# Measuring and monitoring satellite signals with the NRA range of spectrum analyzers

## based on the requirements of satellite operators, teleports and SNG operators

Measuring and monitoring the signals in satellite communications systems is as complex as the tasks of those involved in operating such systems.

**Satellite operators** are normally interested in ensuring that transponder use corresponds to the criteria agreed with users in terms of quality and scope, which also includes the detection of any interference signals.

**Teleport operators** are concerned with making the best possible use of the resources with the communications systems, particularly the space segment. This involves monitoring the transmitted signals, which includes checking the spectrum for unwanted intermodulation products in the case of multi-carrier operation. It is also necessary in stations with uplink power control to ascertain atmospheric attenuation effects in real time if possible to use as input values for the power settings. The power levels of the individual signals radiated by the satellite can also be determined at the teleport.

**SNG operators** need assistance during line-up for aligning the antenna and during operation for monitoring the transmitted signals. It is also useful to evaluate the received signals in order to identify impairments in the transmission path caused by obstacles, for example.

This Application Note describes example measurement principles that cover the above-mentioned applications and for which the NRA range of spectrum analyzers from Narda is particularly suitable.

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## 1 Typical measurement configuration

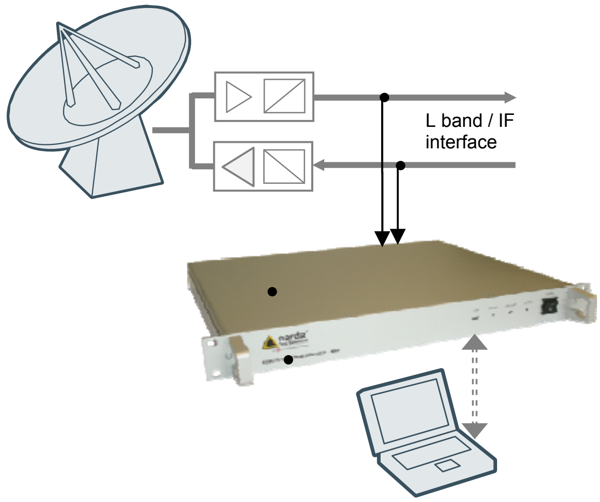



*Figure 1: Typical connection configuration in the L band / IF section of the receiving or transmitting path, with changeover switch if necessary*

Satellite communications stations usually have internal interfaces in the L band, i.e. in the frequency range 950 MHz – 2150 MHz. The spectrum of many transponders can be displayed simultaneously in this broad range. In fact, this 1.2 GHz wide frequency range often covers all the transponders in a satellite.

IF interfaces at 70 MHz or 140 MHz are less common; these each only cover the frequency band of one transponder.

The NRA can be connected in both frequency ranges, although measurements in the L band have the advantage of allowing contiguous evaluation of the entire frequency band including the gaps between the transponders.

A particular asset of the NRA is the very high number of samples (≤ 25,517) per scan, which allows a very fine frequency resolution for the measurement, which can be completed in a comparatively short time (typically 0.2 s).

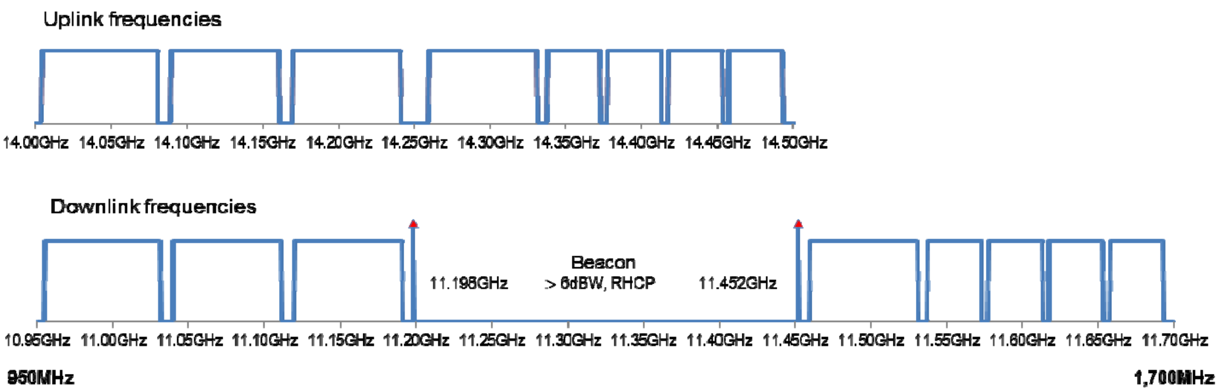



*Figure 2: INTELSAT IX spot beam frequency plan*

It should always be borne in mind when connecting a spectrum analyzer to the receiving system of a ground station that the analyzer's noise figure might affect the measured level of the system noise. Even though the NRA has a distinctly lower noise figure than most instruments on the market (< 19 dB in the L band), it is still a good idea to make an estimation of the noise level. The calculations shown in figure 3 might appear somewhat unusual, but the noise power and spectral noise power density $N_0$ are related to the noise temperature T by the equation $N_0 = k \cdot T$. The noise temperature is therefore amplified / attenuated by the system elements in exactly the same way as the signal power.

