GP2000

GPS Receiver Hardware Design

Application Note

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This Applications note should be used in conjunction with the following literature (available from www.zarlink.com)

Part No	Description	Data Sheet Reference
GP2010	GPS RF Front End	DS4056
GP2015	GPS RF Front End	DS4374
GP2021	12 Channel Correlator	DS4077
P60ARM-B	ARM60-B 32 Bit RISC processor	DS3553
GPS Orion	12 Channel Global Positioning System-Receiver Design	DS4808

Description

This application note shows how to construct a complete 12-channel GPS receiver engine using the GP2000 chipset from Zarlink Semiconductor. The GPS Orion is used as the reference for this engine design. The critical part of the receiver design involves the placement of the RF receiver components in relation to the digital components. This application note will concentrate on the RF application using the GP2015 RF front-end IC with attention to the digital application where this is required.

The data in this application note can also be used to set-up the GP2010 RF front-end, which is the sister product of the GP2015, although there will be differences to pin numbers, and values of peripheral components.
The GPS Orion is a complete 12-channel Global Positioning System receiver design, implemented on a 4 layer printed circuit board of 95mm x 50mm. It utilises the key components from the GP2000 GPS chipset : the GP2015 ultra-miniature RF front-end with Dynex DW9255 SAW filter, the GP2021 12-channel correlator and ARM 60-B microprocessor. It uses memory which includes 32-bit wide SRAM, and GPS firmware stored in EPROM. The GPS Orion operates with a Power Supply Regulator and RS232 support Interface Board. Together with an active GPS antenna with low noise amplifier (LNA), and a computer monitor, the GPS Orion forms a complete GPS measurement sensor, which can be integrated into a multitude of navigation applications. Navigation data output can be either standard NMEA 0183 v2.01, or proprietary ASCII “WINMON” formats. Differential GPS capability has been implemented. RTCM SC-104 corrections can be input to the receiver with Type 1, 2 and 9 messages being extracted.

Components Used

A Block Diagram of the GPS Orion receiver design appears in Figure 1. The GPS Orion receiver board comprises the following components:-

- GP2015 ultra-miniature GPS RF front-end IC, including:-
  - RF input bandpass filter and +5V DC active antenna supply
- DW9255 GPS band-definition SAW filter, supplied by Dynex Semiconductor (www.dynexsemi.com).
- GP2021 12-channel correlator IC, including:-
  - Full memory-management support for the ARM-60B microprocessor
  - Dual UART serial interface
  - Real-Time-Clock using 32.768kHz crystal
- ARM 60-B 32bit RISC microprocessor IC. Zarlink Part Number: P60ARM-B/IG/GP1N
- Memory, including:-
  - 512kbytes 20ns SRAM
  - 256kbytes EPROM, holding GPS Orion firmware
- Sub-miniature 10.000MHz Temperature Compensated Crystal Oscillator (TCXO)
- 0.22F memory - backup capacitor

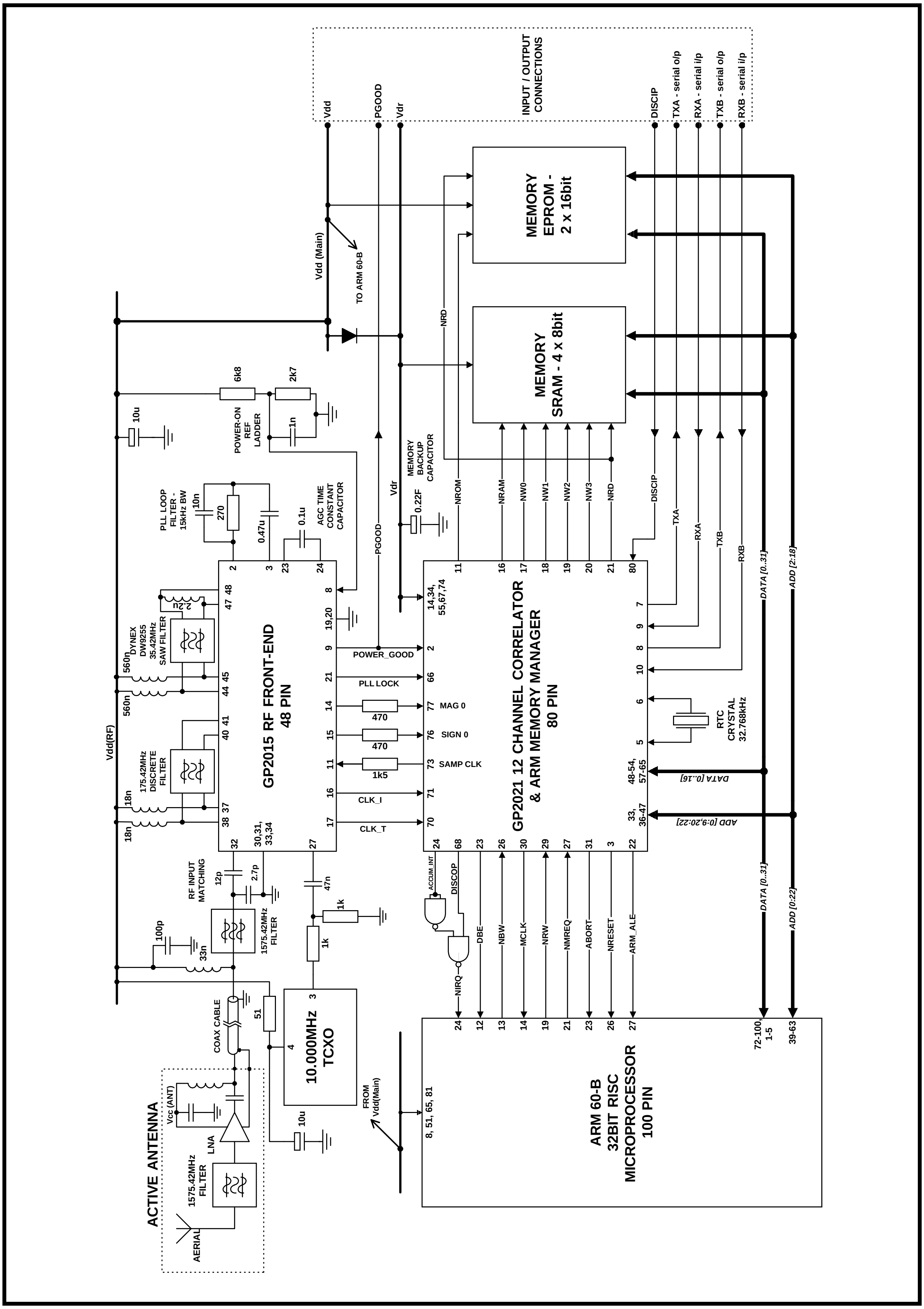


Figure 1. GPS Orion receiver block diagram

A brief description of each of the GP2000 chipset components appears below:-

- **RF Front-End (GP2015)**

The GP2015 is Zarlink Semiconductor's ultra-miniature RF Front-end device, which contains all the circuit blocks (excluding IF filters) to down-convert the direct-sequence spread-spectrum Coarse Acquisition (C/A code) GPS signal in the L1 band (1575.42MHz) from a GPS antenna via a low-noise amplifier, to a final 2-bit quantised digital IF at 1.405MHz. The GP2015 uses a triple-conversion frequency plan and an aliasing 2-bit A to D converter to provide a very high immunity to interference. Filtering for the IF stages occurs off-chip, with a discrete 175.42MHz IF filter and a 35.42MHz SAW filter (Dynex DW9255). An additional image filter is included on-chip, centred on the final analog IF frequency of 4.31MHz. An on-chip phase-locked loop (PLL) including VCO is used to provide the local-oscillator frequencies to the mixers, which is locked to a 10.000MHz reference signal from a TCXO. The GP2015 has been designed to operate with an active antenna which has an LNA with gain of greater than +16dB (at 1575.42MHz), and a Noise-figure of less than 4dB.

The GP2015 is available in a 48-pin TQFP package - 7mm x 7mm x 1.4mm.

A detailed description of this IC is given in the GP2015 data-sheet (No. DS4374).

The GP2010 is also an alternative RF Front-end device. The GP2010 offers all the functions provided by the GP2015, but in a larger 44-pin MQFP package - 10mm x 10mm x 2mm.

A detailed description of this IC is given in the GP2010 data-sheet (No. DS4056).

- **GPS Band Definition SAW Filter (Dynex DW9255)**

The Dynex DW9255 is a Surface Acoustic Wave (SAW) bandpass filter. It is used as a steep bandwidth definition filter for receiving the GPS spread-spectrum signal. It is pre-tuned to the exact 2nd IF filter requirements of the GP2010 and GP2015 RF front-end device, with a centre-frequency of 35.42MHz, and 1dB passband of 1.9MHz (typical). The flat passband response, and steep stopband response of this filter help to improve the immunity to jamming interference of the GP2010 and GP2015 RF Front-end.

The Dynex DW9255 is available in a 12-pin LCC package - 13.55mm x 6.55mm x 2.5mm

A detailed description of this device is given in the DW9255 data-sheet (No. DS3961), available from Dynex Semiconductor.

- **12 Channel Correlator (GP2021)**

The GP2021 is Zarlink Semiconductor's 12 parallel-channel direct-sequence spread-spectrum signal correlator for GPS C/A code signals. The GP2021 comprises of 12 fully independent correlator channels which can be individually de-activated to lower the power consumption. GP2021 is designed to operate with a separate micro-processor via a 16-bit data-bus. Combining the GP2021 with the P60ARM-B microprocessor, a host of memory-management blocks can be utilised to remove the need for additional external logic. GP2021 has an on-chip Real-Time-Clock (RTC) which will continue to operate when the main functions of the GP2021 have been disabled. The GP2021 has 2 UARTs which can be used to access the navigation data of the GPS receiver via external monitoring equipment.

The GP2021 is available in an 80-pin QFP package - 14mm x 14mm x 2mm

A detailed description of this IC is given in the GP2021 data-sheet (No. DS4077).

- **32-bit RISC Microprocessor (P60ARM-B)**

The P60ARM-B is a lowpower (180mW @ 20MHz) general purpose 32-bit RISC microprocessor. It is an implementation of the ARM 6 micro-processor core, with a 32-bit address bus and a 32-bit data bus. The P60ARM-B incorporates pipe-lining which allows all parts of the processing and memory systems to run continuously. It allows a sustained processing bandwidth of 14MIPs with a 20MHz clock, with a 20MIPs peak capability. The GPS Orion employs software with a wide scope to improve the functionality of the receiver since there is approximately 45% spare processing capacity, which allows the software to be tailored to provide additional system facilities (e.g. control of an LCD display with push-button-interface).

The ARM 60-B is available in a 100 pin QFP package - 20mm x 14mm x 2.7mm
A detailed description of this IC is given in the P60ARM-B data-sheet (No. DS3553).

Operating Notes

The GPS Orion receiver board is provided with the following I/O connections:-

NAME	DESCRIPTION	I/O TYPE	CONNECTION
GND	0v supply	INPUT	PIN
Vdr	Memory Backup positive supply	INPUT	PIN
Vdd	+5V prime supply input	INPUT	PIN
PGOOD	Vdd level sense circuit output - used as a “reset” if connected to GND	OUTPUT/INPUT	PIN
DISCIP	Discrete Input line - used to configure GPS data output mode	INPUT	PIN
* TXA	Serial port A transmitted data	OUTPUT	PIN
* RXA	Serial port A received data	INPUT	PIN
* TXB	Serial port B transmitted data	OUTPUT	PIN
* RXB	Serial port B received data	INPUT	PIN
RF INPUT	RF signal input at 1575.42MHz	INPUT	SMA
	+5V DC feed for Active Antenna	OUTPUT	

* Serial ports A and B are outputs from UARTs on the GP2021 correlator IC. The outputs use RS232 protocols at TTL levels.

The GPS Orion receiver board is designed for operation from a +5.0V (±10%) power-supply.
The GP2015 is a key component in the GPS Orion receiver. ALL of the RF local-oscillator frequencies and main digital clocks are produced from a PLL on the GP2015 circuit.
A 10.000MHz TCXO is used as a PLL reference oscillator. The level of this signal into REF 2 (pin 27) of the GP2015 needs to be between 100mV & 1200mV pk-pk (600mV nominal), AC coupled via 47nF. When the TCXO and the GP2015 are powered up together, the GP2015 PLL multiplies up the 10.000MHz to generate a 1.400GHz signal which is used as the first local oscillator. Confirmation that the PLL has locked correctly can be achieved by 2 methods:-

- Check the GP2015 LD (Lock Detect) output (Pin 21) - this should be at Vdd potential (i.e. +5V ±10%).
- Check the GP2015 OPCLK outputs (Pins 16 & 17) - these should have a 40MHz clock of amplitude 100mV pk-pk, at a DC bias of (Vdd - 1)V. The two OPCLK outputs give a balanced differential 40MHz output.

The GP2015 includes a Power-on-Reset circuit, which sets the PGOOD pin to a logic Lo level if the Vdd input to the receiver board goes below a set voltage. In the case of the GPS Orion receiver, this is set to a voltage of ~+4.25V. The PGOOD input (pin 2) to the GP2021 correlator operates as an active Lo disable to all correlator functions (except the Real Time Clock). In this way, if PGOOD toggles Lo due to inadequate voltage level on the Vdd pin, the main clock signal to the ARM 60-B is disabled, and a system reset is initiated. When the GPS Orion is powered-up, PGOOD remains at logic Lo until the level on the Vdd pin is high enough to allow the receiver to operate correctly. When PGOOD becomes a logic HI, the clock to the ARM 60-B is enabled, and the receiver will complete the system reset.

Special Features OF GP2010 & GP2015 RF Front Ends

● VCO Supply Regulator

The GP2010/GP2015 has an on-chip voltage regulator to provide an improved power-supply-rejection-ratio (PSRR) to the VCO. The regulator provides a +3.3V supply to the VCO when used with supply voltages (Vcc) of greater than +4.0V. It is strongly recommended that the VCO regulator is used where possible, in order to improve spurious rejection in the VCO. An improvement of 25dB in the PSRR of the VCO can be achieved using the regulator, over the 100Hz to 1MHz frequency range.

If the supply voltage (Vcc) is less than +4.0V, the function of the VCO regulator cannot be guaranteed, and so it should be disabled (refer to GP2015 data-sheet, DS4374 Figure 7). This is achieved by connecting VEE(OSC) (pins 4 & 6) to VEE(REG) (pin 7) or 0V.

● PLL Test Input

The GP2010/GP2015 is provided with a TEST input, which when set to logic high (>2.0V) will unlock the on-chip PLL, and the VCO will operate at its highest frequency.
In normal operation, the TEST input must be at logic low (<+0.5V), which can be achieved easily by connecting TEST to 0V directly or via a 1kΩ resistor.

● Power-on Reset Circuit

When power is applied to the Vcc & Vdd pins of the GP2010/GP2015, the power-on reset (PRESET) output (pin 9) will toggle from logic low (0V) to logic high (Vcc), when a threshold voltage applied to PREF input (pin 8) exceeds +1.21V. The PREF input can be set such that PRESET toggles high only after all the other parts of the GPS Orion receiver board have been powered up for a short time. PRESET will remain at logic high unless the supply voltagefalls significantly, causing the voltage applied to the PREF input to drop below +1.21V at which point the PRESET output will be set to logic low, indicating a power-supply failure.
A potential divider for use with the PREF input (pin 8) is shown in Figure 2. The component numbers correspond to those used in the RF front-end schematic for the GPS Orion in Figure 35.

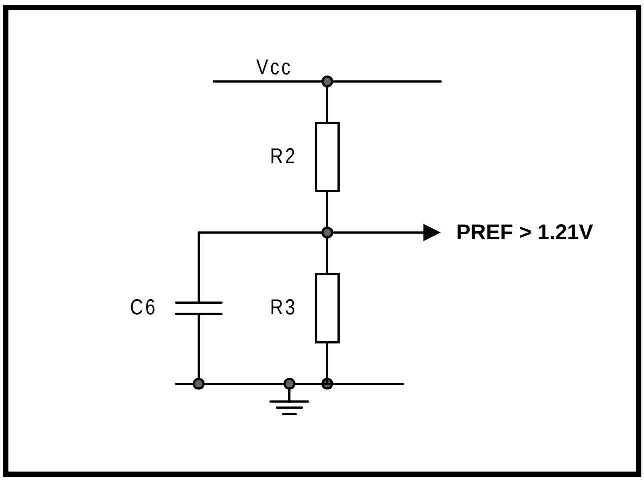


Figure. 2. PREF potential divider

The value of supply voltage (Vcc(thresh)) at which the PRESET output toggles can be adjusted by changing the resistor values in the PREF potential divider, as per the formula:-

$$\text{Vcc(thresh)} = 1.21\text{V} \times \frac{(R2 + R3)}{R3}$$

The use of a filtering capacitor C6 is to prevent noise on the Vcc power-supply from resetting the GP2021 sporadically. A nominal value for this capacitor is 1nF, which will filter out much high frequency interference.

If the value of C6 is made large (in the order of a few uF) the GP2021 can be left in a reset state for a significant period of time after the receiver is powered up, or reset using the “soft-reset” facility.

The values of resistors used on the GPS Orion, which is a 5V receiver design, are:-

R2 = 6k8Ω
R3 = 2k7Ω

These give a value of Vcc(thresh) = +4.25V.
The resistor values can be adjusted to suit the required GPS receiver application.

● Power Down (PDN) Input

The GP2010/GP2015 is provided with a PDN input (GP2010 pin 17 or GP2015 pin 19), which when set to logic high (>+2.0V) will power-down ALL the chip functions (except for the Power-on Reset function) resulting in a greatly reduced current consumption.

In normal operation, the PDN input must be at logic low (<+0.5V). This function has not been implemented on the GPS Orion, and the PDN input is connected to GND.

● Analog to Digital Converter

The GP2010/GP2015 uses a 2-bit analog to digital converter to produce the MAG and SIGN signals for the GP2021 correlator. The duty-cycles for these signals are selected to faithfully re-create the sampled signal in the digital domain, and to provide the GPS receiver with a good immunity to in-band CW jamming interference. Both MAG and SIGN are derived in real-time from the IFOUT signal (GP2010 & GP2015 pin 1) using comparators which are also used to control the AGC in the 3rd IF stage. The signals are latched using the CLK signal (GP2010 & GP2015 pin 11) which is derived from the GP2021 correlator, at a frequency of 5.714MHz. The latching of the data has the effect of aliasing the GPS signal down in frequency from 4.309MHz to 1.405MHz, whilst maintaining the statistical distribution of 1s and 0s.

Both MAG (GP2010 pin 12 or GP2015 pin 14) and SIGN (GP2010 pin 13 or GP2015 pin 15) output data are synchronised to the rising edge of the CLK digital clock.

The SIGN signal is set to give an indication of the polarity of the sampled signal. As a consequence, the duty cycle is set to 50%, to ensure that the sampling recreates the mid-point amplitude of the signal with no additional offset; an offset will appear if the duty-cycle for SIGN was set to a value other than 50%.

The MAG signal is set to give an indication of the magnitude of the sampled signal. Statistics suggest that this signal should have a 30% duty cycle, to ensure the sampling recreates the shape of the signal faithfully.

The principle can be shown by the sampling of a CW signal. The SIGN sample will be logic 1 for a CW signal with a polarity greater than a pre-defined midpoint threshold, and 0 for the remaining time. The MAG sample will be a logic 1 for 30% of the time, when the CW signal is above a positive amplitude threshold, or below a negative amplitude threshold. This principle can be seen in Figure 3. The MAG thresholds are typically set to be ~115mV, which in turn allow the AGC circuit to produce an IFOUT signal of 100mV rms. Note how closely the re-constructed waveform matches the CW input signal. There has been no account taken of the sampling latches in this example.

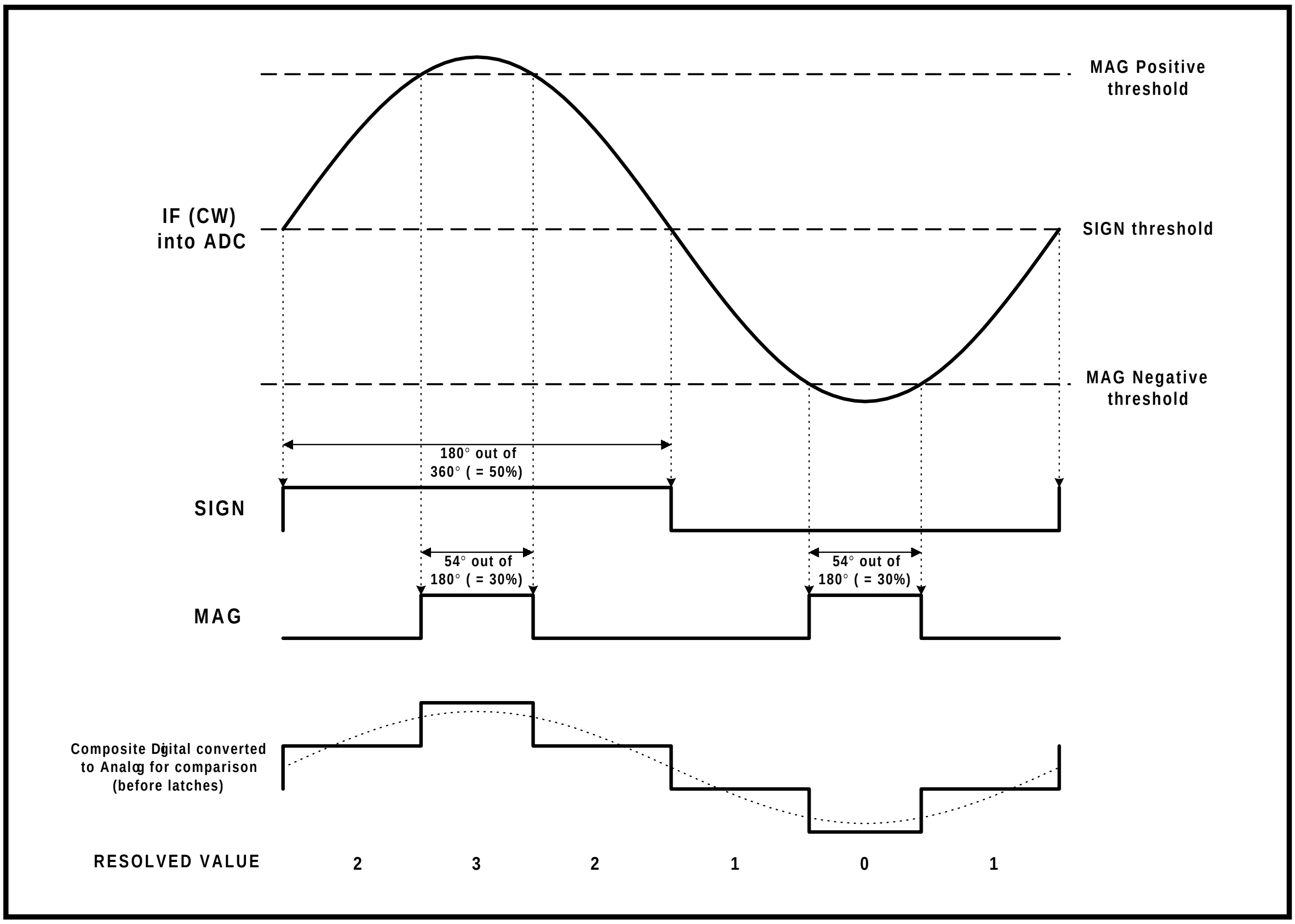


Figure 3 Analog to Digital conversion of a CW IF signal using the GP2010 or GP2015 ADC.

