The Simple PICTIC

Are you an amateur bit by the Time-Nut bug but can't afford a commercial time interval counter with sub nanosecond resolution and a GPIB interface? Did you find a universal counter on eBay with good time interval resolution but became frustrated figuring out the GPIB interface and writing a command script to get the counter data into your PC so you could analyze it? Are you an experienced Time-Nut tired of tying up multiple expensive commercial counters over extended periods comparing multiple frequency standards to GPS just to establish traceability? The Simple PICTIC is a low-cost high-resolution 10-digit interpolating time interval counter with RS-232 serial port designed for GPS monitoring applications to free up your expensive commercial counters for other uses.

The Simple PICTIC is an 8-IC package 3.8" x 2.5" thru-hole evaluation board for amateur construction offering the core functions, time to voltage interpolators, and automatic calibration system used in the PICTIC module. The Simple PICTIC doesn't include a display, input signal conditioning, polarity or trigger point selection, or start channel detection and requires TTL compatible inputs triggering on the rising edge and a small delay between the start and stop events for proper operation. A simple half-can 5v TTL XO is used as the on-board timebase with provisions for connecting and selecting an external TTL timebase. The Simple PICTIC documentation, PIC assembly code, and ExpressPCB files are being offered free of charge to members of the Time-Nuts list allowing incorporation of the interpolator and support code into other amateur projects requiring a high-resolution TIC. Sets of 3 Simple PICTIC circuit boards can be ordered directly from ExpressPCB MiniBoard service for $51 plus shipping for a user assembled cost of about $50 per board to evaluate the PICTIC design for your own applications.

A GPS receiver is limited in how closely it can resolve the 1PPS timing but +/- 1ns accuracy can be achieved with the better timing receivers using GPS sawtooth corrections to correct the TIC data. A TIC resolution of at least 500ps is needed with sawtooth corrections to insure the full GPS receiver accuracy is utilized. The HP 53131 10-digit universal counter is often employed commercially due to its 500ps resolution, serial output, small (3.5" x 8.5" x 13.75") size, and low ($2164.00) cost. For GPS monitoring applications the start and stop inputs are 1PPS TTL rising edge signals from the local standard and GPS receiver so signal conditioning, multiple counter modes, and a display are optional, but a serial port simplifies logging the counter data to a PC for analysis.

The Simple PICTIC provides a 9600-baud RS-232 serial port for logging 250ps resolution 10-digit BCD data to a PC, has no display or power supply so it is very small and easily incorporated into other systems, and can be built by an amateur for about $50. No signal conditioning is used insuring both channels have identical trigger points for improved accuracy. No statistics, accumulation, or averaging modes are included and a simple ASCII terminal program displays the data, logs the results for analysis, and configures the counter using Motorola @@Xy style serial commands. The serial baud rate and number of bits limits the maximum output rate to about 80 updates per second, but the sampling routine can operate at much faster rates.

A Simple PICTIC using a 10 MHz XO timebase, no prescaler, and a unity gain buffer provides a sample resolution of 250ps suitable for GPS monitoring. The recommended 10 MHz 30PPM XO timebase introduces less than a +/- 1-count error across a 0C - 50C temperature range measuring time intervals less than 10us, providing sufficient accuracy for determining small differences in coarsely synchronized 1PPS references. The lower XO stability provides a natural timebase dithering effect, which increases averaging accuracy and simplifies initial calibration of the interpolators as they frequently pass between minimum and maximum values. Once the interpolators are calibrated an automatic calibration mode can be enabled that tracks the interpolator peak-to-peak data values returned over hourly periods (with 1PPS inputs) to determine and correct for interpolator hardware variations with temperature and component age. The automatic calibration mode will not work properly when a high stability external timebase is used, as hourly peak-to-peak variations may not occur with a high stability input so automatic calibration must be disabled when a high stability timebase is used.

The user can vary the resolution of the Simple PICTIC during construction to suit their needs by installing an optional prescaler, selection of the XO speed, the sampling capacitor value, the interpolator charge current, and the buffer gain and offset resistors. In the typical configuration a 10 MHz 30PPM XO is used with 470pf sample caps, a charge current of 10ma, and a unity gain buffer. The charge currents are adjusted for ADC counts from roughly 300 to 700 or a peak-to-peak span of exactly 400 ADC counts representing one clock period or 100ns / 400 = 250ps resolution. The normal unity gain interpolator buffer provides improved temperature stability at the expense of reducing the resolution by half with hourly peak-to-peak span variations of 1-2 counts under typical shop conditions using CD15 series 5% dipped mica sample capacitors. With auto calibration the hardware zero and span variations with temperature and age can be detected and corrected in software to improve the long-term interpolator accuracy.

