HP 740B CHOPPER DRIVER

Rehabilitating Photochoppers in the HP 740, 741, 419, 3420, etc.

Version 1.1, January 2023
Written for microcontroller program version 1.0 and
printed circuit board version 1.3 .
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Disclaimer: I own a 740 only. My driver board should work in the 741, 419, and 3420, but YMMV.
I may need to update the board layout for 419 - the manual shows a turret terminal in the lower left corner. I need a real picture.

INTRODUCTION

HP's photocell choppers were a neat solution to the switching problem. You get a quiet, stable modulator and demodulator in one compact no-maintenance assembly, and all you have to do is light two neon lamps.

This approach has some problems. First, HP had to select pairs of cells that would work well enough. Only cells in a certain range of sensitivity could be used, while measurements today show 1000:1 variation. Second, photocells wear out. (Not from usage but from time.) Many instruments are inoperative today because one or more photocells have become slow or blind.

With a photocell modulator and a photofet demodulator, you can use your two best photocells, the photofets make near-ideal switches at the demodulator end, and with customized brightness and timing, you can make your chopper amplifier better than new.

I came up with a design that fits on the demodulator end of the housing, replacing that pair of photocells with photofet switches and lighting the modulator cells with LEDs. The 740 and 741 models have two amplifiers and need two driver boards.

EQUIPMENT

Scope, dual-trace, triggered
Amplifier
  AC, 50Hz-10kHz
  100K input impedance
  Fixed gain, anything from 1x to 10x
  Output 30V peak-to-peak to 10K load
  I used HP 465A but any audio amp should work
PIC uC programmer for PIC12F752
Photocell Grading Jig
  50uA current source
    Transistor/resistor/dual power supply
  Resistor substitution box
  Power supply or rig a cable from your 740B
Modem Efficiency Jig
  Amplifier, resistors, capacitors
Calibration Jig
  10K pot
  10K resistor
  SPST normally-open momentary-contact switch
  Cable and 5-pin connector for 2.54mm square pins

REQUIRED INSTRUMENT MODIFICATION

SCOPE: 740 only
LOCATION: A3
ACTION:
1. Remove C5 (1uF, Q6 base to emitter)
2. Add C91 (10nF, Q6 base to collector)
REASON: C5 exists to suppress oscillation, but it causes output foldback when the chopper amp is overloaded, and the instrument fails to slew in the positive direction. C91 suppresses the oscillation without foldback.
NOTE: Compatible with all 740, with or without my chopper driver. Not applicable to 741/419/3420.

PREPARATION

My nomenclature: V1/V2 are modulator series/shunt, V4/V3 are demod series/shunt.

1. Remove the chopper module from the instrument, recording how the wires are connected.

2. Tape off the neon driver wires. (419: Disconnect the old driver circuit from the battery to save power.)

3. On the chopper module, mark the photocell positions V1 V2 V3 V4.

4. Remove the neon lamp board and photocells from the chopper module, recording how the cells are wired to the terminals.

We use surface-mount 2835-size to 3535-size LEDs, two per chopper.
I like the Lumileds 2835 series for 9V and 3030HV series for 24V.
I used 2700K 80CRI parts.
For 740/741, you can use 9V or 24V LEDS, powered by -42V/-34V.
For 419, use 9V LEDs on 24V.