With a real GPS signal (noise with the signal buried in it), providing the noise has a Gaussian distribution, the same amplitude of signal will appear at IFOUT (pin 1), as for an equivalent CW signal.

● PLL Loop Filter and VCO Perfomance

The GP2010/GP2015 uses an on-chip PLL to produce all the local-oscillator frequencies for the IF mixers. The recommended PLL loop filter produces a third-order PLL with a second-order external filter comprising 2 capacitors and 1 resistor, as shown in Figure 4.

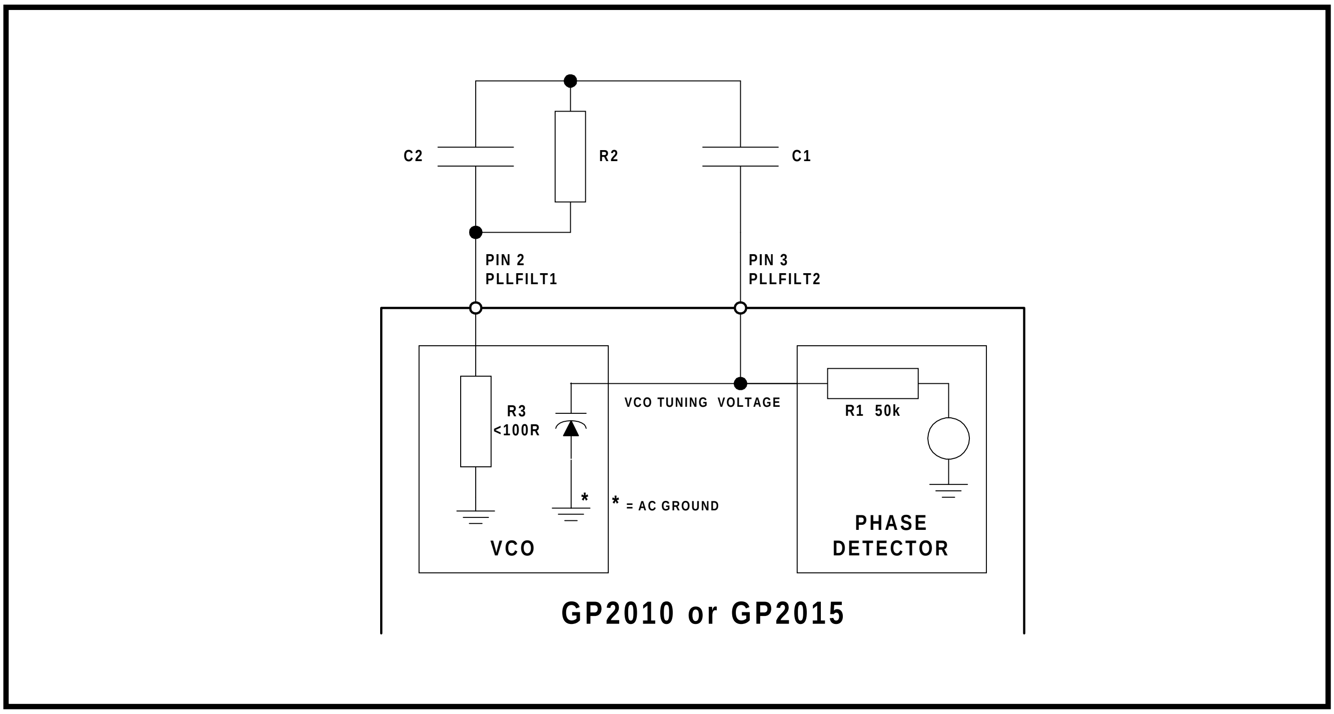


Figure 4. PLL loop filter showing relevent on-chip components

The loop filter is used to roll off the response of the PLL at high frequency, but maintain loop stability at the loop-bandwidth frequency (where loop gain = 1 (0dB)). The optimum values for this PLL loop filter can be calculated knowing the loop-gain, phase-margin and required loop bandwidth.
The loop gain at 1 radian/second can be calculated as a ratio (NOT dBs) as follows:-

$$\text{Loop Gain } (G_L) = \frac{K_D K_V}{N}$$

where :-
K_D = Phase detector gain (Volts/Radian)
K_V = VCO gain (Hz/Volt)
N = Loop division ratio (140)

G_L is between 3.1×10^6 and 100×10^6 for the GP2010 & GP2015 (130dB and 160dB).
The time-constants of the filter can be calculated as follows:-

$$\tau 1 = \frac{G_L}{\omega_n^2}\sqrt{\left(\frac{1+\omega_n^2\,\tau_2^2}{1+\omega_n^2\,\tau_3^2}\right)} \quad \text{..................} \quad (1)$$

$$\tau 2 = \frac{1}{\omega_n^2\,\tau_3^2} \quad \text{..............................} \quad (2)$$

$$\tau 3 = \frac{-\tan\text{ø} + \dfrac{1}{\cos\text{ø}}}{\omega_n} \quad \text{.........................} \quad (3)$$

where:- G_L = PLL loop gain at 1 radian/second
$\tau 1$ = time constant of first filter pole
$\tau 2$ = time constant of filter zero
$\tau 3$ = time constant of second filter pole
ϖ_n = PLL loop bandwidth
ø = PLL phase margin

For the PLL loop filter referred in Figure 4:-

$\tau 1$ = R1C1
$\tau 2$ = R2(C1+C2)
$\tau 3$ = R2C2

Resistor R3 (on-chip on the GP2010/GP2015) can be regarded as an AC ground. Since the value is much smaller than R1 (50kΩ), the value can be ignored.
The recommended PLL loop filter has the following values for external components, giving a nominal loop-bandwidth of 15kHz and phase-margin of 60°:-

C1 = 470nF
R2 = 270Ω
C2 = 10nF

The higher the phase margin(ø) of the loop filter at the loop bandwidth (ωn), the higher the stability of the PLL across the full range of loop gain. The graph in Figure 5 shows the loop filter response for the loop-filter components defined above, and Figure 6 shows the spectrum of the 1400MHz VCO signal from a GP2010/GP2015 at +25°C, with the VCO regulator enabled.

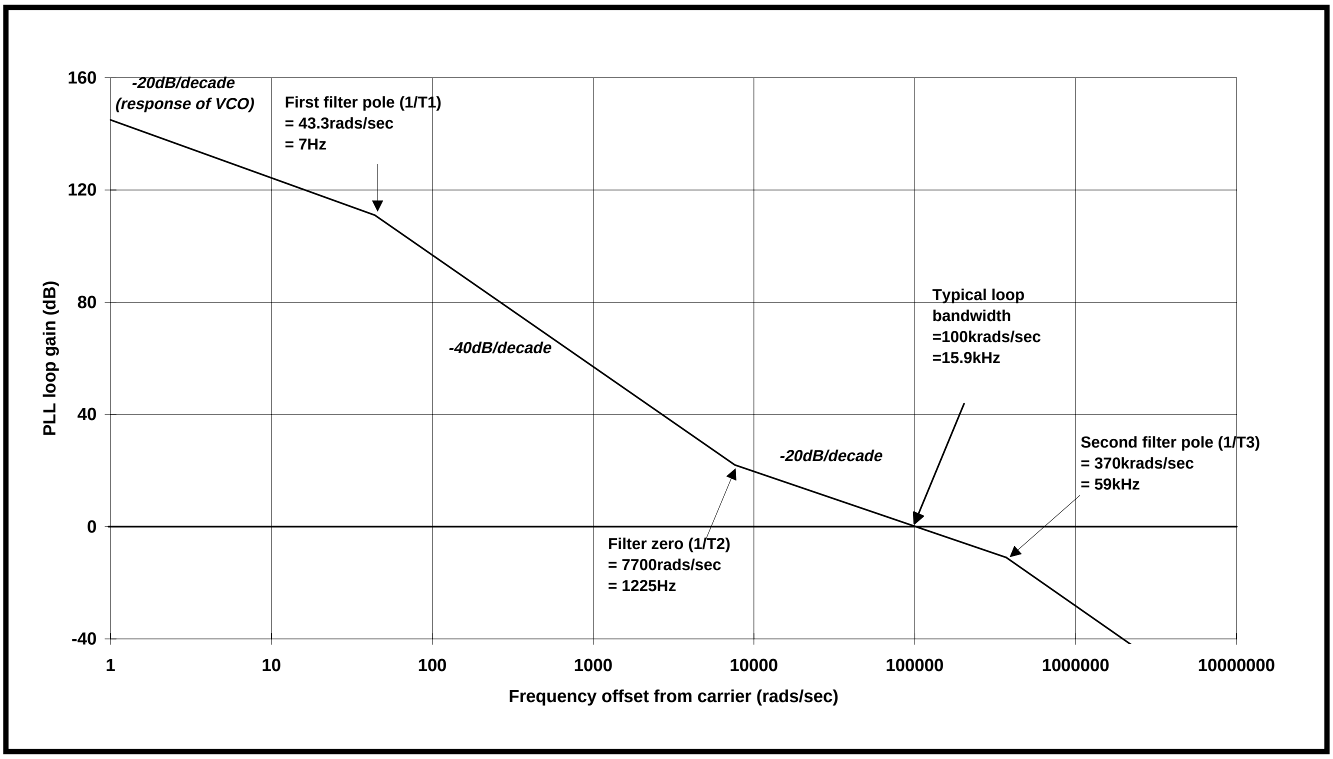


Figure 5 Typical GP2010 & GP2015 PLL loop gain (GL) vs. frequency

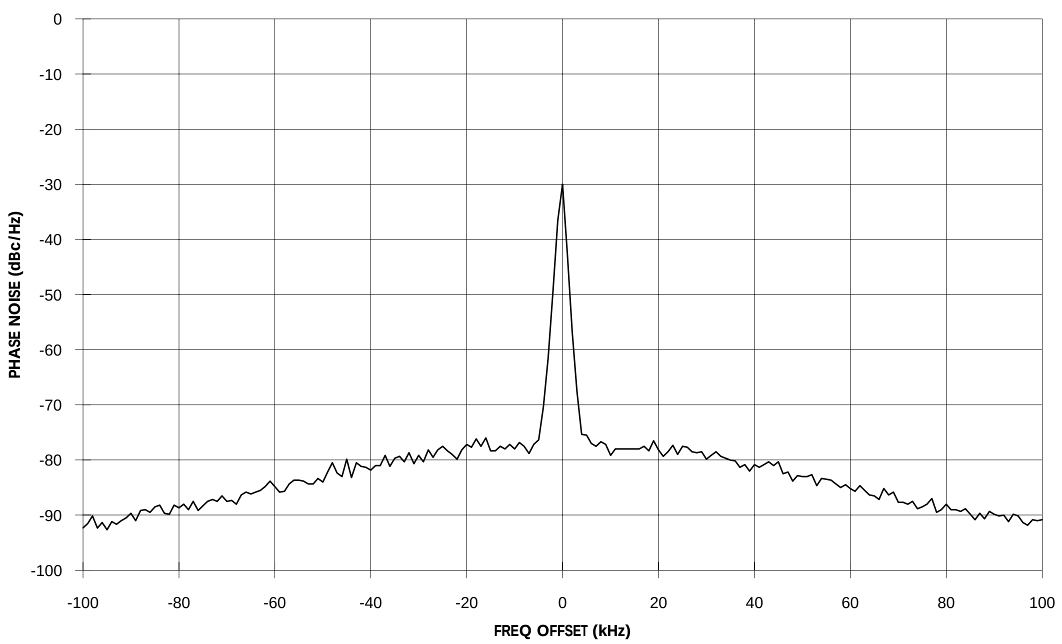


Figure 6 GP2010/GP2015 VCO spectrum using recommended PLL loop filter - VCO regulator enabled - typical at +25°C

Configuring A 10.000MHZ PLL Reference Frequency

All Local Oscillator (LO) and digital clock signals on the GPS Orion are generated from the PLL on the GP2015 RF front-end IC, referenced to a 10.000MHz TCXO. The primary frequency produced by the PLL with the on-chip VCO is 1400MHz; this is used as the 1st LO for mixer 1. ALL other LOs and digital clocks are produced from the 1400MHz signal as shown below:-

FREQUENCY	USED FOR	HOW PRODUCED	COMPONENT USED TO SOURCE
10.000MHz	PLL reference signal	10.000MHz TCXO	TCXO
1400MHz	1st LO for GP2015 Mixer 1	TCXO multiplied by 140 (= VCO)	GP2015
140MHz	2nd LO for GP2015 Mixer 2	VCO divided by 10	GP2015
40MHz	OPCLK for correlator	VCO divided by 35	GP2015
31.1111MHz	3rd LO for GP2015 Mixer 3	VCO divided by 45	GP2015
5.71428MHz	CLK for GP2015 ADC	OPCLK divided by 7	GP2021
MCLK (pin 30 of GP2021)	CLK for ARM-60B	OPCLK divided by 2, with waitstates inserted	GP2021

The GP2010/GP2015 has an on-chip oscillator circuit to produce 10.000MHz in conjunction with an external crystal. However, the stability of a crystal without temperature compensation is not sufficient to guarantee signal acquisition and lock; for this reason, the PLL reference for the GPS Orion is provided by a 10.000MHz TCXO.

It should be noted that the reference frequency variations can have four main effects on the system performance:-

- A small frequency error from nominal (>0.3ppm) at start-up will cause the system to start searching for satellite codes at the wrong doppler-offset frequencies, even when the ephemeris (orbital) data is up-to-date; this will extend the search time and impact the Time To First Fix (TTFF).

- A large frequency error from nominal (>50ppm) will cause the GP2010/GP2015 to impose a significant frequency shift inthe down-converted L1 signal. This can result in a significant part of the ±1.023MHz GPS wanted signal being removed by the tight frequency response of the Dynex DW9255 SAW filter.

- Abrupt frequency changes, of much less than 0.1ppm, can either inhibit satellite-code lock or cause the system to lose satellite lock. Digital temperature compensation schemes can experience this problem.

- Modulation of the reference frequency across a very wide frequency range (10s of Hertz up to 10s of MHz), will translate into spurious signals which can distort the down-conversion of the wanted GPS signal through the RF front-end, and can also mix out-of-band signals into the GPS wanted signal band that can degrade the signal-to-noise of the correlated satellite signals. This can result from noise on the power-supply line to the TCXO, and appropriate supply filtering can alleviate this problem (Refer to “Supply Filtering for the TCXO”).

Although the standard GPS Orion software will fail to acquire GPS signals which are offset by >2.5ppm, the software can be adjusted to look for satellite signals across a very wide doppler frequency range (Refer to GP2021 data sheet). The TCXO selected for the GPS Orion is from a range of sub-miniature 2.5ppm units from either NDK (5111A-ANL50-A @10MHz) or Oscillatek (T-1115@10MHz or OSC-3AO-AUK @ 10MHz or Rakon (TXO200B@ 10MHz). The output level from each of these TCXOs is a 1.0V peak-to-peak minimum clipped sinewave.

If the amplitude of the signal from the TCXO into a GP2010/GP2015 is greater than 1.2V peak-to-peak, a spurious output will appear on the IFOUT signal due to harmonics of the 10.000MHz PLL reference. These can interfere with the 3rd stage mixer and produce interference spurs on the signal at IFOUT(e.g. Third harmonic (30MHz) will produce a spur at 1.111MHz). For this reason, the TCXO output level is attenuated by 6dB using a potential divider network to produce a 600mV peak-to-peak amplitude, and being AC coupled into the REF 2 input (pin 27) of the GP2010/GP2015

Supply Filtering of the TCXO

The components on the GPS Orion Receiver are operated from a common power-supply - Vdd. This means that all the ICs, the active antenna and the TCXO share the same power supply.

The GPS Orion runs software at a typical bus speed of 20MHz (not including wait-states). Consequently, there is a large amount of digital interference produced over a wide frequency range, which can be modulated onto the Vdd power-supply. The GP2010/GP2015 is a RF linear IC, which requires careful placement with respect to all the digital components, in order to reduce the risk of digital interference into the RF receive chain. Combined with this is the need to ensure that the 10.000MHz TCXO has a very clean power-supply. The GP2010/GP2015 PLL is referenced to the TCXO signal - the cleaner the TCXO signal, the cleaner the 1.400GHz VCO signal produced, and hence the cleaner ALL the local-oscillator frequencies and digital clocks will be.
Figure 7 shows the difference in the GP2010/GP2015 1.400GHz VCO quality, between having no low-frequency supply filtering and having optimised low-frequency supply filtering on the TCXO.

Note the dramatic difference in VCO signal quality. When the software is running, and the TCXO has no low-frequency decoupling, there are large digital interference spurs, which are up to -20dBc in amplitude. These can have a detrimental effect on the quality of the down-converted L1 signal, by mixing out-of-band signals into band, and also smearing the L1 spread-spectrum signal. The optimised low-frequency supply filtering removes all detectable low-frequency interference modulation on the 1.400GHz signal. This means that the out-of-band interference rejection of the GP2010/GP2015 is greatly improved, and the amount of jitter in any digital clock is greatly reduced.

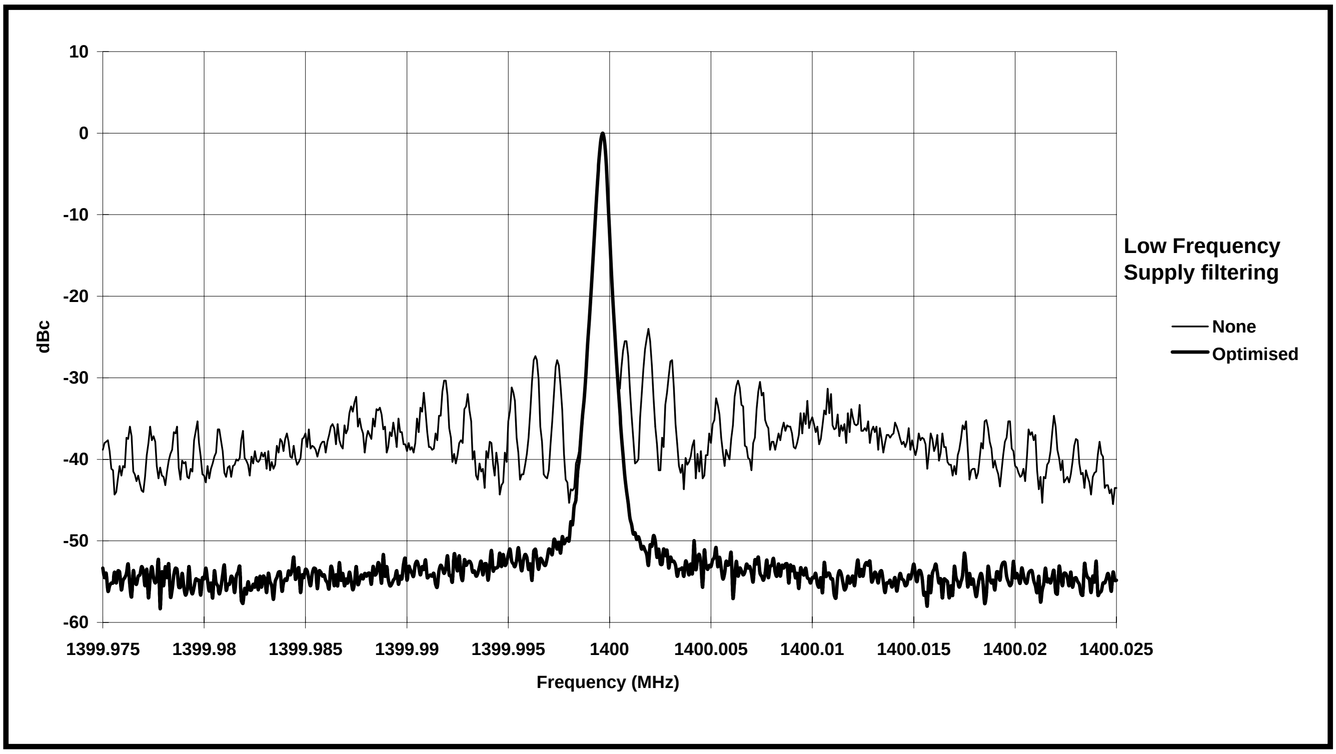


Figure 7 GP2010/GP2015 1.4GHz PLL VCO spectral quality - with and without optimised low frequency decoupling 50kHz span Resolution bandwidth = 300Hz

The low-frequency decoupling which has been used with the TCXO on the GPS Orion, and the connections to the GP2015 are shown in Figure 8. The TCXO supply filtering comprises a series 51Ω resistor in the supply line between Vdd and the supply pin of the TCXO and a parallel 10uF & 100nF capacitor between the TCXO supply pin and GND. The TCXO must not consume more than 5mA or else the voltage drop across the 51Ω resistor will be too large.

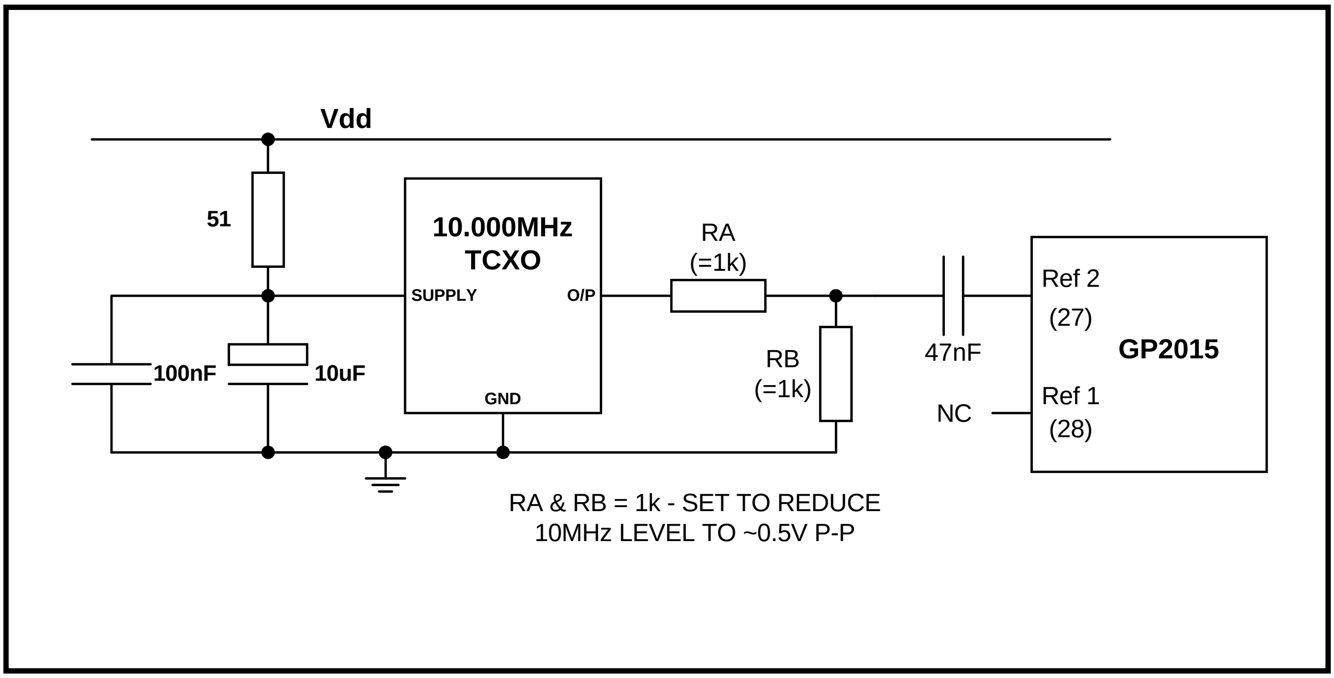


Figure 8 Supply decoupling scheme used with the 10.000MHz TCXO and the GP2015 RF front end IC

Filter Details

The GP2010/GP2015 uses a triple conversion architecture. All three stages can be treated as separate blocks. User-defined filter networks can be used for IF filtering between stages 1 & 2, and between stages 2 & 3.

i) RF filter

The GP2010/GP2015 stage 1 mixer has an on-chip image-rejection filter, with optimum pass band set at 1575.42MHz, and a rejection of the image frequency (1400 - 175.42MHz = 1224.58MHz) of approximately 7dB. Image rejection is not critical at 1224.58MHz due to this frequency being at approximately the GPS L2 frequency (1227.6MHz), so there is only noise at this frequency.

