GNSS Solutions:

Measuring GNSS Signal Strength

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"GNSS Solutions" is a regular column featuring questions and answers about technical aspects of GNSS. Readers are invited to send their questions to the columnist, **Dr. Mark Petovello**, Department of Geomatics Engineering, University of Calgary, who will find experts to answer them. His e-mail address can be found with his biography at the conclusion of the column.

What is the difference between SNR and C/N_0?

GPS receivers built for various applications, such as handhelds, automobiles, mobile phones, and avionics, all have a method for indicating the signal strength of the different satellites they are tracking. Some receivers display the signal strength in the form of vertical bars, some in terms of normalized signal strength, and others in terms of *carrier-to-noise density* (C/N_0) or *signal-to-noise ratio* (SNR).

The latter two terms are regularly used so interchangeably that their fundamental differences are often overlooked. A full understanding of the differences between SNR and C/N_0 is useful both for users of GPS receivers and for GPS receiver designers and testers.

SNR and C/N_0

SNR is usually expressed in terms of decibels. It refers to the ratio of the signal power and noise power *in a given bandwidth*.

$$SNR(dB) = S - N \qquad (1)$$

S is the *signal power*, usually the carrier power expressed in units of decibel/milliwatt (dBm) or decibel/watts (dBW);
N is the *noise power* in a given bandwidth in units of dBm or dBW.

C/N_0, on the other hand, is usually expressed in decibel-Hertz (dB-Hz) and refers to the ratio of the carrier power and the noise power *per unit bandwidth*.

For the GPS L1 C/A signal, one can consider the received signal power as the power of the original unmodulated carrier power (at the point of reception in a receiver) that has been spread by the spreading (ranging) codes when transmitted from a satellite. We can express C/N_0 as follows:

$$C/N_0\ (dB\text{-}Hz) = C - (N - BW) = C - N_0 = SNR + BW \qquad (2)$$

where

C is the *carrier power* in dBm or dBW;
N is the *noise power* in dBm or dBW;
N_0 is the *noise power density* in dBm-Hz or dBW-Hz;
BW is the bandwidth of observation, which is usually the noise equivalent bandwidth of the last filter stage in a receiver's RF front-end.

Typical values in an L1 C/A code receiver are as follows:

C/N_0: ~ 37 to 45dB-Hz

Receiver front-end bandwidth: ~ 4MHz => BW = 10*log (4,000,000) = 66dB
SNR = C/N_0 – BW => SNR ~ (37 – 66) to (45 – 66) => SNR ~ -29dB to -21dB

In order to determine C/N_0, then, one clearly needs to determine the carrier power and noise density at the input to the receiver.

Noise and Signal Power

The sources of white noise in a GNSS receiver are usually described by the antenna noise temperature and the receiver noise temperature. The antenna temperature models the noise entering the antenna from the sky whereas the receiver noise temperature models the thermal noise due to the motion of charges within a device such as the GPS receiver front-end. These noise sources specify the *noise density*, which may be described as follows:

N_0 (dBw/Hz) = 10*log (k*T), where
k is the Boltzmann's constant 1.38×10^{-23} J/K;

T is the noise temperature in degrees on the Kelvin scale.

The noise density for a typical receiver noise temperature of 290K is -204dBW/Hz or -174dBm/Hz.

We may express the received carrier power as

$P_R = P_T - L + G_R$, where

P_R is the received carrier power;
P_T is the transmitted carrier power;
L is the signal power loss primarily due to path loss;
G_R is the gain of the receiver's antenna in the direction of the received satellite signal.

The nominal carrier power received by the receiver is around -158.5dBW. Hence, for GPS L1 C/A, if one just considers thermal noise and the nominal signal power, the nominal C/N_0 is given as -158.5 – (-204) = 45.5dB-Hz.

Signal and Noise Paths from Antenna to Receiver

Figure 1 illustrates the stages of a typical GPS RF front-end. Depending on the particular receiver design, some of these components may be situated either inside or outside of the receiver itself.

When considering signal and noise paths through the front-end, one needs to consider the noise figure of the various components in the front-end. The noise figure is given as

$$NF = SNR_{in} / SNR_{out}$$

and provides an estimate of the amount of noise added by an active component, such as a low-noise amplifier (LNA), or even a passive component, such as a filter or the cable.

The noise figure is related to the noise temperature as

$NF = 10*\log(1 + T / T_o)$, where

T is the noise temperature
T_o is the reference temperature usually 290K.

The well-known Friis formulas can be used to determine the cascaded noise figure or cascaded noise temperature by measuring noise temperatures or noise figures of the individual components in the receiver front-end.