MATERIALS per module

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2    LED, white, surface-mount, 2835 outline, 2700K, 80CRI D1/D2
     Lumileds 2835 series for 9V
     Lumileds 3030HV series for 24V
2    H11F1 photofet optoisolator DIP6 U3/U4
2    5-pin square-pin header, surface-mount, Amphenol 10129380-905001BLF J3/J4
4    2N7002 surface-mount MOSFET SOT23 Q1/Q2/Q3/Q4
1    1uF 25V surface-mount 1206 C1
1    BZX84-A5V1 zener SOT23 D3
1    BZX84-B12V zener SOT23 D4
1    47K 0805 R6
1    resistor 1206 selected R1
1    resistor 1206 selected R2
1    resistor 1206 selected R5
1    resistor 1206 selected R8
1    resistor 1206 selected R11
1    PIC12F752 SOIC8 U1
2    P4KE33CA or SA30CA TVS bi 30V A17CR1 A17CR2 (740 A17 only)
1    LND150 500V depletion-mode MOSFET (740 A17 only)
1    1uF 25V or 50V C5 (740 A17 only)
     Recommend Kemet C331C105K5R5, C340C105K5R5, or C440C105K5R5
     or anything that's physically large but still fits
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The board layout is on file at OSHPARK, user "d44617665@hotmail.com", file "HP-Chopper-Photocell-Driver.kicad_pcb". One order gets you three boards, enough to do one 740/741 plus a spare. Or three 419's. On the version 1.2 board, don't install C2, and jumper across R7. Version 1.3 eliminates C2 and R7.

The microcontroller program is "740B-1Chan.X.production.hex".
Source code is "HP740_1Chan_Chopper_Driver_PIC12F752.asm".
(There's also a file for the PIC12F675.)

BOARD ASSEMBLY

Observe ESD precautions.

Cut one of the 5-pin headers into a 2-pin and a 3-pin.
For 740 and 741, install a two-pin header on V+/V-, and jumper Guard to V+. For 419, install a three-pin header.

See the driver board schematic. Calculate values for R1, R2, and R5 to get the appropriate current at your supply voltage. (You will determine R8 and R11 later.)

Prepare the H11F1's by cutting pins 4, 5, and 6, leaving enough stub to tack-solder a wire.

Put a LED on each of the two discs. Cathode goes on the wide pad. Solder lengths of wire on the back, with the front ends even with the disc so the LED will stand proud of the solder. Use solid wire for mechanical stiffness.

The board is going to mount on the demodulator side of the chopper module, with the discs down the holes where V3 and V4 used to be.

Solder parts onto the board, leaving R8 and R11 unpopulated.

Cut a rectangle of plastic film to insulate the driver board from the module. It has to withstand 500V. I sacrifice a thick polyethylene freezer food storage bag. Lay the material against the back side of the board, and mark the two silkscreen circles. Lay the material against some disposable backing material (I use corrugated cardboard) and cut out the circles. Cut inside the marks. I use a craft knife.

Tack the film to the board. I use Loctite Stik-N-Seal. After it sets, cut away film around the board outline, including the turret terminals.

Thread the disc wires through J1 and J2, on the back side of the board. Each pad has a unique shape.

Temporarily install the board on the module with the discs down the holes. Space the discs close to but not touching the wire mesh that shields V1 and V2. When viewed through the old neon holes, the disc will be just below the “beltline” of the hole.
Solder the wires.

MODULE ASSEMBLY, PART 1

Tack the board to the module. Clamp and let dry.

Cut/drill a backing plate of PCB or plastic to replace the neon board. It must withstand 500V. It must be no larger than the old board, or you may not be able to install the module - 740B A17 is a VERY tight fit. The back side copper is at Guard potential while the front side is Module-ground. If you use copper-clad PCB material, remove the copper around the center screw hole. (Do not think you can use a plastic shoulder washer, it subtracts from the screw length which is critical.)

The rectangle is 2” wide and 1-7/16” high. Put a 9/64” hole in the exact center, then two 3/16” holes ½” to either side and 11/32” above and below. Blacken the area behind the neon holes to reduce light cross-coupling. Set aside.

Air-wire the H11F1 pins 4 and 6 to the turret terminals. U4.6 to Out, U4.4 and U3.6 to Common, U3.4 to Ground.

740 A17 only: Solder C5 (1uF 25V) between Common and the terminal at the lower right corner. This replaces the original C5, which is too short. The recommended parts are X7R; big physical size gives the best DC-bias-capacitance curve. The leads need 500V insulation from onboard parts.