The Image filter is fixed, but can be enhanced by the addition of an external RF filter between the LNA and the RF front-end.

Centre Frequency	1575.42MHz
Pass Band	±1.0MHz minimum (within ±1.0dB)
RF Image frequency	1224.58MHz
Input Impedance	50Ω typical
Output Impedance	50Ω typical
Insertion loss	0.5dB -> 2.0dB

The RF filter is required to remove the 1224.58MHz image noise and to prevent overload by strong out-of-band interference signals of the Stage 1 mixer in the GP2010/GP2015 RF front-end. The required performance of this filter will be influenced by any locally generated interfering signals that may be present (for example, mobile telephone). Ideally, the filter should reject any out-of-band interference to a level, at the GP2010/GP2015 RF input, of at least 10dB below the level at which the Stage 1 mixer will gain compress by 1dB (refer to GP2010 & GP2015 data-sheets for 1dB compression level). The pass-band of this filter should be flat across the 2MHz bandwidth of the GPS C/A code signal. For most filter technologies the bandwidth will be significantly greater than this.

When specifying the RF filter, it is important to consider the filtering effect of the GPS antenna and low-noise amplifier. The majority of GPS antennas are patch types, which have a narrow bandwidth and will therefore provide some filtering. However, some antennas rely on this for out-of band signal rejection. In many applications, it may be necessary to reject large signals which are close to the GPS signal frequency (1575.42MHz). It may be necessary to cascade multiple filters to obtain high out-of-band rejection. Active antennas which incorporate their own RF filters can assist in this. Indeed, if a filter is included between the antenna and an LNA, the tendency for an LNA to be overloaded by a jamming signal will be reduced; the GPS signal will become more resistant to out-of-band jamming signals.

The insertion loss of the RF filter can affect the noise-figure of the GP2010/GP2015. The LNA which boosts the signal from the antenna to the GP2010/GP2015 should be designed so that there is sufficient gain for the RF filter loss to have a negligible effect on overall noise-figure (see Antenna Details).

A typical RF filter will be a dielectric type. Suitable filters are available from a range of manufacturers. A recommended type of RF filter is the Murata DFC21R57P002HHA which is centred on 1575.42MHz and has a 2MHz passband (-3.0dB). The typical insertion loss and return loss responses for this filter are shown in Figure 9.

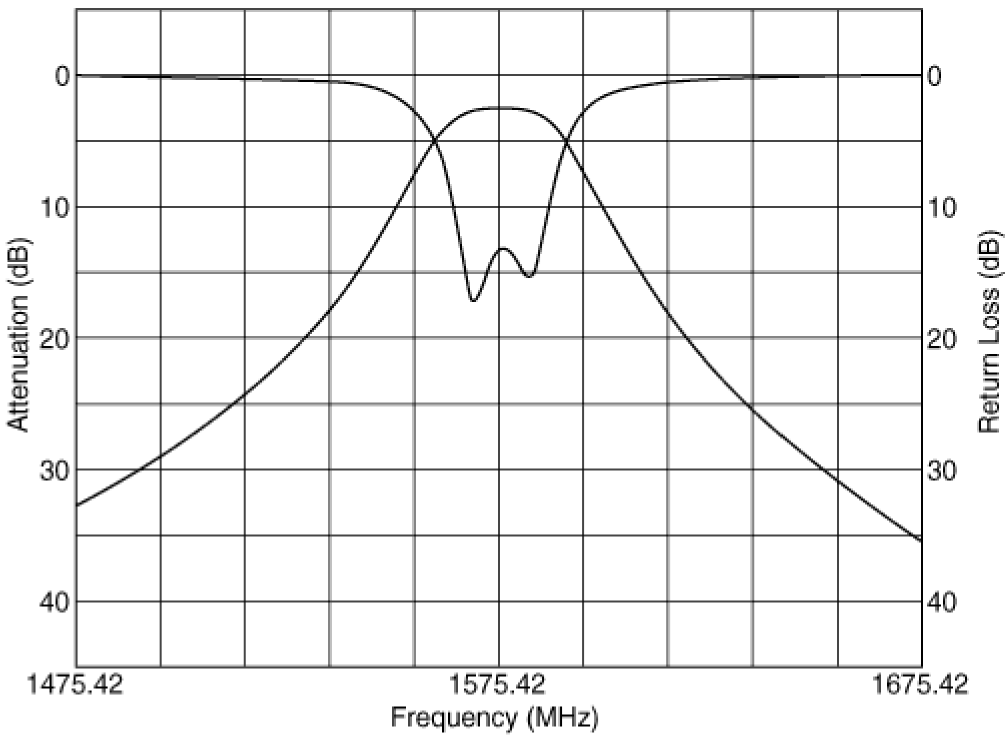
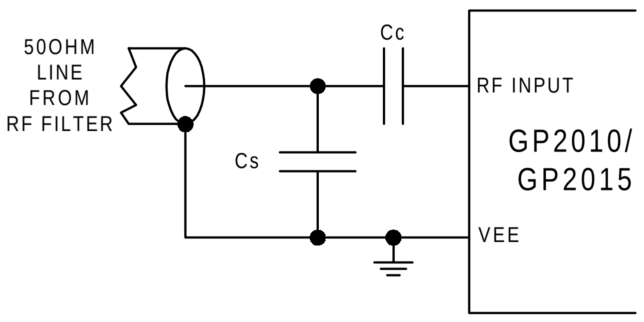


Figure 9 RF characteristics of the Murata DFC21R57P002HHA RF ceramic filter

The GP2010/GP2015 requires components to match the input impedance to that of the RF filter output. Most filters have a 50Ω output impedance, and Figure 10 shows the recommended matching circuit. The Cc capacitor is used also as a DC block between the RF I/P and the +5V feed to an LNA in an active antenna.Note that the matching components for the GP2010 and GP2015 are different, due to the different inter-lead parasitics of the 44-lead MQFP package used by the GP2010, and the 48-lead TQFP package, used by the GP2015.



DIFFERENCES:-

	GP2010	GP2015
Cs	1.5pF	2.7pF
Cc	4.7pF	12pF
RF I/P	Pin 29	Pin 32
VEE	Pins 27,28,30,31	Pins 30,31,33,34

Figure 10 RF input matching circuit

ii) Information on Microstrip Transmission Lines

The RF filter will only operate correctly if the characteristic impedance of the RF transmission lines to it and the RF input of the GP2015 (or GP2010) is set to be 50Ω A typical RF transmission line on a double-sided (or multi-layer) printed circuit board is the “microstrip line”.

The characteristic impedance (Zo) of the signal lines into and out of the RF filter need to be maintained at 50Ω in order to avoid Standing Waves from being set-up in the 50Ω transmission line from the Antenna to the RF filter, and from the RF filter to the RF matching components on the RF input of the GP2015 (or GP2010). Standing Waves can introduce significant attenuation of the GPS L1 received wanted signal at the GP2015 (or GP2010) RF i/p, and so it is important to ensure that the microstrip line between the antenna connector and the RF filter is designed to have a 50Ω characteristic impedance.

A microstrip line is a transmission line where there is a strip of a conductor of a fixed width and thickness sitting on a substrate dielectric which separates it from a ground-plane. The microstrip dielectric is actually a composite dielectric due to the air that exists above the microstrip conductor, and the substrate dielectric which exists below. A representation of a microstrip is shown in Figure 11.

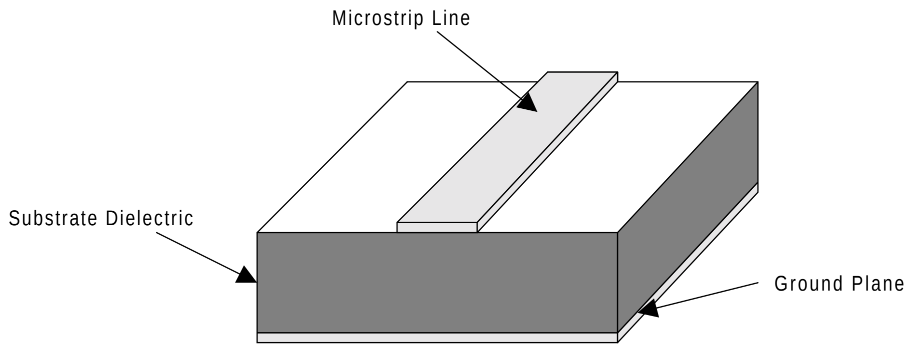


Figure 11 Structure of a microstrip planar transmission line

As the dielectric around the microstrip is a discontinuous mixture of air and substrate material, the propagation of signals down a microstrip are affected by fringing fields. The calculation for the characteristic impedance of a microstrip line is complex as a result, but can be simplified for a limited range of conditions. Figure 12 shows the breakdown of the component dimensions for a microstrip transmission line.

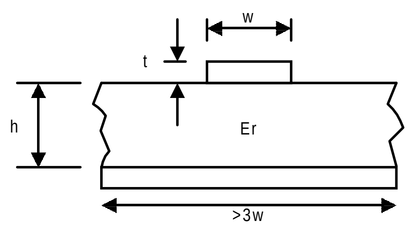


Figure 12 Microstrip transmission line dimensions

For a ground-plane which is at least 3 times the width of the microstrip (w), the ratio of w/h over a range of 0.1 to 3.0, and Er over a range of 1 to 15, the equation for the Characteristic Impedance (Zo) of a planar microstrip transmission line approximates to :-

$$Zo = \frac{87}{\sqrt{(Er + 1.41)}} * \ln\left(\frac{5.98 * h}{0.8w + t}\right)$$

This can be re-arranged to give :-

$$\frac{w}{h} = \frac{5.98}{0.8 * e^{\left(\frac{Zo * \sqrt{Er + 1.41}}{87}\right)}} - t$$

Therefore, the track width for a given characteristic impedance of microstrip is directly proportional to the separation of the microstrip from the ground-plane. The most widely used substrate dielectric for printed circuit boards is fiber-glass epoxy of grade FR4, which has a relative permittivity (Er) of between 4.7 and 5.4. Typically, the copper is coated to a density of 1 ounce, which gives a thickness (t) of 35mm.

Using these parameters, a microstrip line with a 50Ω characteristic impedance has a width (w) as a function of the separation (h) between it and a ground-plane, as shown in Figure 13. A table of the numbers used to generate the plot is shown in Figure 14.

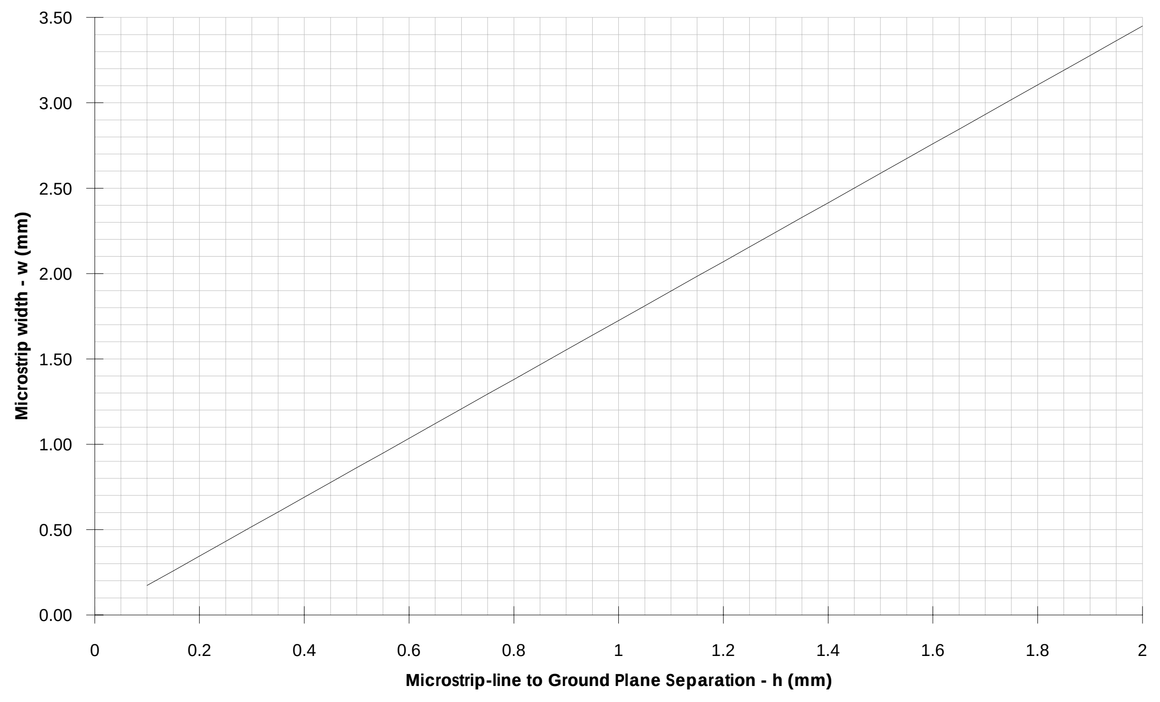


Figure 13 Microstrip width versus separation from Ground plane, for microstrip on fibre-glass board (Zo = 50Ω, Er = 5, copper thickness = 35um (1oz))

Separation (h)	Strip width (w)	Separation (h)	Strip width (w)	Separation (h)	Strip width (w)	Separation (h)	Strip width (w)
0.05	0.08	0.55	0.95	1.05	1.81	1.55	2.67
0.1	0.17	0.6	1.03	1.1	1.90	1.6	2.76
0.15	0.26	0.65	1.12	1.15	1.98	1.65	2.85
0.2	0.34	0.7	1.21	1.2	2.07	1.7	2.93
0.25	0.43	0.75	1.29	1.25	2.16	1.75	3.02
0.3	0.52	0.8	1.38	1.3	2.24	1.8	3.10
0.35	0.60	0.85	1.47	1.35	2.33	1.85	3.19
0.4	0.69	0.9	1.55	1.4	2.41	1.9	3.28
0.45	0.78	0.95	1.64	1.45	2.50	1.95	3.36
0.5	0.86	1	1.72	1.5	2.59	2	3.45

Figure 14 - Data of microstrip width versus separation from Ground-plane, for microstrip on fibre-glass board (Zo = 50Ω, Er = 5, copper thickness = 35um (1oz))

Multilayer boards can have RF microstrip to ground-plane separations which are dependent on the thickness of the board, the number of layers used in the board, and the layer used for RF ground-plane.

With the GPS Orion receiver design, the board is manufactured as a 1.6mm thickness 4-layer board, with the ground-plane implemented on layer 2. There are 4 layers of 35um copper, which occupy 0.14mm of thickness. This leaves approx. 1.45mm of thickness for the dielectric material. With 4 interconnect layers, 2 of the layers (layers 2 & 3) are implemented internally. In order to keep the layers equally spaced, the dielectric is fabricated as 2 planes of 0.5mm thickness, which are stuck together with a plane of 0.45mm thickness. For the RF input microstrip to the RF filter and subsequently the GP2015 (or GP2010), the microstrip needs to be 0.8mm wide to give a 50Ω characteristic impedance.

If the artwork which is used is different to that shown in Figs. 30 to 33, then it is important to ensure that RF microstrip tracks for the L1 GPS signal are set to have the correct impedance. This is particularly true if the board design uses 6 interconnect layers (or more)

iii) 1st IF filter

Centre Frequency	175.42MHz
Pass Band	±1.0MHz minimum (within ±1.0dB)
Insertion loss	3dB maximum
2nd IF Image frequency at 1st IF	104.58MHz
2nd IF Image frequencies at RF	1504.58MHz, 1295.42MHz
Source Impedance	700Ω typical
Load Impedance	700Ωtypical

The first external IF filter for the GP2010/GP2015 RF front-end is connected between the output of Stage 1 and input of Stage 2. It is required to reject the image of the second IF at 104.58MHz (140 - 35.42MHz), which corresponds to an RF input frequency of either 1504.58MHz, or 1295.42MHz. Some rejection of these images at the RF input will have been achieved by the RF filter and the GPS antenna but it is recommended that a 1st IF filter is used to reject this image frequency further. As with the RF filter, the pass-band of this filter should be flat across the 2MHz bandwidth of the GPS Coarse-Acquisition (C/A) code signal. For most filter technologies the bandwidth will be significantly greater than this. It is important to ensure that the filter has no more than 3dB loss, otherwise the gain of the receiver will not be high enough for correct operation of the AGC in the 3rd IF stage.

The first IF filter is also used to reduce the level of interfering signals that reach the Stage 2 mixer input on the GP2010/ GP2015 RF front-end. Consideration should be given to any interfering signals that may be present within approximately ±200MHz of the wanted GPS signal of 1575.42MHz. As with the RF filter, the first IF filter should reject any out-of-band interference to a level, at the Stage 2 mixer input, of at least 10dB below the level at which the mixer gain compresses by 1dB (refer to GP2010 & GP2015 data-sheet for 1dB compression level).

The GP2010/GP2015 stage 1 mixer output needs external DC bias to achieve maximum IF signal handling headroom. The first IF filter should incorporate DC connections to Vcc for this, and can normally be achieved by pull-up inductors. However, the signal path from the Stage 1 to Stage 2 must be AC coupled. In typical applications, a two resonator coupled-tuned LC filter can be used for the 1st IF filter. Figure 15 shows a typical design for the GP2015, which is implemented on the GPS Orion Receiver Board. This design approximates to a 2-pole Chebyshev response with 0.1dB ripple, which has good band-stop attenuation. It also has acceptable group-delay due to the wide bandwidth of the passband (~15Mhz within ±3dB).

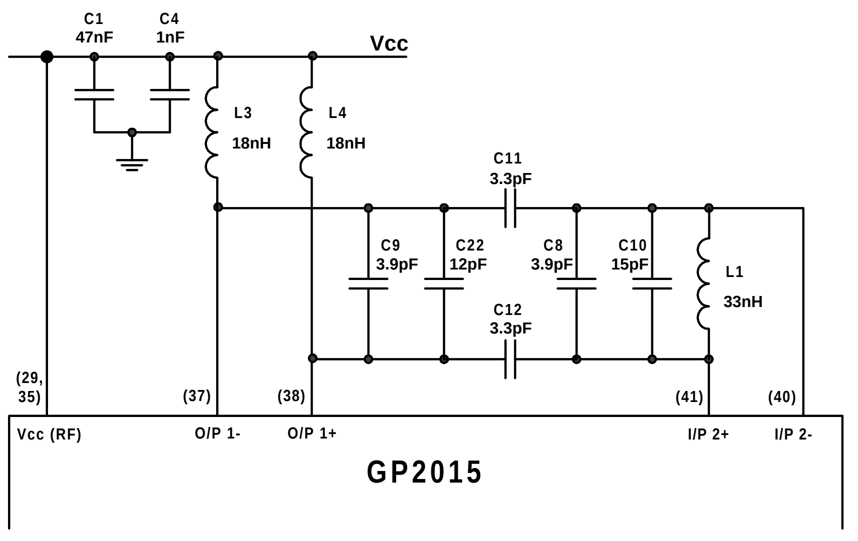


Figure 15 Typical coupled tuned LC 1st filter used with GP2015, including decoupling

This IF filter has a centre-frequency of 175.42MHz, with a nominal 3dB bandwidth of 15MHz. A typical frequency response for this type of filter is shown in Figure 17.

The 175.42MHz IF filter used with the GP2015 comprises the following components:-

L1, L2	-	18nH, 2%	
L3	-	33nH, 2%	
C9 & C22	-	15.9pF,	2% (made up of capacitors in parallel)
C8 & C10	-	18.9pF,	2% (made up of capacitors in parallel)
C11,C12	-	3.3pF,	2%

These filter components need to have a close tolerance to ensure that the frequency response of the filter remains acceptable over the tolerance of component manufacture; 2% tolerance is preferable to 5%. The values may need to be adjusted, if a different board layout to that shown for the GP2015 in Figures 30 to 33 (at the end of this application note) is used.

The GP2010 uses the same type of filter, although the values of components will differ due to varying parasitics in the lead-frames of the GP2010 & GP2015 IC packages. Figure 16 shows a typical design for the GP2010.

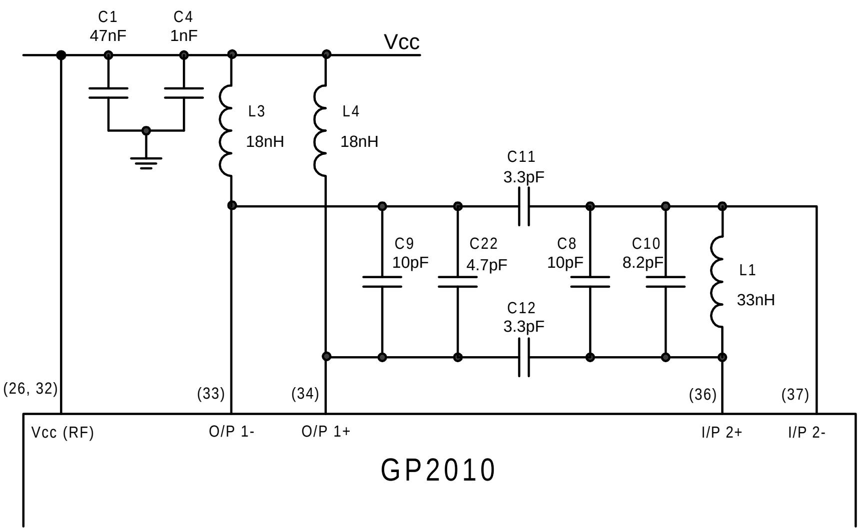


Figure 16 Typical coupled tuned LC 1st filter used with GP2010, including decoupling

The components used with the GP2010 filter are virtually the same as for the filter used with the GP2015, except that the parallel resonant matching capacitors C9, C22, C8 & C10 are of lower value:-

C9 & C22	-	14.7pF,	2% (made up of capacitors in parallel)
C8 & C10	-	18.2pF,	2% (made up of capacitors in parallel)

The Stage 1 mixer on the GP2010/GP2015 has a double-balanced design, and has a high rejection of local-oscillator and RF input signals at the mixer output. The filter needs to supply DC bias to the Stage 1 mixer output. For this reason it is crucial to ensure that the IF filter Vcc is well decoupled over a wide frequency range. The Vcc decoupling has been greatly simplified compared to previous designs that have been produced by Zarlink Semiconductor. The GP2010/GP2015 RF front-end chip implements the most effective RF decoupling on-chip; there is approximately 180pF between Vcc (GP2015 pins 29, 35 / GP2010 pins 26, 32) and GND (GP2015 pins 30, 31, 33, 34 / GP2010 pins 27, 28, 30, 31). Low-frequency decoupling capacitors C1 & C4 are used to reject lower frequency interference from the digital systems on the GPS Orion receiver board.

