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Abstract

An active antenna consists of a passive antenna followed by and combined with a low noise pre-amplifier. Because the combination cannot be separated for measurements it is best considered, with relevant parameters, as a single entity.

This White Paper gives a brief review of receiver noise theory when the receiver is fed from a passive or an active UHF antenna. It shows how an active antenna could be specified in a simple way in terms of total gain and noise temperature. This enables system noise parameters for an active antenna to be readily calculated and compared to the familiar passive antenna.

Key words:, Noise-figure, Noise-temperature, G/T

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Authorisation of the Chief Scientist is required for publication.

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Specifying UHF Active Antennas and Calculating System Performance

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1 Introduction

An active antenna consists of a passive antenna followed by and combined with a low noise pre-amplifier. Because the combination cannot be separated for measurements it is best considered, with relevant parameters, as a single entity. This White Paper gives a brief review of receiver noise theory when the receiver is fed from a passive or an active UHF antenna. It shows how an active antenna could be specified in a simple and useful way. This enables system noise parameters for an active antenna to be readily calculated and compared to the familiar passive antenna.

2 System Noise

The usual way of specifying a receiving system noise performance is to refer and sum all sources of noise power at the receiver input. There are two sources of noise:

a) Noise from the source = kT_sB.

b) Noise from the receiver. When this is expressed as an excess noise contribution at the receiver input, this is $= (F-1)kT_oB)$. Alternatively, $(F-1)T_o$ can be considered as the receiver equivalent noise temperature $T_e = (F-1)T_o$.

Where: T_s = the source noise temperature in kelvin (K).
T_o = the reference temperature (290 K).
T_e = the receiver equivalent noise temperature in kelvin (K).
k = Boltzmann's constant = 1.38×10^{-23} joule/deg.
B = system noise bandwidth in (Hz). (7.61×10^6 Hz for DVB-T).
F = the receiver noise figure (linear ratio).

Note, F is defined and measured with a source at the reference temperature (T_o = 290 K).

The total noise power (Pn) at the receiver input is obtained by adding these two contributions:

$$Pn = (T_s + (F-1)T_o)kB \quad \text{(watts)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Alternatively

$$Pn = (T_s + T_e)kB \quad \text{(watts)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

3 Passive antenna noise and system performance.

The noise temperature of a passive UHF antenna pointing at the horizon is generally taken to be 290 K[1]. This is the same as the reference temperature at which receiver noise figure measurements are made and thus makes the calculation of the total noise at a UHF receiver input very simple.

[1] At lower frequencies the noise temperature increases. At higher frequencies and for antennas pointing skywards the noise temperature can be much lower.

Because $T_s = T_o$ equation (1) simplifies to

$$Pn = kT_oBF \quad \text{(watts)} \quad ....\ (3)$$

It is usual to express units and parameters in logarithmic form, so for DVB-T:

$$Pn\ (\text{dBm}) = -105.2 + F$$

Where F = 10 log F (the receiver noise figure in dB).

4 Passive antenna signal output.

The relationship between field strength and power delivered into a matched load [1] is given by:

$$Psig = E^2\ G_a\ \lambda^2 / 480\ \pi^2 \quad \text{(watts)} \quad ....\ (4)$$

Where: E is field strength in V/m
G_a is antenna gain relative to an isotropic antenna[2]
λ is wavelength in m

Sometimes a loss factor for the downlead is also included in the above expression. Alternatively, the downlead loss can be included as an increase to the receiver noise figure. For a downlead at 270 K the loss (L) dB can be accounted for by increasing the receiver noise figure by (L) dB.[3]

5 Active antenna

An active antenna is no more than a passive antenna followed by and combined with a low noise pre-amplifier. The amplifier d.c. feed is usually via the active antenna output port. Because the RF combination cannot be separated for measurements it is best considered, with relevant parameters, as a single entity[4]. The performance could then be compared with that of a passive antenna and an equivalent passive gain determined.

The relevant parameters will now be analysed.

6 Active antenna signal output

This will be as (3) but increased by the pre-amplifier gain (G_{amp}). So we can write:

$$Psig = E^2\ G_a\ G_{amp}\ \lambda^2 / 480\ \pi^2 \quad ....(5)$$

Example values for G_a and G_{amp} are 3 (5 dB_i) and 5 (7 dB). In practice it may only be possible, but also desirable, to measure[5] the combined or total gain ($G_a\ G_{amp}$). Given this total gain (G_t), which for our example is 12 dB_i , the gain of an equivalent passive antenna can be calculated if the noise temperature of the active antenna is also known.

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[2] It is usual to express UHF antenna gain relative to a dipole (dB_d), where; 0 dB_d = 2.15 dB_i .
[3] Purists may want to make a minuscule correction for temperatures other than 290 K.
[4] Any effect due to mismatch between the passive antenna and pre-amplifier parts of the active antenna is included.
[5] Measurement by comparison with a calibrated antenna is not a trivial exercise.

