# GLONASS/GPS TIME TRANSFER AND THE PROBLEM OF THE DETERMINATION OF RECEIVER DELAYS


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**Abstract**

*GPS and recently also Glonass receivers are widely used for navigation. When these receivers are used for time and frequency transfer, then all the internal delays and their associated stability become very important.For accurate navigation they are in 'common mode' and only need to be constant during an integration period of less than about one minute. This nanosecond level problem is sometimes not understood by manufacturers and users of those GPS and Glonass timing receivers that were converted from navigation receivers. In the paper this problem is addressed and also the specific Glonass problem caused by the Frequency Division Multiplexing (FDM) used instead of Code Division Multiplexing (CDM) used in GPS. Some delay measurement results are presented. The calibration and characterization of these delays is important for the international atomic time scale.*


## INTRODUCTION

Since the introduction of the Global Positioning System (GPS), many manufacturers have developed and produced receivers for navigation or geodetic positioning. Those receivers consist of an antenna unit, a receiver with a correlator to lock to the coded bi-phase modulated satellite signals, a time reference (usually an internal quartz or rubidium clock), and a time interval counter (TIC) to measure the arrival time of the received signal from each satellite s with respect to the time reference (Fig. 1).
For each satellite s, the TIC reading TI(s) is:

the time offset of the satellite clock (1),
+ the propagation time (2) from satellite s to the antenna (including ionosphere delay, Sagnac effect and troposphere excess delays),
+ the signal delay in the antenna unit (3) (including delays in its filters and amplifiers),
+ the signal delay in the cable (4) from antenna unit to the receiver input,
+ the signal delay in the receiver (5) (filters, amplifiers, down converters),

- the time offset (6) of the reference clock (including the reference cable delay in case of the use of an external reference clock)

For each satellite the above delays 3, 4, 5 and 6 are equal, but delays 1 and 2 are different. The clock offset of each satellite clock is transmitted, so can be accounted for.

**Navigation and positioning** use the **propagation delay differences (2)** for their calculations, so the delays 3, 4, 5, 6 in Antenna, Cable, Receiver, Reference and Clock offset are **common** and should only not change within the (short) sequence time to measure 4 or more satellites. The propagation delays (2) are transformed into distances using the speed-of-light constant, these distances are the pseudo-ranges. From pseudo-ranges to 4 different satellites the position of the antenna is calculated.

**Time Transfer** uses known fixed antenna coordinates and calculates the local or internal **reference clock offset** from the **TI(s)**. Then the delays in Antenna(3), Cable (4), Receiver (5), reference cable (6) have to be known in absolute value: they should have been measured and, thus, been **calibrated**. Unknown changes due to changes in temperature, etc. in any of these delays become attributed to the calculated reference clock offset and are limiting the accuracy and precision of the time and frequency transfer.

The **necessity of knowing continuously** the values of hardware delays 3, 4, and 5 as well as the cable delay from delay 6 is often neglected when GPS and Glonass receivers developed firstly for positioning, are being transformed into timing receivers by changing only its software! This extra necessity is also the reason why geodesists have a problem to understand that, while they obtain centimeter position accuracy (equivalent to 30 ps time uncertainty), timing experts obtain for long-term (half day or longer) only about 3 ns time accuracy, which translates into meter position accuracy! This paper will further point to some sources of the (slow changing) delays (3), (4) and (5).

## SOURCES OF SIGNAL OR GROUP DELAYS

The listing below shows a number of sources of signal delays.

Coaxial cables: typical 5 ns per meter for Z =50 Ohm (with solid polyethylene insulator).

Amplifiers with transistors, resistors and (parasitic) capacitances, depending on bandwidth and frequency: wider bandwidth results in lower delay.

HF tuned L-C circuits, high, low and band pass filters, depending on bandwidth and frequency: wider bandwidth and higher frequency gives lower delay.

Surface Acoustic Wave (SAW) filters using ceramic or glass resonators: depending on excitation mode, propagation velocity in the material, bandwidth.

Optical fiber cables: see SAW filters.

## FACTORS OF SIGNAL DELAY CHANGES

When these delays are known once, they may change due to sensitivity to some factors as given in the list below:

Temperature

Humidity

Air Pressure
Mechanical strain
Aging
Reflections in cables/fibers due to mismatch
Supply Voltage
Signal Power level in amplifiers, specially near the compression point

So all such factors should be examined to determine if they may result in significant changes of the delays for GPS, Glonass and Two-Way Satellite Time and Frequency Transfer [11, 12] equipment.