For our discussion, we need only mention that the cascaded noise figure is primarily dependent on the noise figure and gain of the first LNA in the chain as well as any losses incurred prior to the LNA (e.g., caused by cables or filtering) because losses incurred after the LNA will be attenuated by the reciprocal of the LNA gain.

Band-limiting and quantization schemes chosen within the receiver add additional losses to the C/N_0.

The received C/N_0 is now given as:

$$C/N_0 = C/N_0\,(\text{nominal}) - NF_{RX} - NF_{IMP}$$

where

NF_{RX} is the cascaded noise figure of the receiver;

NF_{IMP} represents the losses due to band-limiting and quantization.

For purposes of this discussion, if we assume a cascaded noise figure of two decibels, then the nominal C/N_0 is degraded by two decibels. We can assume an additional noise figure of one decibel due to band-limiting and quantization, which is typical for a two-bit quantized receiver front-end.

For our example, the received nominal C/N_0 is given as:

$C/N_0 = 45.5 – 2 - 1 = 42.5$dB-Hz

Taking into consideration the noise environment and the receiver front-end components, the C/N_0 of a particular tracked satellite will scale relative to the signal power. The signal power of the various satellites being tracked by the receiver will vary in relation to the satellite elevation angle due to differences in path loss and the satellite and receiver antennas' gain patterns. So, for example, if the signal power varies ±4dB of the nominal signal power of -158.5dBW, the corresponding C/N_0 will vary from 38.5dB-Hz to 46.5dB-Hz.

Interpretation and Significance of C/N_0

From our discussions thus far, the C/N_0 output by a receiver clearly provides an indication of the signal power of the tracked satellite and the noise density as seen by the receiver's front-end.

Two different GPS receivers connected to the same antenna and tracking the same GPS satellite at the same time may output different C/N_0 values. If one assumes that the C/N_0 values are computed accurately by both the receivers, the differences in the C/N_0 values can be attributed to differences in the noise figure of the two front-ends and/or the receivers' respective band-limiting and quantization schemes.

The C/N_0 value provides an indication of the signal quality that is independent of the acquisition and tracking algorithms used by a receiver. In contrast to SNR, C/N_0 is also independent of the receiver's front-end bandwidth and can be readily used to indicate the quality of the received signal. (C/N_0 is bandwidth-*independent* from the noise perspective but bandwidth-*dependent* if one considers the correlation losses associated with bandlimiting. However, the latter losses are usually within the error uncertainty of C/N_0 computation algorithm itself; so, for most practical purposes we can say that C/N_0 is bandwidth-independent.)

For a given satellite signal and receiver front-end, the C/N_0 value may also vary due to set up and installation considerations. For example, the use of a long cable before the first LNA stage of the receiver will affect the noise figure and, consequently, the C/N_0. However, the C/N_0 remains constant through the different signal processing stages of the receiver, such as pre-detection, acquisition, and tracking.

