM duty cycle and thus the voltage at pin 9 of IC6, it produces a tone which is then fed to the piezo sounder, to be heard by the operator.

The sounder is silent when nothing has been detected. If the search head detects an object, LED1 lights up and the piezo audio frequency is set to 700Hz. It rises in steps of 120Hz, up to 2500Hz, as the voltage from the metal detection circuitry increases.

Thus, the VCO generates 16 distinct tones for objects producing weaker or stronger magnetic fields or buried at different depths.

When the LEDs light up, a corresponding 16-step bargraph is also displayed on the second line of the LCD.

Power is from a 9V battery, switched by S1, with reverse polarity protection diode D1. A 78L05 regulator reduces the battery voltage to a steady 5V for the rest of the circuit.

The search head includes transmit coil L1, receive coil L3 (half the diameter of the transmit coil) and bucking coil L2 which is wound on top of the receive coil. All three coils are wound using 0.315mm diameter (30SWG) enamelled copper wire.

L1 consists of 80 turns wound anti-clockwise on a 140mm diameter former (eg, a piece of plastic conduit). Once complete, remove the completed coil from the former and wrap it with insulating tape.

Receive coil L3 is made using 160 turns wound anti-clockwise (just like L1) on a 70mm diameter former. Bucking coil L2 consists of 27 turns wound clockwise directly on top of the receive coil.

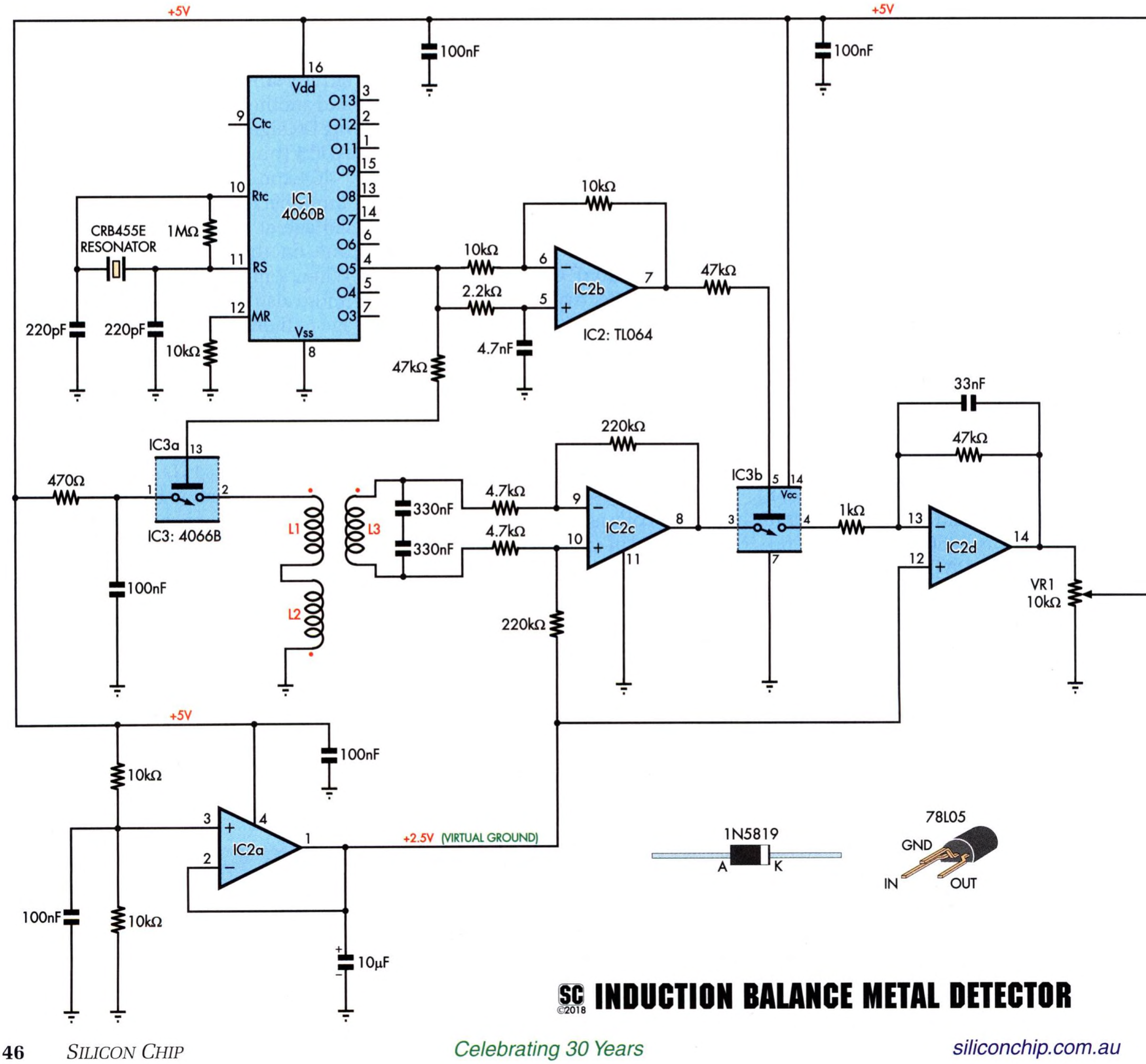
Remove the double coil L2/L3 from the former, then secure them together using strips of insulating tape. Leave a moveable loop of about one half-turn of wire from L3. This will be moved around later, to get a good null when the coils are being balanced.

