LCMeter

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Introduction

This project came about for two reasons: First, because I needed a LC meter, and second, because I wanted to learn AVR assembler. Originally, I planned on using the circuit (or one of the variations) "Surprisingly Accurate LC Meter" that originally appeared in the April 2004 issue of Amateur Radio and write my own firmware. I bread boarded the circuit and found that, while it *did* work, it didn't have the range or scope that I wanted. So, after playing around with several ideas, I settled on the following design.

Overview

Frequency:	0 → ≈20 MHz, 10mv → +-5 v at 10 Hz resolution
Inductance:	1 nh → ≈20 h, auto ranging
Capacitance:	≈10pf → 20,000+ µF, auto ranging
Accuracy:	1% or better, depending on reference caps used.

Revisions

- 1.1 Initial release
- 1.2 Minor changes in program to accommodate major modifications to Math library.

Calibration

Inductance:	Short test leads together and press "zero" switch
Capacitance:	Leave test leads open and press "zero" switch
Notes:	Calibration values are stored in EPROM; recalibration is recommended anytime test leads are changed to offset any changes in parasitic capacitance/inductance. When

measuring values in the pf or nh range, calibration is recommended to offset changes due to the tempco of the components used.

Circuit

I designed this project to be installed in a breadboard I had built and to meet my particular needs, using the parts that I had on hand. As such, there are parts of the design that could certainly be done differently <grin>. All in all, though, it is a pretty simple and straightforward design.

Inductance – Here I used a Schmitt trigger inverter (IC4 - 74HC14) to drive a LC resonant circuit formed from C6 and C7 with either the DUT (Device Under Test) or the reference inductor. C6 and C7 (along with C1 for capacitance measurement) are the only precision components needed. I used some 1%s that I had on hand, although they can be bought from Digikey, Mouser etc. for very little. L1 is in series with one leg of the input and provides both the reference and proper scaling for measuring low values of inductance. Both legs of this oscillator are switched to the inputs by K1. This signal is buffered and shaped by a couple more gates of IC4 and then fed to the NC input of analog switch IC7A. This switch selects between feeding this signal or the frequency counter output to the "`T0`" input if the AVR. The AVR counts the pulses over a period of 1 second to directly measure the frequency of the oscillator corresponding to the function:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Solving for L:

$$L = \frac{1}{C\,(2\,\pi\,f)^{\wedge 2}}$$

gives us the value of the inductor.

When calibrating, the test leads are shorted and the inductance of L1 as well as the parasitic inductance of both the circuit and the test leads are measured and stored. This is then subtracted from later measurements.

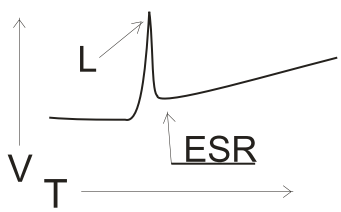
Capacitance – Capacitance is measured by applying one of three fixed current sources to the DUT and measuring the time it takes for the voltage across the DUT to cross between two voltage levels (Δvt). This time is scaled against the time for the reference capacitor C1 and displayed - the range is automatically selected to give the best resolution. The DUT is discharged via Q12 and R15 and the cycle is repeated.

When calibrating, the test leads are kept open and first the parasitic capacitance is measured. Then, the reference capacitor C1 is measured. Both these values are saved in EPROM for later use.

Frequency – The signal input is coupled via C8 to the input circuitry. R23 is used to adjust the 0-volt offset and R20 along with D1 & D2 provide input overvoltage protection. IC6 buffers the input signal and amplifies it 2X before it is fed to the input of comparator IC3. The signal is then buffered and shaped by 2 stages of IC4 before being sent to IC2 which is configured to divide by 10. It is then sent to the NO input of IC7.

The only calibration required is to short the inputs together and adjust for 0v at pin 6 of IC6.

Aside: Since the circuit has three current sources that provide (relatively) long current pulses to the DUT, I could make them provide *short* pulses and thereby have an approximation of the circuit found elsewhere on the web used to measure ESR. In fact, I was originally going to do this; I decided against it for several reasons. First, the response of a capacitor to a voltage pulse:



The initial peak is due to the inductance of the capacitor along with that of the test leads and internal circuitry. The point marked as ESR corresponds the capacitor's actual ESR (along, of course, with the resistance of the test leads etc.) The circuits I could find all operated by feeding the voltage developed across the DUT into one leg of a comparator; starting a ramp generator and feeding that into the other – then waiting for a missing output pulse from the comparator and timing the interval. If the comparator was enabled *before* the pulse was generated, then what wound up getting measured was not the capacitor's ESR, but the circuit's cumulative inductance – as was the case for the published source code; The point you actually want to measure is the one marked ESR; this appears, on average, 2us after the start of the initial pulse. I would assume (hope) that the commercially sold units would take this into account. Anyway, once you know what it going on it is easy enough to work around – the problem with adding it to this circuit, though, is the other stuff that is already there; specifically, the inductance circuitry and the various relays, etc needed to switch between them. A capacitor's ESR is frequently in the low milliohm range – and a relay's contacts can easily vary that much between operations. So, to accurately measure a capacitors ESR you really need a direct, carefully laid-out connection – not easy to do here without resorting to probably-not-working kludges. So, so long to measuring ESR ;-)

