GNSS Antenna

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Most of materials are based on website (GPS World, Inside GNSS), GNSS textbooks and document by Mr. Osamu Arai.

Contents

- GNSS Antenna
- How to estimate C/N0
- Evaluation of GNSS Antenna pattern

What is GNSS Antenna ?

- A GNSS or GPS antenna is a device designed to receive and amplify the radio signals transmitted on specific frequencies by GNSS satellites and convert them to an electronic signal for use by a GNSS or GPS receiver. The output of the GNSS or GPS antenna is fed into a GNSS or GPS receiver that can compute the position.

What is the difference between an active and a passive GNSS antenna?

- An active antenna has an low-noise amplifier built in. This provides gain to help overcome coax cable losses and at the same time provides the proper signal level to the GNSS receiver. The drawback is that an active antenna requires an external power source. Some module manufacturers makes their mPCIe modules provide the power. Others need a biased tee in between to avoid damaging the module.

  A passive antenna doesn't have the low-noise amplifier. This means that the signal may be weaker when it's received by the module so a fix may take longer time, but there's no need for an external voltage source.

GNSS Antenna Properties

- A number of important properties of GNSS antennas affect functionality and performance, including:
    1. Frequency coverage
    2. Gain pattern
    3. Circular polarization
    4. Multipath suppression
    5. Phase center
    6. Impact on receiver sensitivity
    7. Interference handling

Frequency Coverage

- GNSS receivers brought to market today may include frequency bands such as GPS L5, Galileo E5/E6, and the GLONASS bands in addition to the legacy GPS bands, and the antenna feeding a receiver may need to cover some or all of these bands.

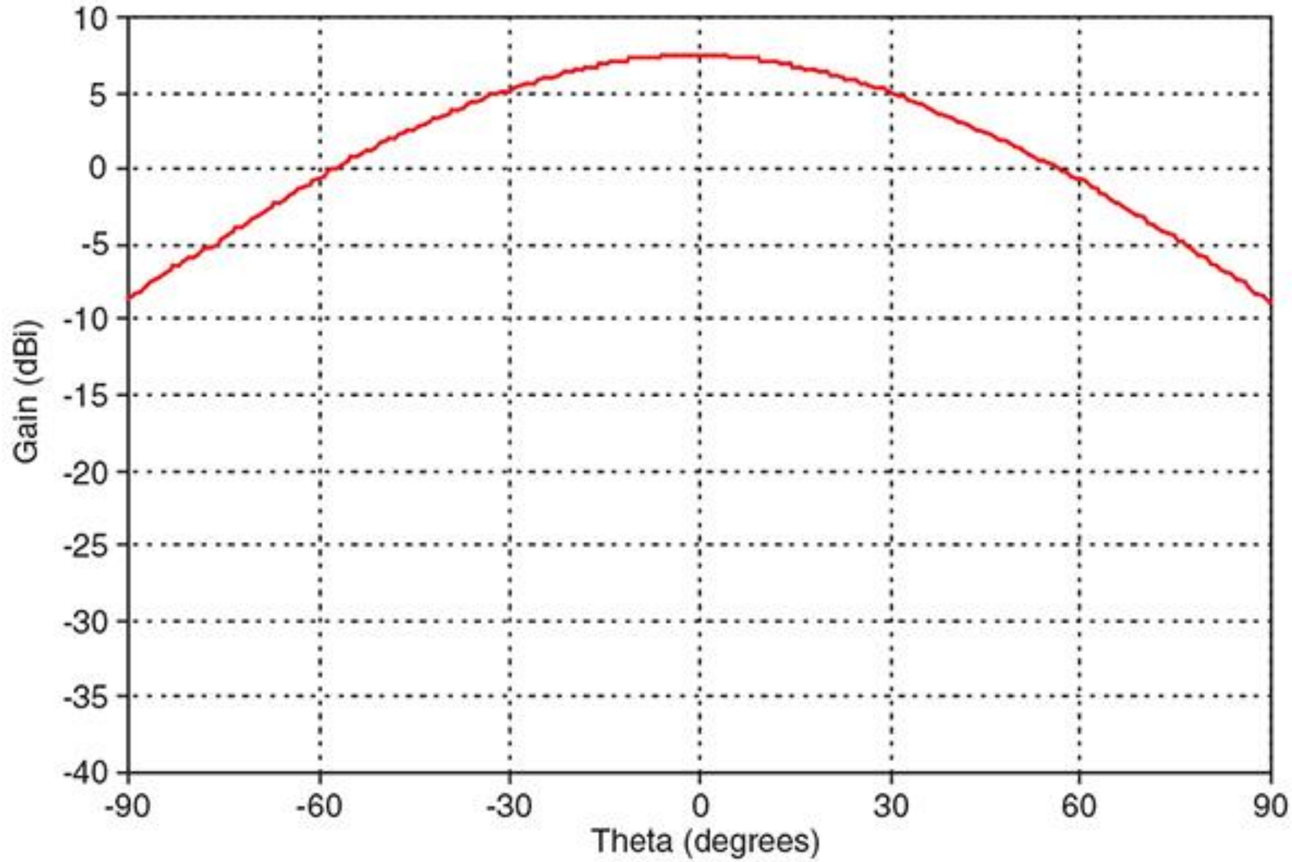
	L1	L2	L5	L6
Center Frequency	1575.42	1227.6	1176.45	1278.75
GPS	L1-C/A	L2C,L2P	L5	
GLONASS				
GALILEO	E1		E5a	E6
BDS	B1C		B2a	
QZSS	L1-C/A,L1C	L2C	L5	L6

FDMA

Gain pattern

- For a transmitting antenna, gain is the ratio of the radiation intensity in a given direction to the radiation that would be obtained if the power accepted by the antenna was radiated isotropically.
- For a receiving antenna, it is the ratio of the power delivered by the antenna in response to a signal arriving from a given direction compared to that delivered by a hypothetical isotropic reference antenna.
- The spatial variation of an antenna's gain is referred to as the radiation pattern or the receiving pattern.