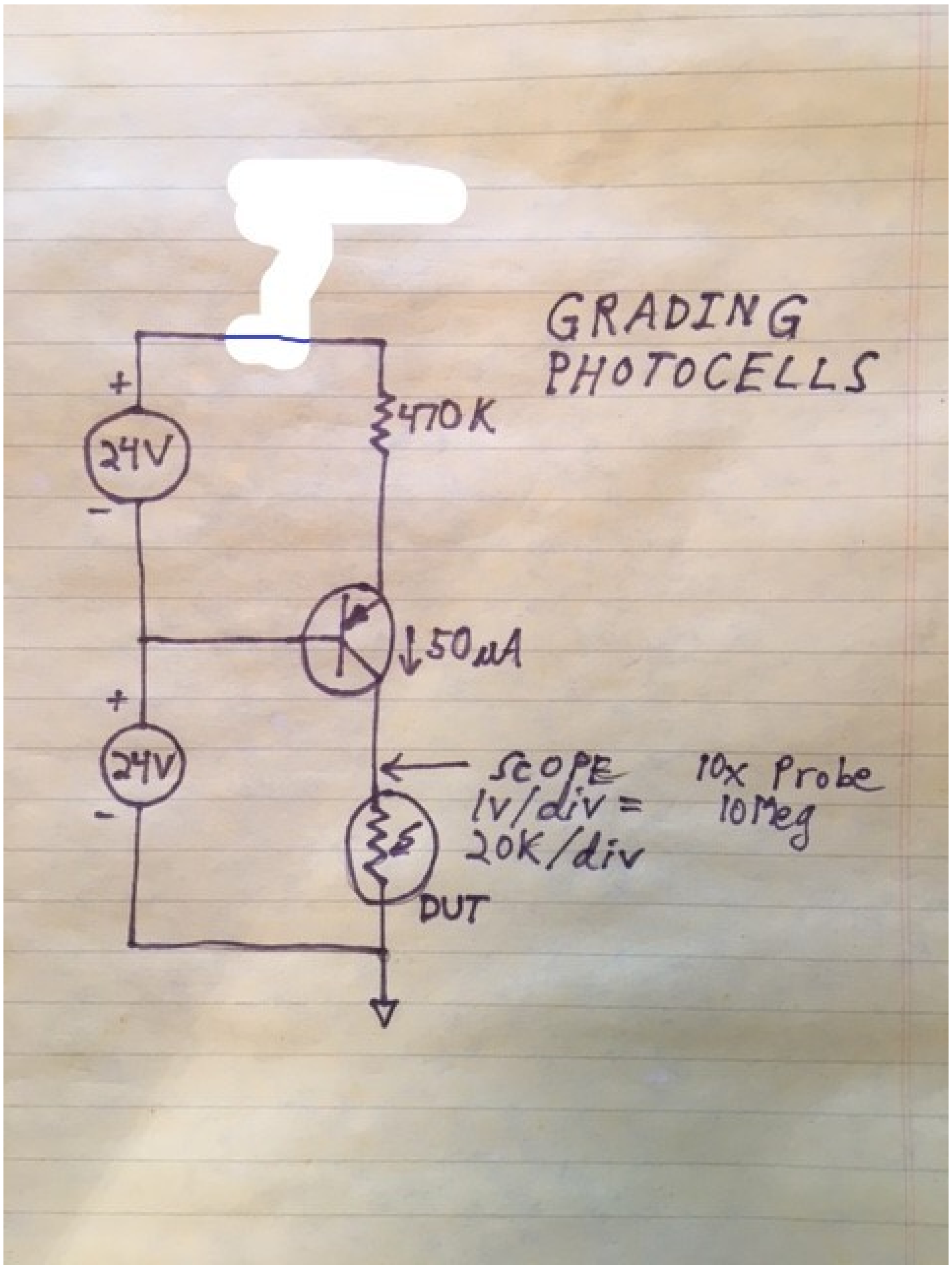
Install the backing plate (fake neon board) using the original long 8-32 screw and spacer. It doesn’t have to be hard-tight, just snug; the screw is really secured by the jam nut on the blank side of the module. Crank that nut tight but not break-the-screw tight. It has to stay put when you install the module in the instrument and tighten another nut on top of the jam nut to secure a ground-wire ring terminal.

