20 MHz GPSDO PLL

This is a preliminary document describing a GPSDO PLL that is to work with a ublox NEO-7 GPS receiver. Eventually it is desired to incorporate an Arduino uP to manage the startup with a simple display and a buffer board that will supply a suitable signal for reference frequency distribution employing 74HCT1G125 drivers.

The First PCB [1.7” x 1.7"] provides a PLL, an interface to the ublox GPS, an Arduino connection and a level converter for the serial communications. There is provision for a battery backup for the ublox NEO-7 that may be implemented in several different ways.

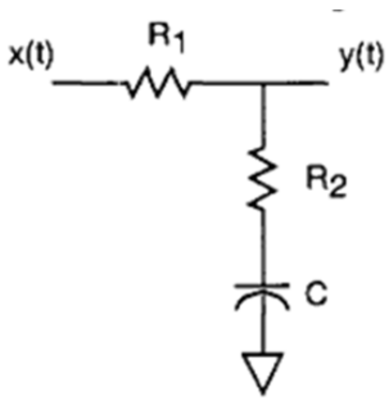
The PLL filter is described by the normal equations found below and exploited in a spreadsheet to be made available later.

Second Order Passive Lead-Lag Filter

$$\tau_1 = C(R_1 + R_2) \qquad \tau_1 = \frac{K_p K_v}{\omega_n^2}$$

$$\tau_2 = C R_2 \qquad \tau_2 = \frac{2\zeta}{\omega_n} - \frac{1}{K_p K_v}$$

$$\omega_n = \sqrt{\frac{K_p K_v}{\tau_1}} \qquad \zeta = \frac{1}{2\omega_n \tau_1} + \frac{\omega_n \tau_2}{2}$$



Also

$$\omega_n = \sqrt{\frac{K\omega_1}{N}} = \sqrt{\frac{K}{R_1 C N}}$$

$$\zeta = \frac{\omega_n}{2\omega_2} = \frac{R_2}{2}\sqrt{\frac{KC}{R_1 N}}$$

K_p is the phase detector gain in volts per radian [(Power Supply/2])/[PI/2] = (Power Supply) / PI

K_v is the VCO gain in radians per volt-second 2*PI*(VCO Slope)

ζ is the damping factor [zeta]

ω_n is the natural frequency of the loop = 2*PI*f

N is the loop frequency devisor

f is the loop frequency in Hz

K = $\boxed{K_V K_p / N}$ = [2 * (VCO Slope) * (Power Supply)] / N   NOTE: The PI's cancel

f	ω_n	ω_n^2	C in F	τ_1	τ_2	R2	R1	C in uF
0.16	1.005310	1.010647491	0.000470000	94.988610	2.575851	5,480.53	196,622.89	470

R1	R2	C	ω_n	ζ	f
196000	6040	0.000470000	1.020842	1.448984	0.162472

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After some additional reading, I have added another tab to the spreadsheet with the damping factor [zeta], ζ = 0.707. As it turns out you can achieve this condition by changing the R1 value to 200.0K and R2 to 3010 Ohms, = 0.7418; C still = 470 µF. Keeping the values of R1 =196.0K and C = 470 µF with R2 = 3.020 K by simply putting two of the 6.040K resistors in parallel and ζ = 0.7245, if you are interested in this value for ζ.

In my opinion, too many of the authors have put far too much emphasis on Floyd Gardner's mathematics and very little on the real world. Gardner shows best performance with ζ = 0.5 and has a "compromise" value of ζ = 0.707. These values reflect loops primarily used for an integer N synthesizer or signal recovery. We are doing neither and overshoot is undesirable, so ζ = 1.3 is number that I have chosen. Professor Long does differentiate in types of loops and suggests that even higher values of ζ may be used.

Another variable, of the few that are available is the loop natural frequency. This design can be considered a high gain loop, because of the VCO slope, the loop divisor N is only 10 and the reference frequency is 2.0MHz. When using reference frequencies of 1pps or up to 10KHz the loop natural frequency needs to be very small and preferably several orders of magnitude less than the reference frequency. I have chosen to keep this value small and still sub Hz at 0.16Hz. It is possible that it could be raised 10 to 100 times without affecting performance. Raising this value would bring the value of C near a level where a high performance film capacitor would be able to replace the Tantalum used for C1.