Three resistors can be added to the interpolator buffer amps to double the resolution by doubling the buffer gain and introducing a fixed offset to reduce the minimum count. Only 80% of the ADC range is used to allow for temperature and age variations in the high gain configuration so the resistors are selected by the user to give ADC counts from 100 to 900 during initial setup for a span of 800 counts and a maximum resolution of 125ps with a 10 MHz timebase. Doubling the buffer gain increases the resolution but also doubles the temperature variations and adds additional variations caused by the gain resistors and offset supply. A high-speed prescaler and faster timebase is recommended for increased resolution and increasing the timebase rate to 66 MHz allows the Simple PICTIC to achieve a maximum 18.75ps resolution. For comparison the SR620 counter uses ECL logic, an 80 MHz timebase, 6x buffer gain, and a 12-bit ADC to provide an interpolator gain of 3000 and a resolution of 4.16ps. For faster timebase rates charge currents up to 40ma can be used with larger sample caps to optimize the transistor switching speed. For common XO frequencies the recommended capacitor values, currents, and sample resolutions in low and high gain configurations is shown below.

XO Speed	CAP	CHG_I	Resolution
10M	470pf	9ma	250ps / 125ps
20M	470pf	19ma	125ps / 62.5ps
25M	470pf	24ma	100ps / 50ps
33M	270pf	18ma	75ps / 37.5ps
40M	270pf	22ma	62.5ps / 31.25ps
50M	270pf	27ma	50ps / 25ps
66M	270pf	35ma	37.5ps / 18.75ps

Simple PICTIC Commands

Command	Function
#	**Aborts current command or data entry**
@@A	**Calibrate A Interpolator Commands**
@@Ac	Set Ch A Center Value (xxx HEX)
@@As	Set Ch A Span Value (xxx HEX)
@@Az	Set Ch A Zero Value (xxx HEX)
@@B	**Calibrate B Interpolator Commands**
@@Bc	Set Ch B Center Value (xxx HEX)
@@Bs	Set Ch B Span Value (xxx HEX)
@@Bz	Set Ch B Zero Value (xxx HEX)
@@C	**Calibration Commands**
@@Cd	Disable Autocal Mode, Manual Cal Only
@@Ce	Enable Autocal Mode
@@Cr	Reset Autocal Peak Detectors
@@Ct	Set Calibration Time in Samples (xxxx HEX)
@@Cp	Print Calibration Values and Time in HEX
@@D	**Select Display Parameters at Update**
@@Dc	Toggle Display Calibration Values in BCD
@@Dd	Toggle Display 10-Digit Time Delay in BCD
@@Di	Toggle Display Corrected Start and Stop in BCD
@@Dp	Toggle Display Peak Detector Values
@@Dr	Toggle Display Raw Interpolator Data in BCD
@@Ds	Toggle Display Status Digits
@@Dt	Toggle Display TIC Counter Data in BCD
@@Dv	Toggle Display Interpolated Value in BCD
@@M	**Operating Mode Commands**
@@Md	Direct Input to Counter
@@Mh	High Gain Mode (Gain = 800)
@@Mn	Normal Gain Mode (Gain = 400)
@@Mp	Prescaler Input to Counter
@@P	**Print Commands - once to serial TX**
@@Pc	Print Calibration Data in BCD
@@Pi	Print Interpolator Data in BCD
@@Ps	Print Status Digits in BCD
@@Pt	Print Calibration Time in BCD
@@R	**Run Command - Resets and starts counter**
@@S	**Stop Command - Stops counter**
@@U	**Update EEPROM Calibration Values**