Indeed, these elements also additionally contribute to the noise temperature, which is $T = (10^{a/10} - 1)\ 290\ K$ for an attenuator and $T = (10^{NF/10} - 1)\ 290\ K$ for an active element with noise figure NF (see Annex).

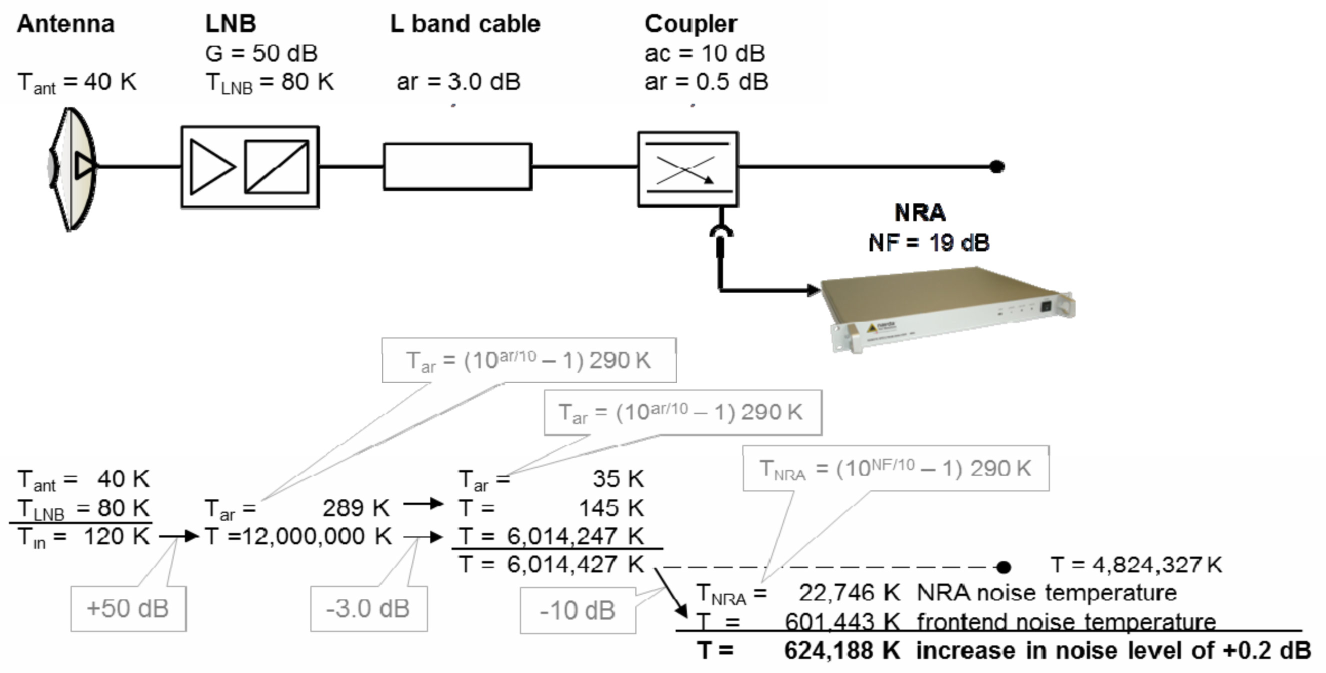



***Figure 3: Determining the noise temperature***

In the example shown, the increase in the noise level is limited to < 0.2 dB in measurements with the NRA when a 10 dB coupler is used. Many competitors' products can only achieve this by direct connection with a cable due to their higher noise figures.

## 2 Monitoring the transmitted spectrum

There are basically two different ways that the transponder is used in satellite communications:

- Operation using a single (wideband) carrier signal per transponder (e.g. for TV broadcasts)
- Multi carrier operation, where usually several stations generate the various signals, which are then fed through the transponder simultaneously. Each station can transmit one or even several carriers in this case.

Since both power and bandwidth are limited resources in satellite communications, the frequency spacing between individual transmission channels is relatively narrow as a rule in order to make maximum use of the available bandwidth.

**Measuring the transmitted signal in single carrier station operation**

Monitoring of the transmitted signal ensures that its spectrum stays within a predefined envelope. This is defined by the upper and lower limit frequencies, the power, and also by the spacing of the spectral sidebands from the central power level of the signal.

For many modulated signals, particularly those with digital phase modulation, the relative height of the spectral sidebands increases over-proportionally the more the system components are operated in the non-linear region, i.e. close to saturation. This increase in the power in the sidebands (so-called spectral regrowth) causes interference in adjacent channels. For this reason, satellite operators generally specify an offset of ≥ 26 dB in the spectral power density (measured in a bandwidth of about 4 kHz).

Monitoring this sideband offset is particularly useful for TV transmitting stations and here above all for SNG transmitters, especially if the transmission level is increased to compensate for strong attenuation in the uplink due to rainfall.

To perform this measurement, the NRA is set so that the tuning range is at least three times the signal bandwidth, to ensure that the upper and lower sidebands are displayed completely. The measurement results delivered by the NRA can be evaluated automatically using a computer connected to it to check compliance with the transmit mask by comparing actual and nominal values.

