DGPS Receiver Hardware Description

This document provides a basic theory of operation. Refer to the schematics at the end of the document for the following circuit block descriptions. The main receiver circuit is shown in Figure 1, while active antenna and accessory circuits are shown in Figure 2.

1. RF Amp

The RF amplifier consists of a JFET input cascode gain stage (Q1, Q2), followed by a 3 pole bandpass filter (T1 - T3), and a final buffer stage (Q3). The input is meant to be driven by an active antenna, which receives +5V power through the signal line via R12 & L1. R12's primary function is to provide current limiting in the event of a short to ground.

The bandpass filter is a simple, but effective circuit that provides a reasonably flat response over the receiver's tuning range. It is based on a design originally provided by Jim Bixby, but uses the smaller 7mm coils to keep the size down.

Voltage gain of the RF amp (measured at U3-1) within the pass band is about 20 (26 dB).

2. Mixer / Local Oscillator

U3 (NE602A) functions as both the local oscillator and the mixer. The oscillator is a Hartley type, with T4, C11, and D1 implementing the tuning circuit. The capacitance of D1 (tuning diode) is controlled by the Phase Locked Loop (PLL) frequency synthesizer (U4 / MC145157), which is set for 500 Hz above the desired station frequency to produce a mixer output of 500 Hz. The network of R16, R17, R18 and C19 functions as the PLL loop filter, while R18/C20 and R14/C17 helps filter the 500 Hz reference frequency from the tuning diode control voltage. Q4 functions as a buffer / amplifier between the oscillator and PLL. A 4 MHz crystal works with the PLL's on-chip oscillator to set the reference frequency , which is also used as the clock for the PIC microcontroller. The tuning diode control voltage is also fed to the antenna amplifier, which allows the use of a high Q tracking tuning stage to improve SNR and out-of-band signal rejection.

The mixer stage provides about 13 dB of gain.

3. 500 Hz Bandpass Filter / Amplifier

The output of the mixer (U3-5) is fed into a 6th order bandpass filter comprised of U1 (LMC660) sections D, A, and B, which has an overall bandwidth of approximately 200 Hz and voltage gain around 30 (30 dB). Low tolerance components (2% caps, 1% resistors) are necessary to insure the desired response.

The gains from each stage are much higher than desired, so resistor dividers are used at each of the inputs. The following table lists significant parameters for each individual stage. Gains take into account attenuation from the resistor dividers, and the negative value is for the signal inversion.

Filter Section	Center Frequency (f_0)	Gain at f_0	Q
U1D	490 Hz	-5.0	4.1
U1A	404 Hz	-8.5	8.5
U1B	595 Hz	-8.5	8.5

The '+' reference voltage for the op amps (R34, R35) is 1/2 the supply voltage to help keep the signal symmetrical in case exceptionally strong signals cause clipping. With a +5V supply, this brings the common mode voltage of the op amps close to their specified limit, but the spec won't be violated as long as the supply voltage tolerance is kept tight, which the LP2950 does. In reality, the receiver will typically work fine even when the supply voltage drops below +4V.

The output from the filter is then fed into a simple gain / limiter stage that uses the remaining op-amp in U1. R41 limits the gain to 100, which results in a limiting threshold of about 4uV at the antenna input. The output is a 1V p-p square wave signal that is fed into a comparator (U2A) which has about 0.5V of hysteresis. The comparator provides a good quality digital signal to the Input Capture ports on the PIC. A symmetrical waveform with fast rise & fall times is desired since the PIC measures the time of each half-period, effectively giving a 1 kHz sampling frequency. Refer to the source code for additional details on how the signal is processed.

3.1 Audio Monitor

By connecting a small earphone to J4, the received signal can be audibly monitor to assess general signal quality. The circuit (with earphone plugged in) draws an additional 1 mA of power.

4. Microcontroller

The microcontroller is a PIC16C76, which provides input capture ports, timers, and a hardware UART. The PIC's main function is to demodulate the DGPS signal and communicate with the GPS. The circuits comprising Q5 and U2B provide serial interface inversion, buffering and input protection, while U6 (93LC46B) is an EEPROM that allows the receiver to save the last station tuned for subsequent power-up's.