## DELAYS IN GPS TIME TRANSFER RECEIVERS

In Fig. 2 and 3 the signal delay calibration curves of two different pre-correlation filters are shown for the GPS L1 frequency (1575.42 MHz). It is clearly seen that wide-band filters exhibit less delay than narrow-band filters. Also, when both filters would have the same percentage of temperature dependancy, the wide filter is more stable with temperature. Of course, the overall temperature coefficient depends on the temperature sensitivity of the used components [1, 3, 6, 7, 8, 9, 10, 11, 12]. For the P-code a ten times wider bandfilter is required compared to the C/A code. That is one reason why (geodetic) P-code receivers (mostly also dual-frequency) receivers generally could have smaller temperature sensitivities compared to C/A (mostly single-frequency) receivers.

Fig. 4 shows an example of a good characterization of a commercial filter, a linear group delay factor is given, as well as a parabolic and a ripple value.

## DIFFERENTIAL DELAY IN DUAL-FREQUENCY L1 & L2 RECEIVERS

The excess delay due to the ionosphere cannot simply be determined. In receivers for the GPS L1 frequency (1575.42 MHz) using the C/A code, a model for the ionosphere and a parameter from the navigation message is used to calculate it. Fortunately, the ionosphere delay is frequency-dependant. So from pseudo-range measurements using the same signal from the same satellite (Fig. 5) but at a different frequency, the momentary ionosphere delay can be determined more accurately. The second frequency, L2, is 1227.6 MHz, and the delay in the receiver for this signal may differ from the L1 delay (see Fig. 9); this differential delay has to be calibrated in advance and should subtracted from the measured L1-L2 pseudo-range difference to obtain the true ionosphere delay difference. Then the absolute ionospheric delay correction at L1 is calculated and used in the positioning and time transfer calculations.

## SIGNAL DELAYS IN GLONASS (=MULTI-FREQUENCY) RECEIVERS

In the GPS all satellites transmit at the same nominal frequency for L1 and L2. The satellite signals are distinguishable because of the difference in their unique codes used for the bi-phase modulation. In the Glonass, the codes on all satellites are equal, but the transmit carrier frequencies are different for each satellite; at L1: (1602 +k*0.5625) MHz and at L2: (1246 +k*0.4375) MHz, (where k=0 to 24), a difference of about 0.5 Mhz between satellites. The L1 frequency range spans 13.5 MHz and L2 needs 10.5 MHz for the 24 satellites. The delay in antenna unit and receiver over these bands should be identical or its frequency dependancy should be calibrated and corrected for (see an example in Fig. 9). This is necessary both for positioning and for time transfer, but is not easy to do at the 1 ns level or better.

A L1 & L2 Glonass receiver, thus, needs 24 L1 and 24 L2 differential calibration values, apart from one L1-L2 differential delay calibration for accurate positioning, and for time transfer at least one additional absolute calibration is needed. Due to the planned re-use of Glonass frequencies, now not all 24 calibrations are needed; in the future 12 will be enough. For Glonass receivers, delay stability with temperature is also a great necessity [2,3,4,5].

## SIGNAL DELAYS IN MULTI-CHANNEL GPS AND GLONASS RECEIVERS

In single-channel receivers all measurements are using the same receiver channel. In multi-channel receivers (Fig. 7) there is a chance of differential delays between channels. These delays should be calibrated and corrected for in the software; or at least these differences should be smaller than a specified level, such as 1 ns.

## SIGNAL DELAYS IN DIGITAL SIGNAL PROCESSORS (DSP'S)

Presently new GPS and Glonass receivers are using digital signal processors for the digitization, correlation, time interval and code-generation functions. The pseudo-ranges are determined using these very fast processors with the appropriate software. The processing in these DSP's take some time, which leads to an apparent receiver delay time, which is equivalent to the delay in filters and in digital circuitry. This delay will normally be identical for all tracked satellites and so will not normally be a problem with positioning applications, but are a big problem for time transfer. This delay has been reported to amount up to 2000 ns! This delay should be calibrated for time transfer applications. A better solution would be to minimize this DSP delay or even avoid it by optimizing the design of the hard and software of the DSP for time transfer.

## CARRIER PHASE AND RECEIVER DELAYS

The use of carrier phase smoothed data for time transfer improves the short-term stability due to averaging more cycles in the same averaging time and less multipath, but the timing of the code sequence is still needed for initially identifying a carrier cycle. For the long term (a half day or longer), the phase of the carrier is also affected by the same filter and cable delay changes due to temperature, humidity, etc. as the coded bi-phase modulated carriers and these receivers need the same precautions to improve its long-term delay stability necessary for time transfer [8,9].