If the NRA is equipped with the “Multi Channel Power” option there is a much easier way to automatically monitor the transmit mask, which involves transfer of much less data between the NRA and the computer, and which, above all, requires almost no programming. To do this, three measurement channels are defined in such a way that the center channel just covers the nominal bandwidth of the signal and the two channels on each side of it are about 70% of this bandwidth to cover the corresponding sidebands. The NRA then determines the signal power in each of these three channels.

The frequency can be monitored at the same time as checking the level difference between the center and the sidebands of the spectrum, because if the transmit frequency is offset, the two side channels will exhibit a marked difference in levels which occurs with even a relatively small shift in the powerful signal. The result is a strong increase in the otherwise low power of the affected side channel. A frequency shift of < 1 % of the signal bandwidth increases the power of the adjacent channel by ≥ 3 dB if the sideband power is about ≥ 26 dB below the nominal signal level.

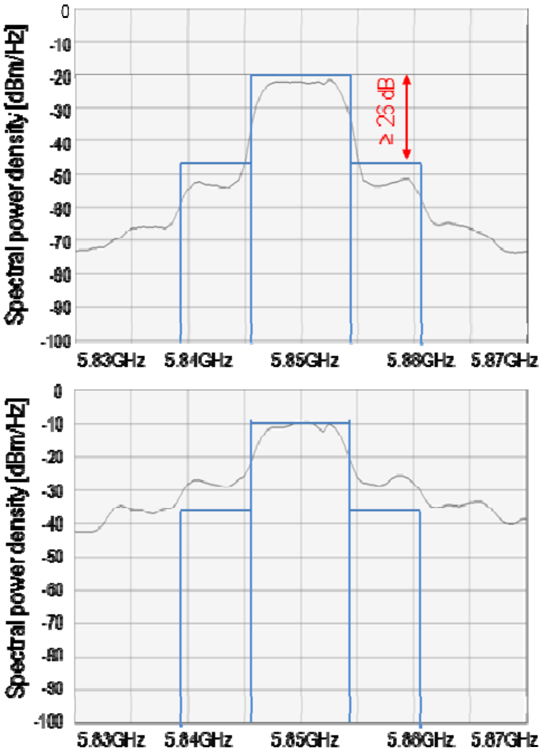



***Figure 4 top: The required sideband offset is met in this case.***

***Figure 4 bottom: The amplifier is operated with low back off in this case, i.e. the output power is close to the saturation value and the sidebands in the signal spectrum exceed the limit value.***

**Measuring the transmitted signal in multi carrier station operation**

Naturally, the transmitted signals in multi carrier operation also need to be checked to see that they comply with the specified spectrum masks. There are, however, other properties of the transmitted signal that have to be tested here.

Whereas increasing the drive level of a non-linear amplifier only results in an increase in the level of the sidebands in single carrier operation, additional intermodulation (IM) products of the signals are produced in multi carrier operation. Above all, it is the third order products $2*f_i - f_j$ and $f_i + f_j - f_k$ that mostly occur as interference within the transmission frequency band.

The most useful measurement for monitoring the power of the IM products and their offset from the actual transmitted signals is to measure the levels of the weakest signal and the largest IM product. Using the “Multi Channel Power” option of the NRA it is possible also in this case to define the frequency intervals to be measured so that the level difference can be monitored easily.

The general objective for multi carrier operation is to keep the power density of the interference down to around > 30 dB below that of the payload signals. If the power of the interference and the payload signals is measured in different bandwidths (e.g. when the interference is in a narrow gap between the payload signals), the power values must be converted to a common reference bandwidth (typically 4 kHz). To do this, the particular measurement bandwidth is divided by 4 kHz and the result in dB = (10*log(BW[kHz] / 4[kHz]) subtracted from the particular power measured in dBm.

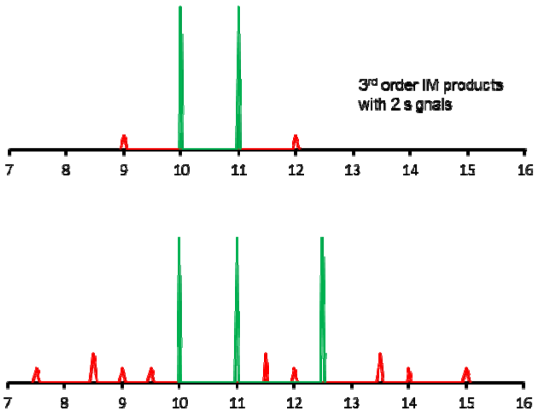



***Figure 5: 3rd order intermodulation products. Increasing the output power of the transmitting amplifier by 1 dB reduces the signal to noise ratio by 2 dB.***

## 3 Measuring and monitoring the received spectrum

Measurement of the received spectrum gives information about the quality of the received signal. In particular, the frequency range of the received signals, their power, and the individual signal to noise ratios can be determined along with a visual assessment of the spectrum.

**Signal frequency measurement**

Prerequisite to exact measurement of the receive frequencies with the NRA connected in the L band or the IF stage are correspondingly stable receiving transponders, which are usually synchronized to a precise 10 MHz reference source.

The measurement is performed over the bandwidth of a transponder (normally 36 MHz or 72 MHz) or just over the parts of the bandwidth that are of interest.

Determining the rising and falling edge of the spectrum is the easiest way to detect the lower and upper limit frequencies of the signals.