Bill of Materials

ID	Description	Mouser Part Number	12/08 Price
C1	0.1uf 50v Ceramic Capacitor	80-C320C104K5R5CA	0.14
C2	0.1uf 50v Ceramic Capacitor	80-C320C104K5R5CA	0.14
C3	10uf 25v Tantalum Capacitor	80-T350E106K025AT	0.67
C4	10uf 25v Tantalum Capacitor	80-T350E106K025AT	0.67
C5	.01 50v Ceramic Capacitor	80-C320C103K5R5CA	0.13
C6	.01 50v Ceramic Capacitor	80-C320C103K5R5CA	0.13
C7	10uf 25v Tantalum Capacitor	80-T350E106K025AT	0.67
C8	0.1uf 50v Ceramic Capacitor	80-C320C104K5R5CA	0.14
C9	0.1uf 50v Ceramic Capacitor	80-C320C104K5R5CA	0.14
C10	470pf 5% Dipped Mica Capacitor	598-CD15FD471JO3F	1.81
C11	0.1uf 50v Ceramic Capacitor	80-C320C104K5R5CA	0.14
C12	0.1uf 50v Ceramic Capacitor	80-C320C104K5R5CA	0.14
C13	0.1uf 50v Ceramic Capacitor	80-C320C104K5R5CA	0.14
C14	1uf 25v Tantalum Capacitor	80-T350A105K025	0.35
C15	1uf 25v Tantalum Capacitor	80-T350A105K025	0.35
C16	1uf 25v Tantalum Capacitor	80-T350A105K025	0.35
C17	1uf 25v Tantalum Capacitor	80-T350A105K025	0.35
C18	0.1uf 50v Ceramic Capacitor	80-C320C104K5R5CA	0.14
C19	470pf 5% Dipped Mica Capacitor	598-CD15FD471JO3F	1.81
C20	1uf 25v Tantalum Capacitor	80-T350A105K025	0.35
C21	.01 50v Ceramic Capacitor	80-C320C103K5R5CA	0.13
C22	.01 50v Ceramic Capacitor	80-C320C103K5R5CA	0.13
D1	LM385 1.2v Reference Diode	595-LM385BLP-1-2	0.80
J1	1x2 0.1" Header	649-69190-202HLF	0.14
J2	1x3 0.1" Header	649-68000-103HLF	0.18
J3	1x4 0.1" Header	649-69190-204HLF	0.18
J4	1x2 0.1" Header	649-69190-202HLF	0.14
J5	1x3 0.1" Header	649-68000-103HLF	0.18
J6	1x3 0.1" Header	649-68000-103HLF	0.18
Q1	2N3906 PNP Transistor	512-2N3906BU	0.07
Q2	2N3906 PNP Transistor	512-2N3906BU	0.07
Q3	2N7000 N-Ch DMOS FET	512-2N7000BU	0.13
Q4	2N3906 PNP Transistor	512-2N3906BU	0.07
Q5	2N7000 N-Ch DMOS FET	512-2N7000BU	0.13
Q6	2N3906 PNP Transistor	512-2N3906BU	0.07
Q7	2N3906 PNP Transistor	512-2N3906BU	0.07
Q8	2N3906 PNP Transistor	512-2N3906BU	0.07
R1	1K 5% 1/4w Carbon Film Resistor	291-1K-RC	0.10
R2	1K 5% 1/4w Carbon Film Resistor	291-1K-RC	0.10
R3	27 5% 1/4w Carbon Film Resistor	291-27-RC	0.10
R4	22K 5% 1/4w Carbon Film Resistor (OPT)	271-22K-RC	0.13
R5	200 10% 1/4w 20 Turn Cermet Trimmer	652-3296Y-1-201LF	2.20