I will put more info on the web site after I get one built.

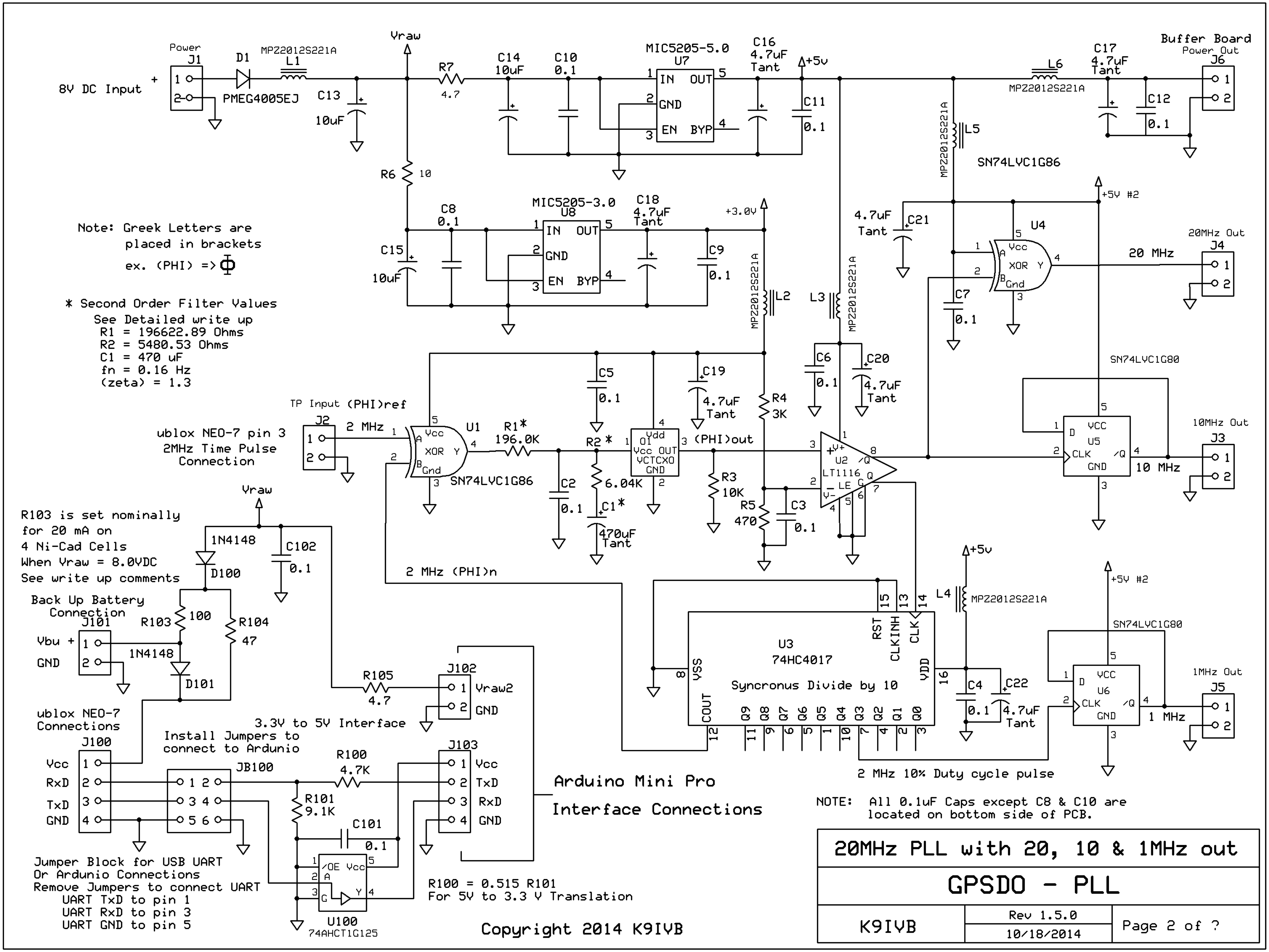
References:

Best, Rolland E. *Phase Locked Loops Design, Simulation, and Applications*, Fifth Edition, New York, McGraw-Hill, 2003

Gardner, F.M., *Phaselock Techniques*, Second Edition, New York, NY, John Wiley and Sons, 1979.

