



International Journal of Research Publication and Reviews

Journal Homepage: www.ijrpr.com ISSN 2582-7421

Design and Analysis of Noise in Antenna Communication Systems

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ABSTRACT

Noise limits antenna-based communication performance through environmental radiation, passive-feed losses, and receiver-generated noise. This paper presents an analytical framework for estimating these contributions and relating them to receiver sensitivity and link performance. The method combines antenna noise temperature, the thermal noise relation $P_n = kTB$, receiver noise figure, equivalent noise temperature, passive-feed loss, and the Friis cascade equation. It distinguishes broadband thermal noise from man-made interference, which may be narrowband, impulsive, or time-varying. A reproducible calculation workflow is outlined with consistent units, reference planes, input provenance, and verification checks. The numerical trends discussed are illustrative rather than experimental: no physical measurement dataset or experimentally verified improvement was supplied. A proposed measurement plan using calibrated references, repeat observations, and environmental metadata is provided for future site-specific validation.

Keywords: antenna noise temperature, noise figure, receiver sensitivity, thermal noise, feed loss, system noise temperature

1. Introduction

A receiving antenna responds to the electromagnetic environment as well as to the wanted signal. Depending on frequency, pointing direction, and installation, received energy can include sky and galactic radiation, atmospheric emission, ground radiation, and man-made emissions from nearby electronic or industrial equipment. The feed network and receiver add further noise. These contributions are particularly important for weak-signal applications such as satellite links, remote sensing, telemetry, and terrestrial links operating near coverage limits.

A single assumed noise value can conceal dependencies on antenna pointing, sidelobes, weather, Feedline loss, and receiver configuration. An increase in a spectrum trace may indicate broadband noise, a discrete interferer, receiver overload, or changed measurement settings. Reliable diagnosis therefore requires source classification and a consistent noise budget.

This paper organizes an engineering method for estimating antenna and receiver noise. Its contribution is to make assumptions explicit, separate analytical examples from observations, and specify checks for later application to a real installation. The objectives are to classify noise sources; relate antenna temperature, receiver noise figure, and system temperature; account for feed loss at a defined reference plane; and connect the budget to noise power, carrier-to-noise ratio (C/N), and gain-to-noise-temperature ratio (G/T).

2. Methodology

2.1 Noise sources in antenna systems

Natural sources include atmospheric emission, the Sun, the Galaxy, and other celestial objects. Their importance depends on frequency, angular extent, antenna beam direction, and observing conditions. At microwave frequencies, atmospheric gases and cloud or rain conditions can affect attenuation and apparent brightness temperature. ITU-R P.372 addresses radio noise, while P.676 and P.618 provide relevant atmospheric and Earth-space propagation methods; the applicable revisions should be checked for a specific design.

Man-made noise and interference can arise from switch-mode power supplies, electric drives, digital electronics, ignition systems, poorly shielded cables, and intentional transmitters. Disturbances may be periodic, impulsive, narrowband, or burst-like. Strong unwanted signals may also cause blocking or intermodulation rather than merely raising a broadband noise floor. Measurement records should include antenna orientation, nearby equipment state, frequency span, resolution bandwidth, detector, and averaging settings.

2.2 Antenna noise temperature

The antenna power pattern weights noise arriving from different directions. A narrow main beam may reduce coupling to some sources, but sidelobes and backlobes can admit radiation from the ground, structures, or nearby emitters. In a simplified brightness-temperature model, antenna noise temperature is:

$$T_A = [\int_{4\pi} T_B(\Omega) G(\Omega) d\Omega] / [\int_{4\pi} G(\Omega) d\Omega] \quad (1)$$

Here, $T_B(\Omega)$ is scene brightness temperature and $G(\Omega)$ is antenna power gain, using consistent pattern normalization. A practical numerical implementation divides the scene into angular cells, weights each cell by gain and solid angle, and sums the contributions. Missing pattern coverage should be flagged rather than silently treated as zero.

2.3 Thermal noise and receiver noise figure

For a matched source at absolute temperature T over noise bandwidth B , available thermal-noise power is:

$$P_n = kTB, \quad k = 1.380649 \times 10^{-23} \text{ J/K} \quad (2)$$

At $T_0 = 290 \text{ K}$, the approximate noise density is -174 dBm/Hz . Integrated noise increases by 10 dB when bandwidth increases by a factor of ten, assuming constant spectral density. For a non-rectangular filter, equivalent noise bandwidth should be used.

Noise factor F is the input signal-to-noise ratio divided by the output signal-to-noise ratio under specified reference conditions. Noise figure is $NF = 10 \log_{10}(F)$, and equivalent receiver noise temperature is:

$$T_e = (F - 1)T_0, \quad NF = 10 \log_{10}(F) \quad (3)$$

The conversion from decibels to a linear factor must be performed before calculating T_e . Receiver specifications should identify the reference temperature and measurement conditions.