One shot of Gain pattern



Elevation 0

Zenith

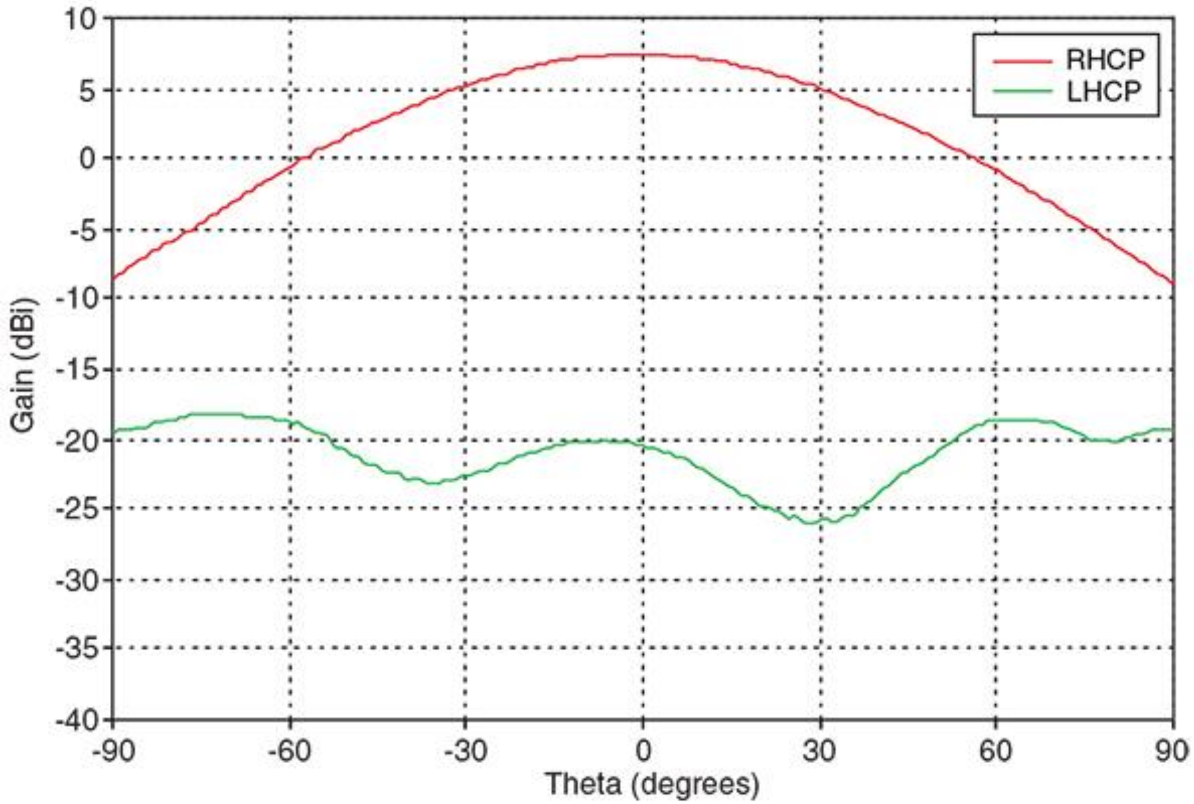
Elevation 0

Circular polarization

- Spaceborne systems at L-Band typically use circular polarization (CP) signals for transmitting and receiving. The changing relative orientation of the transmitting and receiving CP antennas as the satellites orbit the Earth does not cause polarization fading as it does with linearly polarized signals and antennas.
- Furthermore, circular polarization does not suffer from the effects of Faraday rotation caused by the ionosphere. Faraday rotation results in an electromagnetic wave from space arriving at the Earth's surface with a different polarization angle than it would have if the ionosphere was absent.
- This leads to signal fading and potentially poor reception of linearly polarized signals.

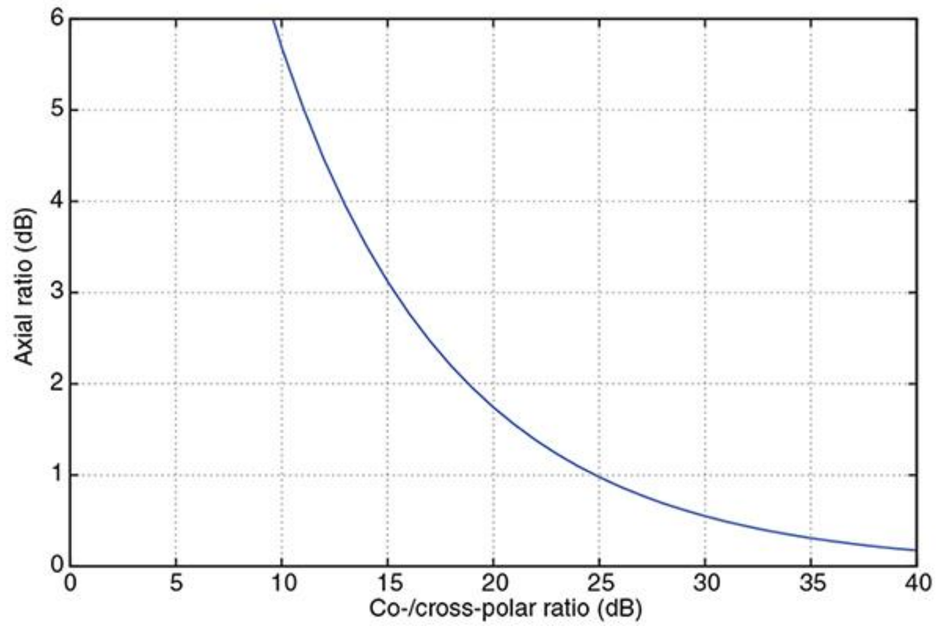
RHCP and LHCP

Antennas are not perfect and an RHCP antenna will pick up some left-hand circular polarization (LHCP) energy. Because GPS and other GNSS use RHCP, we refer to the LHCP part as the cross-polar component

