

Antenna Temperature, System Temperature Defined (1)

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(1) Radio Observer #20, 2/89

Readers of radio astronomy nomenclature frequently encounter terms like antenna temperature, receiver input temperature, system noise, temperature, t minimum etc. It's really important that the student of the technology completely understands the exact meaning of these terms. However, most professional articles assume that the reader knows what the writer is talking about. If any definition of these terms is indeed supplied, it usually involves a string of equations, which-in many cases-tends to confuse the reader even more.

So lets take a non mathematical look at these terms. Once the meanings are clearly understood, the mathematics involved will just become a tool to get a desired answer.

Antenna Temperature

In this study we shall consider the antenna only as a device to receive energy. There are many types and styles of receiving antennas, but they all have one thing in common. Regardless of style or configuration, they are all designed to interface -space with electronic circuitry. The entire strategy for all receiving antenna systems is to *Convert photons to electrons*. It is further noted here that all photons are discrete energy packets and their energy can be equated to a Kelvin temperature.

We begin our study with a simple half wave resonant dipole, At its precise resonant frequency, it has a so called pure *radiation resistance*, Departing to one side of resonance, it begins to look like an inductance, On the other side of resonance it begins to look like a capacitance, A shift of received signal phasing due to the above, inevitably means that received voltage and current will only be in phase at precise resonance. Therefore the antenna under discussion will have a receiving power pattern (Gaussian bandwidth) with its peak at its dimensional, pure resistance resonance.

Suppose we connect our discussion dipole to a more or less natural 50 ohm resistive load, and take it into a shielded chamber where it 'sees' nothing. Lets assume the temperature of the room and our sample is 290°k . What is the antenna temperature? To the communications engineer, there is no antenna temperature, that is to say that the physical temperature of the elements is ignored, even though physics dictates that a small noise power would be flowing in from the termination.

Ignoring the antenna element physical temperature, is based on the assumption that its physical temperature will remain essentially constant throughout an observation. We should note here that this assumption might turn out to be a shaky point of departure, and though commonly ignored, we should never forget that a physical temperature in the feed exists. If the antenna element temperature should radically change in the outside world, while undertaking an astronomical observation, the noise increase can make a large error difference. I recall a story related by a professional radio astronomy maintenance engineer who had his pants catch fire while working in the focus of a huge dish. Focused energy from the sun was the cause, and any antenna feed at the focus of this dish under the same conditions would have given interesting results.

Nevertheless, and passing on from a hair-splitting digression, the reason that a communications engineer would assume the antenna temperature as zero under these isolated room conditions, is that it is *receiving no photons*, (Referring again to paragraph one, the gathering of photons and their conversion to electrons is all we are interested in). We have therefore defined our concept of antenna temperature as being a noise power in the antenna termination *equal only to the number of photons received and their apparent Kelvin temperature energy*.

Though Karl Jansky was the discoverer of radio astronomy, it was communications engineer, ham radio operator, Grote Reber, who first understood that the slight increase in antenna termination noise power could thus be used to *Measure the apparent Kelvin temperature of very remote objects!*

Let's now take our dipole from the room to the outside world, We now point this very simple device towards a radio source. Logic tells us that we now have a minuscule antenna temperature increase, but analysis of the increase reveals that we have a somewhat complex situation, as follows:

1. Some of the antenna temperature increase is due to our desired source.
2. Due to the inherent dipole broad beam pattern, some of the increase is due to sky halo noise background. This is due to billions of stars, and clouds of hot gases, the photons from which enter the beam pattern. The quantified value of this unwanted noise is frequency dependent, but at no frequency is it less than a 2.7 K integrated blackbody photon radiation due to the primordial fireball, (figure 1)
3. We also have an antenna temperature increase due to rear lobe detection of thermal photons from the earth. (There may also be other unwanted terrestrial noise contributions, but shall assume a quiet site for this study).