7 Active antenna noise

First we have to consider the noise contributions at the pre-amplifier input.
The noise here can be found using (1):

$$Pn = (T_s + (F_p - 1)T_o)kB$$

Where: T_s is the source noise temperature
T_o is the reference temperature
F_p is the noise figure of the pre-amp.

The source here is the passive antenna part, and for UHF we can assume $T_s = T_o$.
So this simplifies to:

$$Pn = kT_oBF_p$$

The noise power into a matched load at the pre-amplifier output, which is of course also the active antenna output, is:

$$Pn_{out} = kT_oBF_pG_{amp} \quad \text{....................(6)}$$

If we compare (6) with the noise output from a passive UHF antenna, which is kT_oB, we see that it has increased by a factor of F_pG_{amp}. If we now consider the active antenna to be a single entity[6], then the noise temperature of the source (T_s) is $T_oF_pG_{amp}$.

Example values for F_p and G_{amp} are 2 (3 dB) and 5 (7 dB) respectively.
Thus an example value for the noise temperature of an active antenna is:

$$290.2.5 = 2900 \text{ K}$$

The noise temperature of an active antenna may be measured by using a substitution method and a calibrated noise or noise-like source. Details are given in Appendix 1.

8 'G/T' Figure of merit (m)

One method of specifying overall performance is the idea of a 'gain to temperature ratio' or 'G/T'. Such methods are common for satellite receiving systems where noise temperature is used in preference to noise figure.

$$m\ (dB_i / K) = 10 \log (G/T) = G\ (dB_i) - 10 \log (T_{sys}) \quad \text{..................... (7)}$$

Where: m is the figure of merit in dB_i / K.
G is the antenna gain in dB_i.
T_{sys} is the noise temperature of the total system in kelvin (K).

Note: The noise temperature of the total system is $T_s + T_e$.

[6] This is essential because actual values for F_p and G_{amp} could be a function of the match at the pre-amplifier input. The important parameter is T_s which is measured directly.

9 System performance with active and passive antennas

The system performance with active and passive antennas can be specified in terms of a figure of merit for each system. Engineers familiar with terrestrial systems may prefer the concept of an active antenna being specified in terms of an equivalent passive antenna. From (7) we can write:

$$G_{eq} - 10 \log (T_p) = G_t - 10 \log (T_a)$$

$$G_{eq} = G_t + 10 \log (T_p / T_a) \quad .... \quad (8)$$

Where: G_{eq} is the gain of an equivalent passive antenna in dB_i.
T_p is the noise temperature of the total equivalent passive system in K.
G_t is the total gain of an active antenna in dB_i.
T_a is the noise temperature of the total active system in K.

If a receiver with a noise figure F of 6.3 (F = 8 dB) is to be used, then the receiver equivalent noise temperature $T_e = (F-1)T_o$ is calculated to be 1540 K.
For the active antenna system our example value for T_s = 2900 K. Therefore the noise temperature of the total active system $T_a = T_s + T_e$ = 4440 K.
For the equivalent passive antenna system $T_s = T_o$ = 290 K. Therefore the noise temperature of the total equivalent passive system $T_p = T_o + T_e$ = 1830 K.
Substituting the above values for T_a and T_p into (8):

$$G_{eq} = G_t - 3.8 \text{ dB}$$

Our example active antenna has a total gain G_t of 12 dB_i , therefore this is equivalent to a passive antenna with a gain of 8.1 dB_i. The difference (Δ) is approximately 4 dB.

The term 10 log (T_p / T_a) in (8) can also be considered to be the difference (Δ) in overall system performance between UHF systems using an active antenna compared to systems using a passive antenna with the same gain.

$$\Delta(\text{dB}) = 10 \times \log \frac{T_o + T_e}{T_s + T_e} \quad .... \quad (9)$$

An alternative approach to determine a value for Δ (dB) is to construct a nomograph using familiar 'terrestrial' quantities. This can be done if equation (1) is used:

$$Pn = (T_s + (F-1)T_o)kB \quad ....(1)$$

If the receiver input noise (Pn) is plotted as a function of T_s and F, with different values of T_s then a direct comparison of performance can be readily made. If we include the values of T_s that have been using previously, that is: $T_s = T_o$ = 290 K for a passive antenna and T_s = 2900 K as an example value for an active antenna, then the value for Δ, calculated above, is obtained as shown in Figure 1.