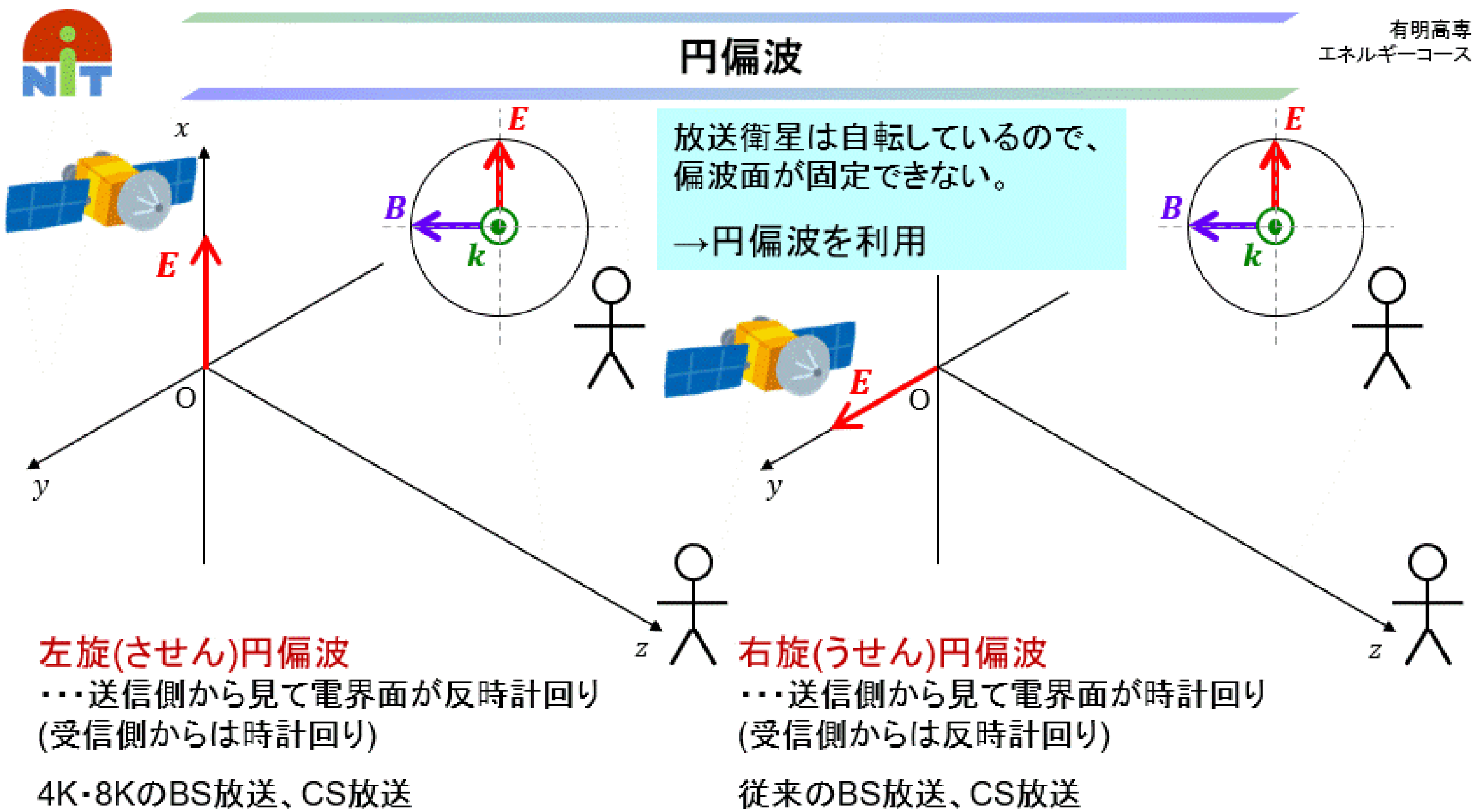


Axial ratio

- We can describe the quality of the circular polarization by either specifying the ratio of this cross-polar component with respect to the co-polar component (RHCP to LHCP), or by specifying the axial ratio (AR). AR is the measure of the polarization ellipticity of an antenna designed to receive circularly polarized signals. An AR close to 1 (or 0 dB) is best



Circular polarization



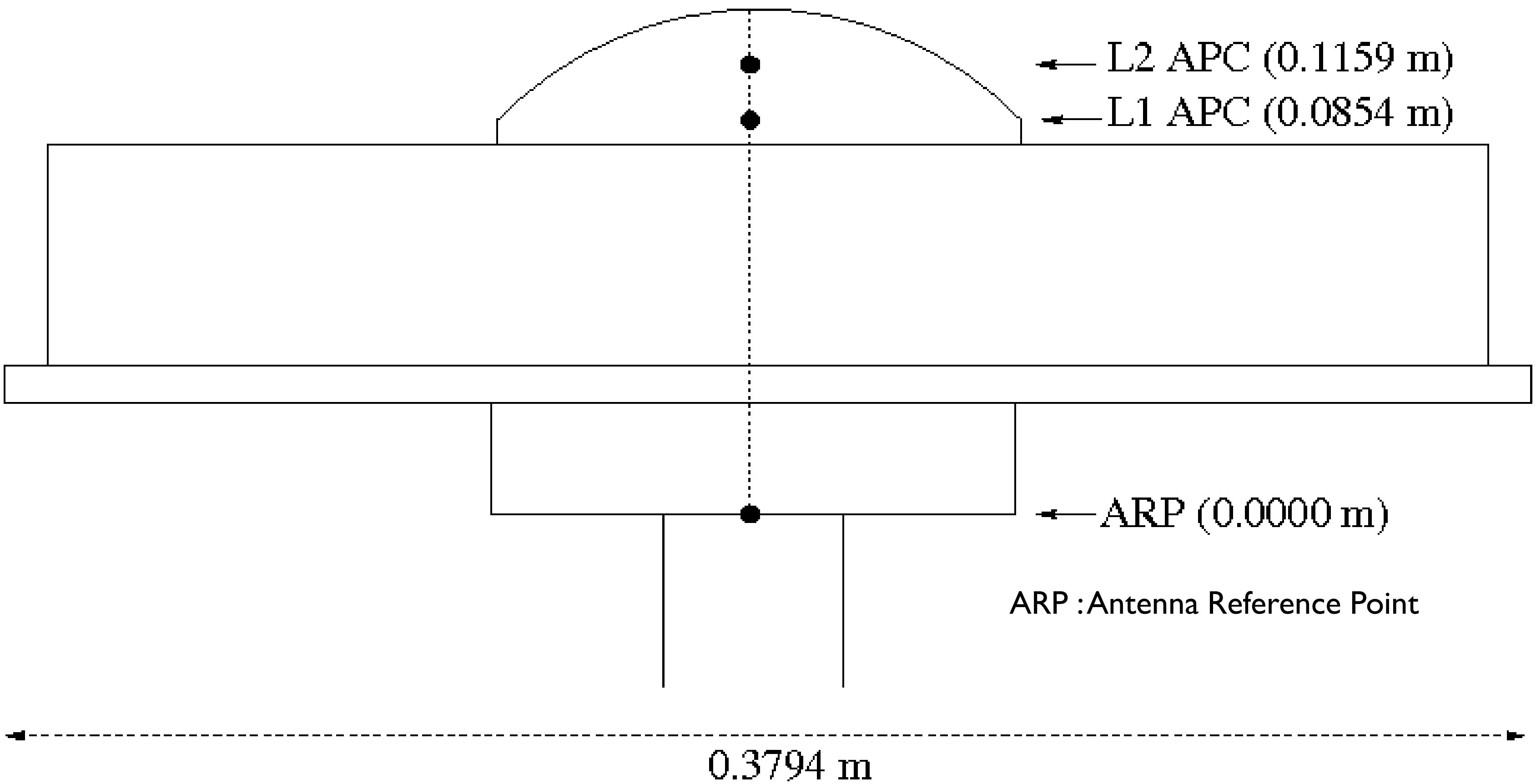
Multipath suppression

- Signals coming from the satellites arrive at the GNSS receiver's antenna directly from space, but they may also be reflected off the ground, buildings, or other obstacles and arrive at the antenna multiple times and delayed in time. This is termed multipath.
- It degrades positioning accuracy and should be avoided. High-end receivers are able to suppress multipath to a certain extent, but it is good engineering practice to suppress multipath in the antenna as much as possible.
- **Reflected signals typically contain a large LHCP component.**
- **Gain pattern : low/high in low/high elevation angle**