4.1 Test Points

A few test points are shown on the schematic, but their primary usefulness is for software development. Connecting an oscilloscope to TP2 through TP4 while tuned to a station allows some visibility into the operation of the software demodulator.

TP1 Connecting this point to ground during power-up causes the unit to enter a test mode. A simple interactive command shell operates through the serial interface. No differential correction data is output. The default communication rate is 19200 bps. Refer to the source code for additional details.

TP2 This is a digital output showing the demodulated data stream prior to being formatted for transmission to the GPS.

TP3 This is a digital output that represents the data stream used in detecting bit transitions. It's basically a 1 bit digitization of the FM demodulated and low-pass filtered 500 Hz input signal. This is the signal that is input to the software phase lock loop (PLL).

TP4 This is the regenerated data clock, output by the software PLL. The rising edge is phase locked to the data bit transitions.

5. Electrical Interfacing

The interface connection to the GPS is through connector J2. The pin definitions are provided in the table below. Serial data traveling between the GPS and DGPS receivers cause a significant amount of RFI (interference). The use of a shielded cable, with the shield connected to the ground pin reduces the problem considerably.

Pin	Function
1	Ground
2	Serial Output (GPS Rx pin)
3	Serial Input (GPS Tx pin)

The default interface speed to the GPS is 4800 bps, which is the standard NMEA rate. The software has a provision to use 9600 bps, which can be selected by strapping the *9600 bps* pin on the PIC (pin 22) to ground.

6. Power Supply

The receiver requires a regulated +5VDC power source capable of supplying 15mA, though the typical draw is less than 9mA.

A good choice for a power source is to use a 9V battery with the LP2950 regulator circuit shown in Figure 2. An alkaline battery should provide 60 - 70 hours of operation. A 9V NiCd could also be used.

Any kind of switching regulator should be avoided since they are a big noise source. The NE602 is especially susceptible to power supply noise when single ended inputs and outputs are used. The current design employs considerable power supply filtering and isolation, which to a large extent is a holdover from an earlier design that used an LTC1516 switched cap power supply running off of a 3V battery. The LTC1516 was abandoned in favor of the simpler (and cheaper) linear regulator / 9V battery, but the filtering was retained as a good overkill measure. Digital switching noise seems to be pretty well subdued.

If powered from a car or boat electrical system, a filter and clamping circuit should be used to protect against over-voltage transients. An example is also shown in Figure 2. This circuit could also be used to supply GPS power as long as the inductor is rated for the required current, such as J.W. Miller 5258.

7. Active Antennas

Two antenna circuits are shown in Figure 2. The following table provides a performance comparison between the two types of antennas.

Whip (E-field)	Loopstick (H-field)
Omni-directional.	Single rod design is bi-directional
Requires good ground.	Ground only needed for weak signals, or when heavy electrical interference is present.
Poor performance in heavily wooded areas.	Superior performance in wooded or hilly terrain, indoors, and around buildings.

7.1 Whip Antenna

The whip preamp connects to the receiver through a coaxial cable which can be any practical length, and derives it's power from the receiver through the coax.

The amplifier uses a cascode configuration similar to the RF amp in the receiver. With a 2N5484 for Q2, the overall voltage gain is about 10. Q3 is a voltage follower that drives the low impedance coax cable to the receiver. L1, C3, and R5 provides some filtering to reject out of band signals. The Q is around 7, which puts the -3dB points near the edges of the beacon broadcast band. L2 and C5 isolates and filters the +5V supply from the signal.

Very slightly improved performance may result by using an MPF-102 for Q2, but this will increase power consumption to 500 uA or more.