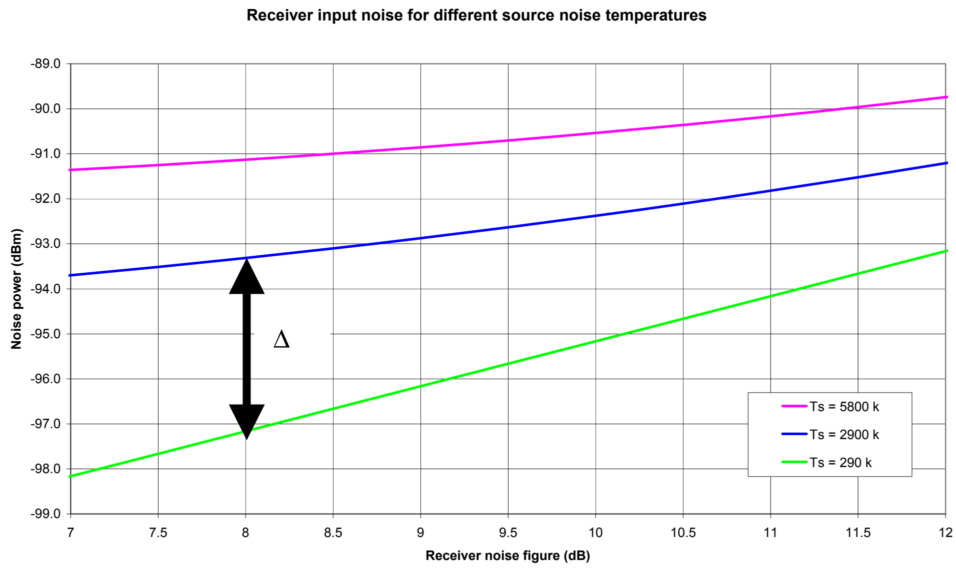

Figure 1: Receiver input noise

For a receiver noise figure of 8 dB the difference in performance (Δ) between a passive and our example active antenna is about 4 dB. The total gain of our example active antenna is 12 dB_i. Thus, this active antenna is equivalent to a passive antenna with a gain of 8 dB_i. The passive antenna part of our example active antenna has a gain of 5 dB_i[7]. So put another way, the effect of the active antenna pre-amplifier (G_{amp} = 7 dB) is to obtain an additional 3 dB of 'passive' gain.

Note that the system performance with the passive antenna is sensitive (dB for dB) to any increase in receiver noise figure. For example, if downlead loss were to be included in the calculation, this would degrade the system by the loss in dB. However, this active antenna is about one half less sensitive to any additional increase in receiver noise figure. A 3 dB increase in noise figure only degrades the performance of the system with an active antenna by about 1.5 dB.

10 Conclusions

If an active antenna is treated as a single entity and specified in terms of total gain and noise temperature, then a direct comparison (Δ) with a passive antenna can be readily made. Additional T_s curves could be included in Figure 1, such as that for Ts = 5800 K, to form a nomograph, although any calculation is not difficult.

It is difficult to determine if there is an 'optimum' design solution as different design factors may take precedence. For example, by reducing the physical size and having an active 'dipole' antenna with a total gain 12 dB_i, Ts would increase to about 5800 k and (Δ) would increase to 6 dB. So, this is equivalent to a passive antenna with a gain of 6 dB_i. For this case, the effect of the active antenna pre-amplifier is to obtain an additional 4 dB of 'passive' gain.

[7] For our example, we can assume this gain is calibrated and perfectly matched to the pre-amplifier.

11 References

[1] H.T. Friis, "A note on a simple transmission formula," *Proc. of the IRE*, Vol. 41, May 1946, pp.254-256.

12 Appendix 1

Measuring the noise temperature of an active antenna

Ideally the active antenna would be placed in an electrically quiet environment away from any structures which might affect its impedance or gain. In practice a screened room of reasonable size should suffice.

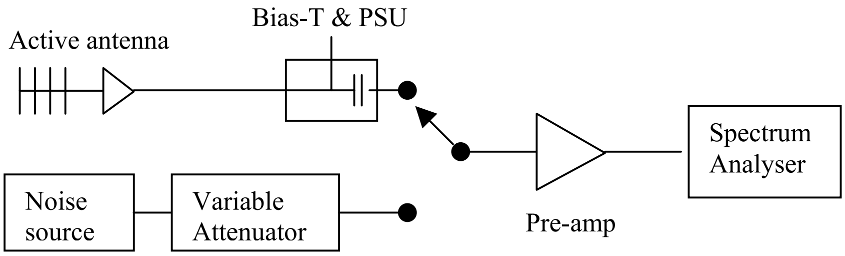

Figure 2: Test set-up

The active antenna is powered via a suitable bias-T network. Its output noise is displayed and the trace stored on the spectrum analyser. Note that the spectrum analyser will require a low-noise pre-amplifier at its input in order to ensure analyzer noise is not dominant.