Receiver Acquisition, Processing Blocks, and SNR

The signal-to-noise ratio is most useful when considered

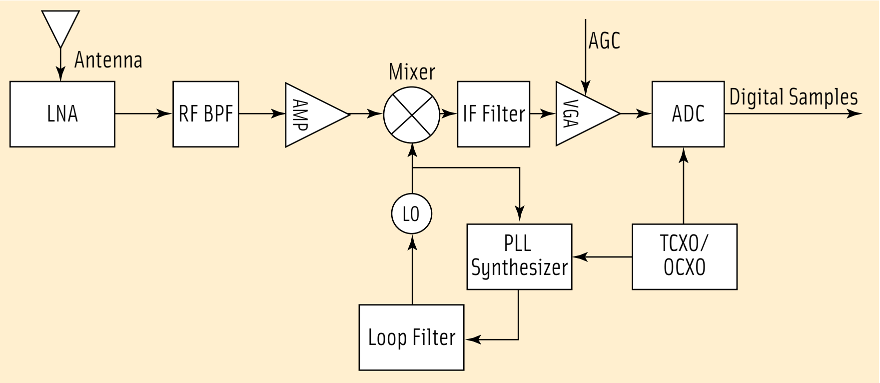

FIGURE 1 GPS receiver RF front-end

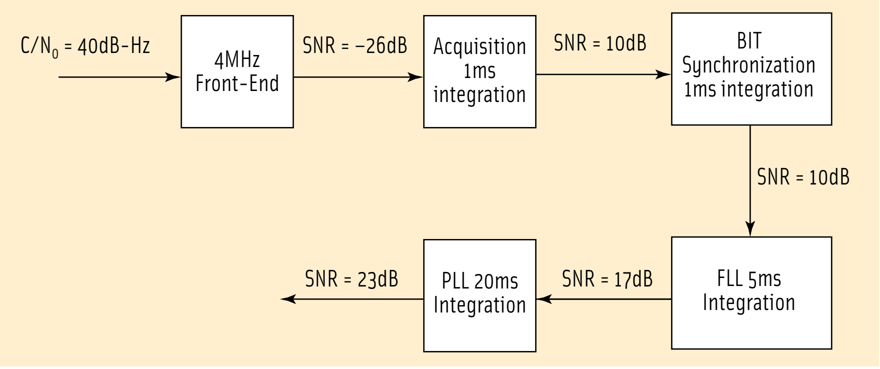

FIGURE 2 GPS baseband processing stages

within the baseband processing blocks of a GNSS receiver. In dealing with SNR, the bandwidth of interest needs to be specified. Typically the *noise equivalent bandwidth* is used, which is defined as the bandwidth of an ideal (i.e., brick-wall) filter whose bandwidth when multiplied by the white noise density of $N_0/2$ will result in the total noise power at the output of the original filter.

As an example, the transfer function of the "integrate and dump" filters that are used in GPS signal processing is given by: H(f) = sin(π*δf*T) / π*δf*T, where

δf is the frequency error in the acquisition or tracking block;

T is the integration time.

The total noise power passed through the filter H(f) is given by

$$P_n = N_0/2 * \int_{-\infty}^{\infty} |H(f)|^2 df$$

However, the noise power passed by an ideal filter is the product of $N_0/2$ and bandwidth (i.e., BW in Equation 2). As such, the integral in the preceding equation is actually the noise equivalent bandwidth of the filter. For the "integrate and dump" filter the integral

$$\int_{-\infty}^{\infty} |H(f)|^2 df$$

evaluates to 1/T. The noise equivalent bandwidth allows one to go back and forth between C/N_0 and SNR as per Equation 2.

A typical GPS receiver implemented using either hardware correlators or a software-based approach needs to acquire and track the satellite signal before pseudoranges and carrier phase measurements can be made.

Figure 2 presents the typical stages in the receiver's baseband processing. The integration times indicated in the different blocks of the figure refer to the integration or accumulation time of the "integrate and dump" filters.

For illustrative purposes, we chose the following integration times: 1 millisecond for acquisition, 1 millisecond for synchronization with the navigation symbols, 5 milliseconds for completing the frequency lock loop (FLL), and 20 milliseconds for the phase lock loop (PLL). Actual receivers may use different schemes, like coherent and non-coherent integrations and longer integration times, which will change the effective SNR.

A receiver's front-end bandwidth determines the SNR that is seen by the input side of the various baseband processing stages of the receiver. In Figure 2 the receiver's front-end bandwidth of four megahertz establishes the SNR of –26 decibels that enters the receiver's base band processing stages.

In Figure 2 we can see that before integration the signal power is below the noise floor, but as the integration time is increased the SNR increases and the signal power rises above the noise power. The SNR gain in this case is also referred to as *processing gain*.

The improvement in SNR as the result of a longer integration occurs because of the reduction in the noise equivalent bandwidth. Note that the performance of the PLL and FLL in the presence of thermal noise is further affected by the bandwidths of the respective loops themselves. The integration time in this case establishes the input SNR and the loop update time for the respective loops.

Interpretation and Significance of SNR

As we have seen, the SNR in a GPS receiver depends on the receiver's front-end bandwidth, acquisition, and tracking parameters. Referencing just the SNR value in a GPS receiver does not usually make sense unless one also specifies the bandwidth and processing stage within the receiver.

The SNR is very useful when evaluating the performance of the acquisition and tracking stages in a receiver. For example, when performing Monte Carlo simulations, the SNR needs to be determined at the various stages of the signal processing chain to properly simulate the receiver. In simulations the required C/N_0 needs to be first converted to an SNR from which the appropriate noise variance can be readily determined.

Furthermore, the SNR is an indication of the level of noise present in the measurement, whereas C/N_0 alone does not provide this information.

In conclusion, we can see that both the C/N_0 and SNR are useful quantities that can be used when designing, evaluating or verifying the performance of a GPS receiver. However the use of one quantity over the other very much depends upon the context and the purpose for which the signal quality measurement is being made or is to be used for and this should be carefully considered when choosing between the two.

Additional Resources

For information on how C/N_0 is computed within a GNSS receiver, refer to the GNSS Solutions columns by B. Badke (*Inside GNSS*, September/October 2009) and E. Falletti *et alia* (January/February 2010). IG

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