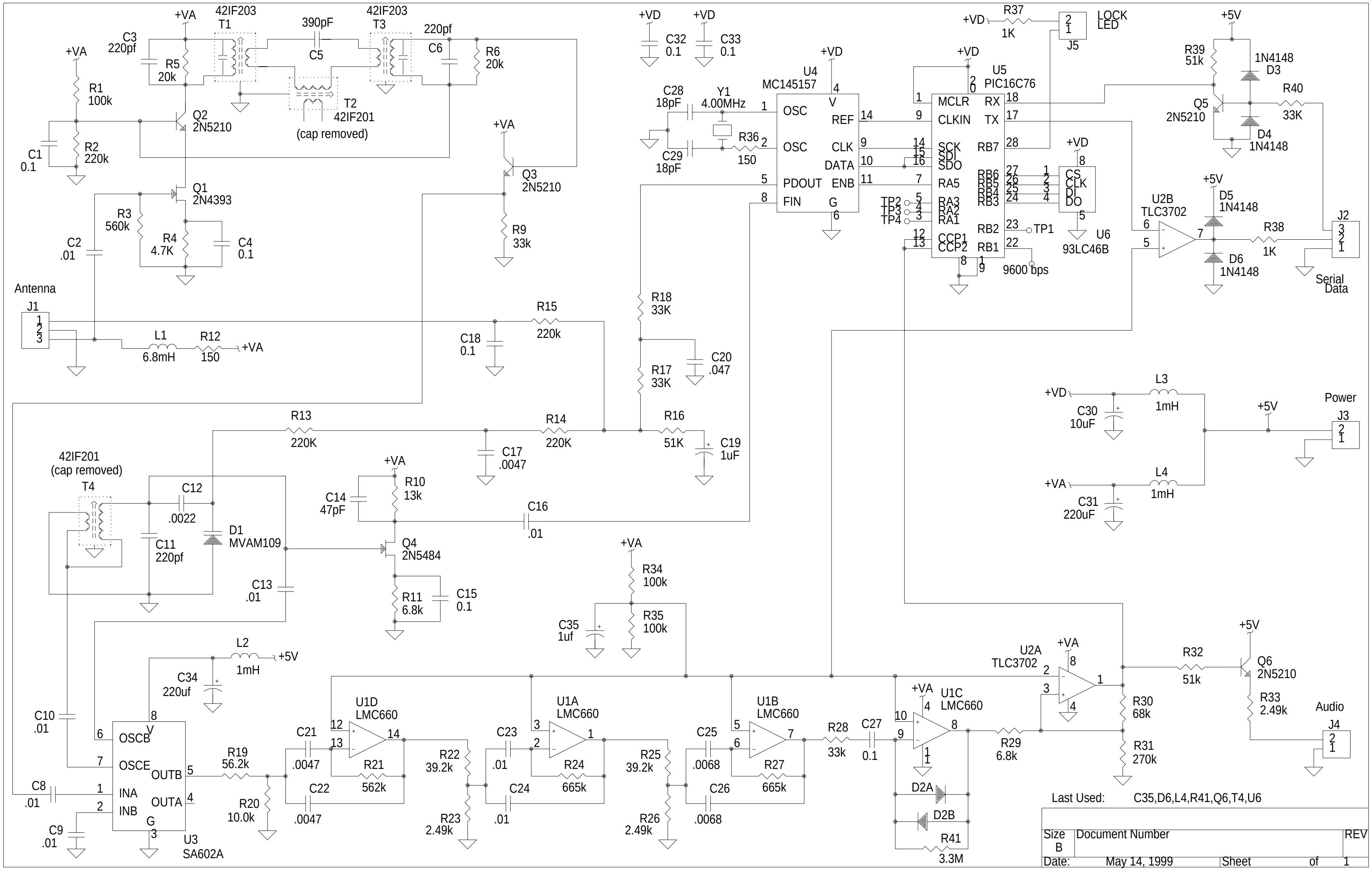
7.2 Single Rod Loopstick Antenna

The loopstick antenna connects to the receiver through a shielded two wire cable. Cable length should be one to two meters for best performance.

The loopstick is a tuned circuit similar to the receiver’s local oscillator, and utilizes the same tuning voltage. The amplifier is a cascode stage that uses L1 in the receiver as it's load, thus the restriction on cable length, but with the benefit of simplicity. This arrangement works best with 75pf to 150pf of cable capacitance, which counteracts the resonant frequency of L1 in the receiver without excess loss of signal gain.

8. Current Limitations And Performance Issues

A potential problem associated with the single conversion architecture of this design is the simultaneous reception of both the desired station and it's image. Since the LO is tuned to 500 Hz above the desired station, a station 500 Hz above the LO will also be received. This situation is possible since the USCG DGPS system specifies station spacing intervals of 1 kHz. I'm not aware of any cases where stations spaced 1 kHz apart are within reception range of one another, and it seems unlikely that type of choice would be made. If it ever did, a simple work around is to tune the lower frequency station at 1 kHz less than it's stated frequency. Solving this problem in the design would add quite a few additional parts, and go against the goals of simplicity, small size, and low weight. The most significant downside of the single conversion approach over one that provides image rejection is that the effective bandwidth to external noise is doubled, resulting in slightly decreased SNR. In practice, this would only be an issue when trying to pick up stations at the very edge of the reception range.