The lower limit frequency is determined when the evaluation program registers an increase in the signal level of about > 3 dB from one sample to the next and the subsequent samples are also at least on this same level.

The upper signal edge is detected on the other hand when the signal level drops by about > 3 dB from one sample to the next and the subsequent values are not larger than this. The upper limit frequency is reached when the signal level is some 3 dB above the average value of several subsequent sample values.

The accuracy of this determination of the limit frequencies depends on the instrument settings for resolution bandwidth (RBW) and averaging (Avg) or the video filter (VBW).

The frequency determination can be performed with greatly reduced data transfer between the NRA and the evaluating computer using the “Multi Channel Power” option as follows: A narrow measurement channel that directly adjoins the channel with the signal bandwidth in the center is defined on both sides of the signal. If different levels are detected in these narrow side channels, the center frequency of the signal is not in the center of the channels. The frequencies of the measurement channels are then incremented or decremented in equal steps by the attached computer until approximately the same power level is measured for both the side channels.

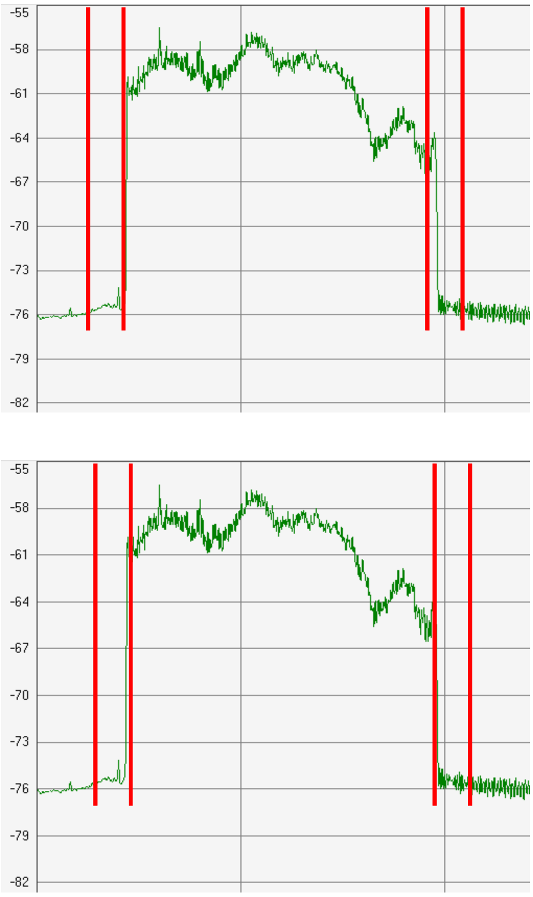



***Figure 6: Determining the frequency in MCP mode (narrow channels on both sides with approximately twice the edge width).***
***In the upper figure, the powers measured in the two sidebands are clearly different; the signal is not in the center. In the lower figure, the powers are only slightly different; the signal is in the center.***

**Determining the signal level at the transponder output**

All the power values for this measurement are referred to the normally very stable level or the effective isotropic radiated power (EIRP) of a satellite beacon.
The first step in the measurement is to locate the satellite beacon within a window of width ± 50 kHz and to measure the received power with a RBW of approximately 2 kHz.
After this, the powers of the individual receive signals are determined in "Multi Channel Power" mode. The EIRP values of the signals can then be determined by comparison with the measured beacon level and its known radiated power. As well as the EIRP value, which is given for the center of coverage (CoC), the number of dB by which the value at the receiving location is below this maximum value must also be known (CoC offset).
The advantage of this measurement method is that losses in the downlink (e.g. rain fade) are eliminated by comparing the powers.

**Beacon (INTELSAT 903)**

| | | |
|---|---|---|
| Beacon EIRP | 12.0 dBW | Polarization RHCP |
| Beacon frequency | 11,452 MHz | |
| Downlink attenuation | 205.7 dB | |
| Receive loss due to polarization mismatch | 3.0 dB | |
| Offset from CoC (center of coverage) | 1.5 dB | |

**SNG receive system**

| | | |
|---|---|---|
| Antenna gain 1.2 m | 41.0 dBi | |
| Noise temperature cs (clear sky) | 150 K | |
| Rain attenuation 1.5 dB | | 85 K |
| System figure of merit G/T | 19.2 dB/K | 17.3 dB/K |

**$C/N_0$ for Clear Sky**

$EIRP - \Delta G + G/T - L - k$ = 12,0 - 3,0 - 1,5 + 19,2 - 205,7 + 228,6 [dBHz]

$C/N_0$ cs 49.7 dBHz

**$C/N_0$ for 1.5 dB rain fade**

$EIRP - \Delta G + G/T - L - a_r - k$ = 12,0 -3,0 - 1,5 + 17,3 - 205,7 -1,5 + 228,6 [dBHz]

$C/N_{0\ 1.5dB}$ 46.2 dBHz

**S/N in RBW**

| Resolution Bandwidth (RBW) | | 5 kHz | 2 kHz | 1 kHz |
|---|---|---|---|---|
| | | 37 dBHz | 33 dBHz | 30 dBHz |
| S/N cs | | 12.7 dB | 16.7 dB | 19.7 dB |
| $S/N_{1.5dB}$ | | 9.2 dB | 13.2 dB | 16.2 dB |
| Resulting measurement error | for cs | ±0.23 dB | ±0.09 dB | ±0.05 dB |
| without averaging the measured values | for 1.5dB | ±0.49 dB | ±0.20 dB | ±0.10 dB |