PROGRAMMING

I program the microcontroller with a PICKIT 3 clone and PickitPlus software. Select PIC12F752, select the hex file ("740B-1Chan.X.production.hex"), click WRITE, and you're done. Pull off the cable.

SELECTING GOOD CELLS

Rig up photocell grading jig as pictured below.



0. If the instrument is a 740 and you’ve replaced HP's A9DS1-etc input protection with my LND150-based circuit, test A9V1 – it may be usable in a modulator. It is more sensitive than the chopper photocells, but that doesn’t matter since we customize the light level anyway.

1. Temporarily wire from the R11 and R8 pads to two resistor substitution boxes. (You will use R8 now, R11 later.)

2. Tack the candidate photocell into the V2 hole.

3. Power the board to blink the LEDs. The default pulse train is 1ms on, 5ms off. This can test all usable photocells. You could also use an external pulsed source.

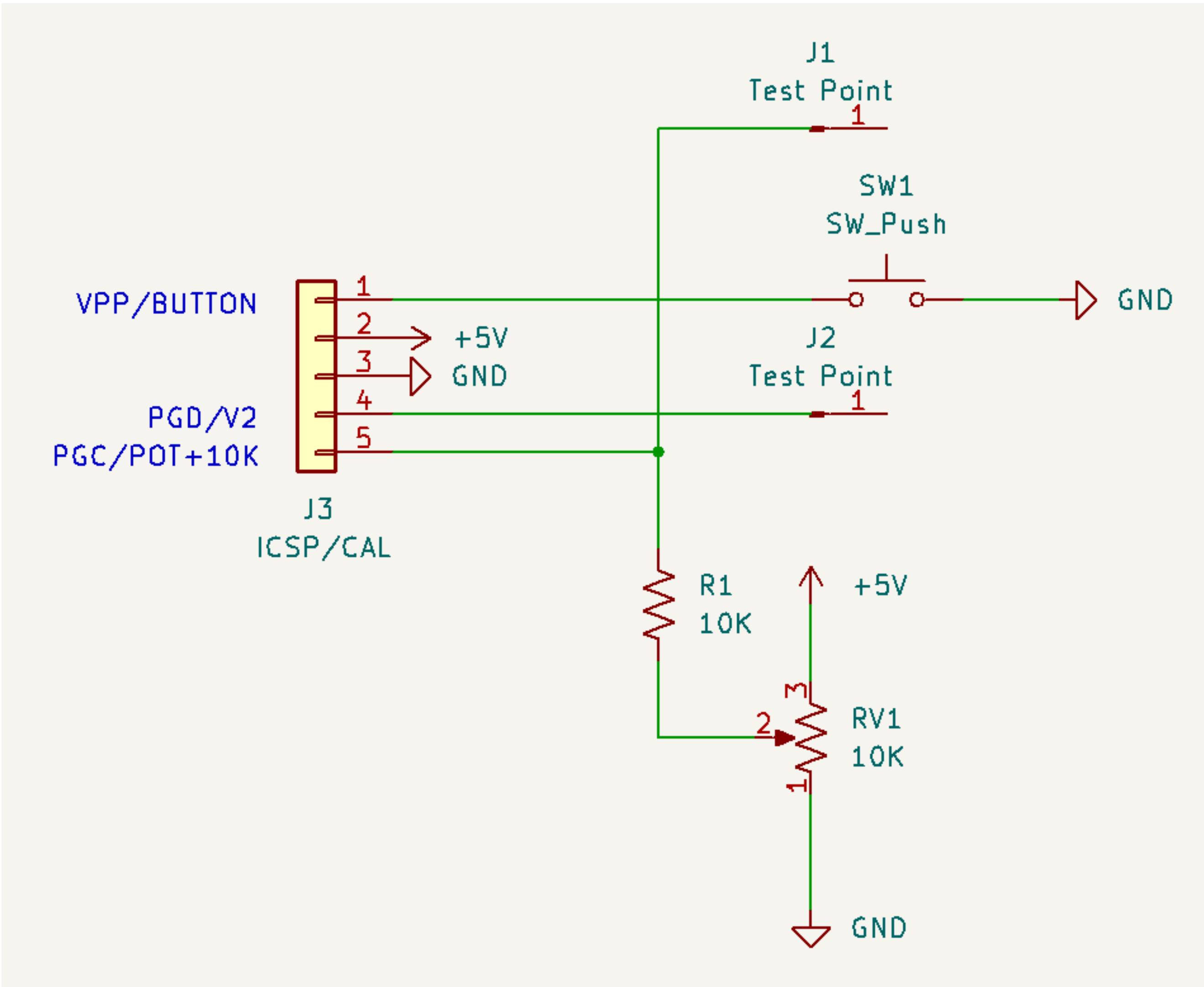
4. Trigger the scope from the LED. Be careful not to short out the rig with conflicting ground connections!