Table 1. Required Delay Calibrations

| Receiver configuration | No. of bands | No. of frequencies per band | Total no. of frequencies | Navigation: no. of Calibrations | Time Transfer: no. of Calibrations |
|---|---|---|---|---|---|
| GPS C/A, single freq. | 1 | 1 | 1 | 0 | 1 Absolute |
| GPS dual freq., P-code | 2 | 1 | 2 | 1 Relative | 2 Absolute = 1 Abs. + 1 Rel. |
| Glonass C/A, single band | 1 | 24 | 24 | 24 Relative | 24 Absolute = 1 Abs. + 23 Rel. |
| Glonass dual band, P-code | 2 | 24 | 48 | 49 Relative | 49 Absolute = 1 Abs. + 48 Rel. |
| Dual system GPS C/A & GLO C/A, Glonass dual band, P-code | 3 | 1/24/24 | 49 | 50 Relative | 50 Absolute =1 Abs. + 49 Relative |

## RECOMMENDATION

It is recommended that manufacturers of GPS and/or Glonass receivers for time transfer provide the values of the relative and absolute delays in each antenna and receiver unit on a calibration report or in a calibration data file; also that the receiver is prepared to use such a calibration file to correct the calculated time transfer data output.

Further research should be done to improve the long-term stability (specially temperature sensitivity) of GPS and Glonass receiver circuitry.

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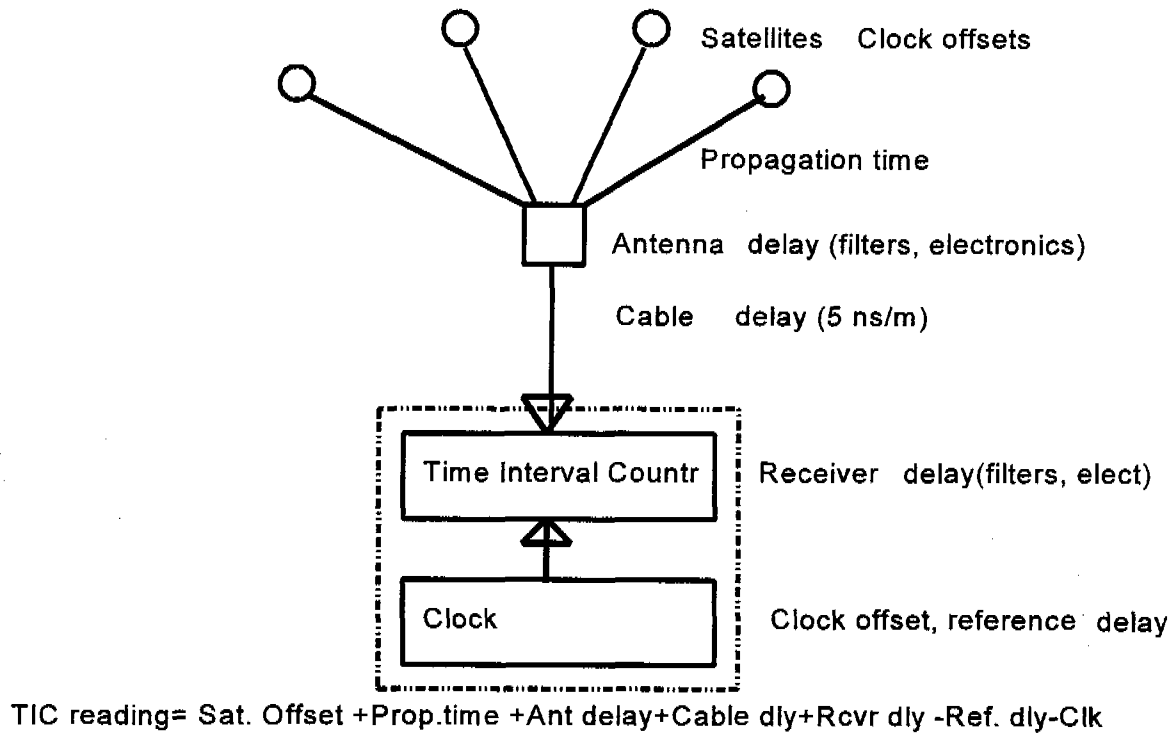