Software

Not too much to say about the firmware other than what is in the (not that well) commented source code. As I said above, I had to learn AVR assembler to do this project, and that learning curve shows, I'm afraid. All of the routines in the include files are designed primarily for ease of use. All registers are restored after calling and I've tried to be as consistent as I can in their parameters. That being said, though, they really do make things easier as long as you don't mind the extra space (especially some of the macros) they take – all of which can be optimized out to fit a specific situation.

Known Issues/Possible Improvements

The only issues that I'm aware of are in the capacitance measurement. When the test leads are open, the circuit will continuously cycle through each range; if a really big honkin' (technical term) capacitor is attached while it is in the 5ua range, it will appear to lock up (actually not, just gonna take a *long* time). This doesn't happen very often and the fix would screw up very tight timing, so just disconnect the cap and try again.

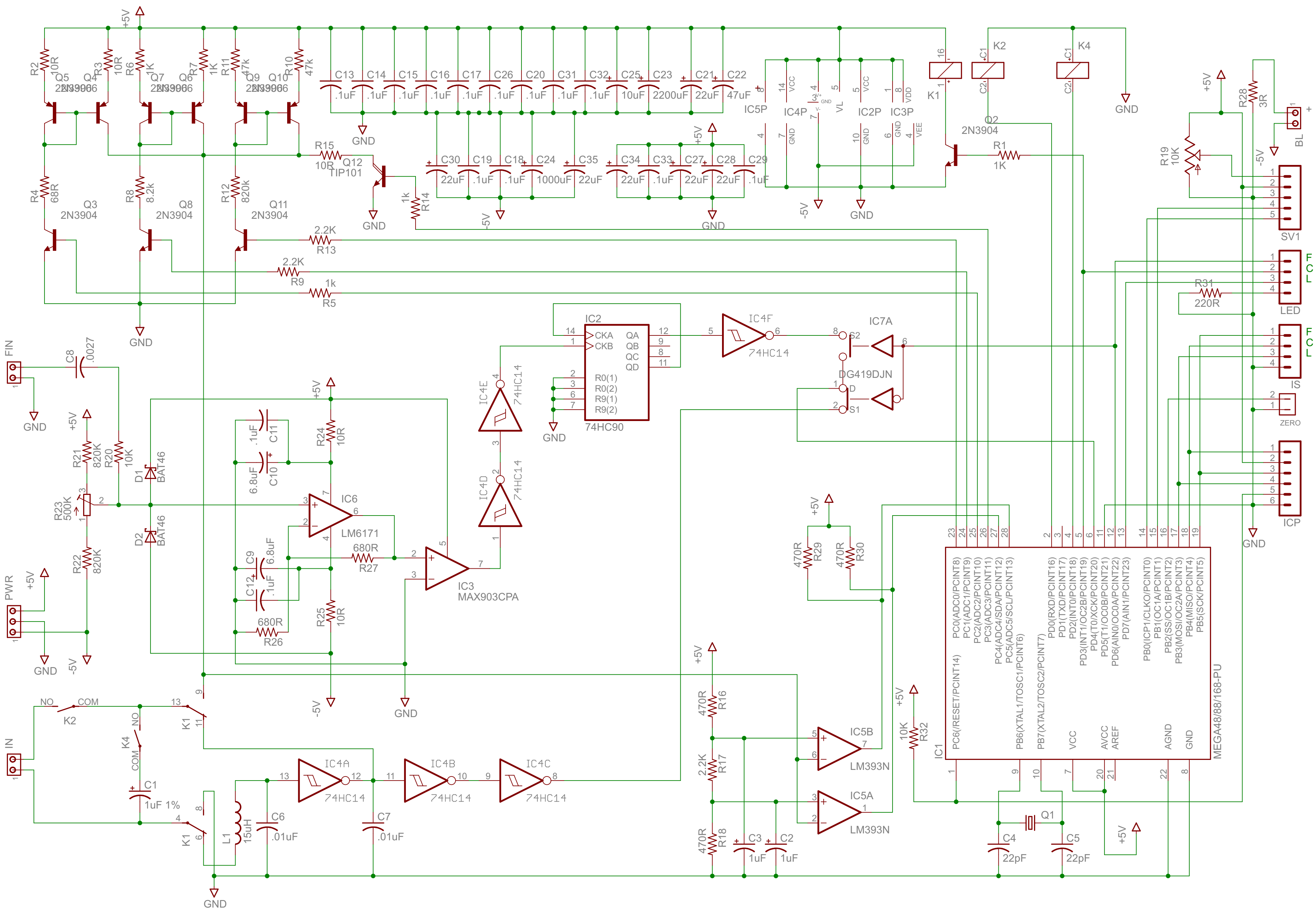
Sometimes you have to press a mode/zero button for a while before it registers – not really a problem, but something that could be tweaked.