5. Adjust R8 for 1V on the scope, i.e. 20K on-resistance.

6. Measure time after LED OFF to reach 5V (100K).
   If 2ms or less, the cell is very good. 2ms-3ms are almost certainly usable. A 3ms-5ms cell may work when teamed up with a fast cell, but you’ll have to perform multi-axis adjustment, see TIPS AND TRICKS below.
   A cell that takes 5ms or longer to relax is not usable.

CALIBRATION

Rig up Calibration Harness as pictured below.



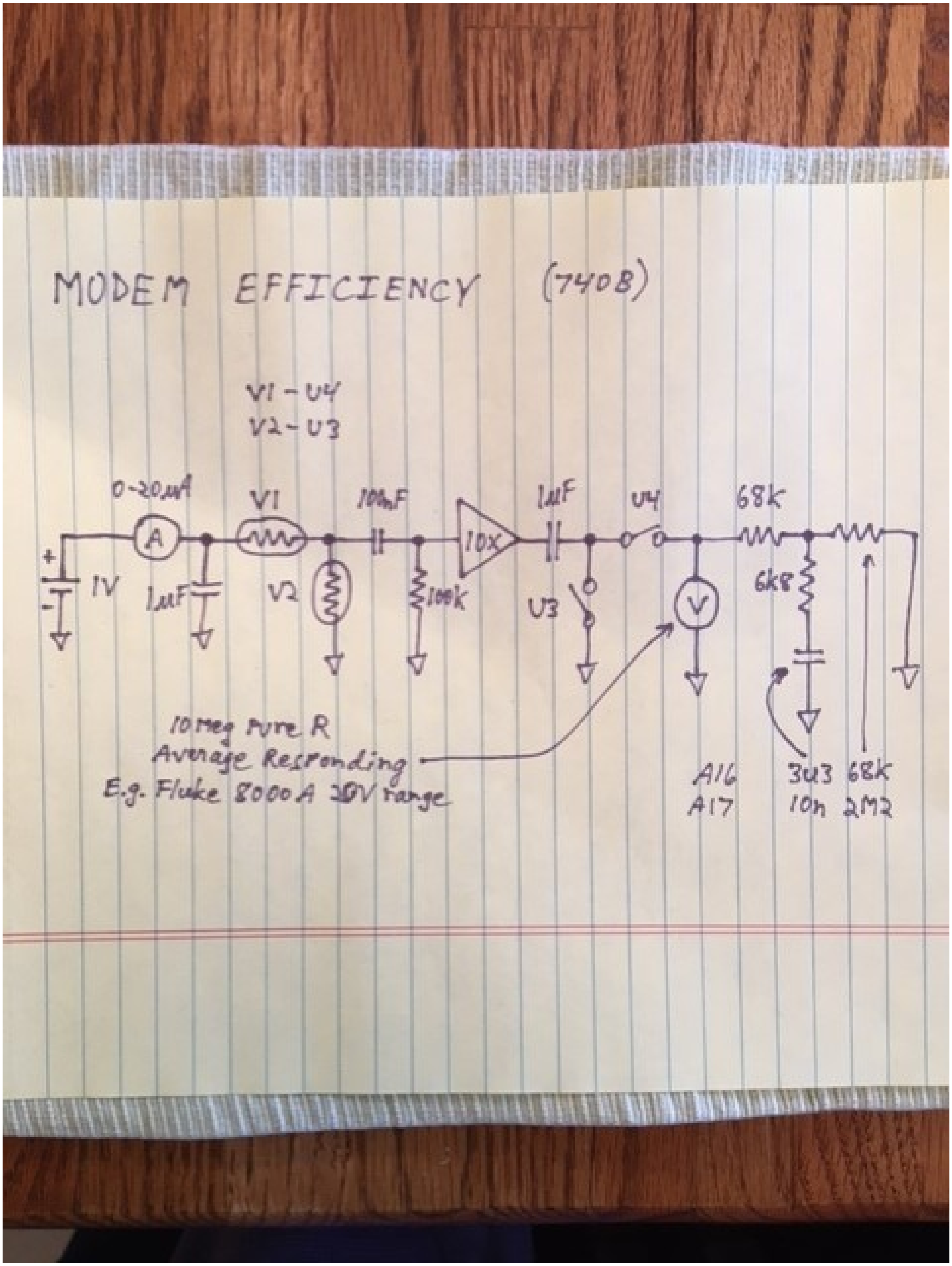
Observe ESD precautions.
Plug in the temporary power cable and the Calibration Harness cable.
Set up the scope to display and trigger on pin 4 i.e. V2, and display pin 5 i.e. the POT signal along with amplifier output.

After power on, press and hold the button more than one second to enable Observe mode. The POT signal cycle is 100us input to read the value, then 4ms of output to say which parameter is being observed. One bit per millisecond. First bit is sign (whether the pot is above or below the setpoint), second/third/fourth bits are the parameter number in binary. Tapping the button will cycle through the parameters.

Parameters are:
0. Select speed; 95Hz or 162Hz
1. Trim the on-chip oscillator
2. Lit-a (V2+V3)
3. Balance between dark-a and dark-b
4. Lit-b (V1+V4)
5. Overhang (V4 persist after V1-off)

On param 0, turn the pot to center.
On other params, turn the pot to where the sign bit changes.
Then press and hold again to enable Control mode.
Now turning the pot will adjust the param. Instead of param number, the POT signal displays on-off-on-off to show the timing of V1-dark-V2-dark. Tap will return to Observe mode and move to the next parameter. Press/hold will save settings and return to Observe mode.

Rig up Modem Efficiency Jig per sketch below.



0. Lit-a (V2-time) default is 1ms. You should not have to change it.

1. Select speed, and trim frequency. 95Hz for 740 A16, 162Hz otherwise.

2. Overhang default is maximum. On 740 A17 change it to minimum.

3. Set lit-b (V1-time) to maximum.

4. Adjust balance for high R-in, biased toward high efficiency.

5. Reduce lit-b until R-in is above the limit.
   160K for 740 A17, 350K for 740 A16, 85K for 741, 60K for 3420,
   TBD for 419.