Figure 1. GPS receiver principle with delays

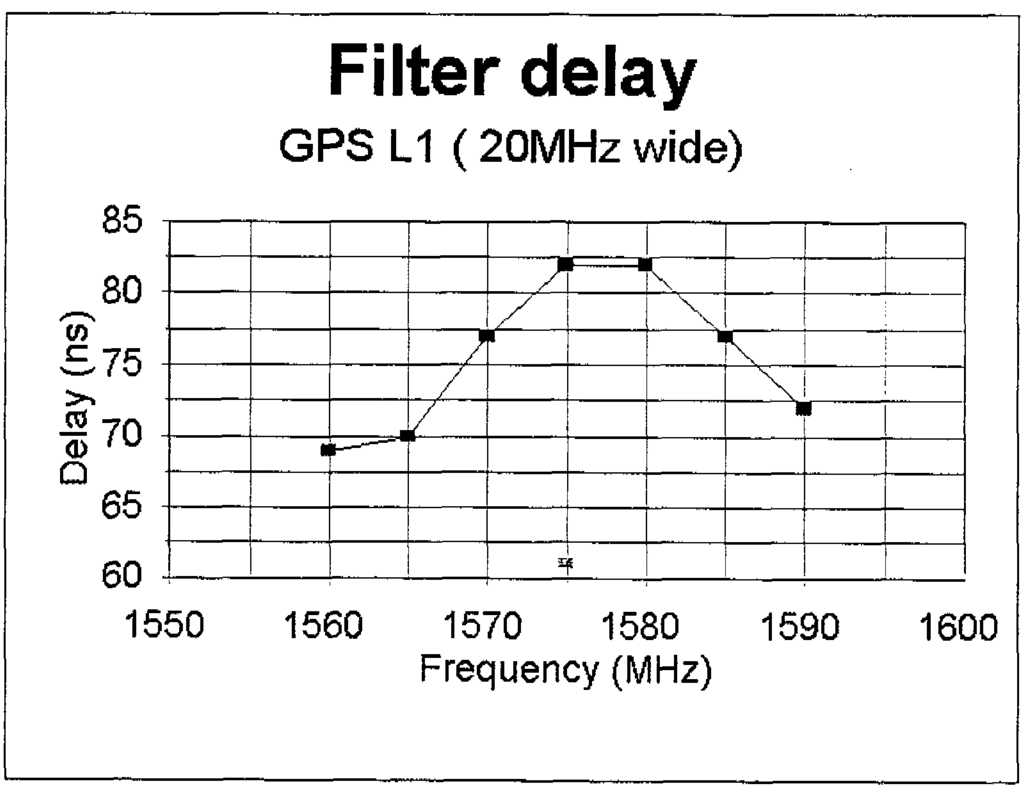



Figure 2. Delay versus frequency

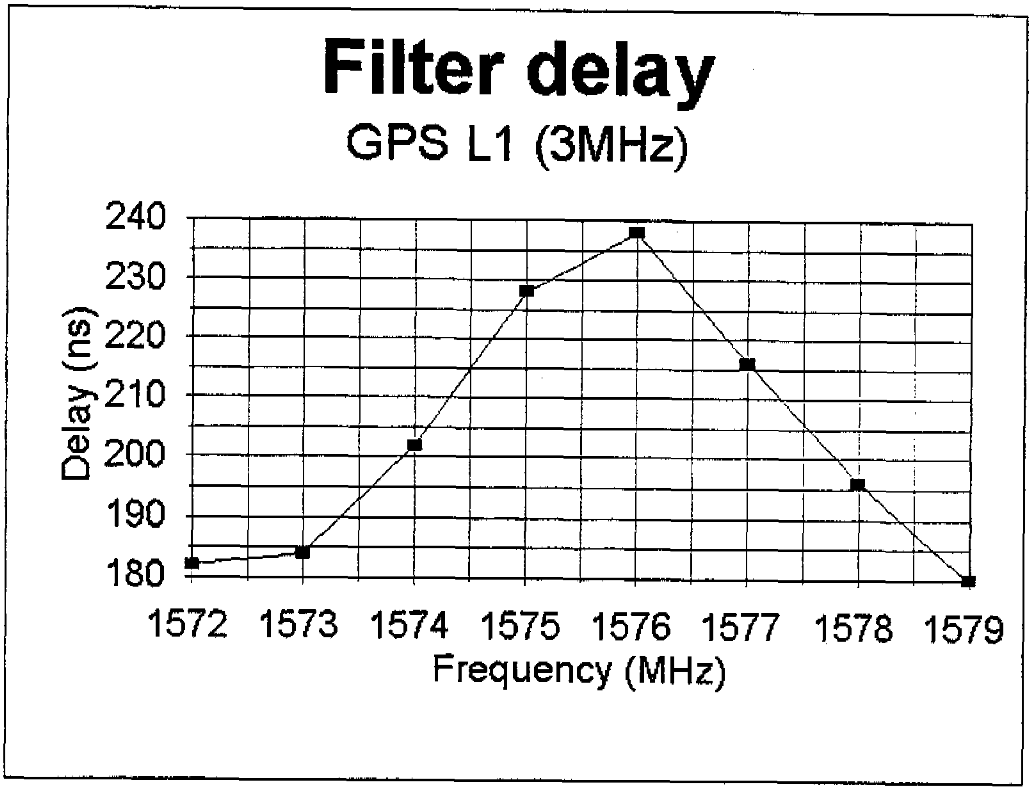
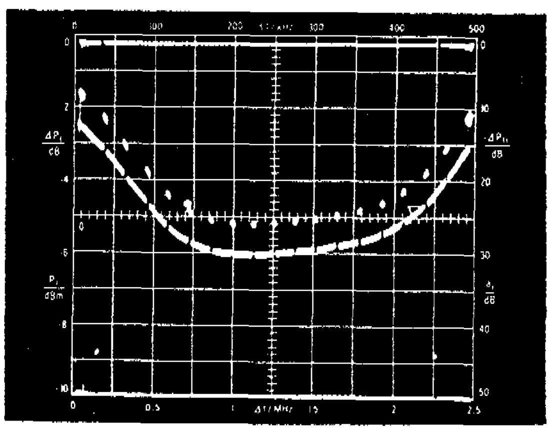