Long. Prof Steve, *PLL_intro_594a_s05.pdf*, UCSB/ECE Department, April 27, 2005

Stevens, Donald R., *PHASE-LOCKED LOOPS FOR WIRELESS COMMUNICATIONS Digital, Analog and Optical Implementations*, Second Edition, NEW YORK, KLUWER ACADEMIC PUBLISHERS, 2002


8V DC Input
Power
J1
D1
PMEG4005EJ
MPZ2012S221A
L1
C13
10uF
Vraw
R7
4.7
C14
10uF
C10
0.1
MIC5205-5.0
U7
IN
OUT
GND
EN
BYP
C16
4.7uF
Tant
+5v
C11
0.1
L6
MPZ2012S221A
C17
4.7uF
Tant
C12
0.1
Buffer Board
Power Out
J6
R6
10
C8
0.1
MIC5205-3.0
U8
C18
4.7uF
Tant
+3.0V
C15
10uF
C9
0.1
L5
SN74LVC1G86
+5V #2
4.7uF
Tant
C21
U4
Vcc
XOR
Gnd
20 MHz
20MHz Out
J4
C7
0.1
L2
L3
C6
0.1
C20
4.7uF
Tant
SN74LVC1G80
Note: Greek Letters are
placed in brackets
ex. (PHI) => Φ
* Second Order Filter Values
See Detailed write up
R1 = 196622.89 Ohms
R2 = 5480.53 Ohms
C1 = 470 uF
fn = 0.16 Hz
(zeta) = 1.3
C5
0.1
C19
4.7uF
Tant
R4
3K
TP Input (PHI)ref
J2
2 MHz
ublox NEO-7 pin 3
2MHz Time Pulse
Connection
U1
R1*
196.0K
R2 *
Vdd
O1
Vcc OUT
VCTCXO
GND
(PHI)out
U2
LT1116
LE
10MHz Out
J3
U5
VCC
CLK
/Q
10 MHz
SN74LVC1G86
C2
0.1
6.04K
C1*
470uF
Tant
R3
10K
R5
470
C3