6. Efficiency must be at least 30% for 740 A16,
   40% for 740 A17, TBD others.
   My best two pairs of cells made around 60% efficiency
   and over 500K R-in. They went into 740B #2.
   The cells I put in 740B #1 also got 60% efficiency,
   with A16 reading 400K and A17 reading 200K.

When you're done calibrating, save the settings and install a jumper across pins 1 and 2 (MCLR and Vdd) to protect the microcontroller from EMI/ESD.

TIPS AND TRICKS

Lit-a charges the demod coupling cap. On large transients, charging current pushes U3 into constant-current (pentode) mode, and full charge requires one millisecond. You can increase lit-a, but once the cap is charged, there's no advantage in staying on longer.

You have to juggle R8, R11, dark-balance, and lit-b, feeling your way to the optimum point of acceptable efficiency and acceptable R-in. R8 and R11 interact strongly. Brightening the LEDs, and increasing lit-b, improves efficiency while degrading R-in. Pick a reasonable setting for R8/R11, then tweak lit-b and balance, rinse lather repeat.

Pairs of cells that are 3ms or slower can’t meet spec, but a slow cell paired with a fast cell may work.
Example: 1.8ms and 4.4ms.

Put the fast cell in V2. You’ll probably end up with low dark-balance (V1 on soon after V2 off), and a large lit-b that is constrained by R-in. You will almost always leave overhang at maximum since any voltage into the load is better than none. (740 A17 benefits from reduced overhang, the load is a peak detector and leaving V4 on drags it down.)

The 741, 419, and 3420 choppers are 162Hz, but try 95Hz if your cells are on the slow side. In the 741 you might get instability if you run the main chopper at 95 but the meter chopper should be fine.

MODULE ASSEMBLY, PART 2

Permanently mount your chosen cells and wire them to the terminals.

Remove the temporary wires and solder in R8 and R11 whose values you have determined.

If 740 with HP's A9DS1-etc input protection replaced by my LND150-based circuit, add A17CR1 and A17CR2, 30V bidirectional TVS diodes, across V1 and V2 respectively (e.g. P4KE33CA, SA30CA) and A17Q1, an LND150 current limiter in series with the modulator output to protect A3 from transients. Drain to V1+V2, Source and Gate to the coax going to A3.

MEASURING CHOPPER AMPLIFIER GAIN

I reduce A3 (Main) and A2 (Meter) AC amplifier gain to bring the chopper amps back down to spec, using 10K pots in series with A2R11 and A3R11.

Main loop gain is measured with the GAIN CHECK button and procedure in the manual. Target gain is 10000. Meter loop gain is "measured" by timing the pointer swing with the 10^4 SENSITIVITY button depressed. The manual is ambiguous, only saying "two to three seconds". I believe they mean 0% to 95%, because that's the spec in another instrument's manual. When 740B#2 goes 0 to 95 in two seconds, chopper amp gain reads about 5000 using the procedure below.

A BETTER WAY TO MEASURE GAIN

Attach a resistor to the summing junction.
Apply negative voltage to the resistor so the meter is full-scale.
(Negative because A2C8 is polar electrolytic.)

For Meter, use 1.4Meg to A2R19/A2Q6.B. SENSITIVITY=10^4.
Gain = V * 1000, where V is the voltage you applied.
4.5V is gain of 4500.

For Main, use 2Meg to A4R2/A4Q1.B. RANGE=10mV, SENSITIVITY=10^2.
Gain = V * 10000, where V is the voltage you applied.
1V is gain of 10000.

FINAL INSTALLATION

I install the power cable first. For 740 (741) it's a two-wire cable from C2 (C12) to a two-pin connector. In the 740 it's at Guard voltage, which can be up to 500V above or below the main chassis. Once inside the guarded chassis, it's effectively low voltage except for anything referred to GND1 or GND2 which again may be 500V away.

For 419 the power cable is three wires: two to the battery (after the power switch), plus Guard.

Connect the cable, then bolt in the module and attach the six signal wires as before.