Figure 3. Delay versus frequency

Measured Group Delay Response, Low Band: 14.020 GHz

1 nsec/div

2 MHz markers



Measured Group Delay:

Linear: .01 ns/MHz

Parabolic: .01 ns/MHz$^2$

Ripple: 6.3 ns peak-to-peak

Figure 4. Filter delay versus frequency (Y-axis top-down)

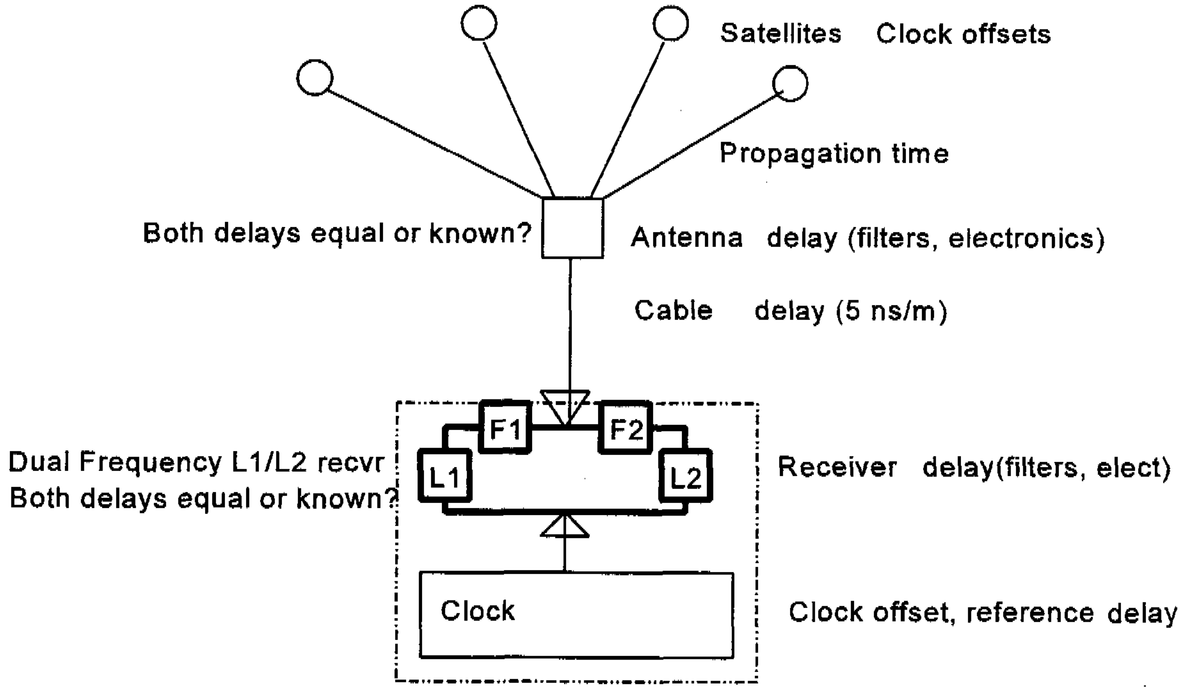



Figure 5, Dual-frequency receiver