0.1
Vraw
R103 is set nominally
for 20 mA on
4 Ni-Cad Cells
When Vraw = 8.0VDC
See write up comments
1N4148
D100
C102
0.1
2 MHz (PHI)n
+5v
L4
MPZ2012S221A
+5V #2
Back Up Battery
Connection
J101
Vbu +
GND
R103
100
R104
47
1N4148
D101
RST
CLKINH
CLK
U3
74HC4017
Syncronus Divide by 10
VSS
VDD
COUT
Q9 Q8 Q7 Q6 Q5 Q4 Q3 Q2 Q1 Q0
C4
0.1
C22
4.7uF
Tant
SN74LVC1G80
U6
1 MHz
1MHz Out
J5
R105
4.7
J102
Vraw2
GND
ublox NEO-7
Connections
J100
Vcc
RxD
TxD
GND
3.3V to 5V Interface
Install Jumpers to
connect to Ardunio
JB100
R100
4.7K
J103
Vcc
TxD
RxD
GND
R101
9.1K
C101
0.1
Arduino Mini Pro
Interface Connections
2 MHz 10% Duty cycle pulse
NOTE: All 0.1uF Caps except C8 & C10 are
located on bottom side of PCB.
Jumper Block for USB UART
Or Ardunio Connections
Remove Jumpers to connect UART
UART TxD to pin 1
UART RxD to pin 3
UART GND to pin 5
/OE Vcc
U100
74AHCT1G125
R100 = 0.515 R101
For 5V to 3.3 V Translation
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20MHz PLL with 20, 10 & 1MHz out
GPSDO - PLL
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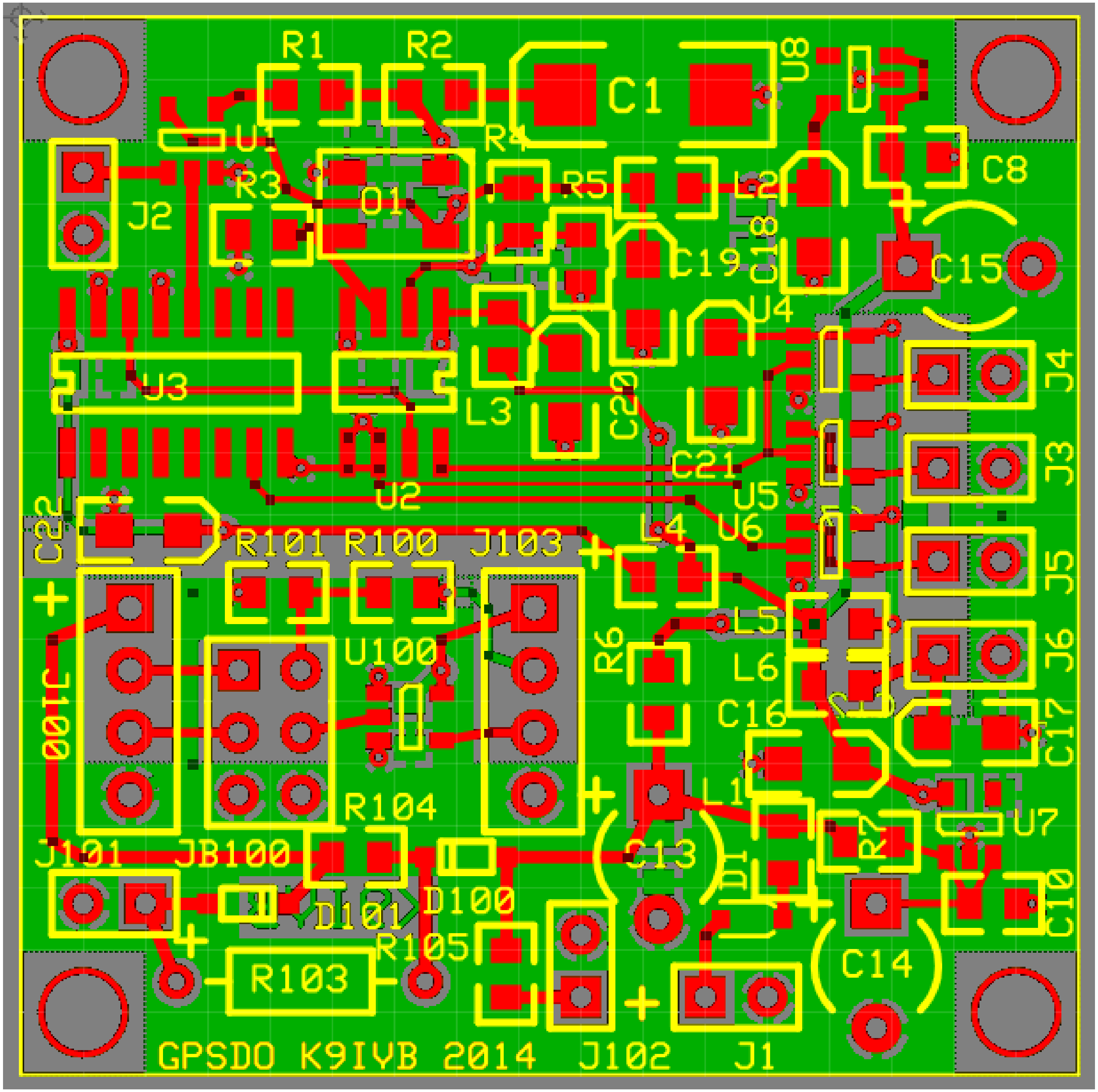