+VA
42IF203
T1
390pF
C5
42IF203
T3
220pf
C6
C3
220pf
R5
20k
R6
20k
T2
42IF201
(cap removed)
R1
100k
R2
220k
C1
0.1
Q2
2N5210
Q1
2N4393
R3
560k
R4
4.7K
C4
0.1
C2
.01
+VA
Q3
2N5210
R9
33k
Antenna
J1
L1
6.8mH
R12
150
R15
220k
C18
0.1
+VD
C32
0.1
C33
0.1
C28
18pF
Y1
4.00MHz
C29
18pF
R36
150
U4
MC145157
OSC
OSC
PDOUT
FIN
REF
CLK
DATA
ENB
G
R18
33K
R17
33K
C20
.047
R16
51K
C19
1uF
R13
220K
R14
220K
C17
.0047
U5
PIC16C76
MCLR
CLKIN
SCK
SDI
SDO
RA5
RA3
RA2
RA1
CCP1
CCP2
RX
TX
RB7
RB6
RB5
RB4
RB3
RB2
RB1
TP1
TP2
TP3
TP4
9600 bps
R37
1K
J5
LOCK
LED
U6
93LC46B
CS
CLK
DI
DO
+5V
R39
51k
1N4148
D3
Q5
2N5210
R40
33K
D4
1N4148
U2B
TLC3702
D5
1N4148
D6
1N4148
R38
1K
J2
Serial
Data
L3
1mH
C30
10uF
Power
J3
L4
1mH
C31
220uF
42IF201
(cap removed)
T4
C12
.0022
C11
220pf
D1
MVAM109
C14
47pF
R10
13k
Q4
2N5484
R11
6.8k
C15
0.1
C16
.01
C13
.01
R34
100k
R35
100k
C35
1uf
L2
1mH
C34
220uf
C10
.01
C8
.01
C9
.01
U3
SA602A
OSCB
OSCE
INA
INB
OUTB
OUTA
R19
56.2k
R20
10.0k
C21
.0047
C22
.0047
U1D
LMC660
R21
562k
R22
39.2k
R23
2.49k
C23
.01
C24
.01
U1A
LMC660
R24
665k
R25
39.2k
R26
2.49k
C25
.0068
C26
.0068
U1B
LMC660
R27
665k
R28
33k
C27
0.1
U1C
LMC660
D2A
D2B
R41
3.3M
R29
6.8k
U2A
TLC3702
R30
68k
R31
270k
R32
51k
Q6
2N5210
R33
2.49k
Audio
J4
Last Used:
C35,D6,L4,R41,Q6,T4,U6
Size
B
Document Number
REV
Date:
May 14, 1999
Sheet
of
1