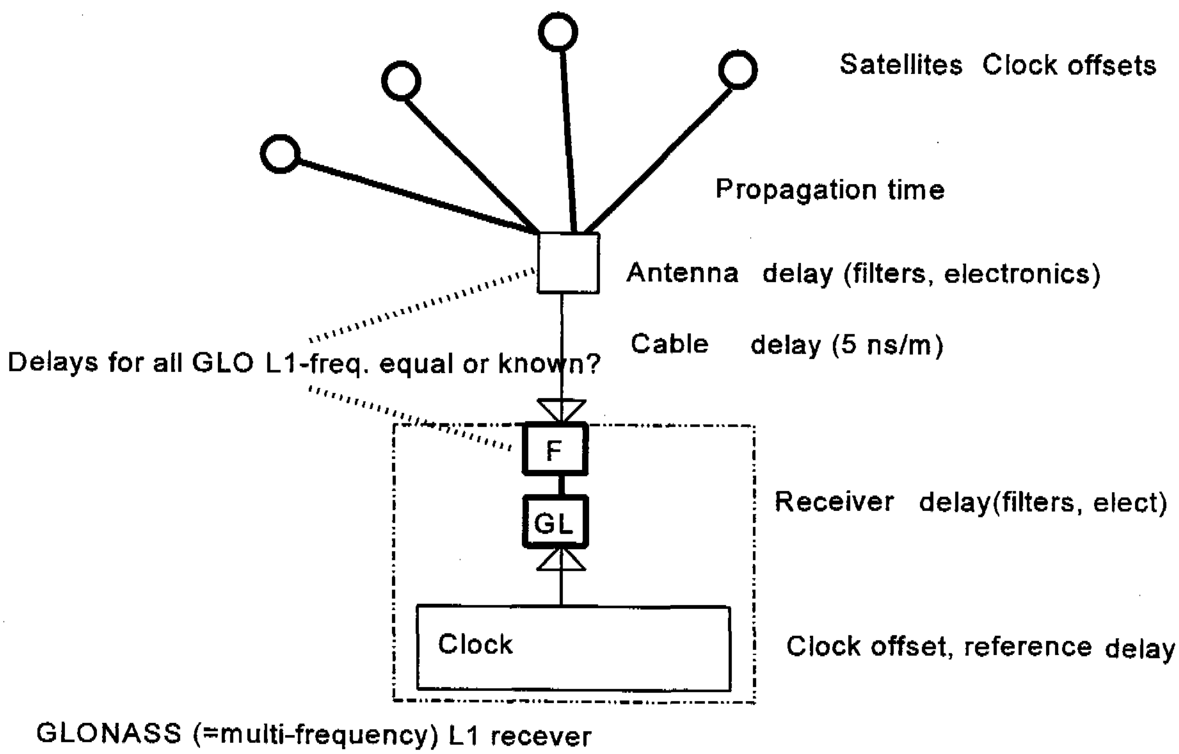



Figure 6. Glonass receiver

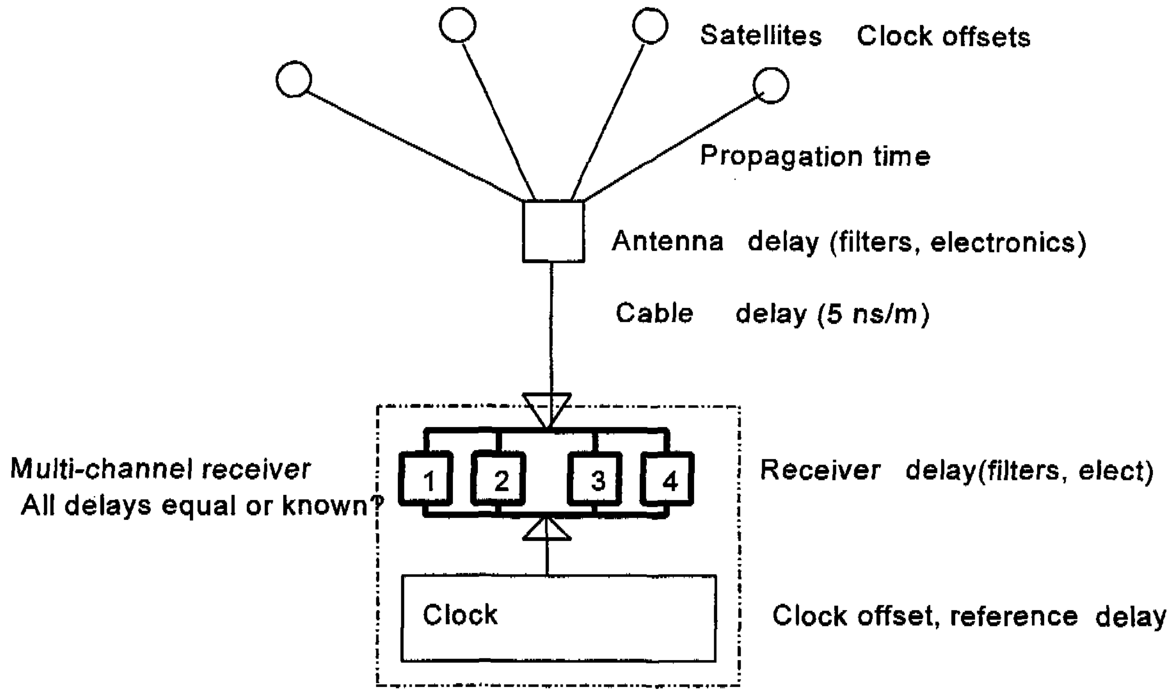
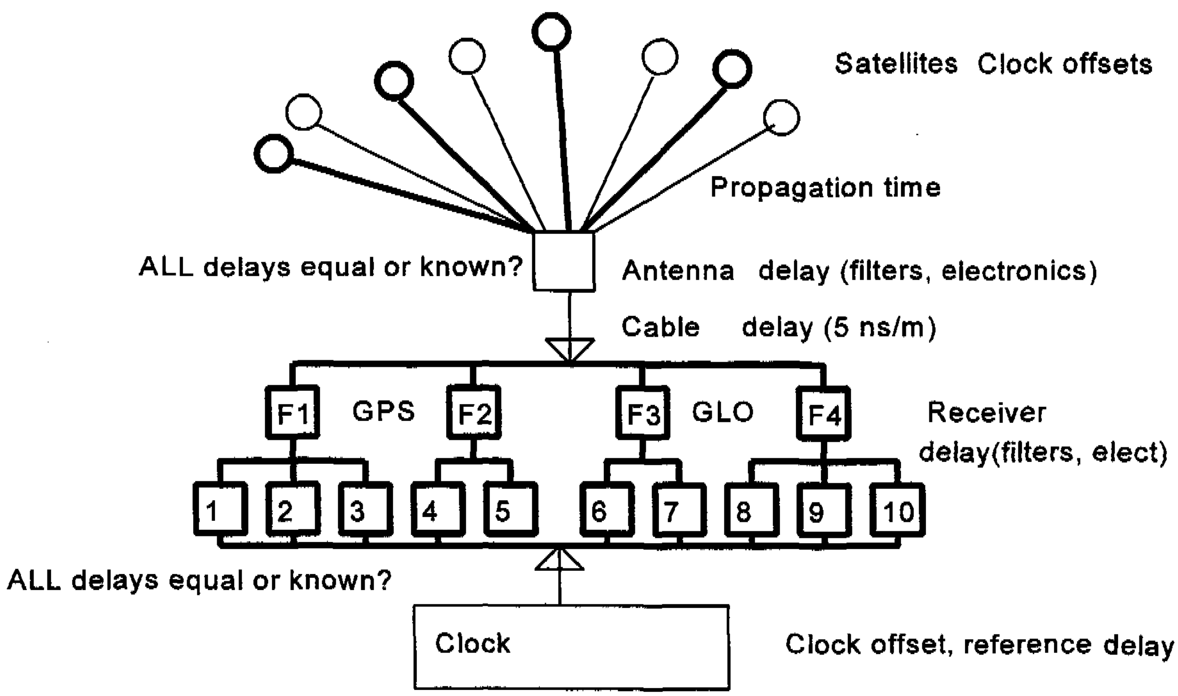



