THE QUARTZLOCK GPS-DO SERIES

The Quartzlock line of GPS disciplined oscillators is based upon the type of combined carrier and code evaluating receivers described above.

i) **Down-converter**:

This is not just a signal preamplifier; it has been designed as an integral part of the receiver. Its purpose is to reduce the frequency of the signals travelling down to the receiver. The arriving signal at the antenna is referenced to the receiver local oscillator. Travelling up the down-converter cable to the receiver will be a 92.07 MHz reference frequency from the local oscillator and DC power from the receiver. The 2^{nd} IF signal (the first being at 102.3 MHz and is confined to the receiver) at 10.23 MHz travels down the cable to the receiver. This will reduce the cable loss cf. the 1.6 GHz carrier signal frequency and thereby allow the use of lighter and more flexible cable.

ii) **Antenna**:

This is a quad-helix antenna and is mounted to the down-converter by means of type N connectors (due to the frequency being transmitted between them). If cable must be fitted between the antenna and down-converter then the maximum (theoretical) loss when carrying the 1.6 GHz carrier signal should be not greater than 3 dB. Thus a short length of RG213 (<2.5m) would acceptable. In order to obtain the peak performance out of the unit, the antenna must have a good view of the sky. Ideally the antenna position should be known accurately (i.e. to within +/- 2m latitude/longitude and +/- 4m altitude) before operation, as this will reduce the time to first fix (TTFF). One advantage of using the quad helix antenna is that troublesome multipath effects are all but eliminated. Multipath is a signal arrival at a receiver's antenna by way of two or more different paths such as a direct, line-of-sight path and one that includes reflections off nearby objects. The difference in path lengths causes the signals to interfere at the antenna and can corrupt the receiver's pseudorange and carrier-phase measurements. Multipath error is the GPS positioning error caused by the interaction of the GPS satellite signal and its reflection. The positioning error is due to interference between the radio signals, which pass from the transmitter to the receiver by two paths of different electric length.

iii) **Time constant**

A short (loop) **time constant** will give a very fast response time, to time errors. The problem with this is that little or no averaging is done to eliminate SA, leading to a significant degradation of the short-term frequency stability. (c.f. free running oscillator stability). This is fine for timing applications. A long time constant will allow for slow response to time errors but will 'ride' over many of deleterious effects of SA and allow the short-medium term stability to be primarily determined by the local oscillator. However, the user must be careful that he does not select a large maximum time constant without knowledge of the (frequency) performance of the local oscillator. The loop time constant may approach the maximum time constant too quickly for the LO, and not correct for errors in the LO. This could cause LO time errors to exceed a certain threshold for a small period of time. However, if this is only for a short period of time, time coherence will not be lost (time accuracy will be restored without any loss or gain of cycles-cycle slips- at a frequency output wrt the 1pps output). This ensures coherence between the time and frequency outputs. A far worse situation will occur if the unit has undergone a power failure. In this case, the error that will have build up in the LO that only way to restore synchronisation will be to reset the time counters in the receiver. Such total loss of synchronisation would cause a red LED to flash, alerting the user to this problem. If the apparent time error δt relative to apparent GPS time has exceeded a predetermined threshold for more than a set time, then the oscillator control time constant is automatically reduced 1s/s until the error drops back below the threshold value.

iv) **Positioning**-

Ideally the antenna position should be known accurately (i.e. to within +/- 2m latitude/longitude and +/-4m altitude) *before* operation, as this will reduce the time to first fix (TTFF). If this is impossible (likely), then the receiver must attempt to estimate the position for itself. This necessitates at least 4 satellites being visible (3 for spatial dimensions and 1 time dimension). In order to be able to assist the receiver, the user has the option of entering an approximate position (and also approximate time) which will help the receiver search for satellites that *should* be visible according to the almanac stored in the receiver. This is a set of parameters similar to the more precise ephemeris data, which is used for approximating GPS satellite orbits. In order for the required 4 satellites to be visible for an acceptable period of time, the aforementioned antenna position must be good. An obstructed view of the sky will reduce the time when at least 4 satellites are visible will drop, the geometry of constellation will be degraded (complicated and difficult to model) and the overall time to determine an accurate position and time will increase.

Studies have shown that there appears to be a 'hole' in the GPS constellation-looking north. It is therefore doubly important that the antenna have a 'good look' south. In order to eliminate single position estimate errors an position averaging procedure is carried out in receiver, with up to a day's worth (86400) of 1-second estimates capable of being averaged. Due to the way memory is assigned in the unit, no further updates are made subsequent to this. One-way of improving the position determination is to turn the unit on for 2 days, note the ~24hr average and then repeat the process as many times as you see fit. Taking the standard deviation will give the precision of the position determination, and will allow manual entry at switch on. The receiver can be forced to then operate on this (entered) position. Determination of accurate altitude, whilst more difficult to do, is more important. This is because the satellites are always at a positive altitude.