Phase center

- A position fix in GNSS navigation is relative to the electrical phase center of the antenna. The phase center is the point in space where all the rays appear to emanate from (or converge on) the antenna. Put another way, it is the point where the electromagnetic fields from all incident rays appear to add up in phase.
- Determining the phase center is important in GNSS applications, particularly when millimeter-positioning resolution is desired.
- **Ideally, this phase center is a single point in space for all directions(ele/azi) at all frequencies.** However, a "real-world" antenna will often possess multiple phase center points (for each lobe in the gain pattern, for example) or a phase center that appears "smeared out" as frequency and viewing angle are varied.

Example of APC and ARP



ARP : Antenna Reference Point

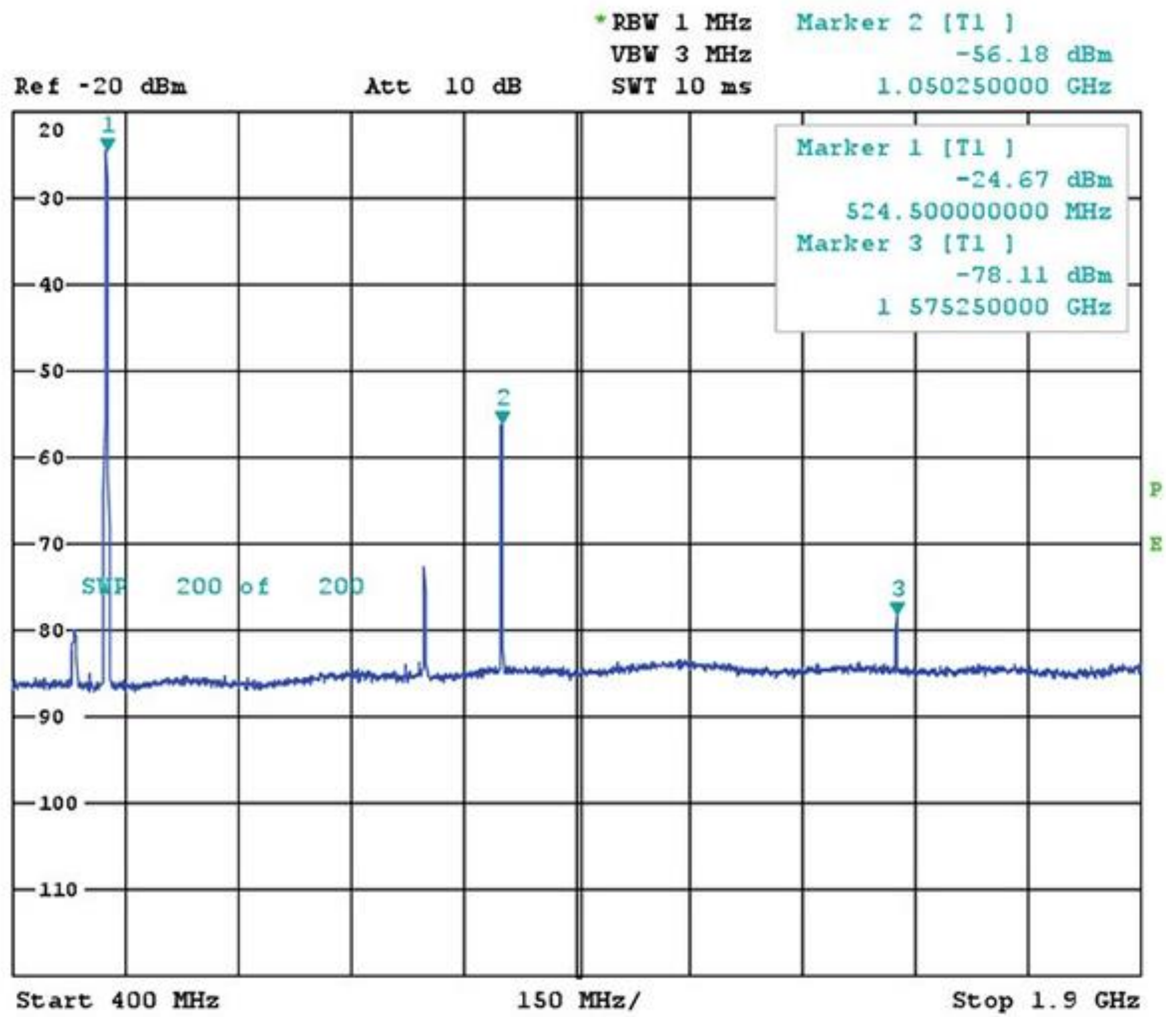
Impact on receiver sensitivity

- The strength of the signals from space is on the order of −130 dBm. We need a really sensitive receiver if we want to be able to pick these up. For the antenna, this translates into the need for a high-performance low noise amplifier (LNA) between the antenna element itself and the receiver.
- Expect to see total LNA noise figures in the 3-dB range for high performance GNSS antennas.
- The other requirement for the LNA is for it to have sufficient gain to minimize the impact of long and lossy coaxial antenna cables — typically 30 dB should be enough.

Interference handling

- Even though GNSS receivers are good at mitigating some kinds of interference, it is essential to keep unwanted signals out of the receiver as much as possible. Careful design of the antenna can help here, especially by introducing some frequency selectivity against out-of-band interferers.
- An out-of-band interferer is generally an RF source outside the GNSS frequency bands: cellular base stations, cell phones, broadcast transmitters, radar, etc. When these signals enter the LNA, they can drive the amplifier into its non-linear range and the LNA starts to operate as a multiplier or comb generator.