Not an issue per se, but you may wonder: I'm powering the LCD backlight from the negative leg of the +-5v supply instead of the positive (not that it really matters, anyway…). The reason applies to the end use for me: part of an existing breadboard I built. It has internal supplies of +-12v and +-5v – and I already have another LCD backlight being run off the +5 leg, so I put this one on the -5 leg to balance.

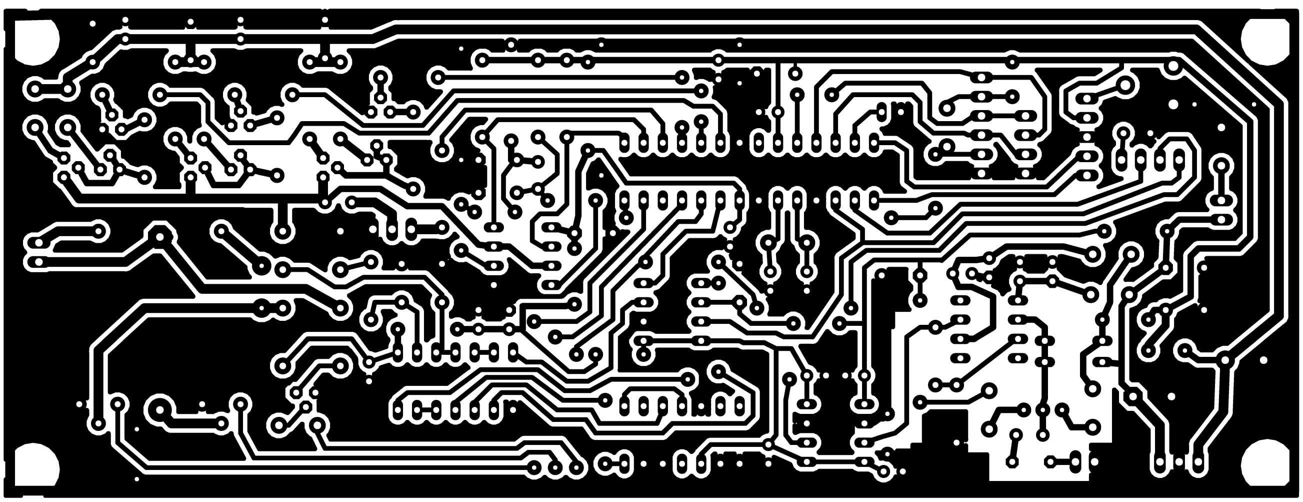
The frequency counter was really thrown in as an afterthought; if all you deal with are logic levels, it could be simplified a good bit. If you *are* interested in analog signal levels, it could be improved and/or expanded – if nothing else, use a bootstrapped input to increase impedence.

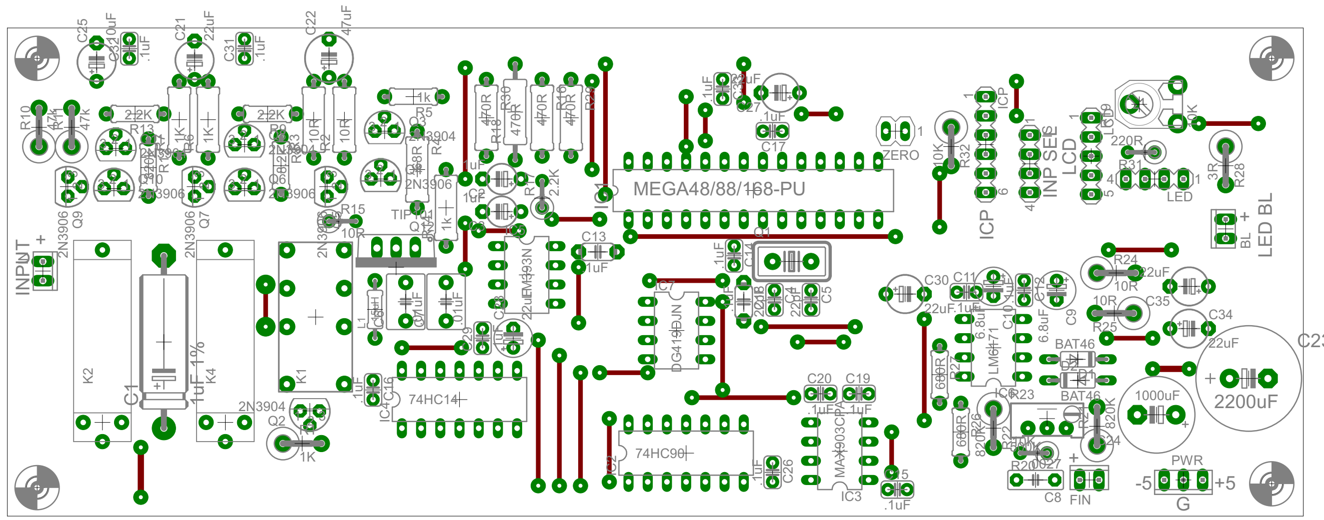
There is not a lot of wiggle room if you are interested in changing components; the HC TTL really does need to be high speed – *don't* replace with LS. The LM6171 could be replaced with a slower part (and the 74HC90 eliminated) if you are only interested in <1-2 Mhz (Although the LM6171/6172 parts are *really* nice – usually just plug and play, no fiddling required).