***Figure 7: Determining the beacon level as a reference quantity. The RBW is reduced down to the point where the beacon just fits completely within one bandwidth.***

## 4 Evaluating the received signal quality

The received signal quality is usually defined by the signal to noise power density ratio ($C/N_0$), where C is the power of the signal and $N_0$ the spectral noise power density, i.e. the noise power per Hz.
The power of the individual signals is either established by integration within the signal bandwidth using the “SPECTRUM_BI_VALUE” function of the NRA, or determined for several channels at the same time in “Multi Channel Power” mode as described above.
The noise power in the gaps between the payload signals is then also measured in the same way, by defining a measurement channel with the corresponding width. The noise power density $N_0$ is calculated by dividing the noise power measured in the particular channel by its bandwidth. The noise power density expressed in dBm/Hz is then: $N_0$[dBm/Hz] = N[dBm] – 10*log($f_{max}$ – $f_{min}$)[dBHz].
It is best to define narrow channels (windows) as close as possible to the payload signals for measuring the noise power because it is actually the value of the noise within the signal bandwidth that determines the signal quality.
Since a spectrum analyzer always measures the sum of the power components (C + N) in the channels, the value (C + N)/N [dB] is shown in the display as the difference between the signal and the noise. The following conversion is then required to obtain the value C/N [dB] or $E_s/N_0$ [dB] (where $E_s$ is the energy per symbol):

$$\frac{C}{N}[\mathrm{dB}] = 10 \cdot \log\left(10^{\frac{(C+N)/N[\mathrm{dB}]}{10}} - 1\right) = \frac{E_s}{N_0}$$

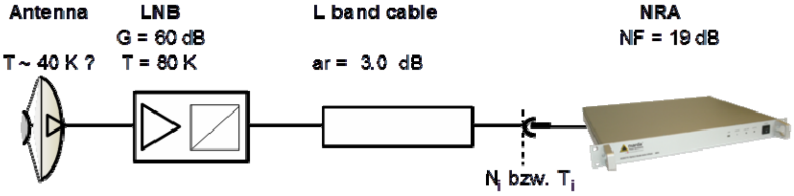
It is important here that the bandwidth in which (C + N) is measured roughly corresponds with the 3 dB bandwidth of the signal.

## 5 Determining the receive system figure of merit (G/T)

The receive system figure of merit (gain to noise temperature ratio, G/T) is critical for the receiving quality of a station (see explanation in the Annex). It is calculated as the ratio of the antenna gain to the system noise temperature ($T_{Ant}$ + $T_{LNB}$) referred to the preamplifier input. When calculating in dB, the system noise temperature is subtracted from the antenna gain (G/T)[dB/K] = G[dB] – T[dBK].

### System noise temperature

If the noise temperature of the preamplifier (low noise amplifier LNA or low noise block converter LNB) is known, then it is quite easy to determine the system noise temperature ($T_{Ant} + T_{LNB}$) using the setup shown below. The test setup is particularly simple if the NRA is equipped with the “LNB Control” option, as no other instruments are needed.
Here, the first measurement is made by moving the antenna away from the satellite keeping the elevation constant until no signal is received from the satellite that would affect the measurement of $N_1$ ($N_1$ is the noise power measured with the antenna pointing to open sky).




$$T_1 = G/a_r \cdot (T_{Ant} + T_{LNB}) + T_{NRA}$$
$$T_2 = G/a_r \cdot (T_{Absorb} + T_{LNB}) + T_{NRA}$$

The noise power $N_i = k * T_i * BW$ is measured in a constant bandwidth BW

$$\frac{N_2}{N_1} = \frac{(T_{Absorb} + T_{LNB}) + T_{NRA}/(G/a_r)}{(T_{Ant} + T_{LNB}) + T_{NRA}/(G/a_r)}$$

$$T_{Ant} + T_{LNB} = (T_{Absorb} + T_{LNB}) \cdot \frac{N_1}{N_2} + T_{NRA} \cdot \frac{a_r}{G} \cdot \left(1 - \frac{N_1}{N_2}\right)$$

For a sufficiently large value of $G/a_r$ or a small value of $T_{NRA}$

$$T_{Ant} + T_{LNB} \approx (T_{Absorb} + T_{LNB}) \cdot \frac{N_1}{N_2}$$ with the measurement error $$T_{error} = T_{NRA} \cdot \frac{a_v}{G} \cdot \left(1 - \frac{N_1}{N_2}\right)$$

**For the example system:**

| | | |
|---|---|---|
| **Antenna** / **LNB** / ***T ~ 40 K?*** / **T = 80 K** | **Cable** T = 289 K → | **NRA noise temperature** T = 22,746 K / T = 145 K |
| **T = 120 K** → | **T = 120,000,000 K** → | **T = 60,142,468 K** |
| | | **$T_1$ = 60,165,358 K** |
| **Absorber** / **LNB** / **T = 290 K** / **T = 80 K** | **Cable** T = 289 K → | **NRA noise temperature** T = 22,746 K / T = 145 K |
| **T = 370 K** → | **T = 370,000,000 K** → | **T = 185,439,276 K** |
| | | **$T_2$ = 185,462,167 K** |