The layout of the filter on a PCB is fairly critical, since any change in the separation of the components can affect inter-component parasitics. Also, the parasitics of the tracks used to connect the components together can affect the response of the filter. Allowance should also be made to ensure there is good isolation between the filter and the RF input signal track

It is recommended that the layout for the GP2015 is not changed significantly from that used in the GPS Orion receiver board.
The frequency response of the 1st IF filter is shown in Figure 17.

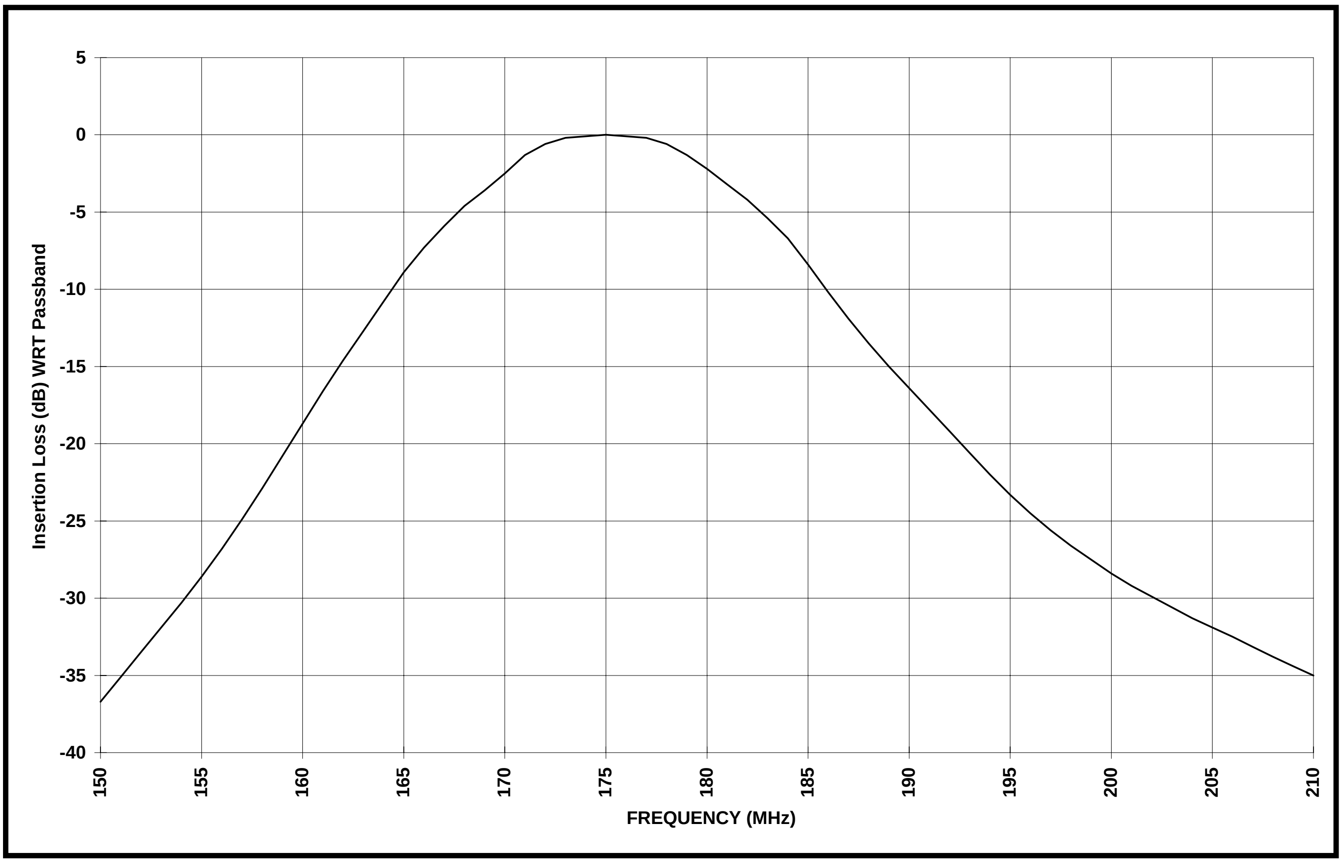


Figure 17 typical frequency response of 1st IF filter

iv) 2nd IF filter

Centre Frequency	35.42MHz
Pass Band	±1.0MHz (within ±1.0dB)
Insertion loss	14-18dB
Stop band	>10dB within ±2.0MHz
Group-delay ripple	<300ns (34.62MHz to 36.22MHz)
Maximum Group-delay	<1.7us
3rd IF Image frequency at 2nd IF	26.8MHz
3rd IF Image frequencies at 1st IF	166.8MHz, 113.2MHz
3rd IF Image frequencies at RF	1566.8MHz, 1513.2MHz, 1286.8MHz, 1233.2MHz
Source Impedance	500Ωtypical
Load Impedance	1000Ω typical

The second external IF filter used with the GP2010/GP2015 is connected between the output of Stage 2 and input of Stage 3. The bandwidth of the RF section of the GPS receiver is critical to the receiver performance. The filter should be flat across the 2MHz bandwidth of the GPS Coarse-Acquisition (C/A) code signal. It should also have high rejection (greater than 20dB) beyond this bandwidth, and so should have a brick-wall type response at these extremes. This can be realised with a specifically designed SAW filter, the Dynex DW9255, available from Zarlink Semiconductor, (refer to Data Sheet number DS3861). The Dynex DW9255 SAW filter provides a 1dB Bandwidth of typically 1.9MHz centred on 35.42MHz, with a typical pass band ripple of 0.8dB, when the SAW input and output capacitances are resonantly matched with inductors of optimum value. The out-of-band signal rejection is better than 21dB at ±2.0MHz, and better than 35dB at ±7.5MHz.

The frequency response of the Dynex DW9255 SAW filter with matching components is shown in Figure 18.

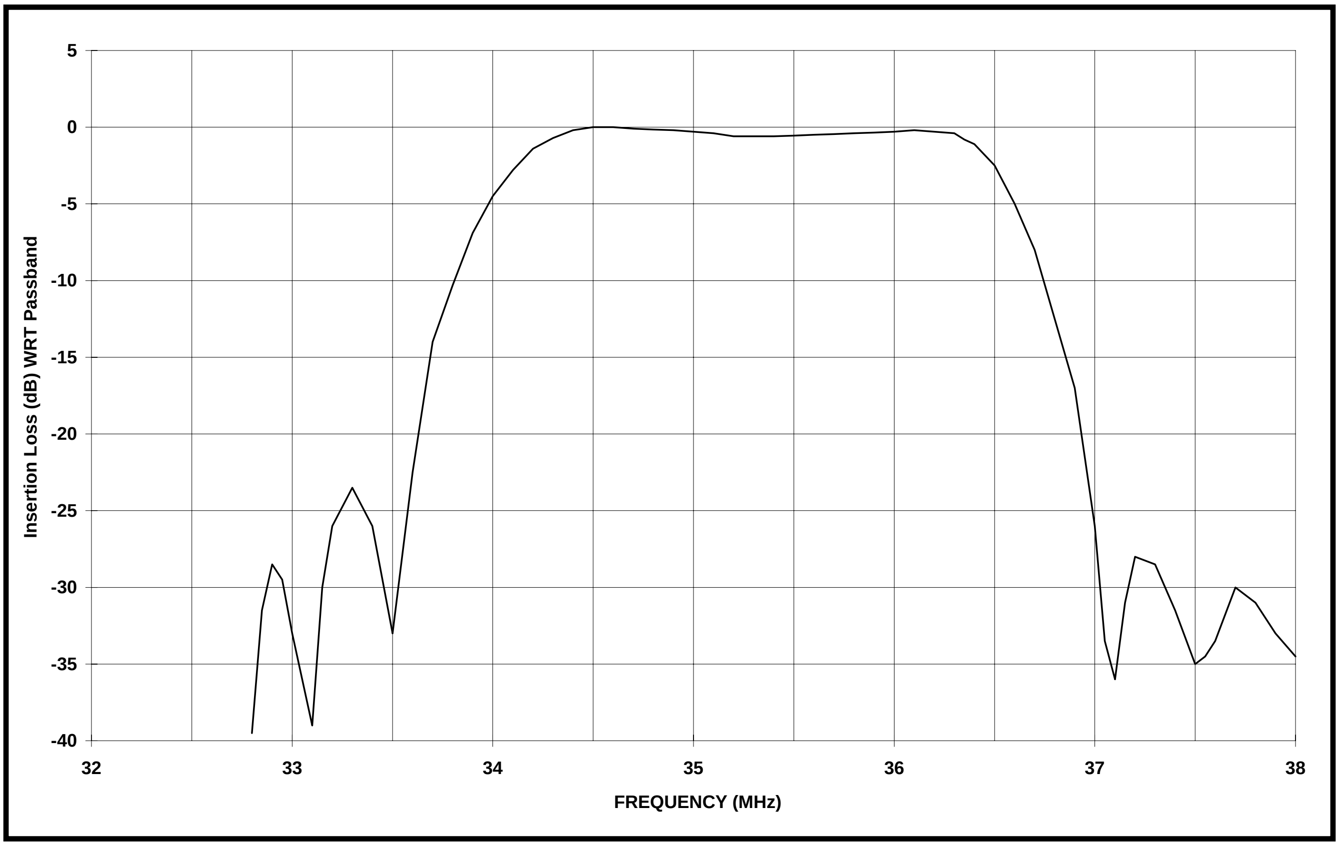


Figure 18 Typical frequency response of Dynex DW9255 SAW filter used as 2nd IF filter

v) 3rd IF filter

Centre Frequency	4.3MHz	
Pass Band	see	GP2010 data sheet DS4056,
	or	GP2015 data sheet DS4374 - “Electrical characteristics”

The third IF filter is on-chip on the GP2010/GP2015. The performance of this filter is defined in the data sheet. The overall RF bandwidth of the GPS receiver is defined by the 2nd IF filter, so the third IF filter is used to reject out-of-band noise and interference from entering the on-chip analogue to digital converter. The response is essentially band pass, with a low pass operating above 10MHz, and a high-pass filter with a corner frequency of 2.0MHz which is used between the point which the IFOUT signal is connected, and the analogue to digital converter. Hence, the IFOUT signal will NOT show the high-pass response.

The final IF can be monitored via the IFOUT test-point before the signal is digitised. This test-point is a high-impedance output, buffered by an on-chip 1kΩ resistor. To monitor this point, it is imperative that the signal is AC coupled, since there is a DC bias from the GP2010/GP2015.

The frequency response of the third IF filter is shown in Figure 19, with 3 traces:-

IFOUT RESPONSE - spectrum observed at IFOUT pin,

ZERO RESPONSE - response calculated between IFOUT pin and analog to digital converter,

ADC I/P RESPONSE - IF spectrum of stage 3 calculated at analog to digital converter input.

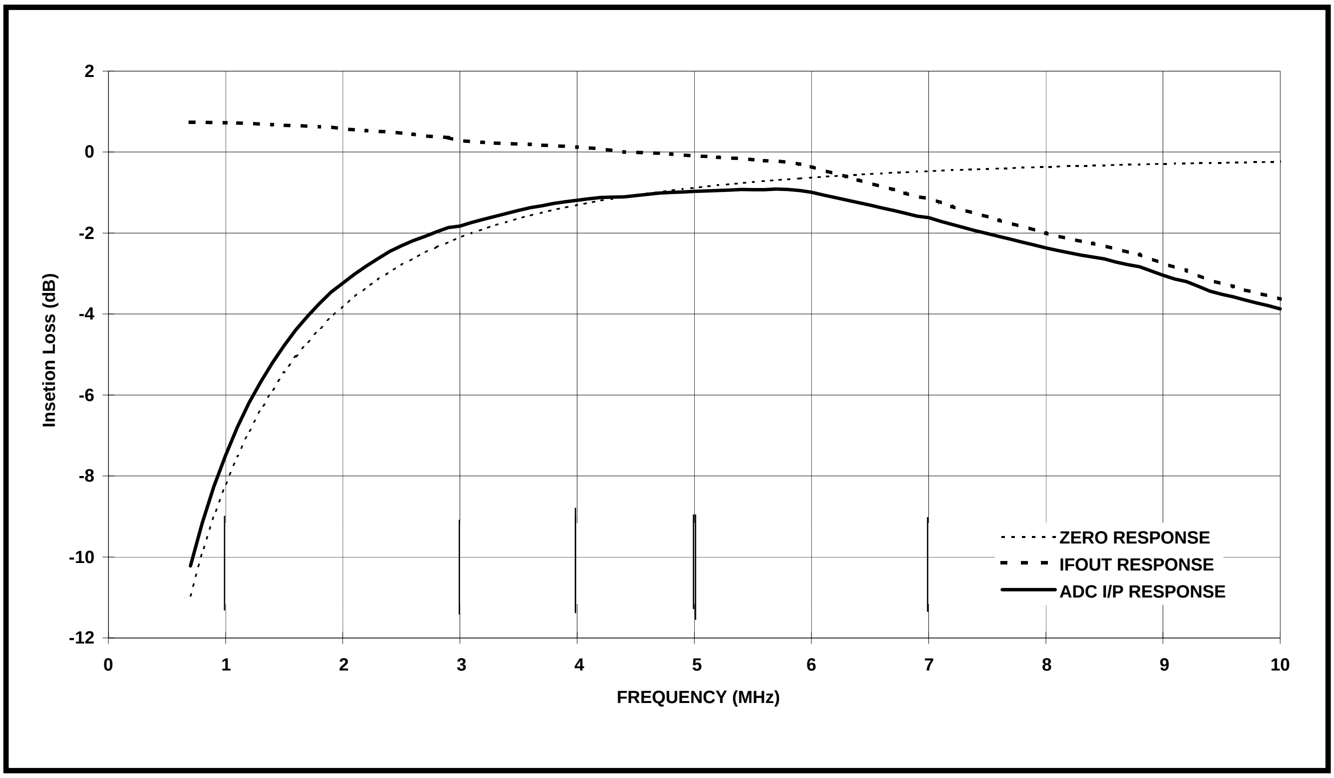


Figure 19 Typical frequency response of 3rd IF filter (on-chip on GP2010/GP2015)

AGC Time Constant and Monitoring of Gain Level

The third IF stage of the GP2010/GP2015 has an Automatic Gain Control (AGC) to ensure that the level of the IF signal at the input to the Analog to Digital converter remains constant, giving a duty-cycle for the MAG data output of 30%.

In most applications, the time-constant (Δt) of the AGC can be fixed to approximately 2ms with the connection of a 100nF capacitor between the pins AGC+ (pin 22) and AGC- (pin 21). However, there are now applications using “pseudolites” for aircraft landing systems where the AGC will need to have a much shorter time-constant, maybe in the order of 50ms, to cope with the huge difference in RF signal level from these and the satellites in the sky.

The time-constant of the AGC with a given capacitor (Cagc) connected between AGC+ and AGC- is dependent on the required gain change.

The ratio of gain adjustment (ΔGain) to the change of voltage across the AGC capacitor (Δ Vagc) is approximately 400dB/V (although NOT linear over the whole gain adjustment range, 0.4dB/mV is a reasonable approximation).

For the case of a large interfering signal (in close proximity to a pseudolite, for example) driving the AGC to reduce gain, the recovery time after the interfering signal disappears depends upon the rate of change of $\Delta Vagc$. For large gain changes the AGC capacitor is charged/discharged by a 50uA current.

$$\frac{\Delta \text{Vagc}}{\Delta t} = \frac{50\mu\text{A}}{\text{Cagc}} \qquad \therefore \Delta t = \frac{\text{Cagc x } \Delta\text{Gain}}{400 \text{ x } (50 \text{ x } 10^{-6})}$$

For example, a 40dB change in gain gives:-

ΔVagc = 100mV and Δt = 2000 X Cagc

The level of gain reduction by the AGC can be monitored by measuring the change in differential voltage across the AGC capacitor (Cagc). This voltage can also be used to drive a differential amplifier to give a voltage change with respect to 0V (Vee), see Figure 20.

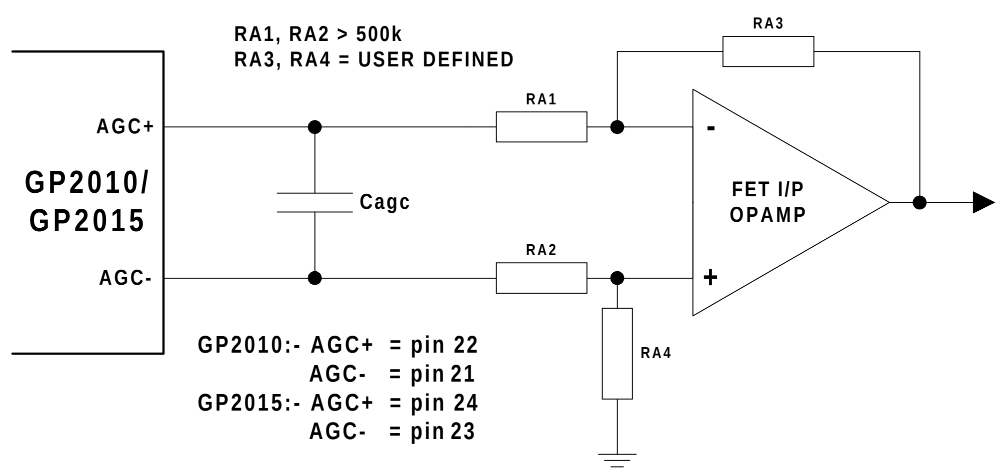


Figure 20 A differential amplifier buffer used to monitor AGC gain setting

The following points should be noted when applying this circuit to the GP2010/GP2015:-

1) The output DC bias on AGC+ and AGC- can vary from Vcc to (Vcc-0.4V) maximum. The op amp should have the capability of measuring these DC voltages with a high common-mode-rejection-ratio (CMRR).

2) The load impedance of the differential amplifier must be greater than 1MΩ, to ensure the AGC performance is NOT affected.

3) An op amp with a very-low input offset should be used (e.g. FET input).

This circuit will not provide an indication of received GPS signal power, since this is buried in the background noise over a 2MHz bandwidth. A change in AGC differential voltage will provide an indication of jamming signals and whether the front-end LNA (connected between the antenna and GP2010/GP2015) is operating correctly.

Figure 21 shows how the voltage on AGC+ (GP2015 pin24) varies with respect to the voltage on AGC- (GP2015 pin 23), when a CW signal at 1575.42MHz is applied to the RF input of a GP2015 on a GPS Orion receiver board.

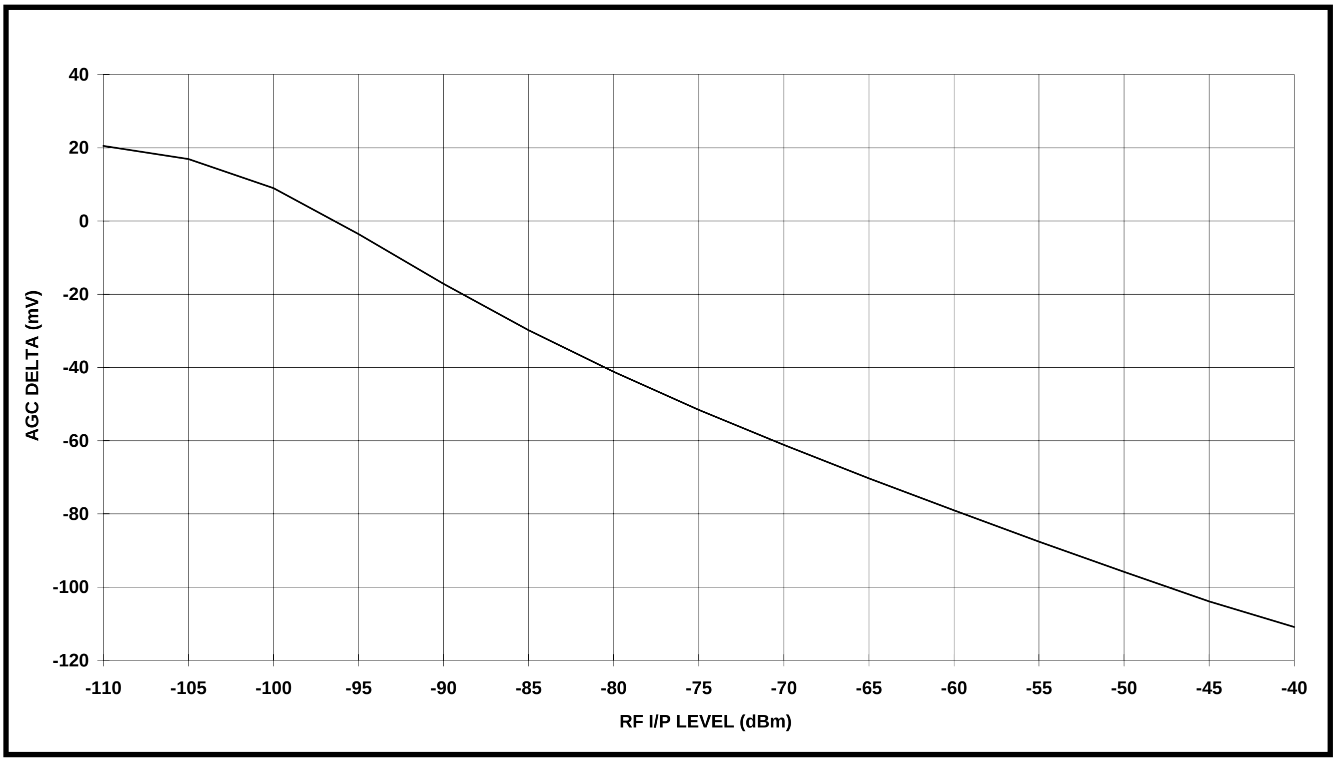


Figure 21 Typical variation in voltage across AGC capacitor (AGC + -> AGC-) with change in GP2015 RF input level-typical at +25°C

IFOUT Spectrum

The GP2010/GP2015 has an IFOUT (pin 1), which is a high impedance (1kΩ) monitor point for test purposes only. This can be used to monitor the output of the IF chain before the signal enters the on-chip analog-to-digital converter. Hence it is the one point in the RF down-conversion where the quality of all of the down-conversion stages can be monitored.

Figure 22 shows the IFOUT spectrum across 0 to 20MHz, for a fully functional GPS Orion receiver, with an active antenna (with +26dB gain LNA) connected and GPS software fully working in the ARM 60-B microprocessor.

The rejection of self-generated interference is excellent, with only minor interference in the spectrum outside the 3.2 to 5.4MHz band. Within the 2to 6MHz band is the tailored response produced by the Dynex DW9255 SAW filter, after going through a down-conversion in the 3rd stage mixer of the GP2015. The wanted signal appears within this tailored “inverted bath-tub” response.