R6	15K 1% Metal Film Resistor	(OPT)	271-15K-RC	0.13
R7	47K 1% Metal Film Resistor	(OPT)	271-47K-RC	0.13
R8	1K 5% 1/4w Carbon Film Resistor		291-1K-RC	0.10
R9	24K 5% 1/4w Carbon Film Resistor		291-24K-RC	0.10
R10	10K 1% Metal Film Resistor	(OPT)	271-10K-RC	0.13
R11	22K 1% Metal Film Resistor	(OPT)	271-22K-RC	0.13
R12	1K 5% 1/4w Carbon Film Resistor		291-1K-RC	0.10
R13	27 5% 1/4w Carbon Film Resistor		291-27-RC	0.10
R14	18K 1% Metal Film Resistor	(OPT)	271-18K-RC	0.13
R15	200 10% 1/4w 20 Turn Cermet Trimmer		652-3296Y-1-201LF	2.20
R16	1K 5% 1/4w Carbon Film Resistor		291-1K-RC	0.10
R17	1K 5% 1/4w Carbon Film Resistor		291-1K-RC	0.10
U1	74AC74 Dual D F/F		512-74AC74PC	0.54
U2	74AC175 Quad D F/F		512-74AC175PC	0.56
U3	74AC74 Dual D F/F		512-74AC74PC	0.54
U4	74AC163 4-bit binary counter	(OPT)	512-74AC163PC	0.67
U5	74AC86 Quad XOR Gate		595-SN74AC86N	0.40
U6	MAX232 RS-232 Converter		595-MAX232N	0.90
U7	16F688 PIC Micro Controller		579-PIC16F688-I/P	1.67
U8	L78L05 100ma 5v Regulator		511-L78L05ACZ	0.30
U9	UA78L06 100ma 6.2v Regulator		595-UA78L06ACLP	0.36
U10	TS274 Quad CMOS Op-Amp		511-TS274AIN	2.46
XO	10 MHz 30PPM 5v TTL Oscillator		815-ACH-10-EK	1.30
				Total $27.28

Notes:

U4 prescaler is optional at timebase rates below 16.7M

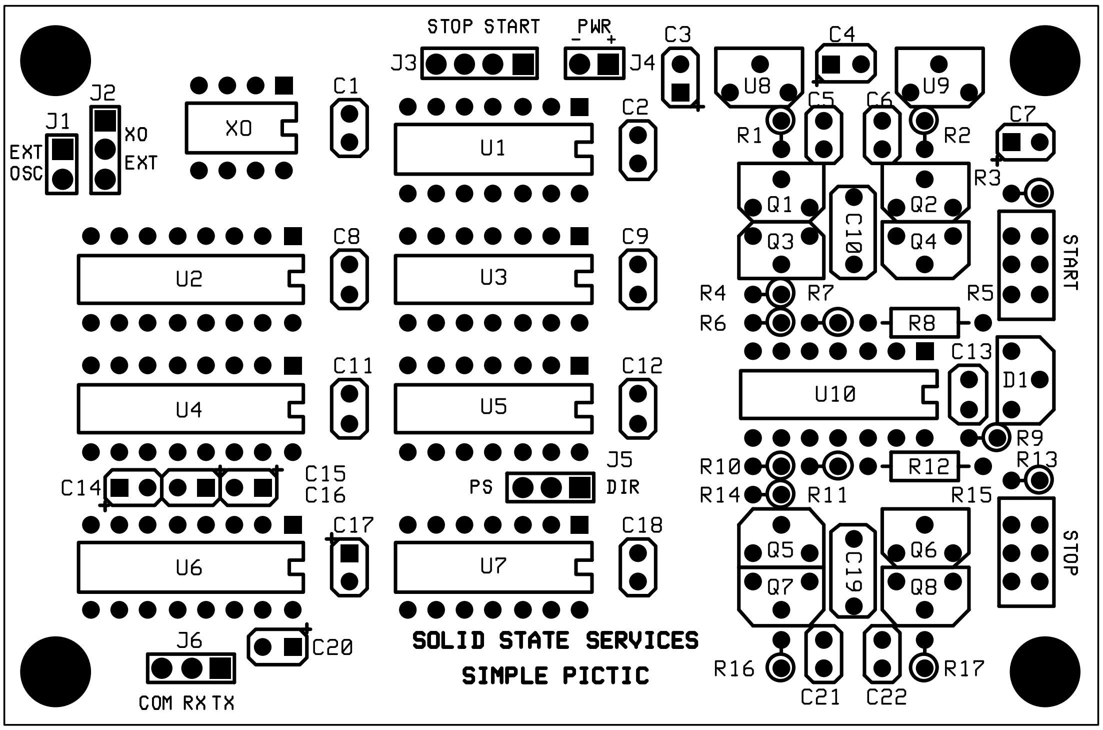
Charge currents can be adjusted over an 8:1 range for use with common sample capacitor values of 470pf or 270pf over a wide range of frequencies. Larger capacitor values with higher currents reduce the effect of stray capacitance and produce more stable results.