−30-dBm-strong interferer at 525 MHz generates a −78 dBm spurious signal or spur in the GPS L1 band.



dBm and dBW

$$dBm = 10 \lg\left(\frac{P_1}{1\,mW}\right)$$

$$dB = 10 \lg\left(\frac{P_1}{P_0}\right)$$

$$dBW = 10 \lg\left(\frac{P_1}{1\,W}\right)$$

$-130\text{dBm} = 10^{-16}\,\text{W}$

dBm to Watt, mW, dBW conversion table

Power (dBm)	Power (dBW)	Power (watt)	Power (mW)
-100 dBm	-130 dBW	0.1 pW	0.0000000001 mW
-90 dBm	-120 dBW	1 pW	0.000000001 mW
-80 dBm	-110 dBW	10 pW	0.00000001 mW
-70 dBm	-100 dBW	100 pW	0.0000001 mW
-60 dBm	-90 dBW	1 nW	0.000001 mW
-50 dBm	-80 dBW	10 nW	0.00001 mW
-40 dBm	-70 dBW	100 nW	0.0001 mW
-30 dBm	-60 dBW	1 μW	0.001 mW
-20 dBm	-50 dBW	10 μW	0.01 mW
-10 dBm	-40 dBW	100 μW	0.1 mW
-1 dBm	-31 dBW	794 μW	0.794 mW
0 dBm	-30 dBW	1.000 mW	1.000 mW
1 dBm	-29 dBW	1.259 mW	1.259 mW
10 dBm	-20 dBW	10 mW	10 mW
20 dBm	-10 dBW	100 mW	100 mW
30 dBm	0 dBW	1 W	1000 mW
40 dBm	10 dBW	10 W	10000 mW
50 dBm	20 dBW	100 W	100000 mW
60 dBm	30 dBW	1 kW	1000000 mW
70 dBm	40 dBW	10 kW	10000000 mW
80 dBm	50 dBW	100 kW	100000000 mW
90 dBm	60 dBW	1 MW	1000000000 mW
100 dBm	70 dBW	10 MW	10000000000 mW

SNR and C/N0

- 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
- 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.

C/N_0

- 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-Hz) = C − (N − BW) = C − N_0 = **SNR + BW**
- 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 case

- 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.

GPS baseband processing stages

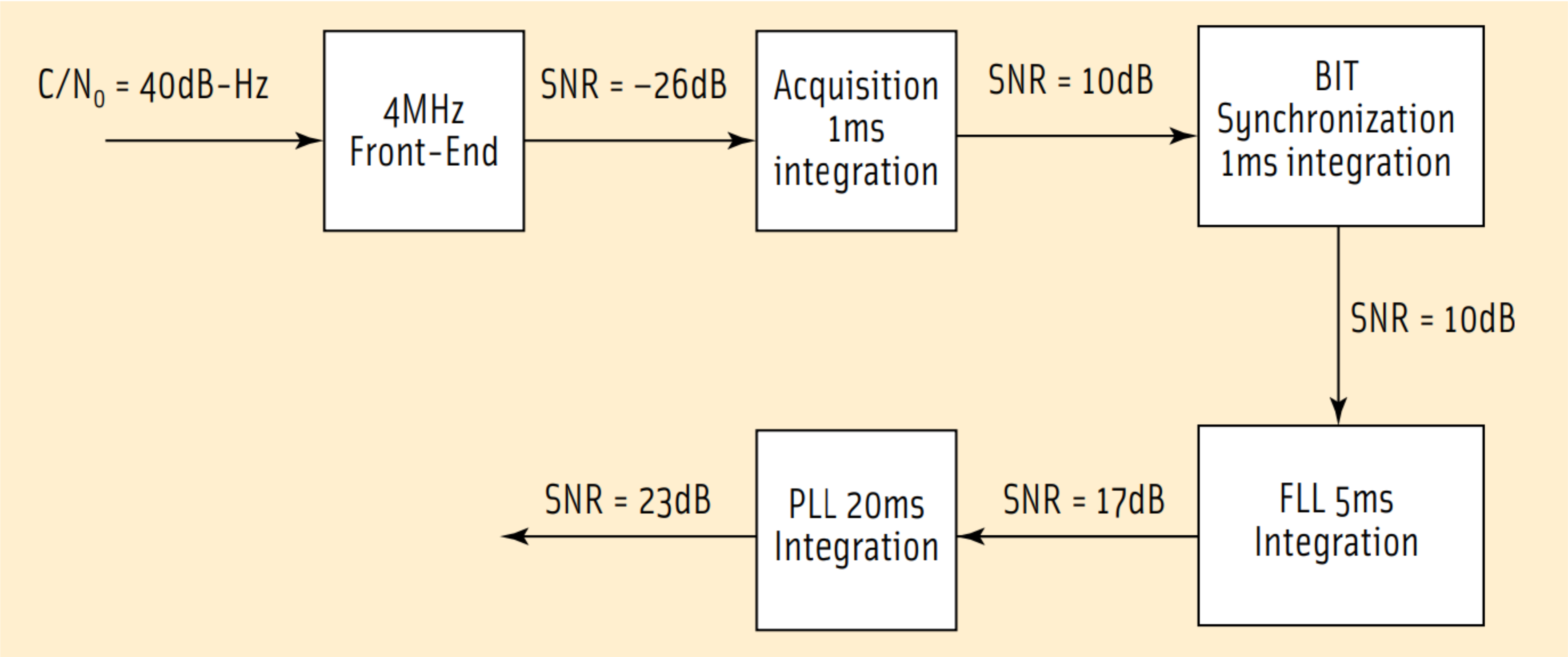
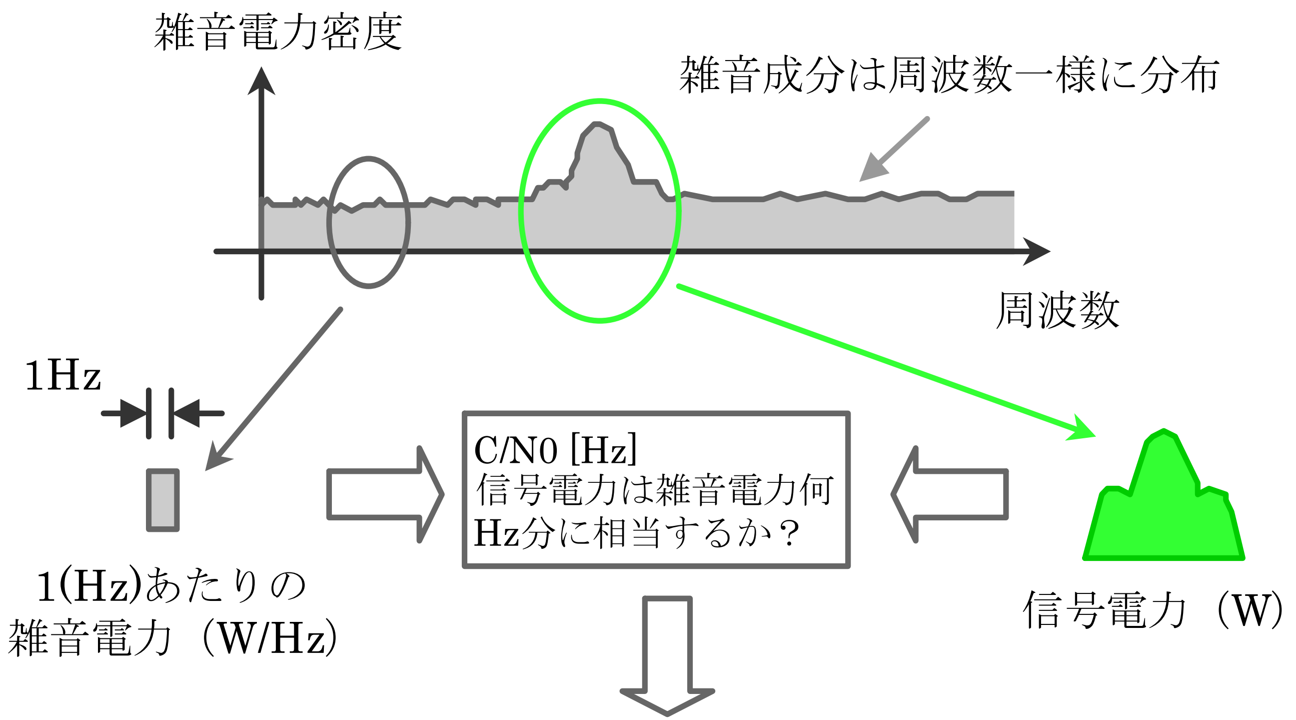