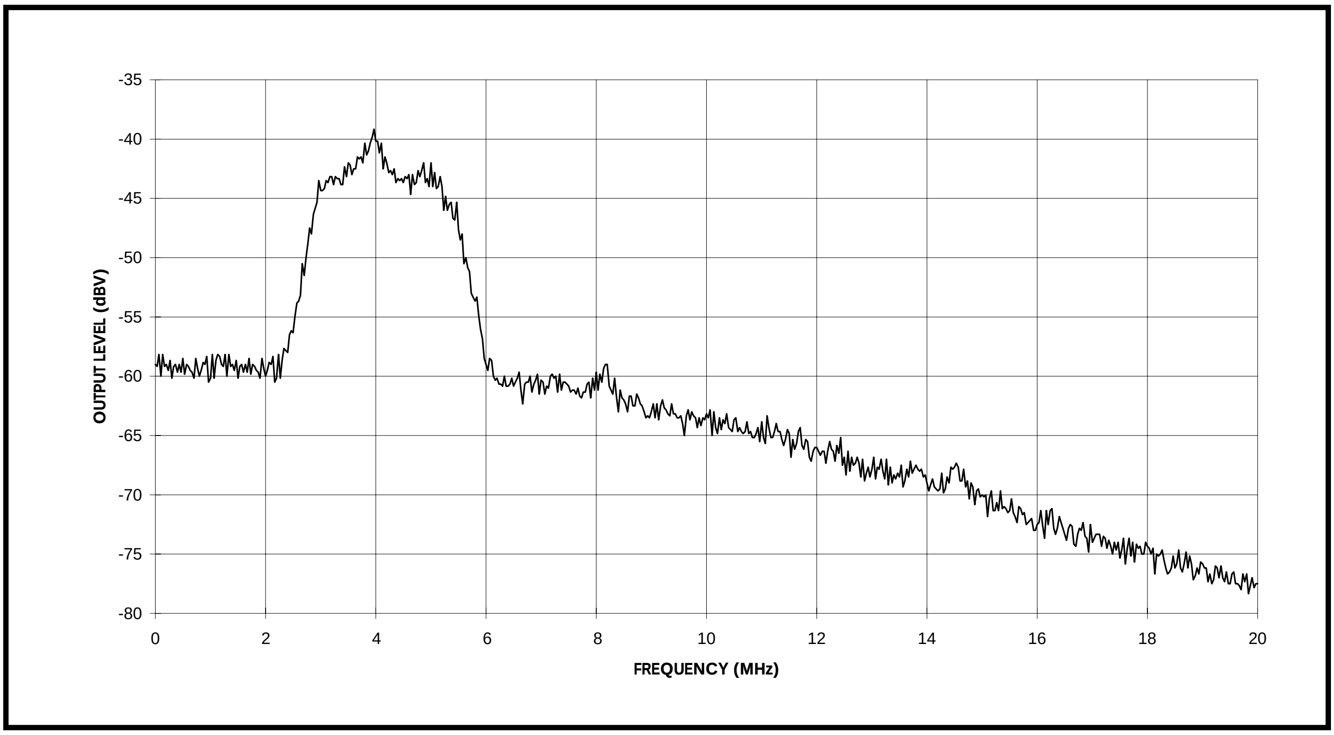


Figure 22 Typical IFOUT Spectrum (Res BW = 300kHz) - with GPS Orion fully working - active antenna connected

The plot in Figure 22 shows that the GP2015 IF spectrum can be virtually untouched by digital interference, provided the layout of the components on the receiver board is optimised. However, if the board layout is poor, it is easy to get a very poor spectral response, with many interference spurs.

An example of the IF spectrum for a poor board layout is shown in Figure 23, which was for an early GPS receiver prototype using the GP2000 GPS chipset. A large number of spurs is in evidence, due to the close proximity of one of the key IF components to a data-bus track, being clocked at 20MHz.

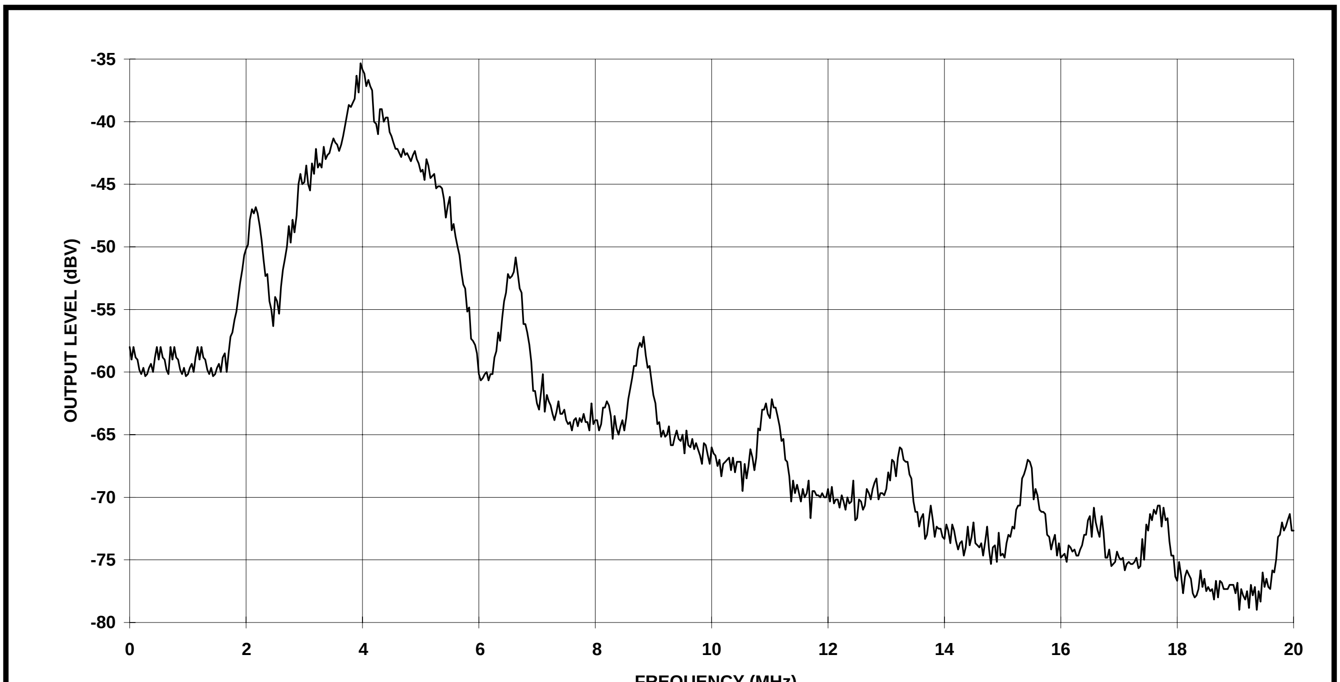


Figure 23 Poor IFOUT spectrum (Res BW = 300kHz) - early receiver prototype - active antenna connected

Figure 24 shows the GP2015 IFOUT spectrum across 0 to 20MHz, for a fully functional GPS Orion receiver with the digital section disabled. An active antenna is still connected but the GPS software has been reset. This shows that the perceived IF spectral purity from the RF front-end is NOT significantly degraded by the digital chips running the GPS software.

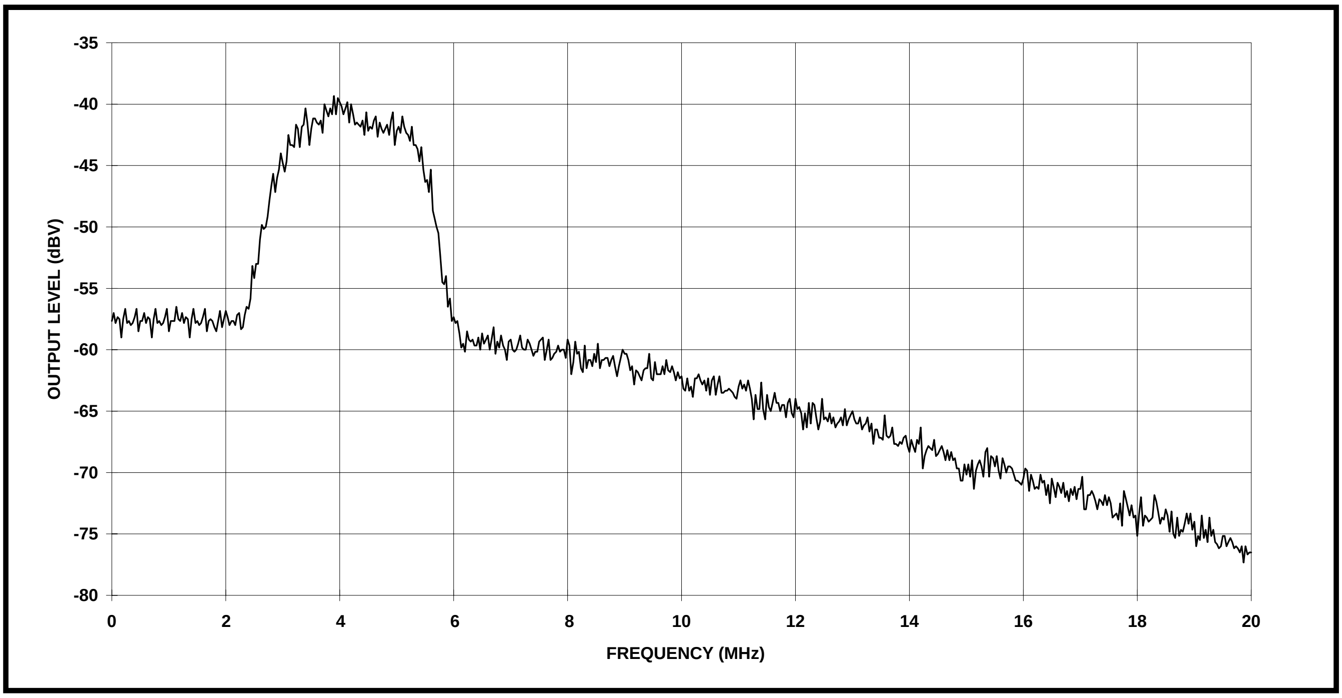


Figure 24 Typical IFOUT spectrum (Res BW = 300kHz) - with GPS Orion digital section disabled - active antenna connected

Techniques for Eliminating Spurious Signals in the IF Spectrum

For the GPS Orion to receive GPS signals correctly, the GP2015 RF front-end must be allowed to extract the L1 GPS signal and down-convert it cleanly to a 1.405MHz digital 2-bit IF. In turn, this means that the final linear IF signal which appears at IFOUT (GP2015 pin 1) must be free of interference generated from the digital electronics on the GPS Orion board. The GP2010/GP2015 has an AGC circuit, as part of the 3rd-stage mixer, to allow the analog-to-digital converter to produce a 2-bit output. The AGC operates on the amplified background-noise which is produced in the band of the GPS wanted signal; the GPS wanted signal is typically buried in noise with a signal to noise ratio of ~-20dB.

Any IF spurs should be suppressed to a level of less than 10% of the nominal IFOUT level to keep the AGC from attenuating the noise in the band of the mixed-down GPS L1 signal to a level at which the correlator will cease to track GPS satellite signals.

The GP2010/GP2015 uses a balanced-signal architecture, and is largely immune to spurious signals. However, there are some exceptions (refer to spectral plots of IFOUT in Figures 22, 23 & 24):-

i) Direct interference from connections between GP2015 RF Front-end and GP2021 Correlator

Care should be taken to ensure that harmonics of the SAMPCLK signal from the GP2021 are kept to a minimum so that they do not become mixed in-band in the IF chain. The SAMPCLK signal produced by the GP2021 is fed into the GP2010/GP2015 at a frequency of 5.71MHz. Spurious signals can appear on the IFOUT pin at frequencies of 8.25MHz, 2.54MHz and 3.17MHz (due to the 4th, 5th and 6th harmonics of CLK respectively), and they can jam the AGC if they are large, and hence affect the GPS data from the MAG and SIGN outputs.

Note: the CLK signal on the GP2010/GP2015 RF front-end IC (pin 11) corresponds to the SAMPCLK signal derived from the GP2021 correlator IC (pin 73).

Harmonics due to the CLK signal input to the GP2015 can be reduced by decreasing the current drive of the SAMPCLK signal from the GP2021. This has been done on the GPS Orion by inserting a 1k5Ω resistor in series between the SAMPCLK output (pin 73) of the GP2021, and the CLK input (pin 11) of the GP2015. This allows the upper harmonics of the SAMPCLK signal to be rolled off by creating a pole with the input capacitance of the CLK pin on the GP2015.

A similar approach is used for the MAG & SIGN signals, which are sourced within the GP2010/GP2015. Since these signals contain components of the CLK signal, the same harmonics can still be generated from MAG & SIGN. The current drive has been reduced by inserting 470Ω resistors in series between the MAG / SIGN outputs (GP2010 pins 12/13, GP2015 pins 14 / 15) of the RF front end, and the MAG0 / SIGN0 inputs (pins 76 / 77) of the GP2021 correlator.

As can be seen in Figure 22, the IF spectrum has almost no digital interference at 8.25MHz, 2.54MHz and 3.17MHz, proving that the method described does work.

ii) Power supply decoupling and routing

The GPS Orion runs off a single +5V power-supply - Vdd (Note:- a backup-supply connection, Vdr, also exists for use when Vdd is powered-off for extended periods of time). Since the main power (Vdd) supplies ALL the components on the GPS Orion receiver, care must be taken to ensure that the main power remains clean across a wide frequency range in order to avoid interference on the GP2015 RF chip. The following key frequency ranges need to be decoupled as completely as possible:-

FREQUENCY RANGE	REASON	DECOUPLING METHOD
DC -> 1MHz	1.400GHz VCO purity	• Use GP2015 on-chip voltage regulator, with 100nF between pins 5 & 6 (5V only) • Use 10uF Electrolytic decoupling to GP2015\ chip • TCXO supply filtering
1MHz -> 15MHz	IFOUT signal quality:- • Rejection of CLK, MAG, SIGN interference • Rejection of 10.000MHz harmonics	Use capacitors as close as possible to affected pins:- • 47nF between GP2015 Vdd(pin 18) and GND • 100nF between GP2015 Vcc (dig) (pin 26) and GND
15MHz -> 50MHz	Rejection of digital signals / harmonics in region of 2nd IF (35.42MHz) These can result from harmonics of the MCLK signal (~20MHz generated by the GP2021), and the OPCLK ± signal (40MHz) generated by the GP2015).	Use 33nF (or larger) capacitors as close as possible to each of all Vdd/Vdr pins on all digital chips. Ideally the opposite side of each capacitor should be connected to the adjacent Vss pin: this keeps the inductance in decoupling lines to an absolute minimum and is particularly important for the GP2021 device.
>50MHz	Elimination of RF signals from Vcc lines, and spurious oscillations, produced from the GP2015 RF front-end	Use small value decoupling capacitors as close as possible to all Vcc pins on GP2015 - 1nF or less, depending on frequency.

The above-defined frequency ranges are the most critical to the GP2015 (or GP2010) performance. Most of the IF gain (75dB) for the GP2015 occurs in the 3rd-stage mixer, which frequency converts the 2nd IF at 35.42MHz to the IFOUT frequency of 4.3MHz. The output from the Dynex DW9255 SAW filter is hence the most sensitive part of the IF chain, to external interference.

Supply decoupling as defined above will remove much of the risk of interference from digital signals. The routing of Vdd power-supply connections is important, in order to avoid further interference problems:-

- The Vdd connection to the digital chips (Digital Vdd, + tap-off to Vdr with memory backup capacitor), and the Vdd connection to the RF section (RF Vdd), must be separate and star-pointed at the Vdd input point onto the receiver board (JP5 pin 9).

- The Vdd(IO) connection to the GP2015 RF front-end (pin 18) needs to be fed from the main Digital Vdd (NOT RF Vdd). This connection must NOT approach the Dynex DW9255 SAW filter, or any of the PLL filter and VCO regulator circuitry connected between pins 1 & 5, and the IF filter circuitry between pins 29 & 44. Digital harmonics may still exist on Vdd(IO) connection which could interfere with the IF stages of the GP2015, if the track is in close-proximity to any IF components, especially the SAW matching inductors.

iii) Critical-component placement and Ground-planes

The following components are critical to the performance of the GPS Orion receiver, and their location on the GPS Orion receiver board has been optimised to keep spurious interference to a minimum:-

Dynex DW9255 SAW filter

The Dynex DW9255 is used to tailor the pass-band response of the GP2010/GP2015 IF to a 2MHz wide pass-band, before the stage 3 mixer applies a significant amount of conversion-gain (up to 75dB). Since the centre-frequency IF of the Dynex DW9255 is 35.42MHz, care must be used to inhibit digital interference. With the GPS Orion, the Dynex DW9255 is mounted as close as possible to the GP2015 RF front-end, by mounting it on the opposite side of the PCB. It is also mounted as far away as possible from ALL digital components.

It is important to ensure that the Mixer 2 outputs from the GP2010/GP2015 - pins 44 & 45 are connected to the inputs of the Dynex DW9255 SAW - pins 1 & 2 and NOT the outputs (pins 7 & 8). The phasing of the connection is not critical - i.e. the signal from pin 44 of the GP2015 can connect to either pin 1 or 2 of the DW9255, provided GP2015 pin 45 is connected to the other input pin on the Dynex DW9255. The same philosophy applies to the GP2010 also.

The outputs from the Dynex DW9255 (pins 7 & 8) must be connected to the Mixer 3 inputs on the GP2015 (pins 47 & 48). Again, the phasing of the connection is non-critical.

2.2uH SAW output matching inductor (L5).

The SAW matching inductors are vulnerable to interference over a wide frequency band of approximately 10MHz to 60MHz. At the resonant frequency of the 2.2uH output matching inductor (L5) and the Dynex DW9255 SAW (i.e. 35.42MHz), the impedance of the inductor is high (~490Ω), which has a side-effect of allowing it to operate as an effective antenna to interference at similar frequencies. Therefore, the GPS Orion receiver uses monolithic magnetically-shielded inductors for SAW matching. This has proven to be a most significant way of removing interference from the 2nd IF frequency signal, and is very strongly recommended.

Ground-plane

A Ground-plane is included in the GPS Orion receiver board, as this is vital to the performance of the RF components. A ground-plane can also help with the digital components in order to reduce ground-bounce with digital clock signals. The ground-plane must be common to both RF and digital sections of the printed circuit board, but there must be a distinct break in the ground plane to help avoid pick up of ground signals by the RF components from the digital components. The ground-planes for RF and digital sections are linked via a thin track at the edge of the PCB.

This therefore means that the RF and digital sections of the PCB are best kept separate - no RF components placed over digital ground-plane area and no Digital components placed over RF ground-plane area. This can be clearly seen in the layout of the ground-plane layer, shown later in this application note in Figure 33.

Antenna Details

The GPS Orion receiver board uses the GP2015 RF front-end, which has been designed to use the signal from a remote GPS antenna with a low-noise-amplifier (LNA) attached (i.e. Antenna at least 1 meter from the GPS receiver). The noise-figure of the complete receiver will then be dominated by the low LNA noise-figure. However, care should be taken to ensure that the gain of the LNA is high enough to allow the GP2015 to function correctly in a GPS receiver. It is also possible to mount an antenna close to the receiver with some additional board design issues. - see "ON_BOARD ANTENNA CONSIDERATIONS"

LNA Gain considerations for GP2010/GP2015

The GPS signal is spread-spectrum modulated with a 2.046 MHz bandwidth, and received power is in the region of -130dBm. The noise power over a 2MHz bandwidth is 63dB up on the background noise in a 1Hz bandwidth (-174dBm/Hz), giving a power of -111dBm. Therefore the GPS signal is buried within the background noise. The GP2010/GP2015 AGC operates on the noise in the band of the GPS signal and not on the GPS signal itself. The de-spreading of the GPS signal by the GP2021 12-channel correlator restores a positive signal-to-noise ratio.

Consider also the following values (with reference to the “IF filter details” section and the Electrical Characteristics table in the GP2010/GP2015 Data-sheet):-

Maximum IF gain of GP2010/GP2015 (minimum guaranteed)	= 106dB	...(a)
Maximum attenuation of external IF filters	= 21dB	...(b)
Nominal IFOUT level with AGC operating (Stage 3)	= 100mV rms	...(c)

Notes:-
a) The maximum IF gain taking account of the loading effects of the IF filtering (but excluding filter losses)
b) The attenuation is the sum of the losses in 1st and 2nd IF filters
c) 100mV rms is equivalent to -7dBm in a 50Ω load

When the background noise within a 2MHz bandwidth is applied directly to the GP2010/GP2015 RF input (with no LNA or RF Input filter) and all IF filters included, the minimum signal produced at the IFOUT will be:-

-111+106-21 = -26dBm

For the AGC of the 3rd IF stage to operate correctly on the applied signal, the signal level at IFOUT should be at -7dBm. This gives a shortfall in signal level of 19dB.

So an RF LNA with combined RF filter needs to provide at least 19dB more noise at the input to the GP2010/ GP2015 than would be provided by a passive antenna alone, to allow the GP2015 to operate correctly. This 19dB should be made up as:-

19dB = LNA gain(dB) + LNA noise-figure (dB).

It is recommended that the LNA gain be kept to below 30dB, so as NOT to overload the GP2015 RF input.

On-Board Antenna Considerations

It is possible to mount the GPS Antenna in close-proximity to the GPS Orion receiver, and still operate the receiver successfully. However, there are a number of issues that need to be considered, which will affect the selection of an appropriate Antenna LNA.

IN-Band Digital Interference at L1

A GPS Antenna, which is mounted close to the digital components of the GPS Orion board, will pick-up radiated digital spurious from those components. This can be a problem if there are harmonics of the data clocks running to and from the memory devices, which produce in-band interference close to L1 (1575.42MHz). The GPS Orion software is known to produce an interference harmonic at a frequency of 1575.555MHz - in-band at L1. This signal can be high enough in amplitude to affect the RF front-end AGC, and hence reduce the level of GPS wanted signal at the input to the RF Front-end Analog to Digital converter.

Tests have been done which suggest that this problem can be removed by ensuring the following things are included in a modified GPS Orion board layout:-

Mount a screening can over the ARM60 microprocessor and SRAM memory devices on the lower side of the GPS Orion Receiver Board.

Mount a screening can over the GP2021 correlator, and ROM memory devices on the upper side of the GPS Orion Receiver Board.

For both screening cans, ensure that ALL data and address-bus tracks are screened completely.

Also for both screening cans, ensure that the internal Ground Plane of the GPS Orion Receiver board is as complete as possible, and that NO slot gaps appear in it. Ensure that each screening can is in complete contact with a soldered guard-ring attached to a solid ground-plane on the GPS Orion Receiver board. There must NOT be any slot gaps greater than 5mm long between the screening can and the guard ring.

Each screening can should be made of 0.5mm thick tin-plate.

IN-Band LNA Instability at L1

A GPS Antenna which is mounted close to the RF components of the GPS Orion board will introduce instability in the receiver, typically at (or near to) the L1 frequency (1575.42MHz). This is due to the close proximity of the Antenna to the Mixer 1 o/p inductors in conjunction with an LNA gain that is high. A positive feedback loop can be set-up between the GP2015 Mixer 1 output inductors (L3 and L4) and the GPS Antenna. The LNA gain in conjunction with the forward gain of the GPS Antenna (anything from +0.5dBi for small patch antennas through to 5dBi for larger ones), can be sufficient to produce a feedback loop gain of >0dB at L1. This instability can be erratic in frequency, but more importantly the amplitude of any instability can be sufficient to affect the RF front-end AGC, and hence reduce the level of GPS wanted signal at the input to the RF Front-end Analog to Digital converter. This in turn will degrade GPS satellite SNR levels.

Reducing the LNA gain can help with this, but the preferred method is to ensure that the Mixer 1 output inductors are screened.