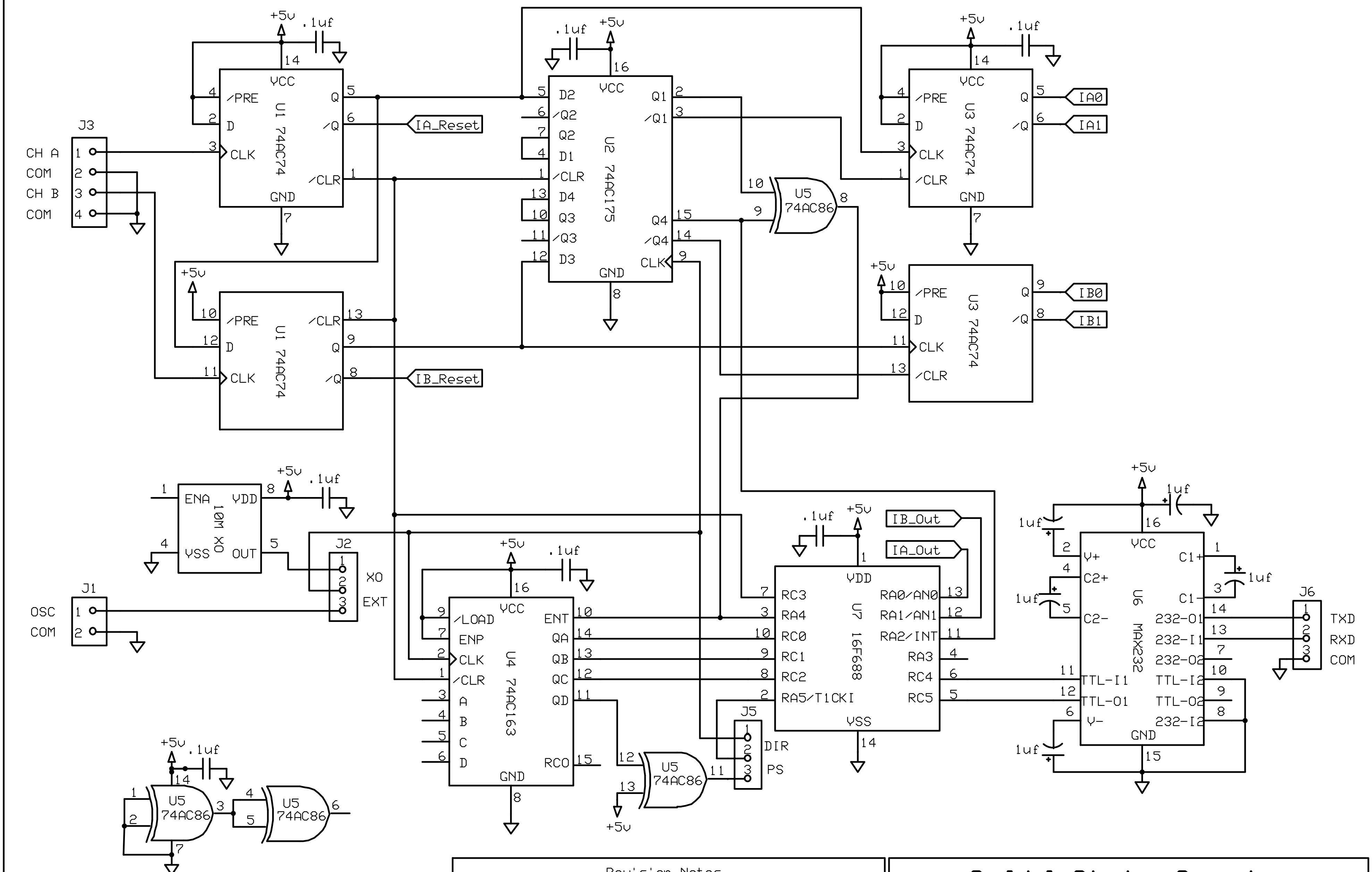
High Gain Option

Gain varies by the ratio of the feedback resistor and the parallel resistors to V+ and Gnd on the inverting input. Resistors are user selected based on the Min/Max count range at a unity gain span of 400 counts. Values shown were determined experimentally on similar hardware and may require adjustment. Use 1% Metal Film resistors for R4, R6, R7, R10, R11, and R14 and use the same resistor values in both interpolators for best temperature stability in the high gain configuration.