FIGURE 2 **GPS baseband processing stages**

Concept of C/N_0

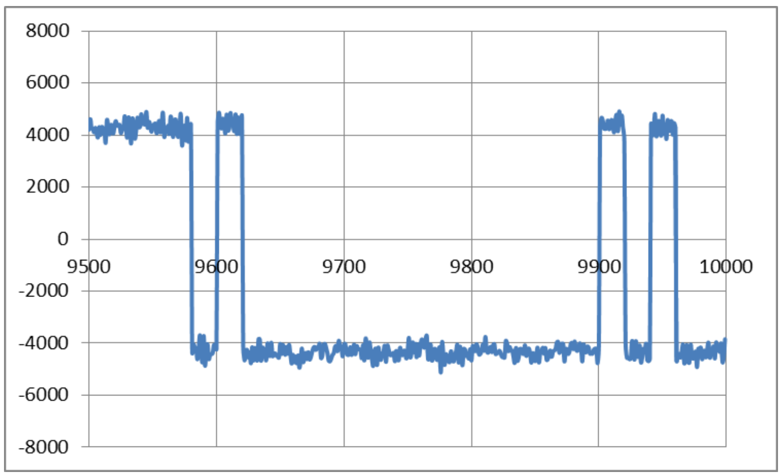


*dB*で表わす場合、

$$C/N_0 = 10\log_{10}(\text{信号電力}/1\text{Hz当りの雑音電力})[dB-Hz]$$

Estimating C/N0 in GNSS Receiver

$$S/N = 20\log_{10}(IP/T/noise\_for\_FE)$$
$$C/N_0 = S/N + 30.0$$



IP is deduced from real values of IP on tracking stage.
T is integration time. IP value for 1 ms is noisy.
Noise_level for each front-end(FE) : We need to prepare the noise for each FE. For example, we got IP value under uncorrelated condition.
What is 30.0 ? Next slide...

Estimating C/N0 in GNSS Receiver

As stated earlier, many receivers display SNR as a figure of merit for a given signal. Typically, this SNR equation is

$$SNR = 10 \cdot \log_{10}\left(\frac{\overline{I^2_{ACC}}}{2 \cdot \overline{Q^2_{ACC}}}\right) \text{dB}$$

Given this definition of SNR and the derived C/N_0, the two are related as follows:

$$\frac{C}{N_0}(dB\text{-}Hz) = SNR(dB) + 10 \cdot \log_{10}\left(\frac{2 \cdot NBW}{f_s \cdot \tau}\right)$$

This conversion from SNR to C/N_0 is specific to the given definition of SNR. However, regardless of how a manufacturer defines SNR, an analysis similar to that given in this article can be applied to determine C/N_0.

ACC : accumulator

NBW : noise bandwidth
fs : sampling frequency
τ : accumulation period

NBW=fs/2
τ :=0.001
$10\log_{10}(1000)=$**30.0**

What about Carrier-to-Noise Density and AI for INS/GPS Integration?

2009 Sep/Oct in insidegnss.com

NovAtel GPS703 GGG : Specification sheet

Performance

3 dB Pass Band

L1	1580.5±28.5 MHz (typical)
L2/L5	1210.0±45.0 MHz (typical)

Out-of-Band Rejection

L1±100 MHz	30 dBc (typical)
L2±200 MHz	50 dBc (typical)

LNA Gain **29 dB (typical)**

Gain at Zenith (90°)

L1	+5.0 dBic (minimum)
L2	+3.0 dBic (minimum)
L5	+3.0 dBic (minimum)

Gain Roll-Off (from Zenith to Horizon)

L1	12 dB
L2	13 dB
L5	13 dB

Noise Figure **2.0 dB (typical)**

VSWR **≤2.0 : 1**

L1-L2 Differential Propagation Delay **5 ns (maximum)**

Nominal Impedance **50 Ω**

Altitude **9,000 m**

Physical and Electrical

Dimensions **185 mm diameter[1] x 69 mm**

Weight **500 g**

Power

Input Voltage	+4.5 to +18.0 VDC
Power Consumption	36 mA (typical)