Tests have shown that using this method the Quartzlock model can ascertain it's position to within +/- 2m latitude/longitude and +/-4m altitude to within a 95% (2σ) certainty. The last digit on the display in the position menu has a resolution of about 1.8m longitude and 1.8cosX, where X is the latitude of the receiver. At 55°N this gives about 1.2m. This means that if two co-located receivers agree down to this last digit, they agree to within to within 1.8m and 1.2m in longitude and latitude respectively. However, in the serial port data, which is viewable through specially designed monitoring software, an extra digit is supplied, allowing precision down to the ~10cm level. By performing the manual averaging procedure at this level of precision the user gets unrivalled antenna position determination, and the associated benefits this brings.

Like most GPS receivers of this type, this series references its position to the world geodetic system 1984 (WGS 1984) with the altitude being relative to the geoid. Whilst the geoid is much more complex than the simple ellipsoid, it is an approximation of the true shape of the earth and is therefore closer to mean sea level for most places on earth. The difference between the ellipsoid and geoid is stored within the almanac data contained in the navigation message. The receiver has a plausibility checking method to ensure that erroneous entered positions are not used, making continuous comparisons against it's own averaged position. This should prevent undue timing errors resulting. The user should also ensure that after 24 hours the averaged position agrees with the entered position to within +/- 3m latitude/longitude. If this is not the case, the entered position was wrong! It is also important to tell the unit what position to use. If the user has a very accurate position, determined either through a geodetic survey or repeated position averages (both with same unit and different co-located similar units), then the user must instruct the unit to use this (not the result from the last position average estimate)

v) **Warnings**

In order for the unit to operate properly the unit must be set up as detailed in **[5]**. If a fault exists at the power up of the unit, indication is likely to be given via a front panel warning display. An common example is if the entered position failed the plausibility check, i.e. the receiver has switched to using averaged position or if satellites have been found that *should* be below the horizon according the almanac data for that position). Many of these initial problems will go away as the averaged position is used or the almanac data is updated (after about 15-20 minutes after switch on). Other problems like a missing antenna; down-converter or cable (or indeed if any of these are faulty) will only be detected once the internal LO (normally OCXO or rubidium) has warmed up. These can take up to 10 minutes depending on the type of oscillator used. Such messages would need to be thoroughly investigated if normal operation is to be obtained from the unit. Indeed, the amount of noise detectable is a good indication of the health of the receiver. A partially or totally obscured antenna could cause insufficient or no satellites to be seen.

However, quantification of GPS-DO signal degradation due to different levels of antenna obstruction is difficult, but work is on hand to do this. It is important to remember that the RMS errors in apparent (i.e. as realised locally) GPS time will be greater than with a full constellation. The solution, as always, is to improve the antenna position, to reduce the instances when this might happen. Other errors may occur if the user was tracking a particular satellite and it went (temporarily) out of view. The receiver in this case would resort to an 'all in view' mode.

Another important message indicates whether the control voltage, which is applied to the local oscillator to correct for frequency excursions, is above a certain normal threshold. Abnormally high voltages being applied (c.f. what the receiver believes should be applied) indicate problems with the local oscillator associated primarily with drift/ aging of quartz crystals or possible failure of the rubidium physics package. Normal operation (i.e. output precision is not necessarily adversely affected) is continued whilst this message is displayed, but future investigation should take place. If it occurs during the first few minutes of operation in a rubidium oscillator, it may well simply be a result of the control DAC limiting. This is due to the very small adjustment range of the Rb oscillator (the software for the rubidium option is different for the rubidium LO than for the OCXO LO, to account for their different characteristics). This message will then go away after the rubidium has warmed and settled.

vi) Delay

The **delay** option enables the user to select the delay to be applied to the 1pps output with a maximum of ±500ms thus effectively providing any required time offset with 1ns resolution. This is designed to calibrate out ionosphere and troposphere delays, and antenna/down-converter/cable delays. This is important if the GPS-DO is to be used for time dissemination i.e. not as a frequency standard. Note that changing the delay once the "locked" condition has been achieved may result in loss of lock and will almost certainly cause transient timing and frequency errors. The 1pps delay should be corrected before lock has been achieved.

vii) Time

The time will be displayed including seconds as soon as the receiver has started tracking at least one satellite. Upon turn on the seconds are suppressed because of the uncertainty associated with only having the internal back-up clock as a reference. During the period between power up and satellite tracking commencement, the user is free to alter the time manually because the internal master clock is not 'set'. Setting involves confirmation by a satellite. Manually altering the time to within ~30 minutes of GPS time reduces the TTFF by providing a time estimate for the receiver to 'going-on' with. Occasionally almanac data stored in the receiver will be too old for UTC to be calculated from GPS (i.e. once locked) until new almanac data is downloaded from the space vehicles. During the time taken to achieve lock (i.e. δt & $\delta f/f$ are within prescribed limits-different for each LO and are of opposite signs) the 1pps remains inactive.