R6, R10 both use same values of 15K, 12K or 10K as needed (Gain Adjust)
R4, R14 both use same values of 22K, 20K or 18K as needed
R7, R11 both use same values of 47K, 43K, 30K, or 22K as needed (Offset Adjust)

Circuit Board Layout





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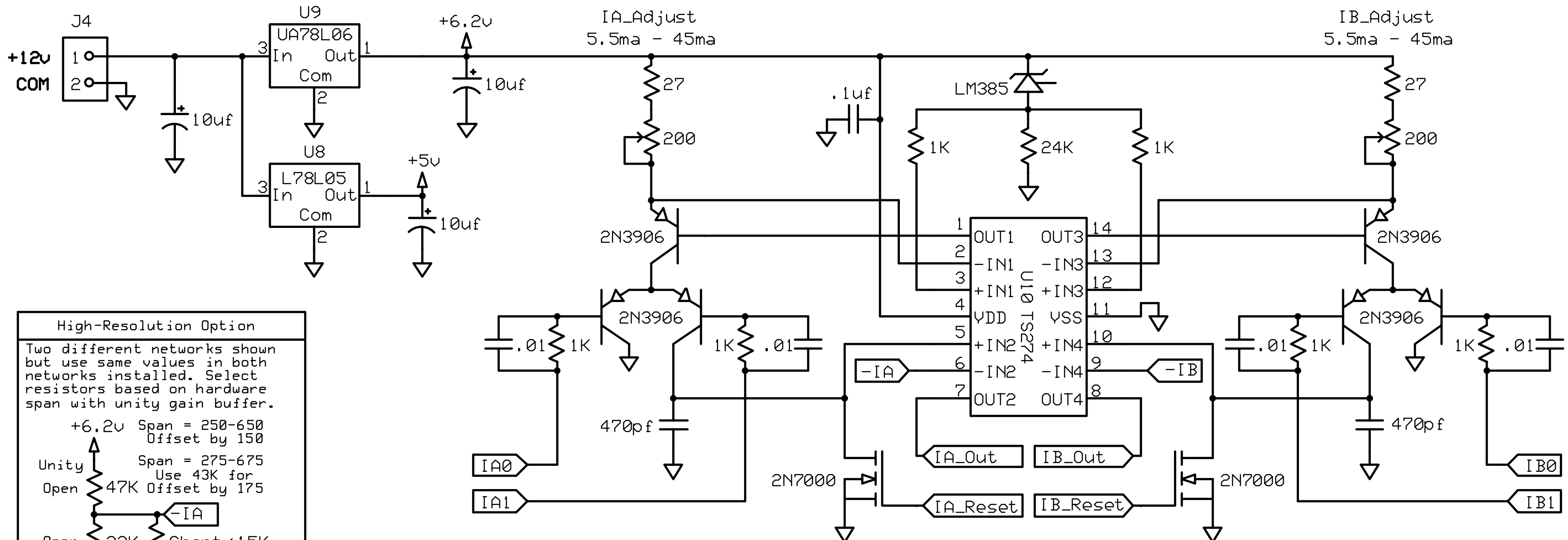

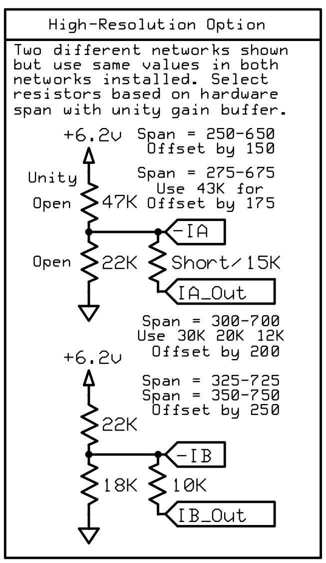

Charge current affects switching time of 2N3906 as shown below. Insure current is high enough so switching time < 1 clock period

5ma = 60ns   30ma = 14ns
10ma = 30ns   40ma = 12ns
20ma = 18ns   50ma = 14ns

For current selected use CD15 series dipped mica sample cap with cap value determined by I / C = 4 / 2 x clock period

High Resolution Option

High resolution option doubles the resolution by increasing the buffer gain to 2 and adding a negative offset voltage. Remove the jumpers between U10 pins 6 & 7, 8 & 9 and install the resistor networks above to increase the interpolator gain to 800. The unity gain span of 300 to 700 changes to 100 to 900 with the high resolution option installed. After installation adjust the gain for a span of 800 counts with an offset between 50 and 150 counts, adjust network if req'd

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PICTIC Interpolator

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