 K9IVB 11/08/2014

GPSDO-PLL BOM

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Ref Des	Value	Description	Part Number	Mfg	PAD	Mouser	Qty
C1	470uF	Tantalum Capacitors - Solid SMD 6.3V 470uF 10% "Y" Case	TAJY477K006RNJ	AVX	[7343]	581-TAJY477K006RNJ	1
C2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 101, 102	0.1	Multilayer Ceramic Capacitors MLCC - SMD/SMT 25volts 0.1uF X7R 10%	C0805C104K3R	KEMET	[0805]	80-C0805C104K3R	13
C13, 14, 15	10uF	Aluminum Electrolytic Capacitors - Leaded 16volts 10uF 4X7mm L/S=5.0mm Ammo Crmp	EEA-GA1C100B	Panasonic	0.2" LS	667-EEAGA1C100B	3
C16, 17, 18, 19, 20, 21, 22	4.7uF Tant	Tantalum Capacitors - Solid SMD 10V 4.7uF 10% "A"	T491A475K010AT	KEMET	1206	80-T491A475K010	7
D1	PMEG4005EJ	Schottky Diodes & Rectifiers 40V 0.5A	PMEG4005EJ,115	NXP	SOD-323	771-PMEG4005EJ-T/R	1
D100, 101	1N4148	1N4148, SOD-323F		Fairchild	SOD-123	512-1N4148WS	2
J1, 2, 3, 4, 5, 6, 101, 102		1x2 .100" Header					8
J100, 103		1x4 .100" Header					2
JB100		2x3 .100" Header					1
L1, 2, 3, 4, 5, 6	MPZ2012S221A	FERRITE CHIP 220 OHM 3A	MPZ2012S221A		[0805]	810-MPZ2012S221A	6
O1	VCTCXO		ASVTX-09-20.000MHz-T			815-ASVTX-09-20.0MT	1
R1	196K	Thin Film Resistors - SMD 0805 196Kohm 0.1% 25ppm	ERA-6AEB1963V	Panasonic		667-ERA-6AEB1963V	1
R2	6.040K	Thin Film Resistors - SMD 0805 6.04Kohm 0.1% 25ppm	ERA-6AEB6041V	Panasonic		667-ERA-6AEB6041V	1
R3	10K	Thick Film Resistors - SMD 1/10watts 10Kohms 5%	RK73B1JTTDD103J	KOA Speer	[0805]	660-RK73B1JTTDD103J	1

R4	3K	Thin Film Resistors - SMD 0805 1/8W 3Kohms 0.1% 0805	ERA-6AEB302V	Panasonic	[0805]	667-ERA-6AEB302V	1
R5	470	Thick Film Resistors - SMD 1/8W 470ohm 1%	AC0805FR-07470RL	Yageo	[0805]	603-AC0805FR-07470RL	1
R6	10	Thick Film Resistors - SMD 1/8W 10ohm 1%	AC0805FR-0710RL	Yageo	[0805]	603-AC0805FR-0710RL	1
R7, 105	4.7	Thick Film Resistors - SMD 1/8W 4.7ohm 1%	AC0805FR-074R7L	Yageo	[0805]	603-AC0805FR-074R7L	2
R100	4.7K	Thick Film Resistors - SMD 1/8W 4.7K ohm 1%	AC0805FR-074K7L	Yageo	[0805]	603-AC0805FR-074K7L	1
R101	9.1K	Thick Film Resistors - SMD 0805 9.1Kohms 1% Tolerance	ERJ-6ENF9101V	Panasonic	[0805]	667-ERJ-6ENF9101V	1
R103	100	Metal Film Resistors - Through Hole 100ohm 1/4W 1%	MFR-25FRF52100R	Yageo	axial	603-MFR-25FRF52100R	1
R104	47	Thick Film Resistors - SMD 1/8W 47ohm 1%	AC0805FR-0747RL		[0805]	603-AC0805FR-0747RL	1
U1, 4	SN74LVC1G86	Logic Gates 2 Input XOR		TI	SOT-23-5	586-SN74LVC1G86DBVR	2
U2	LT1116		LT1116CS8	Linear Technology	SOIC-8		1
	alt	Analog Comparators High Speed Comp	TL3116CD	TI	SOIC-8	595-TL3116CD	
U3	74HC4017	Counter ICs 5-STAGE JOHNSON DECADE COUNTER [syncronus]	74HC4017D,653	NXP	SO-16	771-74HC4017D-T	1
U5, 6	SN74LVC1G80	Flip Flops Positive Edge Trig	SN74LVC1G80DBVR	TI	SOT-23-5	595-SN74LVC1G80DBVR	2
U7	MIC5205-5.0	LDO Voltage Regulators 5V 150mA 1% Low Noise LD	MIC5205-5.0YM5 TR	Micrel	SOT-23-5	998-MIC5205-5.0YM5TR	1
U8	MIC5205-3.0	LDO Voltage Regulators 3.0V 150mA 1% Low Noise LD	MIC5205-3.0YM5 TR	Micrel	SOT-23-5	998-MIC5205-3.0YM5TR	1
U100	74AHCT1G125	Buffers & Line Drivers Tri-State Single Bus	SN74AHCT1G125DBVR	TI	SOT-23-5	595-SNAHCT1G125DBVR	1