Connector **TNC female**

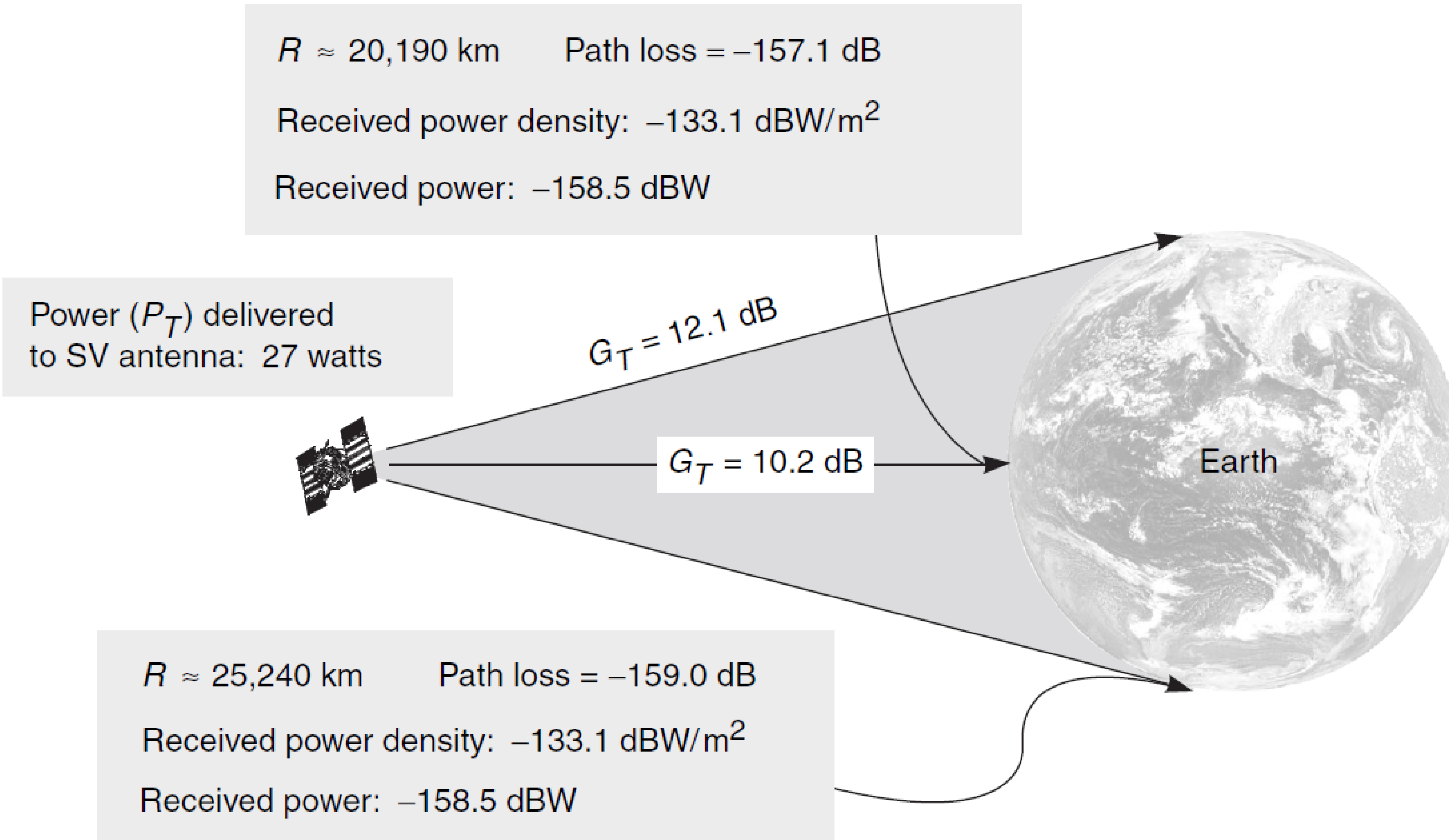
Environmental

Temperature	
Operating	-40°C to +85°C
Storage	-55°C to +85°C
Humidity	95% non-condensing
Vibration (operating)	
Random	MIL-STD-810F
Sinusoidal	SAEJ1211, Section 4.7
Shock	IEC 68-2-27 (Ea)
Bump	IEC 68-2-29 (Eb)
Salt Spray	MIL-STD-810F, 509.4
Waterproof	IEC 60529 IPX7
RoHS	EU Directive 2002/95/EC

Compliance **FCC, CE**

VSWR(Voltage Standing Wave ratio)

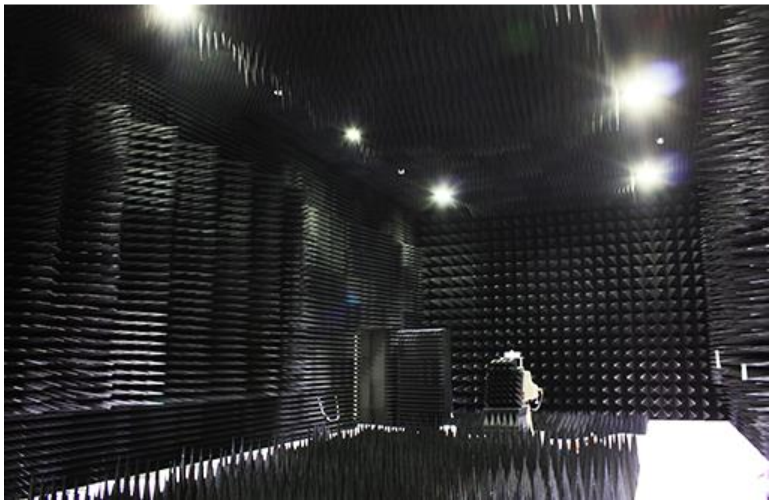
- VSWR is a measure of how efficiently radio-frequency power is transmitted from a power source, through a transmission line, into a load (for example, from a power amplifier through a transmission line, to an antenna).
- VSWR measures these voltage variances. It is the ratio of the highest voltage anywhere along the transmission line to the lowest. Since the voltage doesn't vary in an ideal system, its VSWR is 1.0 (or, as commonly expressed, 1:1). When reflections occur, the voltages vary and VSWR is higher – 1.2 (or 1.2:1), for instance.

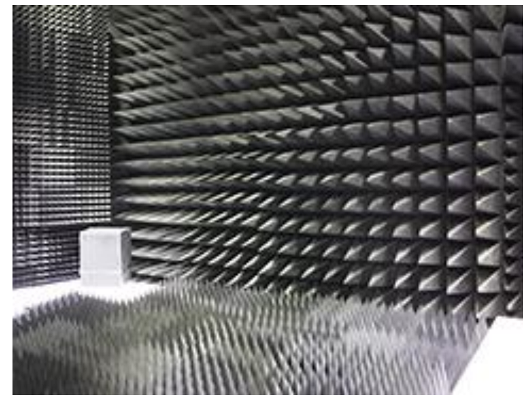

$R \approx$ 20,190 km Path loss = –157.1 dB
Received power density: –133.1 dBW/m^2
Received power: –158.5 dBW
Power (P_T) delivered to SV antenna: 27 watts
G_T = 12.1 dB
G_T = 10.2 dB
Earth
$R \approx$ 25,240 km Path loss = –159.0 dB
Received power density: –133.1 dBW/m^2
Received power: –158.5 dBW