Once the three coils have been made, cut a 160mm diameter circle from 3mm plywood or similar. Mount L1 and then the double coil L2/L3 at its centre. All the three coils are positioned coplanar and concentric with one another so that they are all centred on a common axis. Connect the coils to the circuit according to the schematic.

Notice that the bucking coil L2 is connected in series with the transmit coil L1 but with its phase reversed. The most sensitive part of the search head is the area under the receive coil.

For more details on the construction of coplanar concentric coils, refer to US patent 4293816 or visit this site: siliconchip.com.au/link/aait

Having built the unit, you will need to program microcontroller IC4. The software is written in BASIC and a



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HEX file is supplied along with it. This was generated from the BASIC code using BASCOM for Atmel AVR. A free trial of this compiler is available at **siliconchip.com.au/link/aacw**

Upload the HEX file to the ATmega chip using a compatible programmer, then set VR1 to maximum, place the search head well away from any metal object and switch the detector on.

It starts up in non-ferrous mode 1, which should cause non-ferrous metallic objects to be picked up and ferrous objects to be rejected. The current mode is shown on the left-hand side of the first line of the LCD.

Move around the half-turn moveable loop of the bucking coil L2 until the ADC voltage on the right-hand side of the first line of the LCD reads 2.20-2.25V. Then fix the moveable coil in place using glue. Turn VR1 down until the ADC idle voltage on the LCD is between 1.95 and 1.99V. The sounder falls silent when the ADC voltage is below 2.00V DC.

Now bring a coin close to the centre of the search head. The ADC voltage should increase and LED1 should light up. At the same time, the sounder should produce a tone. The closer you bring the coin to the search head, the higher will be the frequency of the audio output and the higher the number of the LED that lights up. Only one of the LEDs is on at a time.

The bargraph on the second line of the LCD also proceeds proportionately from the left to right as the strength of the field increases. With the strongest signal, LED10 will light up, the sound frequency will be 2500Hz and the bargraph will fill the width of the LCD.

Now push mode switch S2 to cause the circuit to switch to the ferrous metal detection mode, mode 2. Turn VR1 up to set the ADC idle voltage to 2.01 to 2.05. In this mode, when the ADC voltage is above 1.99, the sounder falls silent. Bring a small ferrous object, like an iron screw or bolt, close to the search head. The ADC voltage decreases but LED1 will light up and the sounder will produce a tone.

As the ferrous object is brought closer, the other LEDs will light up in turn and the tone will increase in pitch. The bargraph also proceeds to the right.

Mahmood Alimohammadi, Tehran, Iran. ($80)