$N_1$ and $T_1$ as well as $N_2$ are increased by noise of the NRA

The error in this case is, however, only $T_{error}$ = 0,03 K

*Figure 8: Determining the system noise ($T_{Ant} + T_{LNB}$)*

For the second measurement, the antenna feed system is screened completely with absorber material. The effectiveness of this can be verified first if necessary by checking that the signals are completely swamped by noise when the antenna is aligned with the satellite. Using the same settings of the NRA, the power $N_2$ and (if increased accuracy is required) also the temperature $T_{Absorb}$ are now measured. Neither the gain G of the LNB nor the cable loss $a_v$ need to be known for this measurement, since both of these are only in the second summand of the formula which can be ignored, resulting in an error $T_{error}$. This is where the advantage of the considerably lower noise figure of the NRA becomes clear, because this is directly included in the error as a result of $T_{NRA} = (10^{(NF[dB]/10)} - 1)*290[K]$.

If the noise temperature of the preamplifier $T_{LNB}$ is not known when determining G/T, it can be ascertained using a similar procedure.

For this, the antenna is replaced by a noise diode which can be switched between two known noise temperatures by applying and removing a DC voltage: $T_{hot}$ when the voltage is applied and $T_{cold}$ ~ 290 K when no voltage is applied.

The same equations then apply as above, with $T_{Absorb}$ replaced by $T_{hot}$ and $T_{Ant}$ by $T_{cold}$. The equation shown opposite is the result. The summand containing $T_{NRA}$ can also mostly be ignored, at least when a low noise instrument such as the NRA is used for the measurement.

$$\frac{N_2}{N_1} = \frac{(T_{hot} + T_{LNB}) + T_{NRA}/(G/a_v)}{(T_{cold} + T_{LNB}) + T_{NRA}/(G/a_v)}$$

$$T_{LNB} = \frac{T_{hot} \cdot N_1/N_2 - T_{cold}}{(1 - N_1/N_2)} + T_{NRA} \cdot \frac{a_v}{G}$$

***Determining the preamplifier noise temperature***

**Antenna gain**

If the antenna gain is not known, it can also be determined with a measurement using the NRA. For this, the antenna is aligned with a satellite and the beacon level measured with the NRA. The antenna is then first moved away in the azimuth direction until the level drops by first 3 dB and then 10 dB. The corresponding angle values are recorded. After this, the antenna is first moved back to the satellite position and then the angles in the opposite direction are recorded for which the level drops by 3 dB and 10 dB. The corresponding angles moving the antenna in the elevation direction are determined in the same way.

If the angle values of the antenna as well as the measurement values of the NRA are recorded synchronously, evaluation is particularly simple and accurate using the formula opposite.

The feed system losses (a few tenths of a dB) then need to be deducted from the gain determined from the diagram as a result of the directivity of the antenna in order to obtain the effective gain of the antenna referred to the LNB input.

$G = 31.000/(\Delta\varphi_{az} \cdot \Delta\varphi_{el})$ $\Delta\varphi$ is the 3 dB beam width

$G = 44{,}9\ [dB] - 10 \cdot \log(\Delta\varphi_{az}[°]) - 10 \cdot \log(\Delta\varphi_{el}[°])$

$G = 91.000/(\Delta\varphi_{az} \cdot \Delta\varphi_{el})$ $\Delta\varphi$ is the 10 dB beam width

$G = 49{,}6\ [dB] - 10 \cdot \log(\Delta\varphi_{az}[°]) - 10 \cdot \log(\Delta\varphi_{el}[°])$

***Determining the antenna gain from measurement of the beam width***

## 6 Determining the atmospheric attenuation from the received signal quality

Precise determination of the atmospheric attenuation is done with the aid of a radiometer, which for calibration has a switch in front of the preamplifier (LNB) that can connect it through to either the receiving antenna or the switchable reference signal source with the known noise temperatures $T_{hot}$ and $T_{cold}$.
The following method for estimating the atmospheric attenuation from the signal to noise ratio of the satellite beacon is much simpler.
In the following example, the measured beacon level in rain is 2.9 dB less than the value in clear sky. That this reduction in level is not due to a reduction in the beacon transmit level (EIRP) can be easily verified by the increase in the noise temperature or noise power density $N_0 = k*T$.