2.4 Feed loss and cascaded stages

A passive component with linear loss $L \geq 1$ at physical temperature T_p contributes an input-referred equivalent noise temperature $T_p(L - 1)$. If a feed at approximately T_0 precedes a receiver with equivalent noise temperature T_R , a simplified input-referred expression is:

$$T_{\text{sys}} = T_A + T_0(L - 1) + LT_R \quad (4)$$

This expression depends on the selected reference plane and assumes a matched passive feed at the stated temperature. For multiple stages, each contribution must be transformed consistently. The Friis relation for cascaded noise factors is:

$$F_{\text{total}} = F_1 + (F_2 - 1)/G_1 + (F_3 - 1)/(G_1 G_2) + \dots \quad (5)$$

Here, G_i and F_i are linear power gain and noise factor. The first active stage has disproportionate influence, while loss before that stage directly worsens the input-referred budget. Gain, linearity, filtering, stability, and overload tolerance must also be considered.

3. Modeling And Analysis

3.1 Communication performance measures

Noise power at a stated reference plane is $kT_{\text{sys}}B$. If carrier power remains fixed, an increase in system noise temperature reduces C/N. Antenna figure of merit is commonly expressed as $G/T = G_{\text{dBi}} - 10 \log_{10}(T_{\text{sys}})$, in dB/K when gain is in dBi and temperature is in Kelvin. Receiver sensitivity also depends on modulation, coding, implementation loss, and the required error-rate threshold; thermal noise alone does not determine the minimum usable signal.

3.2 Proposed calculation workflow

First, validate units, frequency range, bandwidth, and reference planes. Estimate antenna temperature from a scene model and antenna pattern, or label a simplified value as assumed. Convert insertion loss to linear form using $L = 10^{(L_{\text{dB}}/10)}$, avoiding double-counting mismatch and insertion loss. Convert receiver noise figure to a linear noise factor and equivalent temperature, or use a documented receiver temperature. Combine antenna, passive-feed, and receiver contributions at a common reference plane, then calculate $kT_{\text{sys}}B$ and any required C/N or G/T metric. Save inputs, intermediate results, assumptions, uncertainty notes, and software/version information.

3.3 Verification checks

The workflow should be tested against limiting cases. With zero feed loss, the feed-added temperature should approach zero. Increasing feed loss should not improve sensitivity when other conditions are fixed. Reducing receiver noise should not drive total system temperature below the external and passive-network contribution. Results should be flagged if required inputs are missing, the pattern does not cover the intended scene, or a discrete interferer is treated as white Gaussian noise without justification.

4. Results And Discussion

The source study provides an analytical framework but no physical measurement dataset. Therefore, the following discussion reports relationships and expected trends, not experimental findings. Numerical values should not be interpreted as measurements or as a validated performance improvement.

4.1 Bandwidth dependence

From $P_n = kT_{\text{sys}}B$, noise power is proportional to bandwidth when temperature and spectral density remain constant. A tenfold increase in bandwidth adds 10 dB to integrated noise power. Narrowing bandwidth may improve the noise contribution to C/N, but the usable bandwidth must still accommodate the signal spectrum and required modulation.

4.2 Feed-loss and receiver-noise effects

Equation (4) shows two penalties from a lossy feed before the receiver: the feed adds thermal noise and scales the receiver contribution when referred to the antenna input. Reducing cable and connector loss, or locating the first low-noise amplifier closer to the antenna, is therefore a potential design improvement. The benefit must be balanced against weatherproofing, power delivery, stability, and overload risk. A lower receiver noise figure is most valuable when receiver-added noise is a substantial part of the total; if environmental noise dominates, the gain from reducing receiver noise may be modest.

4.3 Mitigation and validation

If antenna temperature is dominated by ground pickup or a local emitter, changing antenna position, pointing, or sidelobe response may be more effective than replacing the receiver. If feed loss dominates, improving the feed or moving the first amplifier may help. If discrete interference is present, source identification, filtering, shielding, cable bonding, and spatial separation may be more appropriate than a thermal-noise-only remedy.

A future measurement campaign should use a calibrated noise source or reference termination, record receiver settings and calibration date, and repeat antenna-connected and baseline measurements under comparable settings. Antenna pointing, polarization, weather, nearby equipment state, frequency span, resolution bandwidth, video bandwidth, detector, and averaging should be logged. Repeated observations and uncertainty estimates are required before a mitigation is described as effective. No such validation is claimed here.

5. Conclusion

This paper presents a structured approach to analyzing noise in antenna communication systems by combining pattern-weighted antenna noise temperature, thermal noise, passive-feed loss, and receiver noise figure at consistent reference planes. The method connects these quantities to system noise temperature and communication metrics while distinguishing analytical scenarios from physical measurements. Its practical value lies in traceability: explicit assumptions, unit checks, source classification, and repeatable calculation steps support meaningful design comparisons. Future work should implement the workflow in MATLAB or Python, use measured antenna patterns and site-specific environmental data, and validate predictions through calibrated, repeatable measurements.

Acknowledgements

The author acknowledges the academic guidance and institutional context described in the source paper. Please revise this statement to reflect support actually received.

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