The resistors used in the current sources – *especially* the 50ma – really should be 1% metal film; not for precision but for thermal stability. It's no big deal if you use 5% carbon comps, though – just calibrate more often.



+5V
R2 10R
R3 10R
R6 1K
R7 1K
R11 47k
R10 47k
Q5 2N3906
Q4 2N3906
Q7 2N3906
Q6 2N3906
Q9 2N3906
Q10 2N3906
R4 68R
R8 8.2k
R12 820k
Q3 2N3904
Q8 2N3904
Q11 2N3904
R15 10R
Q12 TIP101
R14 1k
R13 2.2K
R9 2.2K
R5 1k
GND
C13 .1uF
C14 .1uF
C15 .1uF
C16 .1uF
C17 .1uF
C26 .1uF
C20 .1uF
C31 .1uF
C32 .1uF
C25 10uF
C23 2200uF
C21 22uF
C22 47uF
C30 22uF
C19 .1uF
C18 .1uF
C24 1000uF
C35 22uF
C34 22uF
C33 .1uF
C27 22uF
C28 22uF
C29 .1uF
-5V
IC5P
IC4P
IC2P
IC3P
VCC
VDD
VL
VEE
K1
K2
K4
Q2 2N3904
R1 1K
R19 10K
R28 3R
BL
SV1
LED
IS
ZERO
ICP
R31 220R
F
C
L
FIN
C8 .0027
R21 820K
R20 10K
R23 500K
R22 820K
D1 BAT46
D2 BAT46
PWR
C11 .1uF
C10 6.8uF
R24 10R
IC6 LM6171
R27 680R
C9 6.8uF
C12 .1uF
R26 680R
R25 10R
IC3 MAX903CPA
IC4E 74HC14
IC4D 74HC14
IC2 74HC90
CKA
CKB
QA
QB
QC
QD
R0(1)
R0(2)
R9(1)
R9(2)
IC4F 74HC14
IC7A DG419DJN
S2
D
S1
R29 470R
R30 470R
IN
NO
COM
C1 1uF 1%
L1 15uH
C6 .01uF
C7 .01uF
IC4A 74HC14
IC4B 74HC14
IC4C 74HC14
R16 470R
R17 2.2K
R18 470R
C3 1uF
C2 1uF
IC5B LM393N
IC5A LM393N
R32 10K
IC1 MEGA48/88/168-PU
PC0(ADC0/PCINT8)
PC1(ADC1/PCINT9)
PC2(ADC2/PCINT10)
PC3(ADC3/PCINT11)
PC4(ADC4/SDA/PCINT12)
PC5(ADC5/SCL/PCINT13)
PC6(/RESET/PCINT14)
PB6(XTAL1/TOSC1/PCINT6)
PB7(XTAL2/TOSC2/PCINT7)
PD0(RXD/PCINT16)
PD1(TXD/PCINT17)
PD2(INT0/PCINT18)
PD3(INT1/OC2B/PCINT19)
PD4(T0/XCK/PCINT20)
PD5(T1/OC0B/PCINT21)
PD6(AIN0/OC0A/PCINT22)
PD7(AIN1/PCINT23)
PB0(ICP1/CLKO/PCINT0)
PB1(OC1A/PCINT1)
PB2(SS/OC1B/PCINT2)
PB3(MOSI/OC2A/PCINT3)
PB4(MISO/PCINT4)
PB5(SCK/PCINT5)
VCC
AVCC
AREF
AGND
GND
Q1
C4 22pF
C5 22pF




MEGA48/88/168-PU
74HC14
74HC90
2200uF
1000uF
C23
INPUT
LED BL
LCD
ICP
ZERO
PWR
-5
+5
G
FIN
TIP41
1uF 1%
BAT46