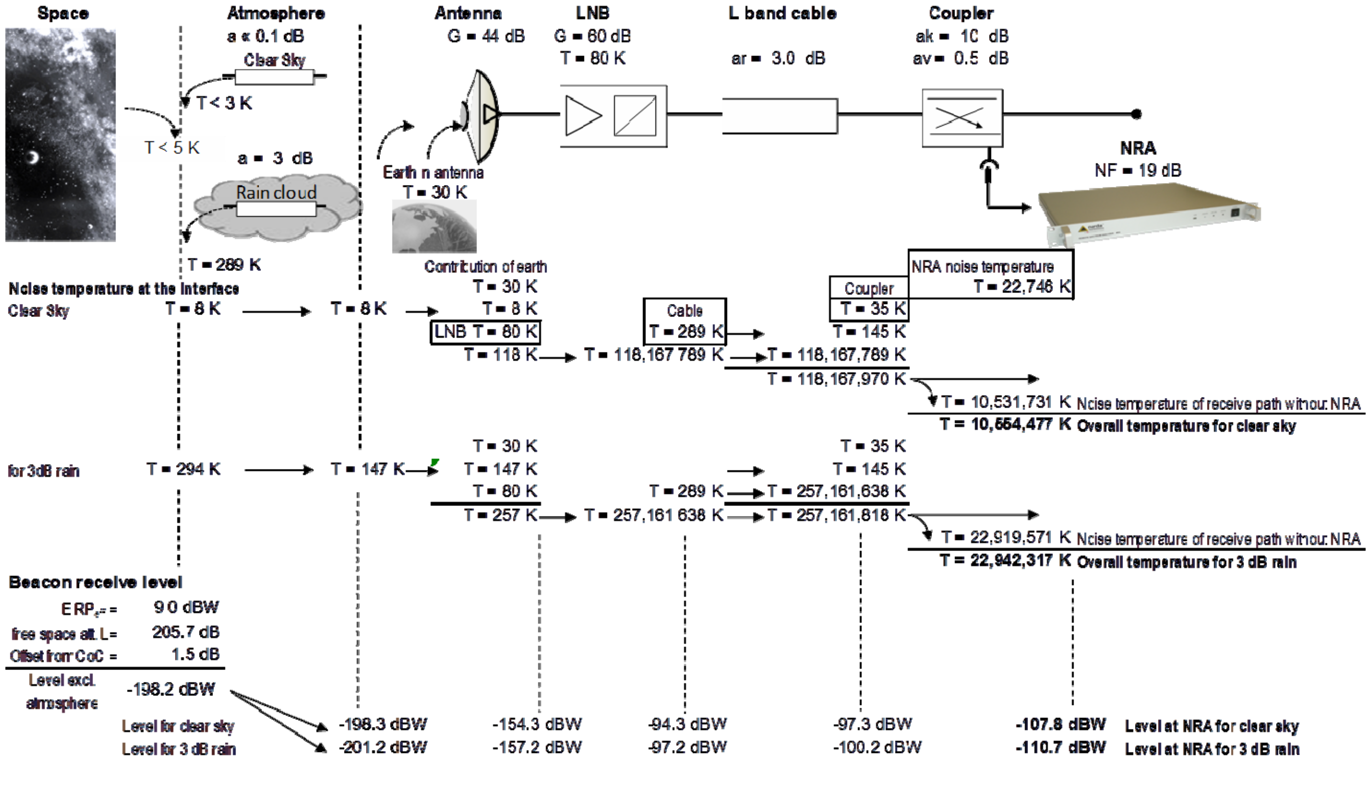



*Figure 9: Determining the atmospheric attenuation by measuring the reduction in beacon level when the noise is increased simultaneously*

In general, the receive system noise temperature is known from the receive system figure of merit G/T for clear sky and the antenna gain G (T = 118 K in the example). Comparing the noise power density for clear sky with that for rain gives a ratio of 22.942/10.554 = 2.17. A correspondingly increased noise temperature of the receiving system T = 118*2,17 K = 257 K is therefore measured when it is raining.

The noise temperature is thus increased by 139 K due to the rain. The rain fade can be determined quite accurately using the relationship: a = -10*log(1-ΔT/290 K) which gives:

a = -10*log(1-139 K/290 K) = 2.9 dB.

The calculation above shows something that is often neglected when considering the system: Atmospheric attenuation causes **both** a reduction in the level of the received signal **as well as** an increase in the noise of the receiving system. This means that atmospheric attenuation results in a two-fold reduction in the received signal quality.

If the values of the beacon receive level and the clear sky noise power density are saved on an attached computer, it is very easy to determine the atmospheric attenuation of the downlink using the method described above.

## 7 Time domain measurements with the NRA (Scope mode)

Several interesting measurements can be made on the signals with very high time resolution using the optionally available Scope mode of the NRA. These measurements are useful among other things for investigating pulsed payload and interference signals. Such signals are used in satellite communications for time multiplex systems, i.e. in communications networks where the individual stations transmit one after the other in time. This is the case in TDMA systems (time division multiple access), where each station has a transmit timeslot. Figures 10 and 11 illustrate such TDMA signals.

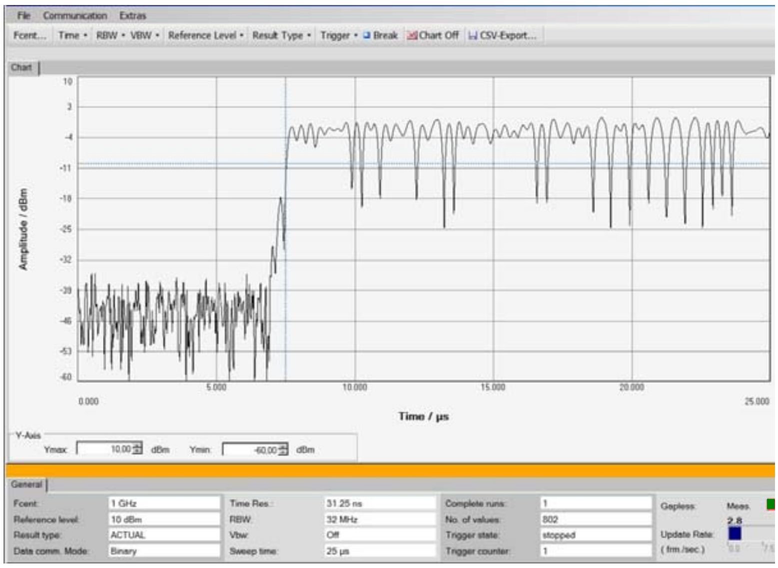



*Figure 10: Rising edge of a TDMA signal (rising edge duration approx. 0.5 µs, frequency 1 GHz, symbol rate 3 Msym/s)*