Noise-Figure Considerations

To a first approximation, the noise-figure (NF) of the whole RF front-end in a GPS Receiver will be:-

$$\mathrm{NF(dB)} = 10\mathrm{x}\ \mathrm{LOG}_{10}\ \mathrm{x} \left(10^{\left(\frac{F1}{10}\right)} + \left(\frac{10^{\left(\frac{F2}{10}\right)} - 1}{10^{\left(\frac{(G1 - L1)}{10}\right)}} \right) \right)$$

where

F1	=	noise-figure of Active Antenna LNA (dB)
F2	=	noise-figure of GP2015 IC (dB)
G1	=	RF signal gain of Active Antenna LNA (dB)
L1	=	RF signal loss due to RF filtering and cabling after LNA (dB)

This equation can be plotted for variable LNA noise-figure and variable LNA gain and cable loss difference (G1 - L1) as shown in Figure 25. In this plot, the typical noise-figure for the GP2010/GP2015 is set to be 9dB. Note that the noise-figure minimum is set by the LNA in the antenna. Also, the higher the LNA gain, for a given LNA noise-figure, the less the dependence of the Total receiver noise-figure on the GP2015 noise-figure. In noise-figure terms, the GPS Orion receiver will benefit most from using an Active antenna with very low LNA noise-figure, with moderately high LNA gain (>+19.0dB), and a very low cable loss (< -2.0dB).

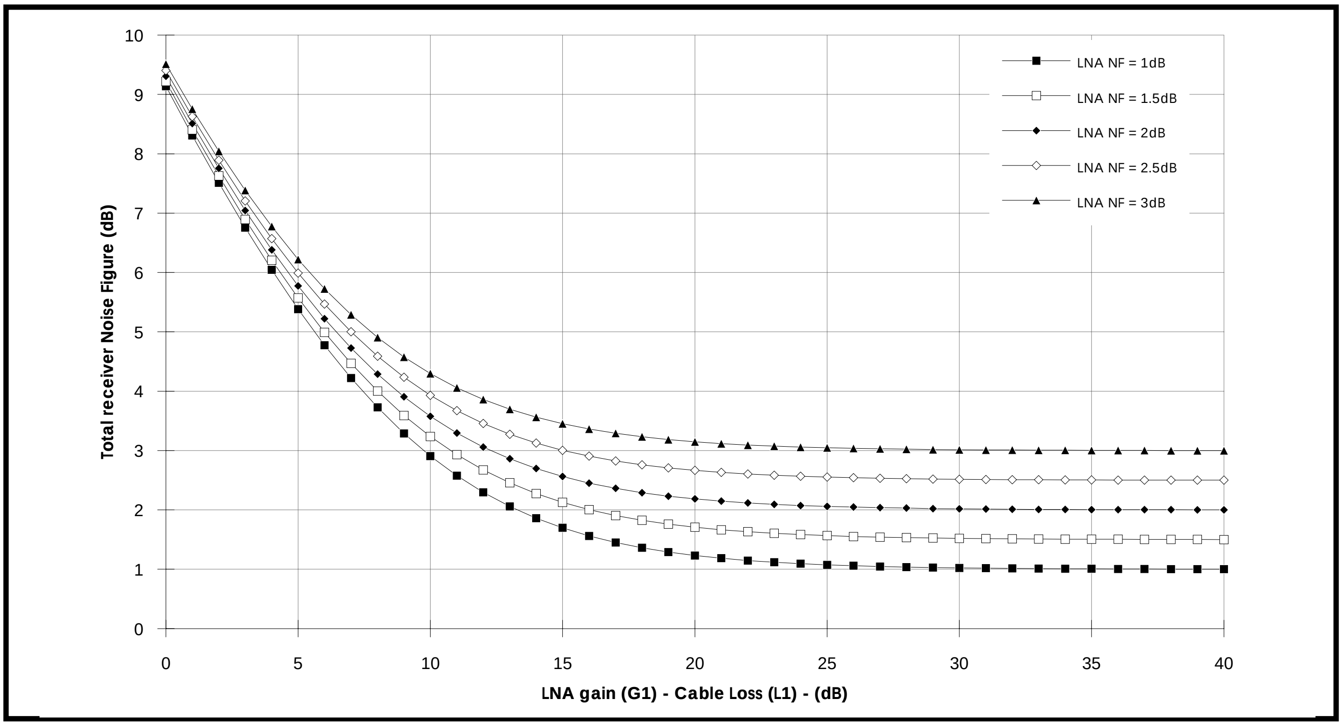


Figure 25 Variation of GPS receiver noise figure with LNA Gain, Cable Loss and LNA noise figure.

The typical noise-figure of the GP2010/GP2015 is quoted as 9dB. A typical noise-figure for an LNA is 2.0dB. A typical gain for an Active Antenna LNA is 26dB. The loss in a length of coaxial cable from an Active Antenna to the GP2010/ GP2015, including additional RF ceramic bandpass filtering, is variable.

In this instance we shall assume a 2m length of coax and the bandpass filter insertion loss giving a total loss (L1) of 2.5dB. A typical receiver noise-figure will be ~2.1dB.

Antenna Types

GPS antennas can be of either patch or helical type. It is recommended that whichever type is used, on-board RF bandpass filtering is included. This will prevent the LNA from gain-compressing the wanted GPS signal, if a large out-of-band interference signal is received. This is particularly important where there are high power RF signals in the vicinity of the GPS receiver (from mobile telephones, for example).

Helical antennas tend to have a more uniform antenna forward-gain pattern than Patch antennas. This however comes at the expense of a larger physical size. Patch antennas can be made to have a good forward gain characteristic, as shown in Figure 26.

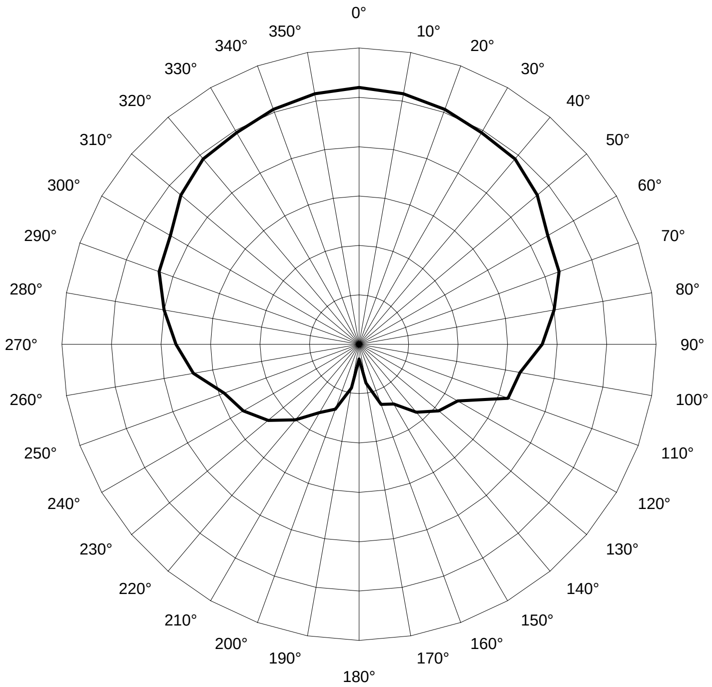


Figure 26 Typical Patch Antenna forward-gain characteristic (10dB/div)

A recommended active GPS patch antenna is available from *M/A COM* - the *ANPC-131*, which has an LNA gain of +26dB and a noise-figure of 1.5dB at the wanted signal frequency of 1575.42MHz. It is also enclosed in a protective radome.

The *M/A COM ANPC-131* is available in a number of different configurations, and consequently there are a number of different ordering codes - full details available from M/A COM website at *http://www.macom.com:-*

Model Number	Radome Colour	Mount	Cable Length	Connector
ANPC-131	**X** = none **B** = Black	**-C-** = Suction Cup **-M-** = magnet **-N-** = no show bracket **-V-** = visible bracket **-X**- = no mounting provision	in inches	**-BP** = SMB male **-BR** = SMB right-angle **-NM** = N type male **-NF** = N type female **-P** = output pin **-SM** = SMA male **-SF** = SMA female **-TM** = TNC male **-TF** = TNC female **-XF** = OSX female **-XM** = OSX male **-XR** = OSX right-angle **-X** = no connector

For example:-

ANPC-131B-M-120-XM would call for an ANP-C-131 active antenna in a Black Radome, Magnetic Mount, 120 inches of cable and an OSX male RF connector.
Another recommended antenna is the GPS-P1MA, available from the Allis Communications Company Limited in Taiwan.

GPS ORION RF Jamming Susceptability

a) Introduction

The GPS Orion has been proven to have a very high resistance to RF jamming interference.

The GPS Orion uses the GP2015 RF front-end IC, which uses a triple-conversion frequency plan in conjunction with tightly defined RF / IF filtering and 2-bit IF digital quantisation, to provide a superior anti-jamming performance. The L band is increasingly being used for more RF applications besides GPS (Cellular telephones, for example) and so it will become more congested with GPS hostile signals over the next few years.

The jamming susceptibility of the GPS Orion has been measured (and compared to a competitive GPS receiver) by applying a constant level GPS signal to the RF input of the receiver, and adding to it a high-level CW jamming signal of fixed amplitude, which is swept across a wide frequency range.

The GPS signal is produced by a GPS simulator - a Nortel STR2760, which guarantees a more constant level of GPS signal over the course of the measurement than an antenna capturing true GPS signals from satellites.

The CW jamming signal is produced by an RF synthesised signal generator.

The correlated Signal to Noise Ratio (SNR) of one of the 12 GPS correlator channels is monitored for each jamming frequency applied, from an NMEA data output port. In the case of the GPS Orion, the NMEA data can be obtained from the Port B RS232 output.

The resistance to jamming interference is proven if the SNR level of a correlated GPS signal remains unchanged at each jamming frequency selected.

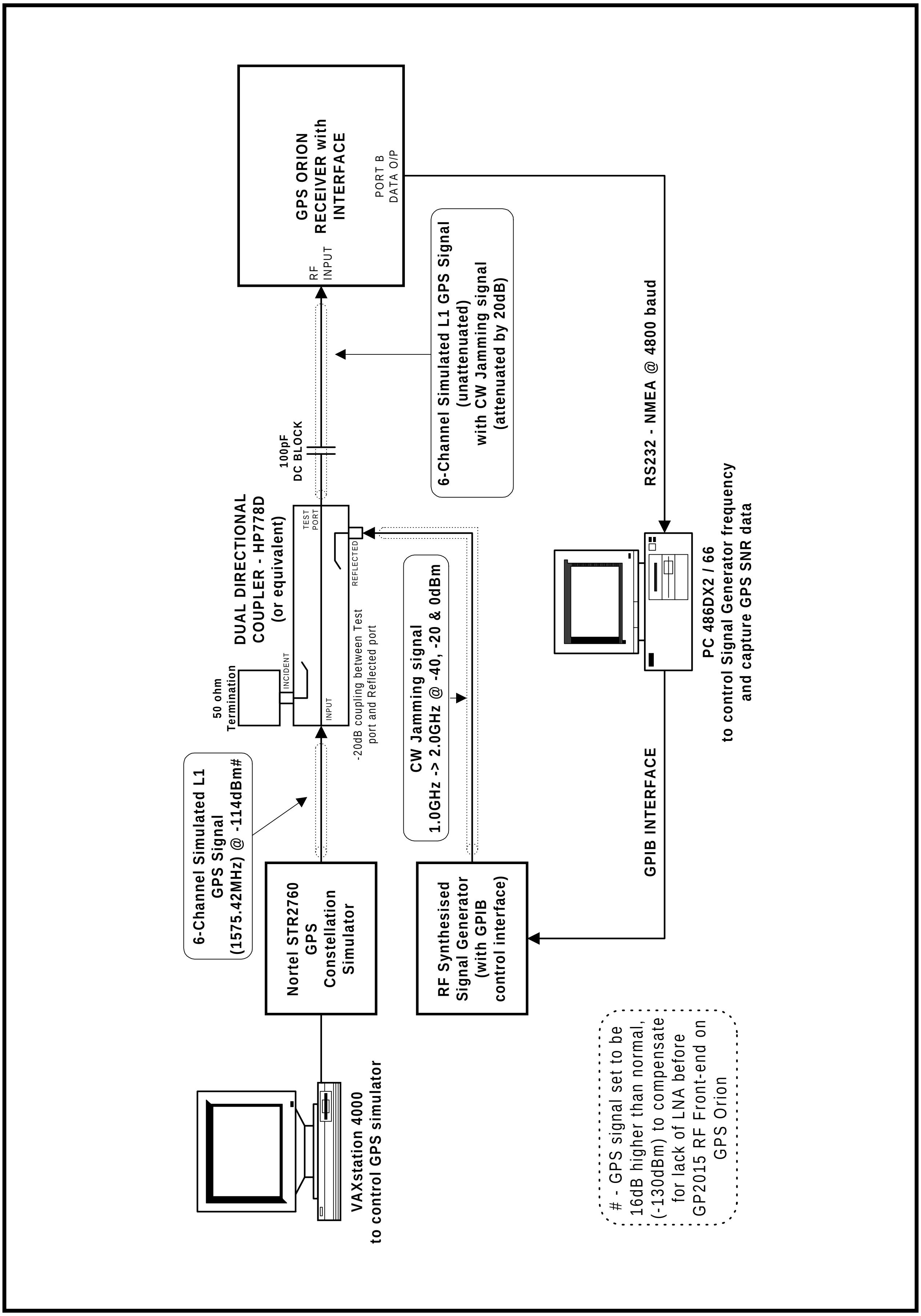


Figure 27 Set up used to measure GPS Orian Jamming susceptibility

b) Equipment Set-Up and Measurement Method

A computer is used to control the jamming signal frequency output from a GPIB controlled signal-generator, whilst the RS232 data output from the GPS receiver is monitored for SNR level. The jamming signal frequency is swept between 1000MHz to 2000MHz. A data file is produced which maps CW jamming frequency to SNR level of one correlator channel.

A block-diagram of the equipment used for jamming susceptibility measurement is shown in Figure 27.

A Dual-Directional Coupler (DDC) is used to add the jamming signal into the simulated GPS signal. The use of the DDC ensures that the jamming signal goes to the GPS Orion receiver only, and NOT to the RF output stage of the GPS simulator. The RF output of the GPS simulator should hence NOT limit the level of the GPS signal, as a consequence of the high-level jamming-signal.

The GPS signal amplitude is set to be approximately 16dB higher than that typically received by a GPS antenna (-130dBm), to compensate for the lack of LNA in the signal path between the GPS signal simulator and the GPS Orion receiver. The signal to noise-ratio is left at approximately -20dB, as would be expected from a raw GPS signal. The DDC has negligible signal loss in the forward signal path, but has a -20dB coupling loss to the “incident” and “reflected” signal ports. Consequently, the jamming signal provided by the RF signal generator will be attenuated by 20dB before reaching the GPS Orion, by virtue of the jamming signal being applied to the “reflected” energy port of the DDC.

The RF input to most GPS receivers has a +5V DC bias connected to it, to allow for the use of active antennas. A DC block (100pF capacitor) is inserted between the GPS receiver and the DDC in order to prevent a low-impedance DC path to GND.

The GPS receivers are configured to output an NMEA 0183 v2.1 data-stream, at 4800 baud. Within the NMEA data-stream, there is the “$GPGSV” sentence (GPS Satellites in View). Each sentence outputs the SNR for each of 4 correlated satellite signals. There can be upto 3 “$GPGSV” sentences in a 12-channel GPS receiver. Since the Carrier / Noise ratio for NMEA data-output mode is displayed in dB Hz over a 1kHz bandwidth (the repetition rate of the GPS Gold-code), this introduces a 30dB addition to the numbers, compared to the SNR which is displayed in WINMON mode in dB Hz in a 1Hz bandwidth

c) Signal Level Considerstions

A series of 3 measurements at differing CW jamming power-levels have been made on a GPS Orion receiver and the GPS receiver from another manufacturer . The jamming signal is swept from 1000MHz to 2000MHz in steps of 3MHz, at each of 3 power-levels:-

- -60dBm - this is approximately 33dB higher than the noise-floor provided by a 16dB active antenna with 2dB noise-figure (equivalent to -93dBm total in a 2.046MHz BW).
- -40dBm - this is approximately 53dB higher than the noise-floor.
- -20dBm - this is approximately 73dB higher than the noise-floor.

The power-levels were chosen to give a wide-range of interference amplitude. In the case of the GPS Orion receiver, the -20dBm jamming level comes close to the maximum input power-level which the GP2015 RF front-end can withstand before the first-stage mixer goes into gain-compression (-16dBm level for 1dB gain-compression, typical). The use of an RF input ceramic filter will reduce the transmission of out-of-band interference into the GPS receiver, but in-band it will behave like a direct connection.

The de-spreading of a GPS spread-spectrum signal gives a correlated SNR level from each satellite signal which approximates to the following equation (assuming absolute code phase-tracking in the correlator, and adequate IF gain in the RF front-end to lift the GPS signal up to a suitable amplitude for quantisation):-

Correlated SNR (dB in 1Hz BW) = (Raw GPS SNR) - NF + dsGain

Raw GPS SNR = Signal to noise ratio in dB of the uncorrelated (Raw) GPS spread-spectrum signal at input to active antenna (typically -30 to -18dB - signal buried in noise. Noise floor over 2.046MHz BW approximates to -111dBm. GPS signal level approximates to -130dBm);

NF = noise-figure of GPS receiver in dB - dominated by NF of LNA in active antenna

dsGAIN = De-spreading gain of GP2021 correlator in dB, which is calculated as a ratio of the spread-spectrum modulation rate (1.023Mbps), to the correlated GPS data-rate (50bps):-

$$10\mathrm{Log}_{10}\frac{1023000}{50} = 43\mathrm{dB}$$

d) Measured Jamming Suscepibility

The plot in Figure 28 shows the jamming susceptibility of the GPS Orion receiver. The measurement was taken from 1.0GHz to 2.0GHz, but the data is displayed from 1.2GHz to 1.8GHz only.

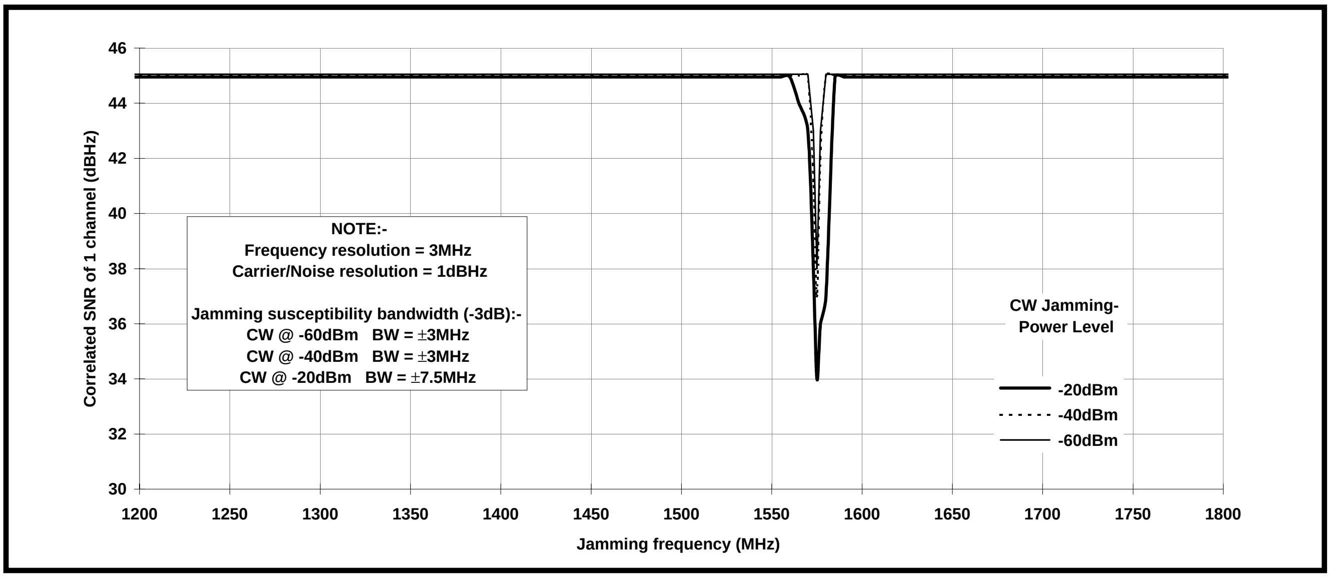


Figure 28 GPS Orion - Correlated GPS data SNR integrity with swept Jamming signals across 1.2GHz to 1.8GHz

A similar set of measurements has also been conducted on a competitor's GPS receiver. The plot in Figure 29 shows the jamming susceptibility of the competitors unit. This receiver uses a 1-bit IF quantisation, dual-stage down-conversion and a simple IF filter.

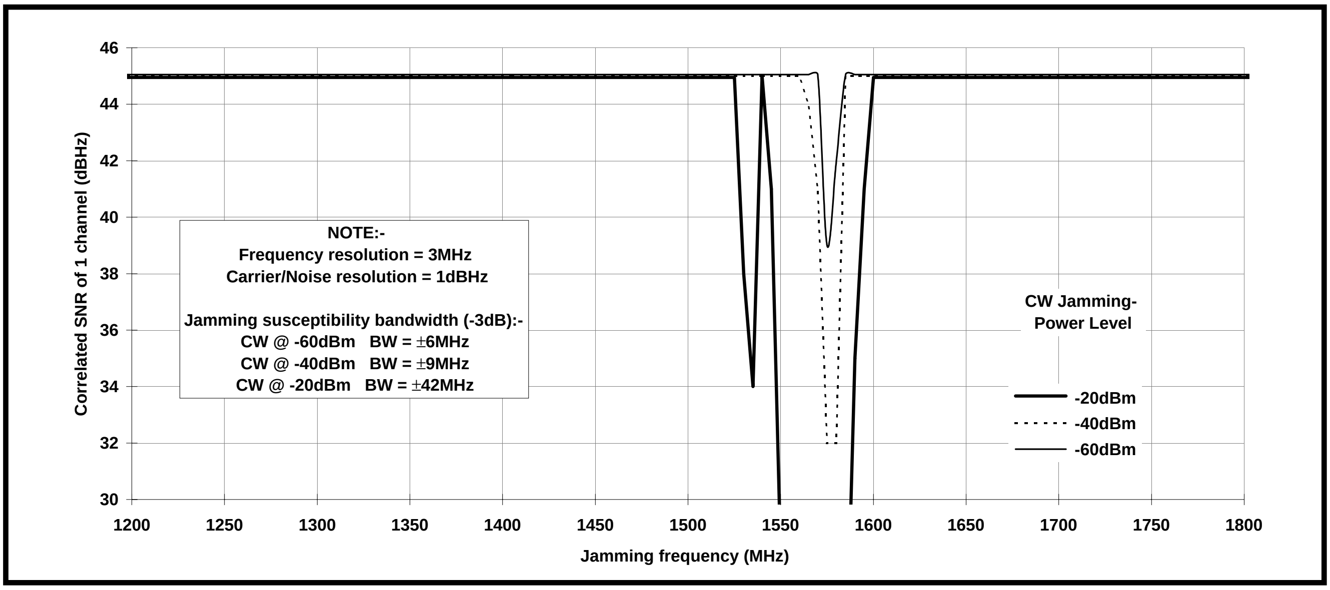


Figure 29 Competitive GPS receiver GPS data SNR integrity with swept Jamming signals - 1.2GHz to 1.8 GHz

If a jamming signal is of high enough amplitude to degrade the correlated SNR, this normally means that the jamming signal is either:-

i) gain-compressing a mixer stage in the RF front-end;

ii) dominating the AGC detector (in the case of the GP2015 RF front-end) and consequently reducing the gain of the wanted signal frequency.

In terms of the above analysis of SNR, jamming has the effect of increasing the GPS receiver Noise-figure (NF), by essentially adding an insertion-loss in the receiver for the wanted GPS signal.

e) Result Analysis

The plots in Figures 28 & 29 show a large difference in the Jamming susceptibility of the GPS Orion compared to a competitive GPS receiver.