The active antenna is now substituted for a calibrated noise source whose output is adjusted to be identical to that coming from the active antenna.

The noise source could be a proprietary wideband excess noise source with a calibrated excess noise ratio (ENR). Such devices are designed to measure noise figure by a 'Y factor' method. When set to 'hot' the noise output is: $(\alpha+1)kT_o$. The factor α is defined as the excess noise ratio (ENR) of the source and is often quoted in dB (=10 log α). A typical value may be 15.7 dB. Two things have to be considered:

a) The substitution noise level is to be varied with a calibrated attenuator. The noise temperature of this attenuator has to be accounted for. We will assume it to be 290 K.

b) The substitution noise level has to be expressed as a noise temperature. So some calculation is required to produce a calibration chart.

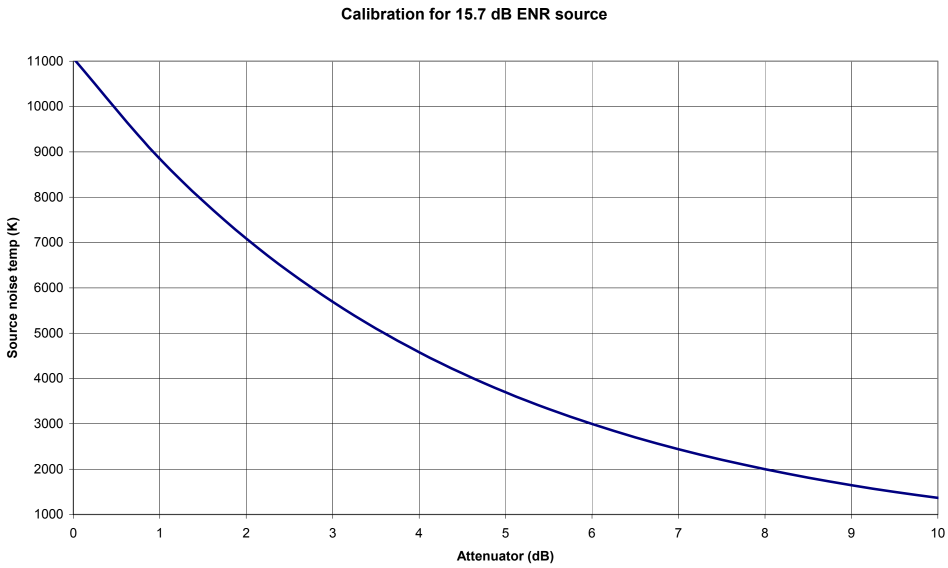

Figure 3: Calibration chart for 15.7 dB ENR source

An alternative source to use would be a noise-like signal such as DVB-T. This source is not wideband, but it can be readily calibrated, for example at –60.0 dBm, with a power meter. A greater amount of calibrated attenuation is required than would be the case if an ENR source were used. The same two considerations as above also apply and a calibration chart has to be produced.

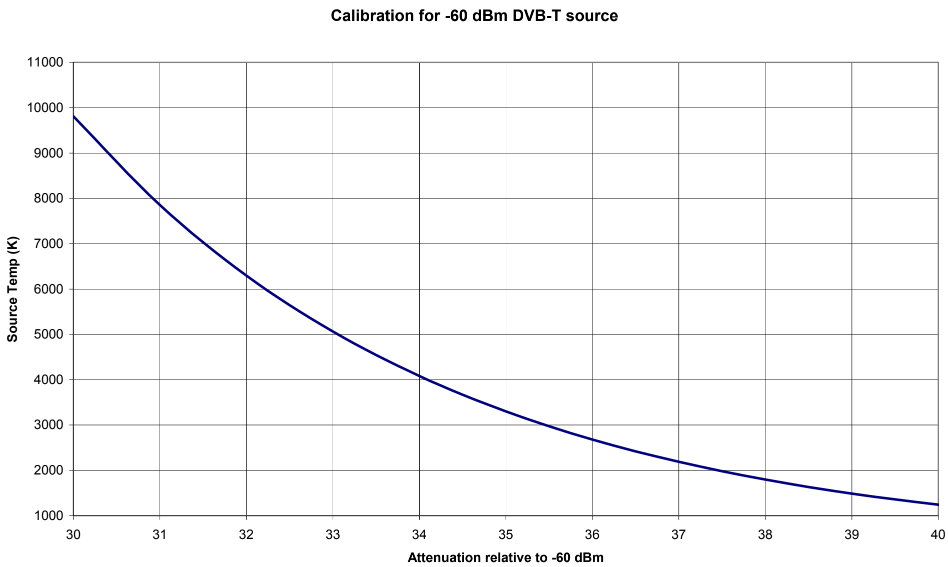

Figure 4: Calibration chart for -60 dBm DVB-T source