As well as the display of the signal amplitude shown in figure 10, which can be made with a time resolution of ≥ 31 ns, it is also possible to display the complex voltage of the signal as an I / Q diagram (I = in phase, Q = quadrature phase) and exported for further processing if necessary, allowing further assessment of the quality.

Figure 11 shows both the I and Q components versus time as well as a so-called constellation diagram of the pulsed signal (after a simple evaluation in Excel).

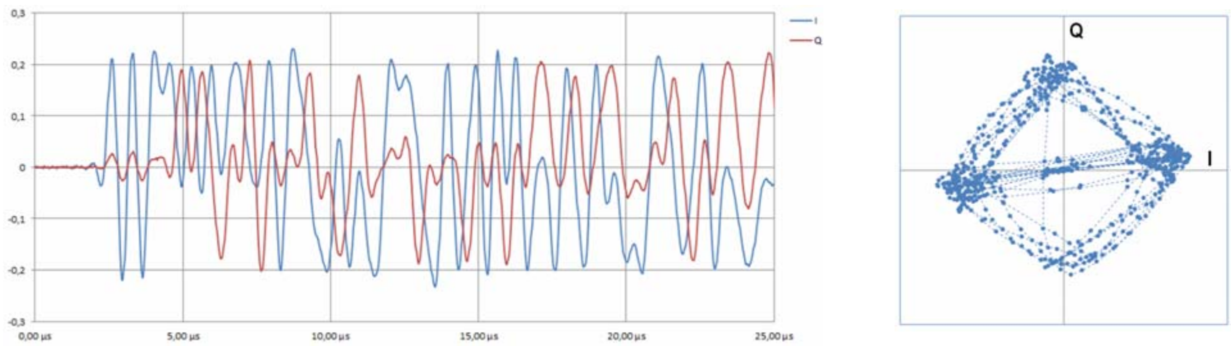



***Figure 11: TDMA signal displayed as a complex voltage with I and Q components and as a "constellation diagram".***
***In the latter, the in-phase (I) components are shown parallel to the X axis and the quadrature phase (Q) components parallel to the Y axis. The diagram shows that the signal is QPSK modulated (4 cluster points as the corners of a square).***
***Since the sampling rate of the NRA is considerably higher than the symbol rate, intermediate values are seen between one corner and another, i.e. the transition from one symbol to the next.***

## Information, formulas and abbreviations

- The NRA range of spectrum analyzers from Narda is distinguished by its lower intrinsic noise compared with other devices.
- It is a good idea to check the noise power level when making measurements on receiving systems.
- The easiest way to do this is by means of a noise temperature calculation, since noise power and temperature are related by the well-known Boltzmann equation.
- In a cascade of system elements, the noise temperature is amplified or attenuated by the individual elements just like the signal power. However, the intrinsic noise at the input of each element is added to the noise temperature of the output of the preceding element.

| | |
|---|---|
| $a_r$ [dB] | Attenuation loss of a resistive passive system component (= noise figure) |
| $a_c$[dB] | Coupling attenuation (divisor, noiseless) |
| G [dB] | Gain factor of an active system component |
| N = k*T*BW [dBm] | Noise power in the bandwidth BW |
| $N_0$ = k*T [dBm/Hz] | Spectral noise power density |
| k = -198.6 [dBm/(Hz*K)] | Boltzmann's constant |
| T [K] = $(10^{NF[dB]/10} - 1)$*290 [K] | Noise temperature of a system component with noise figure NF |
| T [K] = $(10^{a[dB]/10} - 1)$*290 [K] | Noise temperature of an attenuator with attenuation a |
| EIRP = P [dBW] +G [dB] | Effective isotropic radiated power with output power P and antenna gain G |
| $C/N_0$ [dBHz] = EIRP [dBW] + (G/T) [dB/K] – L [dB] – {k [dBW/Hz*K]} | Signal to noise power density ratio of the received signal |

$(G/T)$ [dB/K] = G [dB] – {T [K]}

Receiving system figure of merit, where T is the system noise temperature, which is composed from $T_{Ant} + T_{LNB}$
If the system is poorly configured, i.e. the subsequent stages in the receive path make a significant contribution to the noise, they must also be taken into account in the system noise temperature.

L [dB] = $20*\log(4\pi*r/\lambda)$ Free space attenuation of the signal with wavelength $\lambda$ and distance r between transmitter and receiver

$E_b/N_0$ [dB] = $C/N_0$ [dBHz] – {$R_b$ [dB bit/s]}

"Energy per bit / noise density" referred to noise power density, defines the bit error rate when receiving digitally modulated signals. $R_b$ is the information bit rate (payload rate excluding any redundant bits added for error correction)

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