The jamming susceptibility can be defined in terms of a parameter we shall call the Jamming Susceptibility BandWidth (JSBW), which is the jamming frequency band over which the SNR of the correlated GPS signal is degraded by more than -3dB.

With a low-level jamming signal at -60dBm, the in-band jamming reduces a typical correlated GPS signal SNR by a mere 7dB in the GPS Orion. The JSBW is very narrow - only ±3.0MHz around L1 (1575.42MHz). The JSBW of the competitive GPS receiver under the same conditions is ±6.0MHz around L1 with a similar reduction in GPS signal SNR.

At higher jamming signal levels, the correlation between the 2 GPS receivers measured seems to disappear. With a -20dBm jamming signal, the in-band jamming removes the tracking capability of the GPS receiver for all satellite signals, for both the receivers tested. However, the GPS Orion has a JSBW of ±7.5MHz around L1, whereas the JSBW of the competitive GPS receiver under the same conditions is ±42MHz around L1.

These measurements show a high degree of resistance to RF jamming interference with the GP2000 chipset, in terms of the narrow bandwidth over which high-level jamming interference will affect the receiver.

The rejection of signals at the image frequencies also seems to be very good with the GPS Orion. The table below shows the derivation of image frequencies related back to the RF input.

Mixer	Nominal INPUT Freq.	LO Freq.	Nominal IF Freq.	Image filter	Image INPUT Freq.	Image INPUT Freq. at RF I/P
1	1575.42MHz	1400MHz	175.42MHz	Ceramic 1575MHz	1224.58MHz	1224.58MHz
2	175.42MHz	140MHz	35.42MHz	Discrete 175MHz	104.58MHz	1504.58MHz
3	35.42MHz	31.111MHz	4.309MHz	Dynex DW9255 SAW	26.802MHz	1566.802MHz
ADC	4.309MHz	5.714MHz	1.405MHz	GP2015 on-chip filter	-7.119MHz	1563.23MHz

There is no effect of applying GPS jamming signals at the image frequencies for Mixers 1 & 2.

The competitive GPS receiver is a dual-conversion design with a first mixer image frequency of approximately 1535MHz. It can be seen in Figure 29 that the susceptibility to jamming interference at this frequency is poor.

The reason that the GPS Orion has better success at resisting jamming interference than for the other receiver reviewed here, is primarily due to the resistance of a 2 bit IF quantisation to CW jamming interference. Also the use of a 2MHz bandpass IF filter (Dynex DW9255 SAW) helps to limit the bandwidth over which this occurs.

NOTE:- A similar jamming susceptibility performance will be achieved by using a GP2010 RF front-end IC in place of the GP2015.

GPS ORION Receiver Board Parts List

Part Type	Part No	Value Used	Qty	Size	Designators				
Thin film chip resistor		51R	1	0603	R6				
“		270R	1	0603	R1				
“		470R	2	0603	R8	R9			
“		1K	2	0603	R4	R5			
“		1K5	1	0603	R10				
“		2K7	1	0603	R3				
“		6K8	1	0603	R2				
“		680K	1	0603	R11				
“		10M	1	0603	R12				
Ceramic chip capacitor COG		2p7F	1	0603	C20				
“		3p3F	2	0402	C11	C12			
“		3p9F	2	0402	C8	C9			
“		12pF	1	0603	C21				
“		12pF	1	0402	C22				
“		15pF	1	0402	C10				
“		22pF	2	0603	C26	C27			
Ceramic chip capacitor X7R		100pF	1	0603	C24				
“		1nF	5	0603	C4	C5	C6	C7	C23
“		10nF	2	0603	C13	C14			
“		33nF	2	0603	C28	C43			
“		47nF	3	0603	C1	C2	C3		
“		100nF	10	0805	C19	C32	C33	C34	C35
					C36	C37	C38	C39	C40
“		100nF	3	0603	C16	C17	C18		
“		470nF	1	0805	C15				
Ceramic chip capacitor Y5U		33nF	3	0402	C30	C31	C44		
Tantalum chip capacitor 10v		10uF	2	7227	C25	C29			
Supercap 6v		0.22F	1		SC1				
Coilcraft inductor		18nH	2	0805	L3	L4			
“		33nH	2	0805	L1	L2			
Magnetic shielded chip inductor	TDK MLF Series	560nH	2	0805	L6	L7			
“ “		2.2uH	1	0805	L5				
RF Front end	GP2015		1	TQFP48	IC1				
Correlator	GP2021		1	QFP80	IC2				
NAND gate	74S00		1	SO14	IC3				
Processor	P60ARM-B		1	QFP100	IC4				
RAM 128K x 8	HM628127HBLJP		4	SOJ32	IC6	IC7	IC8	IC9	
EPROM 64K x 16	HN27C-1024HCC		2	PLCC44	IC10	IC11			
SAW Filter	Dynex DW9255		1		SF1				
Ceramic BP Filter	Murata DFC2 1R57P002HHA		1		FILT1				
Schottky Diode	Gen. Inst. SS12		1		D1				
TCXO	NDK 5111A-ANL50-A (or Oscillatek T-1115)	10MHz	1		XOSC1				
Watch Crystal		32KHz	1		XTAL1				
SMA			1		J1				
9-PIN Header			1		JP5				

Parts List Summary

Chip passive components	53 off	GP2021	1 off
Supercap	1 off	ARM60-B	1 off
Inductors - Coilcraft Hi-Q	4 off	Dynex DW9255	1 off
- Mag shielded	3 off	74S00 NAND gate	1 off
128K x 8 RAM	4 off	TXCO	1 off
64K x 16 EPROM	2 off	Sundries	3 off (Diode, Xtal, filter)
GP2015	1 off	Connectors	2 off (1 RF ; 1 9-way)

Useful Component Suppliers Internet Addresses

The majority of the components used in the design of the GPS Orion can be obtained by contacting the following companies:-

INDUCTORS	-	COILCRAFT	-	http://www.coilcraft.com
	-	TDK	-	http://www.tdk.com
TCXO	-	NDK	-	http://www.ndk-j.co.jp
	-	OSCILLATEK	-	http://www1.otek.com
	-	RAKON	-	http://www.rakon.com
MEMORY	-	HITACHI	-	http://www.hitachi-eu.com/hel/ecg/index.htm
		ISSI	-	http://www.issiusa.com/
CAPACITORS		MURATA	-	http://www.murata.com
		ROHM	-	http://www.rohm.com

GPS ORION Receiver Printed Circuit Board (PCB) Layout

The GPS Orion uses a printed circuit board with 4 inter-connect layers implemented on 1.6mm thick FR4 substrate of area 95mm x 50mm. The 4 layers are separated by 0.5mm (i.e. equally spaced). The top and bottom layers are interconnect, the inner layer nearest the top is a ground plane, and the inner layer nearest the bottom is also an interconnect layer.

The diagrams below show the relationship of the top-layer copper to the top overlay layers (Figure 30), and the bottom-layer copper to the bottom overlay layers (Figure 31). Also included are plots of the internal ground-plane layer (Figure 32), which is immediately below the top layer copper, and the internal interconnect layer (Figure 33), which is between the bottom-layer copper and ground-plane layers.

NOTE:- the diagrams in Figures 30 to 33 are for reference only and are NOT to any defined scale.

Further details on the design, layout , construction and test of the GPS Orion receiver are available from Zarlink Semiconductor. Design files are available for the GPS Orion receiver board, on request.

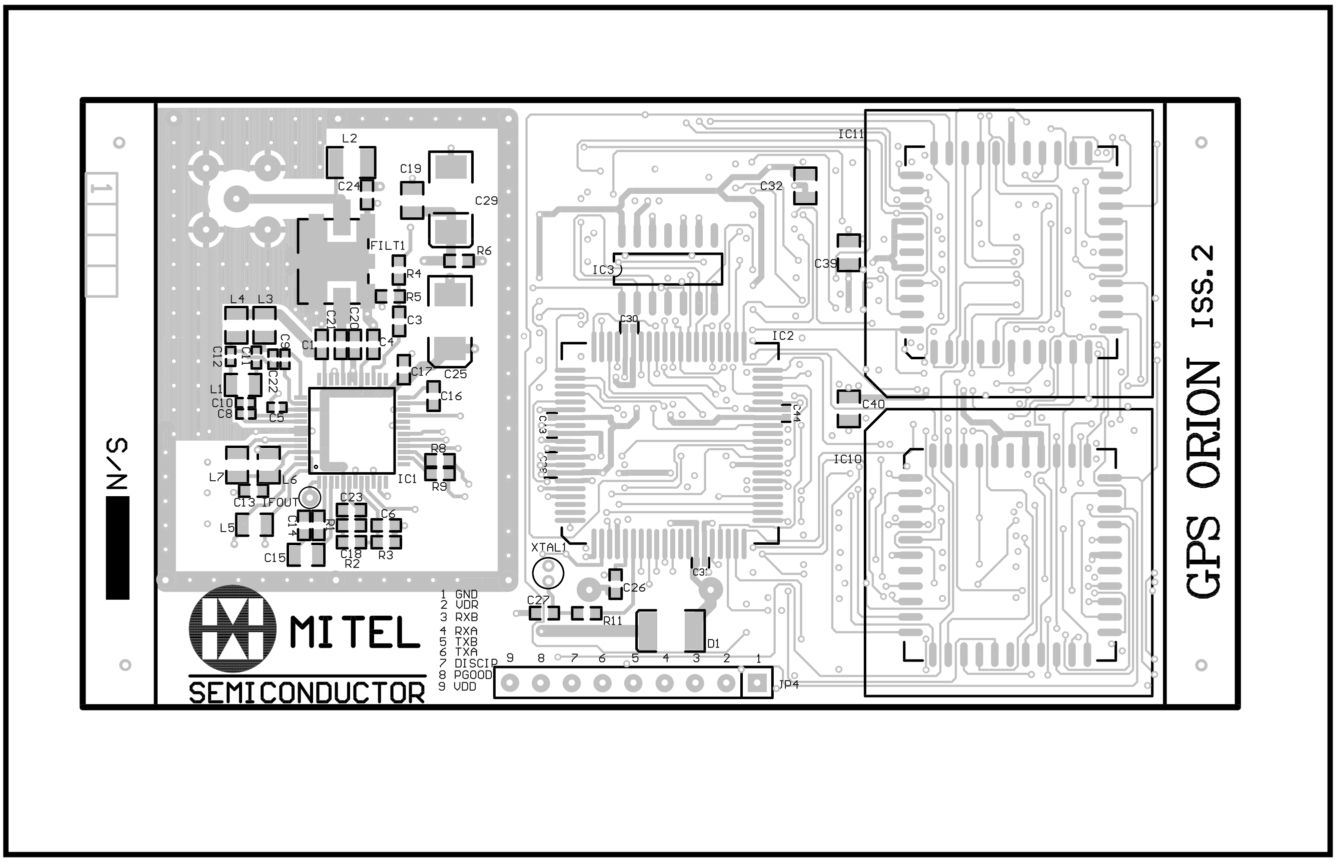


Figure 30 GPS Orion Receiver Board Top View

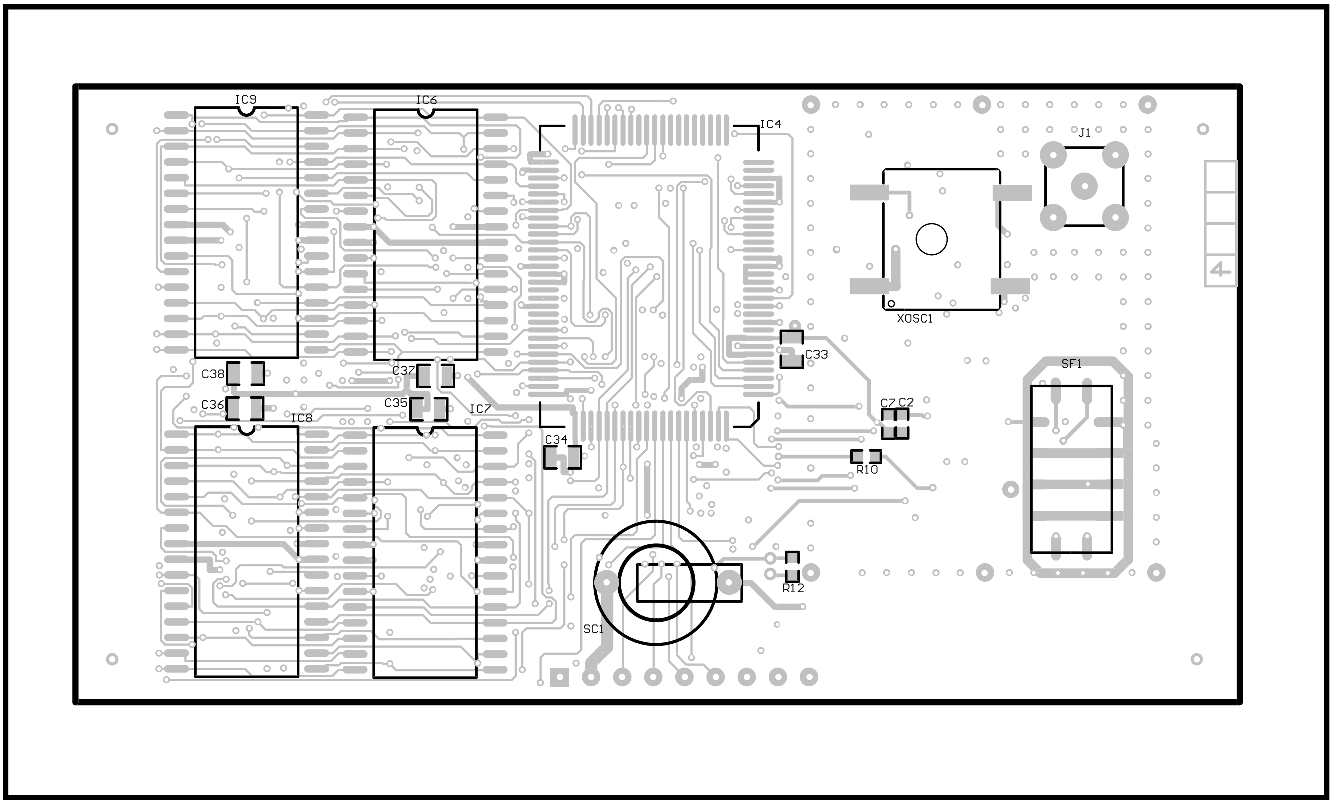


Figure 31 GPS Orion Receiver Board Bottom View

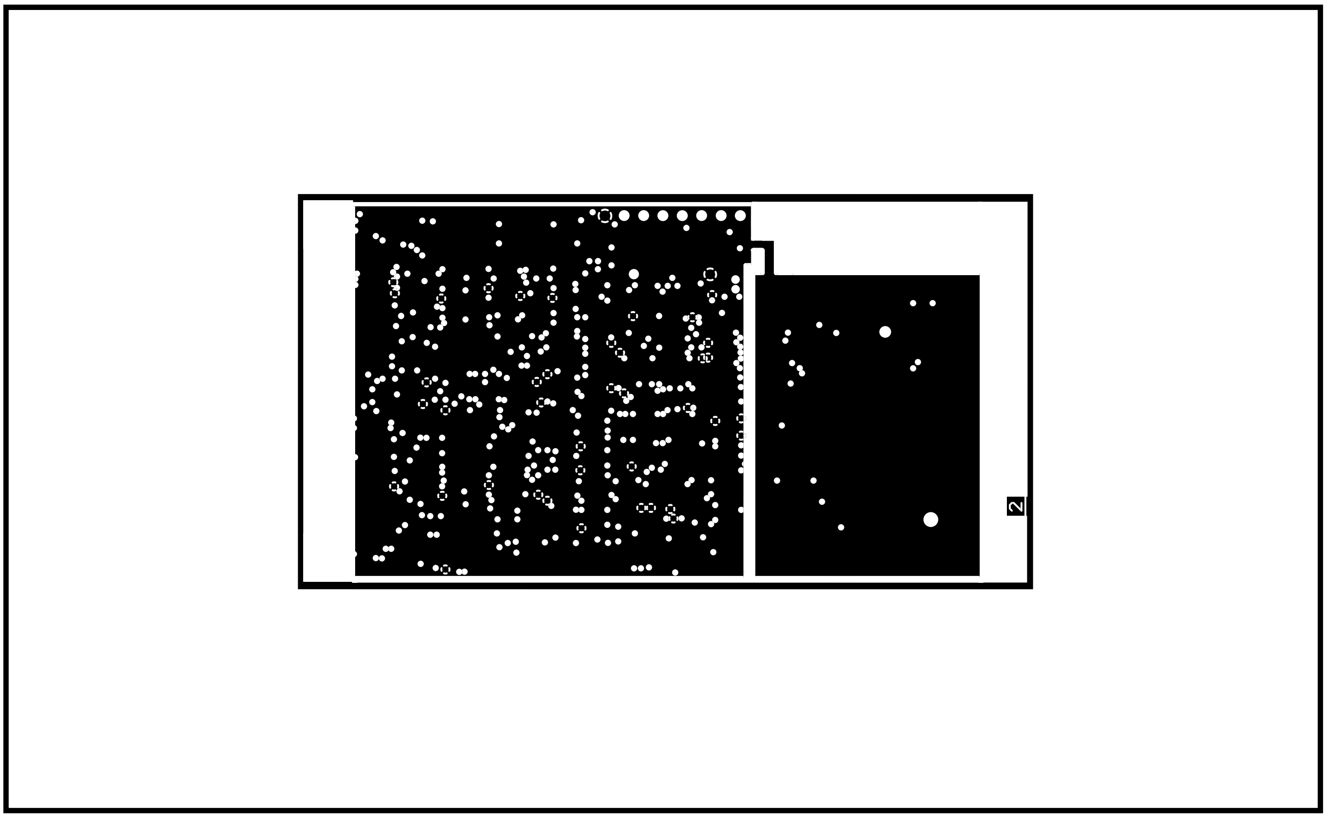


Figure 32 GPS Orion Receiver Board Internal interconnect layer

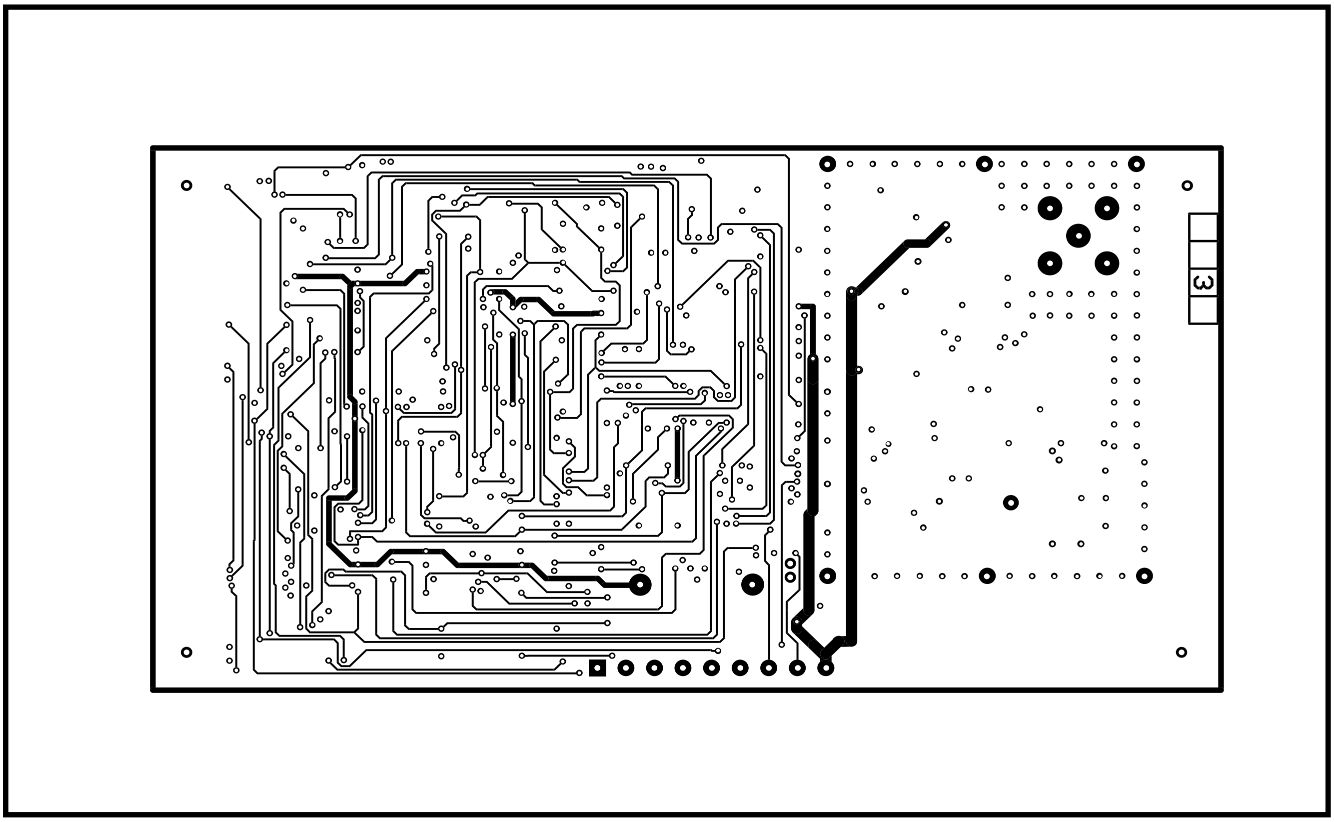


Figure 33 GPS Orion Receiver Board Internal interconnect layer

GPS ORION RECEIVER PRINTED CIRCUIT BOARD SCHEMATICS

The circuit schematic is represented by Figure 34 to 38, with Figure 34 showing the top-level relationship between the major circuit blocks, and Figures 35 to 38 showing the schematic for the RF Front-end, Correlator, ARM-60B and Memory respectively.