Figure 1

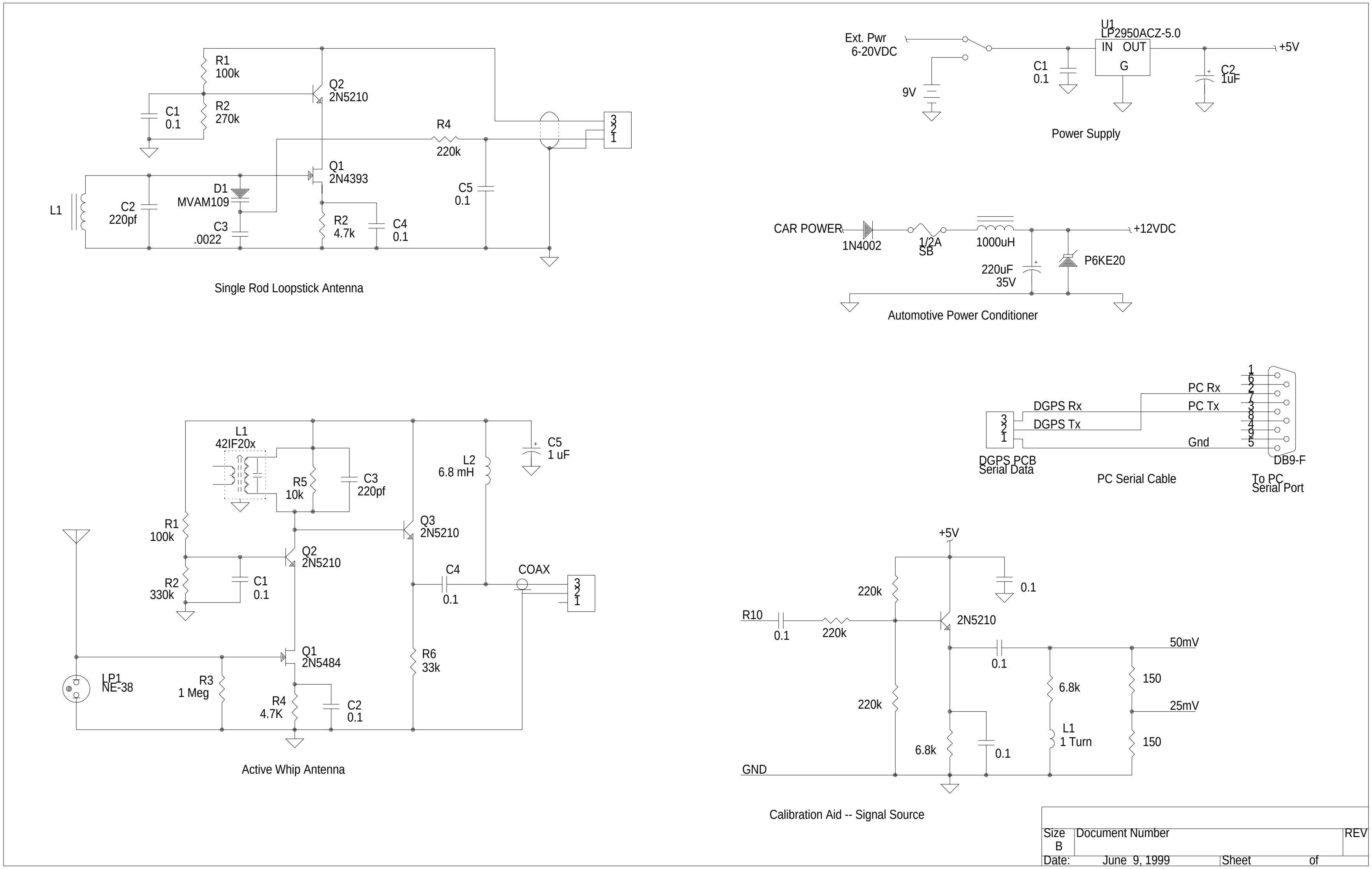

R1
100k
R2
270k
C1
0.1
Q2
2N5210
R4
220k
Q1
2N4393
D1
MVAM109
C2
220pf
L1
C3
.0022
R2
4.7k
C4
0.1
C5
0.1
3
2
1
Single Rod Loopstick Antenna
Ext. Pwr
6-20VDC
9V
C1
0.1
U1
LP2950ACZ-5.0
IN OUT
G
C2
1uF
+5V
Power Supply
CAR POWER
1N4002
1/2A
SB
1000uH
220uF
35V
P6KE20
+12VDC
Automotive Power Conditioner
L1
42IF20x
R5
10k
C3
220pf
L2
6.8 mH
C5
1 uF
R1
100k
Q3
2N5210
Q2
2N5210
R2
330k
C1
0.1
C4
0.1
COAX
3
2
1
LP1
NE-38
R3
1 Meg
Q1
2N5484
R4
4.7K
C2
0.1
R6
33k
Active Whip Antenna
DGPS Rx
DGPS Tx
PC Rx
PC Tx
Gnd
3
2
1
1
6
2
7
3
8
4
9
5
DB9-F
DGPS PCB
Serial Data
PC Serial Cable
To PC
Serial Port
+5V
220k
0.1
R10
0.1
220k
2N5210
0.1
50mV
220k
6.8k
150
25mV
L1
1 Turn
6.8k
0.1
150
GND
Calibration Aid -- Signal Source
Size
B
Document Number
REV
Date:
June 9, 1999
Sheet
of

Figure 2