Received signal power for C/A-code signal

	Low Elevation (5)	Moderate Elevation (40)	Zenith (90)
Received power density	$4.9*10^{-14}$ W/m^2 -133.1 dBW/m^2	$7.8*10^{-14}$ W/m^2 -131.1 dBW/m^2	$4.9*10^{-14}$ W/m^2 -133.1 dBW/m^2
Effective area of an omni-directional receive antenna	$2.87*10^{-3}$ m^2 -25.4dBm^2	-	-
Receive power available from an isotropic antenna	-158.5 dBW	-156.5 dBW	-158.5 dBW
Gain of a typical patch receive antenna	-4 dBic	+2 dBic	+4 dBic
C/A-code received power	-162.5 dBW	-154.5 dBW	-154.5 dBW
Noise power density	-201 dBW	-201 dBW	-201 dBW
C/N_0	38.5 dB-Hz	46.5 dB-Hz	46.5 dB-Hz

電子航法研究所の電波暗室





内部寸法(外寸):	32.0m×6.2m×4.2m
使用周波数帯域:	1-110GHz
無反射範囲:	23m 以上
反射減衰量(中心部):	50dB 以上
遮蔽減衰量(中心部):	90dB 以上

電波暗室でのアンテナパターン測定

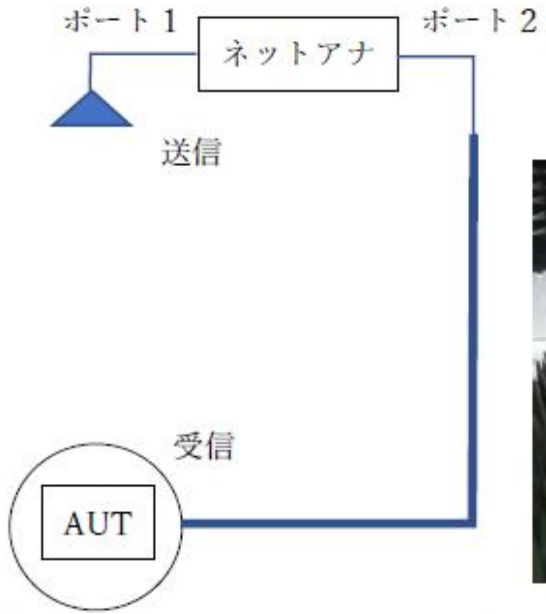


図1 ネットワークアナライザによる測定系

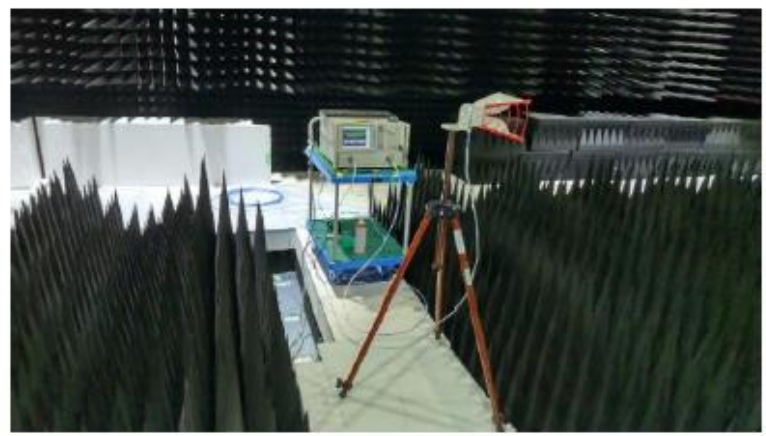


図2 送信側

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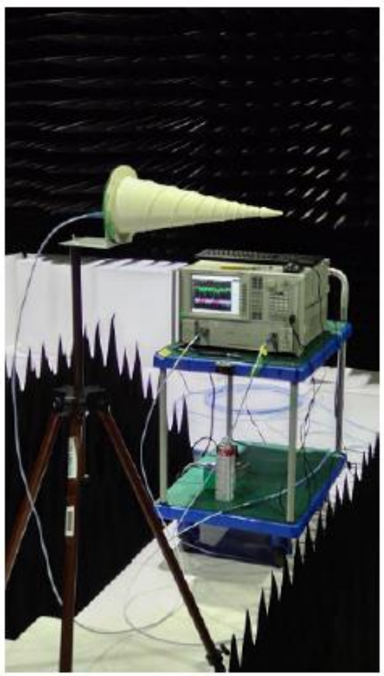
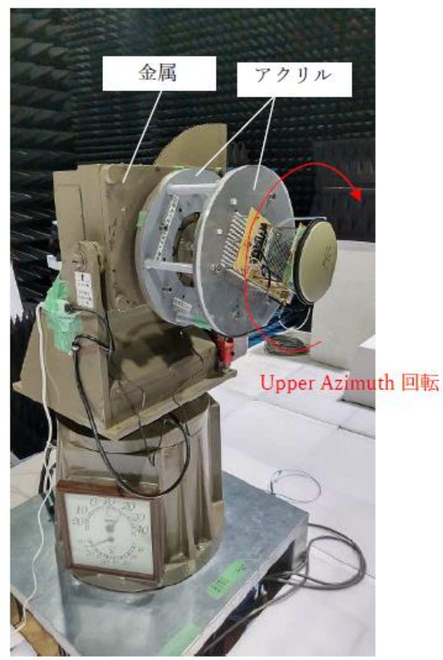
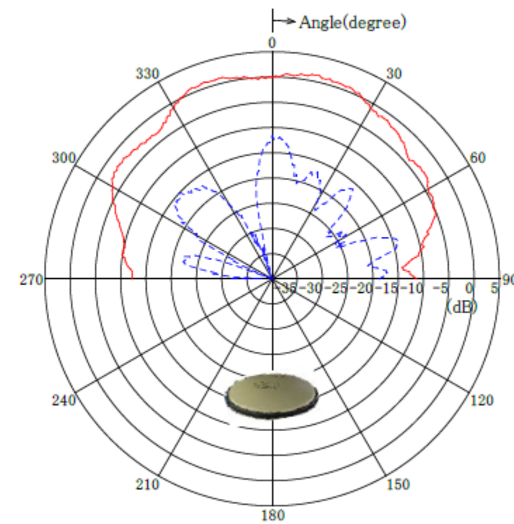
電波暗室でのアンテナパターン測定







Antenna Radiation Pattern
1.176GHz

電子研毛塚様提供

今回利用するアンテナ

- NovAtel社のGPS-703-GGG (2班に分かれます　1.5H×2)
- u-bloxのF9P付属：AMO社のアンテナ(2班に分かれます 1.5H×2）
- ドローンに適した軽いヘリカルアンテナ（後日データを提供頂く）

今回の測定では、アンテナの特性のキーとなる利得パターンと軸比を測定します。