Figure 7. Multi-channel receiver




Dual System (GPS& Glonass), Dual Frequency, Multi-Channel, L1 &L2, P & C/A Rec

Figure 8. Combined Glonass / GPS receivers

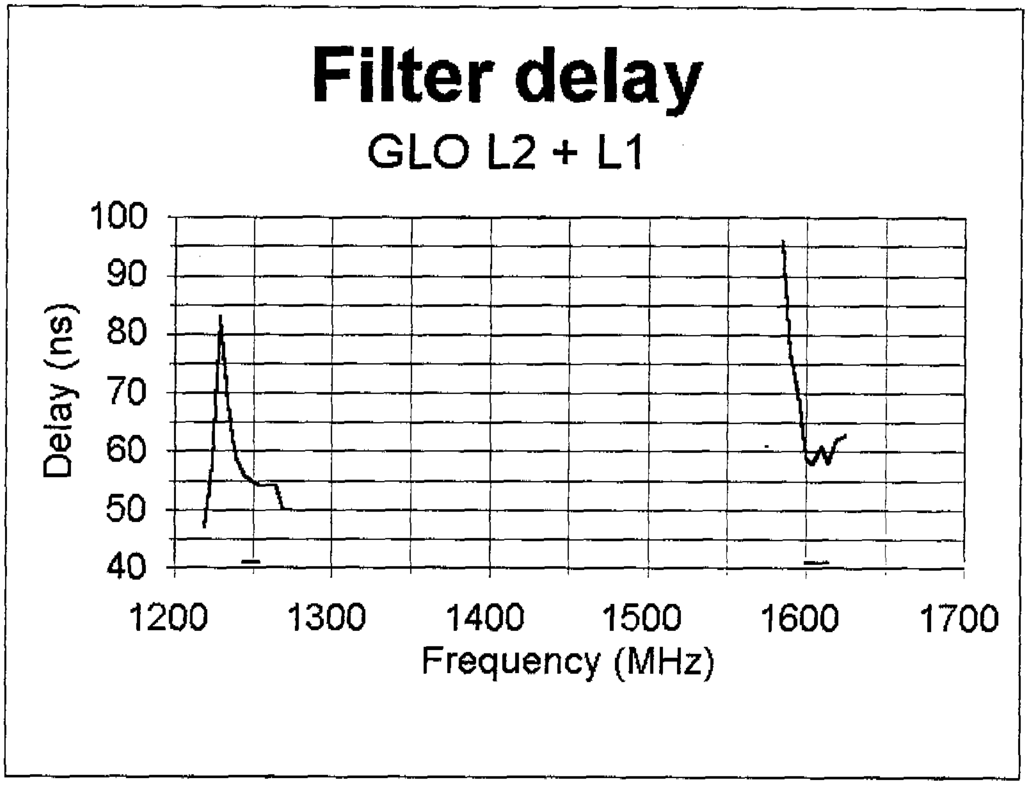



Figure 9. L2 & L1 filter delays

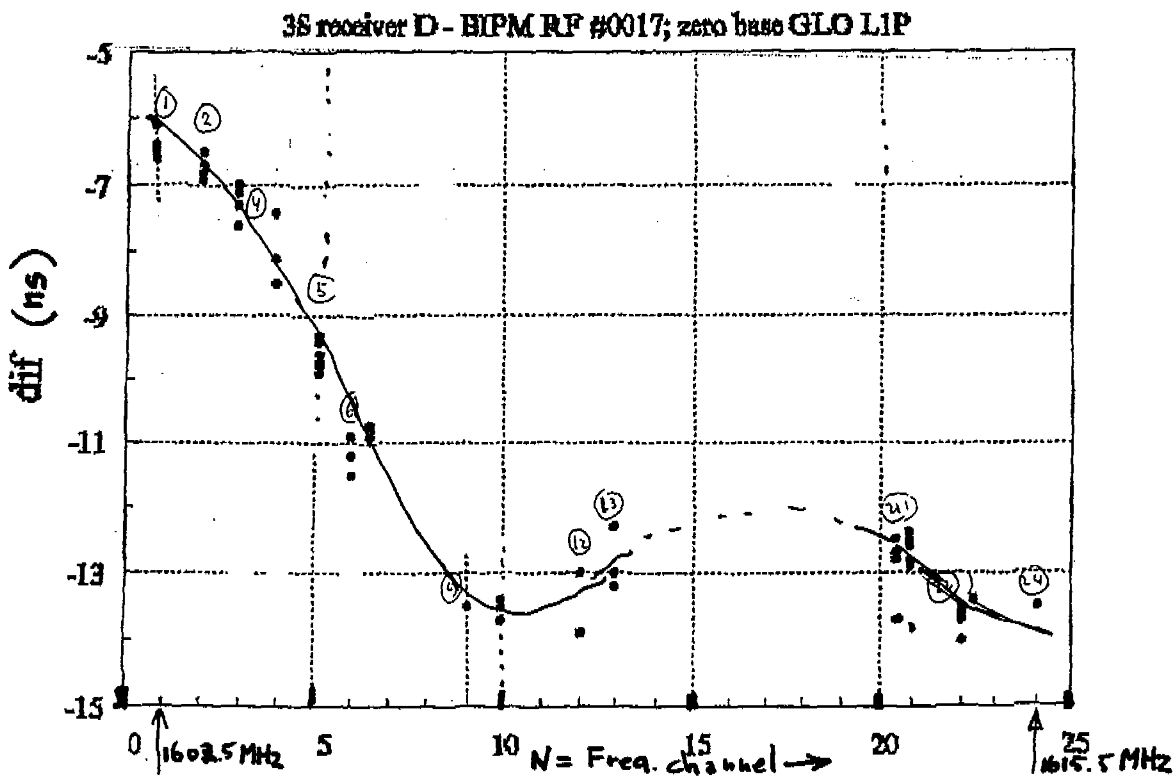



Figure 10. Delay difference of two Glonass :receivers versus freq. channels