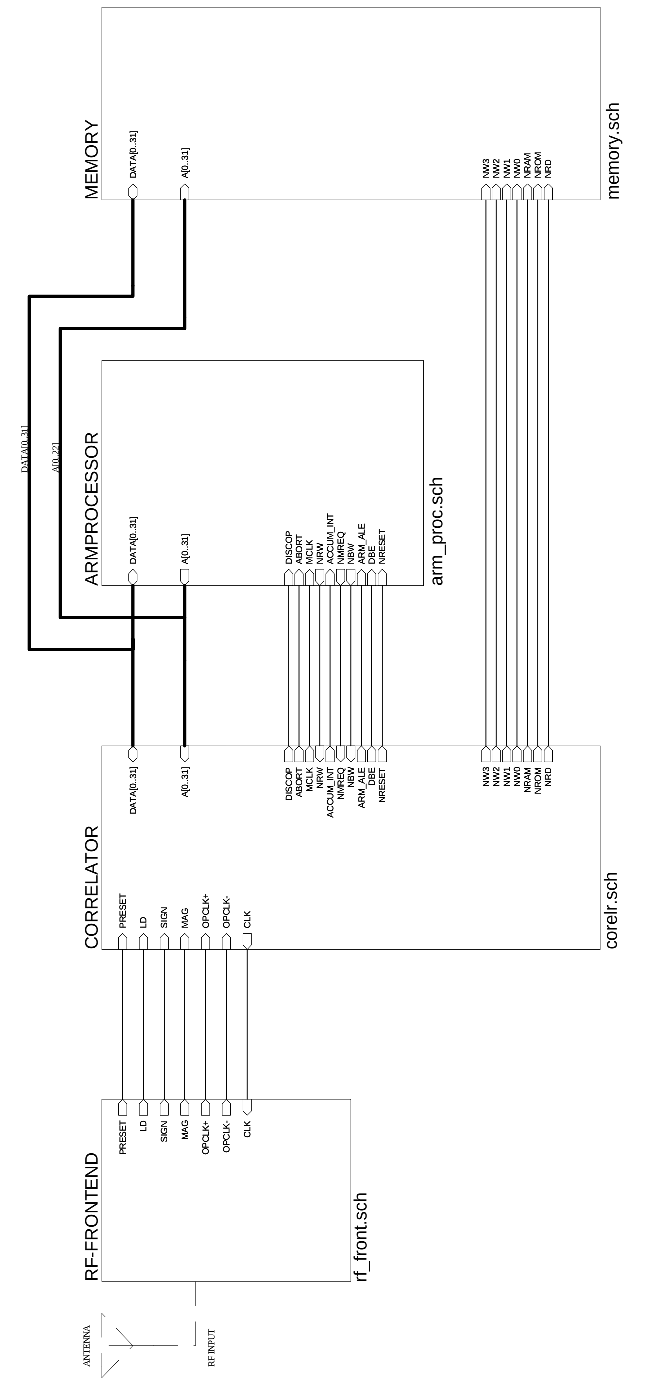


Figure 34 GPS Orion receiver - Top Level hierarchy

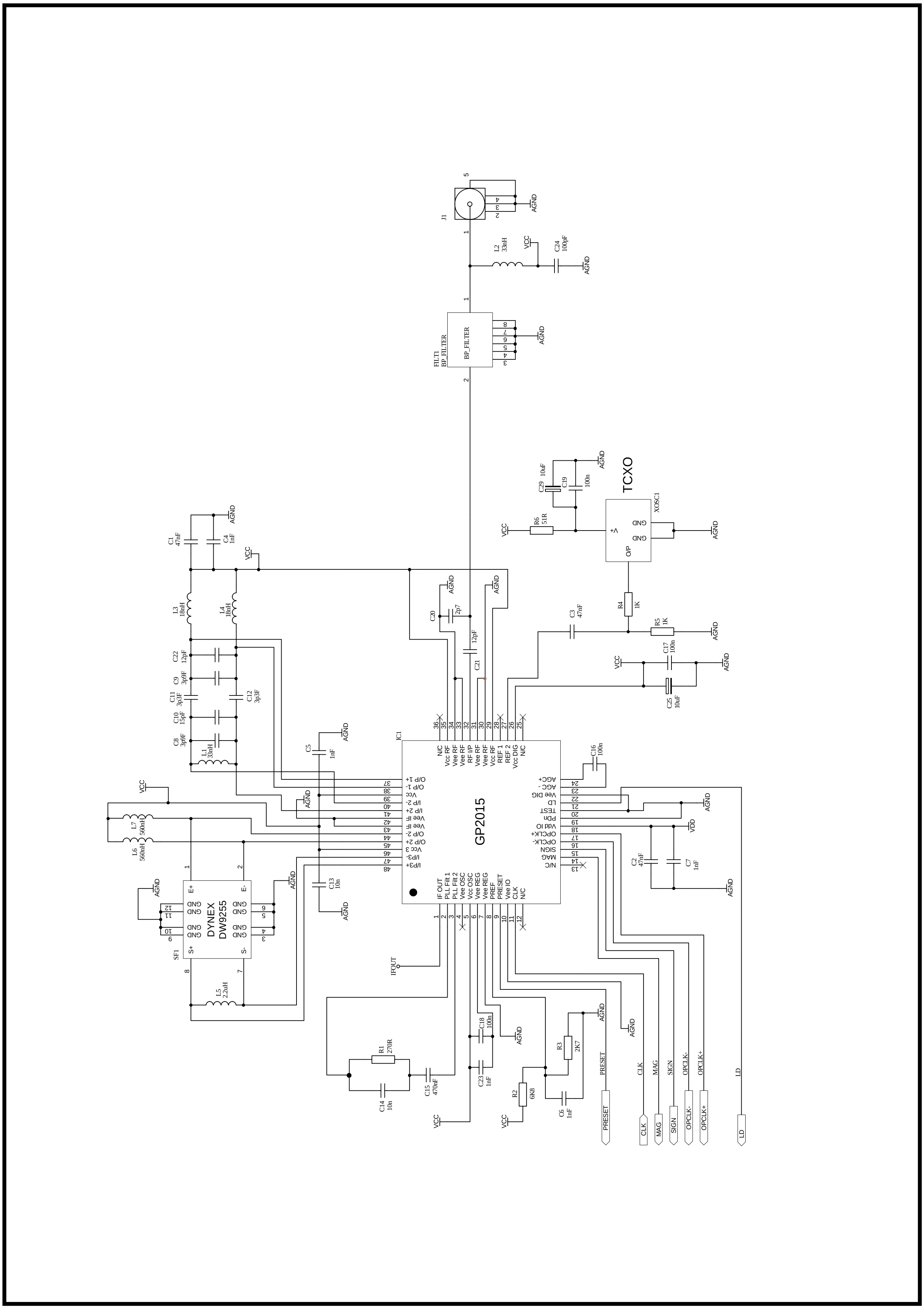


Figure 35 GPS RF Front End circuit

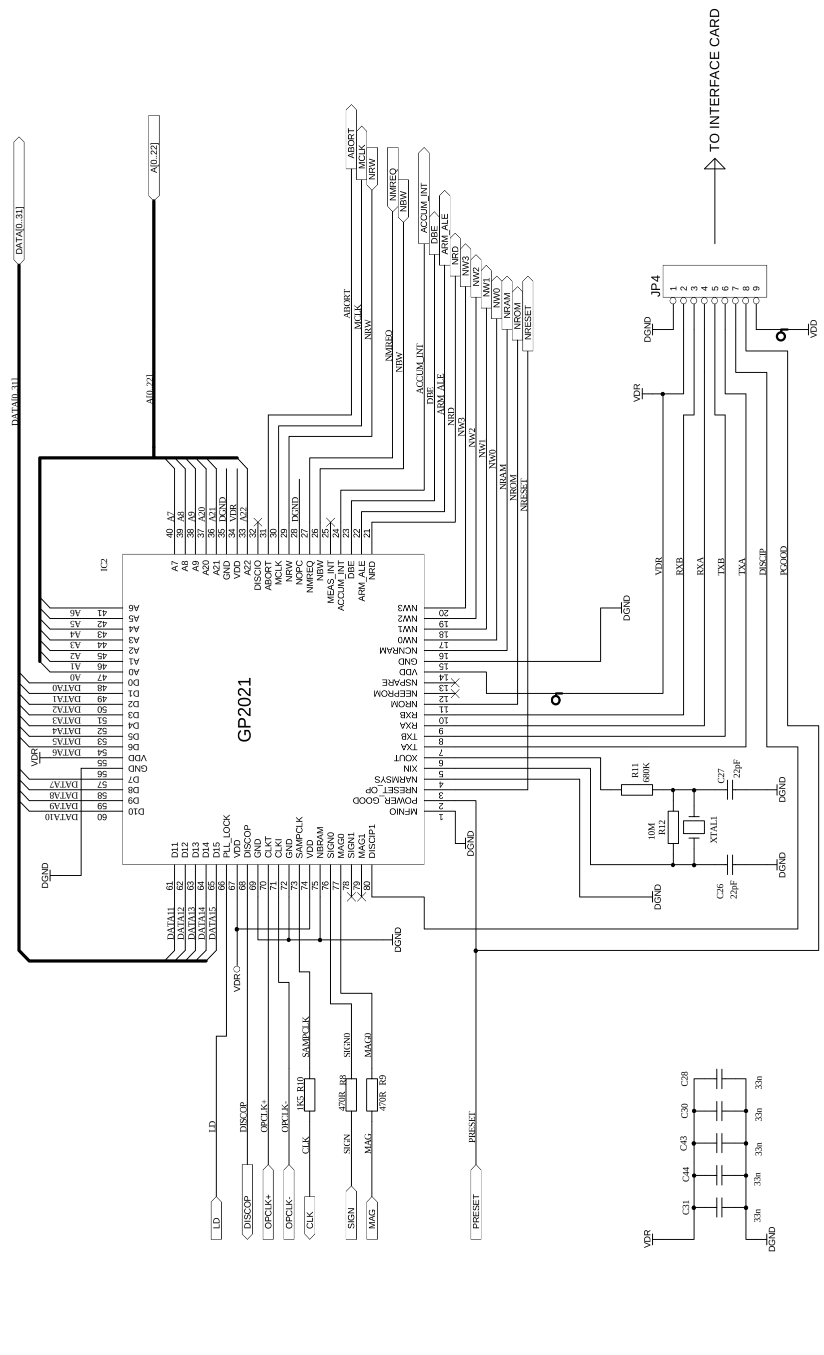


Figure 36 GP2021 12 Channel Correlator circuit

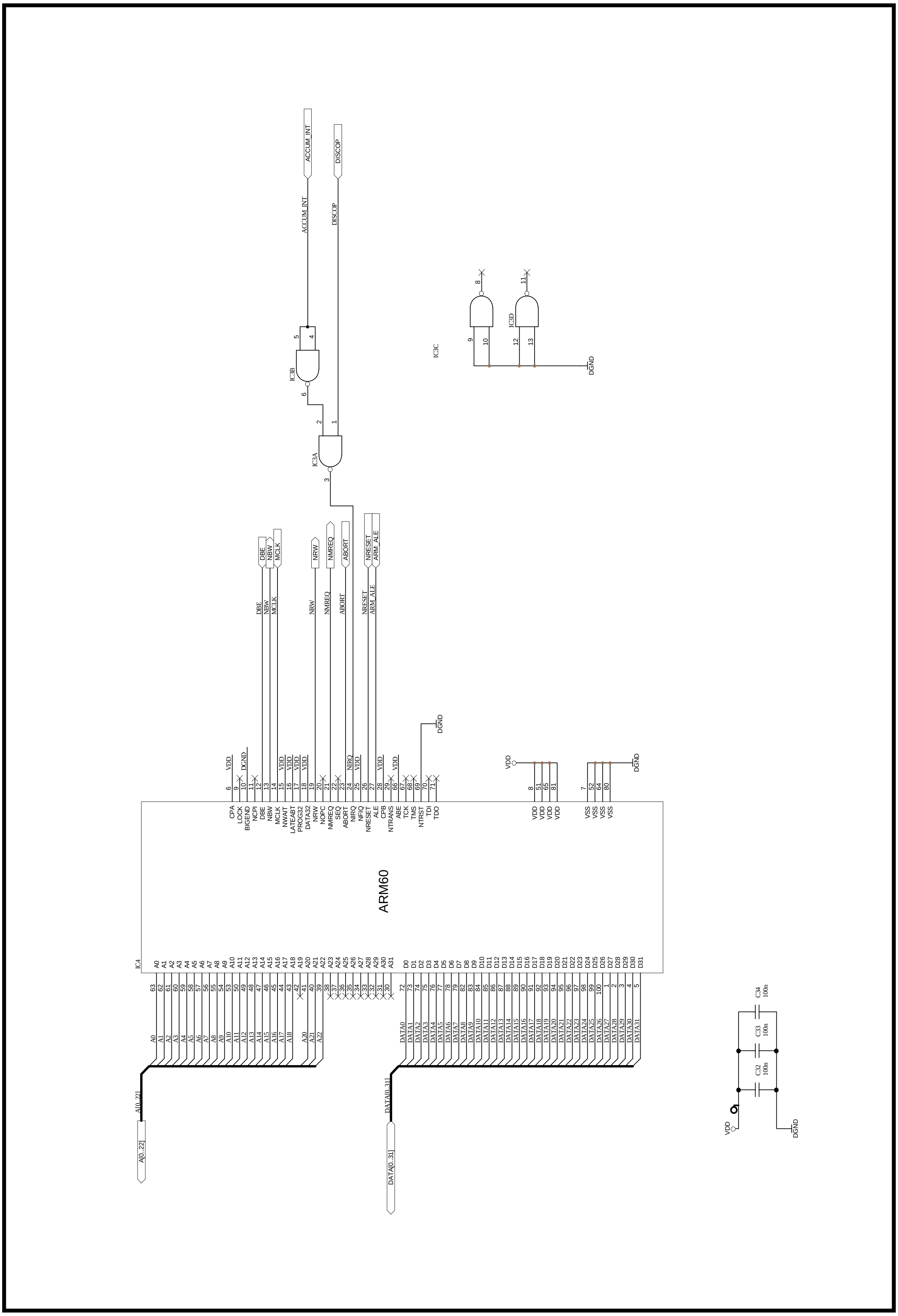


Figure 37 ARM60 - B 32 bit RISC Microprocessor circuit

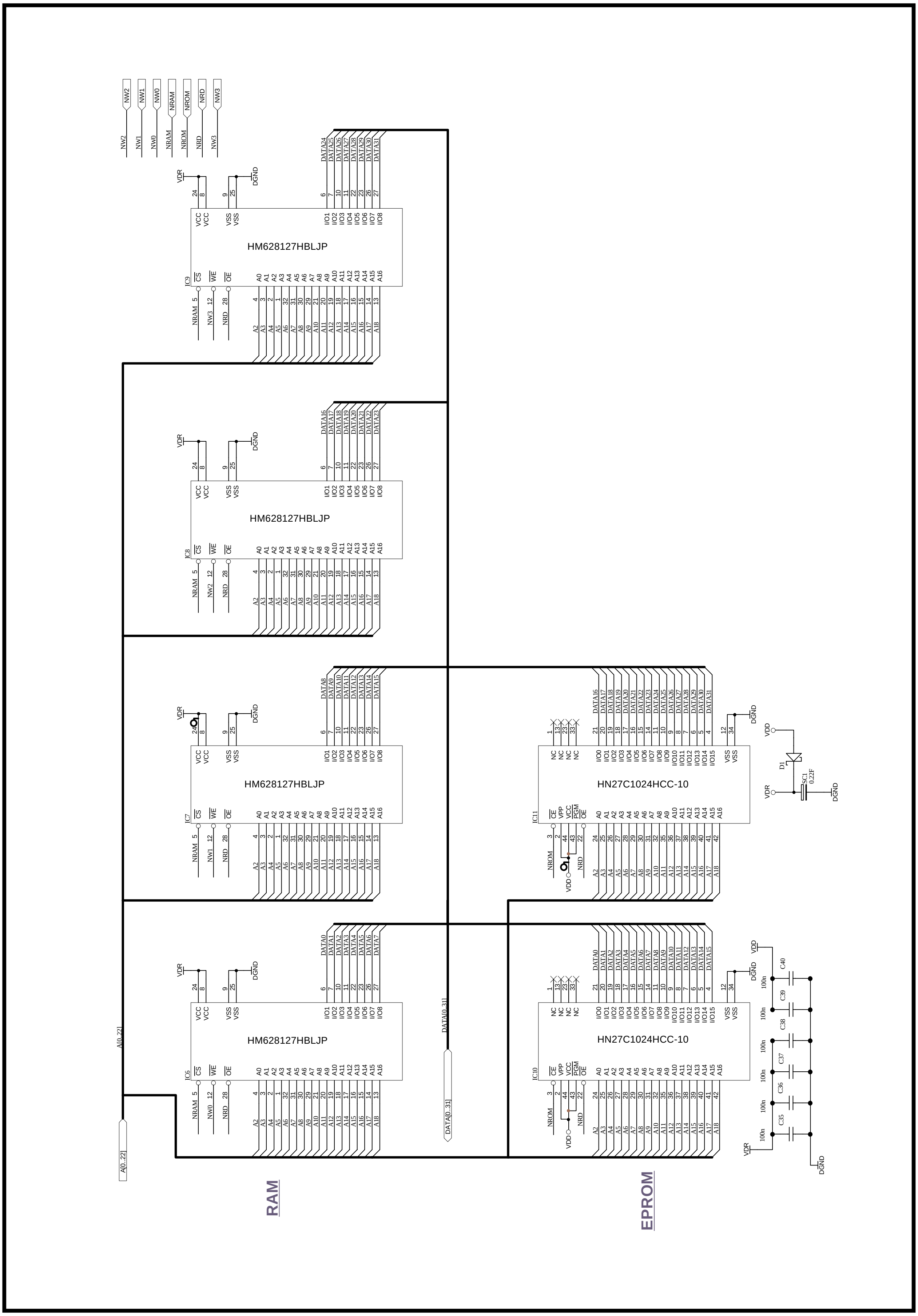


Figure 38 SRAM / EPROM memory circuit

Optimising the GPS ORION for a Production GPS Receiver

The GPS Orion receiver, which is covered in this application-note, is a reference GPS receiver design used to demonstrate the capabilities of the GP2000 GPS chipset. The GPS Orion design has not been produced for high-volume GPS receiver manufacture, although a large amount of the design can be used in a production receiver. Here are some ideas of how to optimise the bill-of-materials of a GPS receiver using the GP2000 chipset.

Use a small format RF i/p connector

The GPS Orion design makes use of a SMA RF connector as an interface to an Active antenna. This was used to allow multiple connections & disconnection from an Antenna for demonstration purposes.

In an end-user GPS receiver, the Antenna ought to be permanently connected to the receiver, and as such will not require a robust connector, such as SMA.

It is recommended that the SMA connector is removed, and replaced with a small format coaxial connector, e.g. OSX, MCX or AMP - all of which are generally available.

Care should be used to ensure that any RF tracks leading from the connector are maintained with a 50Ω characteristic impedance (see “Information on Microstrip Transmission Lines”).

EPROM memory capacity

The GPS Orion has been provisioned with an excess of EPROM and SRAM memory space to allow flexibility with increased application code sizes. This was considered important to give the design some flexibility to accept larger GPS algorithms to improve the receiver performance - e.g. adding Carrier phase tracking, adding Kalman filtering, adding an enhanced GPS user interface (- these facilities are not available yet). The principle used in the GPS Orion is to copy ALL the application code from 2 wait-state (100ns) EPROM down into 0 wait-state (20ns) SRAM, and run all the application code from SRAM. This closely matches the way in which code development operates in the GPS Architect development system, and hence makes the transfer of GPS Architect developed application code to a self-booting system comparatively straight forward.

The size of the executable code, stored in EPROM is approx. 40k x 32 bit. The EPROMs procured for the GPS Orion design (Hitachi HN27C1024HC-10) are the optimum size needed for the software - 2 pieces 64k x 16-bit packages.

The GPS Architect system is required for any application code modifications. So if there is a requirement to introduce a facility which is not available on the GPS Orion, the GPS Architect GPS development system will need to be purchased. The algorithms developed by the GPS Architect user will then determine the amount of EPROM required.

Reduce SRAM memory capacity

As stated previously, the GPS Orion has been provisioned with an excess of EPROM and SRAM memory space to allow flexibility with increased application code sizes.
The principle used when the GPS Orion software runs, is for a self-booting routine to copy ALL the application code from 2 wait-state (120ns) EPROM into 0 wait-state (20ns) SRAM, and run all the application code from SRAM.

The GPS Orion design uses 128k x 32 bit SRAM memory in 4 packages of 8-bit wide capacity. The ARM 60 treats every byte of memory as a 32-bit word, and hence the least-significant address bit of the memory (A0) is connected to the least significant 32-bit word address line (A2) of the ARM 60. Hence the memory is addressed in blocks of 4 bytes, starting at ARM address 00004h in steps of 00004h. The resulting maximum ARM address for 128k x 32 bit SRAM is 128k x 4 = 80000h.

There are a number of things that can be done to reduce the requirement for SRAM:-

a) Relocate Non-Volatile Memory area - reduces SRAM memory to 64k x 32 bits

The GPS Orion software uses part of the SRAM memory space for Non-Volatile-Memory (NVM) storage of GPS data, such as Satellite Almanac, Satellite Ephemeris, and Initial position. This is used to enable a fast Time To First Fix (TTFF), when the receiver almanac, Ephemeris and initial position are known at start-up.

The NVM memory space is set to be the top 8k x 32 bits of the SRAM. The NVM data space is set to be 17E001h to 17FFFCh.

With a GPS Architect development system, the application code can be modified to change the location of the NVM storage area in memory. The GPS Orion code supplied by Zarlink will operate with NVM data storage with SRAM capacity of 64k x 32 bits. The GPS application code uses 40k x 32 bits; the Task-switching stacks use 9k x 32 bits; the NVM storage space uses 8k x 32 bits; additional space is also allocated by the ARM microprocessor for the storage of variables. The NVM data area addresses can be adjusted to be 13E001h to 13FFFCh in order for NVM to operate in 64k x 32 bits of SRAM.

b) Implement a Time-Slice operating system - saves 8k x 32 bits of SRAM memory

The GPS Orion software operates a task-switching operating system. This gives flexibility in terms of the ability to add new tasks, with varying levels of priority and processor usage, but also increases memory (RAM) usage due to the need to save each software task's context. A task-switching operating system also makes it difficult to control the processor loading to give a smooth and continuous loading level. Hence, a task-switching operating system fits with the concept of a development system.

Alternatively, a time-slice operating system could be used. This reduces the flexibility of the system but also has the benefit of reducing memory (SRAM) usage and enables the processor loading to be spread out to reduce the occurrence of processing peaks. Hence, a time-slice operating system fits with the concept of a production system where the software functionality would not change significantly.

The current software uses the following tasks (in decreasing priority order):

Task	Stack size (bytes)
TTakesMeas	9000
Tnav	5000
Tdisplay	9000
TRTCM	2000
TProcSbf	2000
Talloc	9000
Total	**36000**

Hence, the current task stack RAM usage of about 36kbytes (9k x 32 bits) could conceptually be reduced to that of the individual largest stack, i.e. 9kbytes, (2.2k x 32 bits) via use of a time-slice operating system.

For the time-slice operating system to operate correctly requires that all the processing in any one time-slice can always be completed within the time-slice period.

The conversion of the operating system from a task-switched to a time-sliced type is complex, and involves significant software code re-writing, which will require the use of a GPS Architect system.

c) Implement a Scatter-loaded system - saves upto 35k x 32 bits of SRAM memory

As stated previously, the GPS Orion boots code resident in 2 wait-state (120ns) EPROM straight into 0 wait-state (20ns) SRAM at start-up and all the code execution occurs from within SRAM. The reason this was done was to allow easy transfer of GPS Architect developed code into the GPS Orion.

This scenario is acceptable in a software development environment, when there is a need to vary the application code size to try out various GPS algorithms. In a production system, this is inefficient because the EPROMs become redundant immediately after the software boots into SRAM, and as a result the EPROMS and the SRAM together take up significant amount in the Bill of Materials for the GPS receiver.

It is possible to set-up what is known as a Scatter-loaded application with the ARM-60 microprocessor. With this it is possible to run most of the GPS Receiver software from within the EPROM memory, without copying all of the code into SRAM before running it. This can save a significant amount of SRAM space.

The thing to remember here is that EPROMs generally have slower access times than SRAMs. Code that is run within suspendable tasks in a task-switched operating system could be executed from within EPROM, provided the processing bandwidth of the ARM-60 isn't compromised severely by the memory wait-states. Code which is always running or needs to be run on receipt of an interrupt (i.e. the Operating System, the Interrupt Service Routine, the Correlator (GP2021) Accumulator Buffer access routines and Data Synchronisation routines) cannot be run in wait-state memory, and so must be copied across to 0 wait-state SRAM.

Detailed information on the concept of scatter loading can be found in documentation for the GPS Architect and associated application notes for the ARM microprocessor, available on the World Wide Web from:-

http://www.arm.com/Documentation/AppNotes/

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