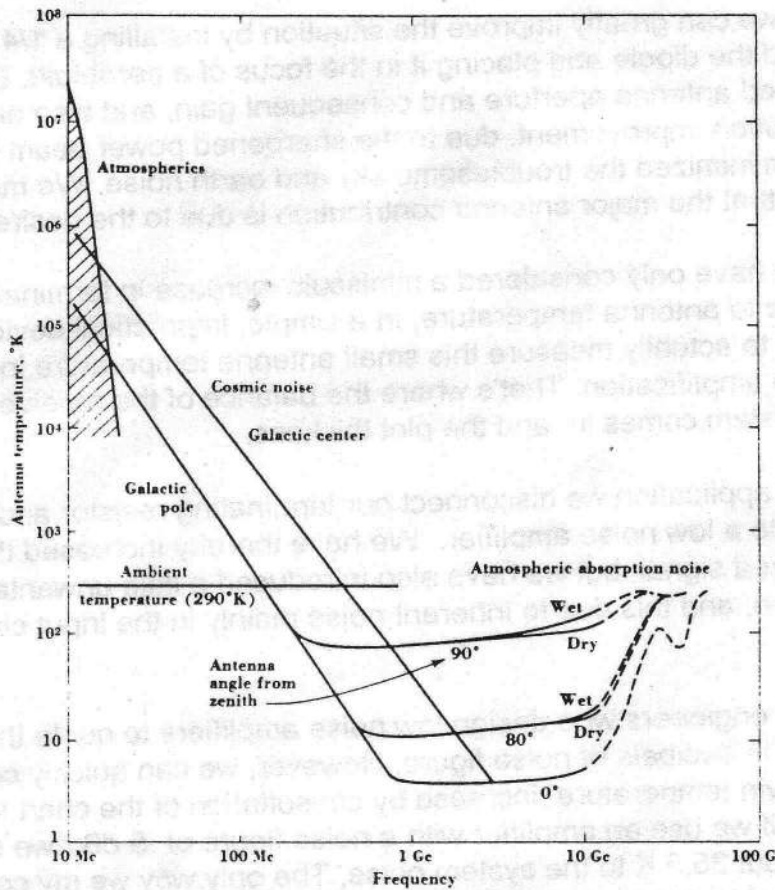


Figure 1. Sky Noise Diagram (After Kraus, Radio Observer #20, 2/89)

The above is a chart due to the work of John D. Kraus, which shows degrees K noise contribution of the sky cosmic background at all of the various frequencies considered for radio astronomy. Note that above about 1400 MHz. the cosmic background

interference falls to the 3 K fireball residual. This is one reason why SETI workers prefer observations in the so-called waterhole radio spectrum. i.e. where ground state hydrogen atoms and CH molecules emit. Another reason is that SETI workers assume that an intelligent society would know of these facts, and would choose to 'meet' around the cosmic waterhole.

Our intent in radio astronomy is to observe only the desired source. Therefore we take steps to eliminate as much of the two unwanted noise sources as possible. We should note here that nature will never permit us to disregard these factors entirely, and in any rigorous data evaluation, these two noises must be taken into account.

Nevertheless, we can greatly improve the situation by installing a $1/4$ wave reflector behind the dipole and placing it in the focus of a paraboloid. Due to greatly increased antenna aperture and consequent gain, and also due to angular resolution improvement, due to the sharpened power beam pattern, we have certainly minimized the troublesome sky and earth noise. We may now safely assume that the major antenna contribution is due to the desired source.

Up to now, we have only considered a miniscule increase in termination noise power equitable to antenna temperature, in a simple, impractical device. It would be very difficult to actually measure this small antenna temperature increase without suitable amplification. That's where the balance of the receiver amplification system comes in, and the plot thickens.

In any practical application we disconnect our terminating resistor and connect the dipole feed to a low noise amplifier. We have thereby increased the power gain of the desired signal, but we have also introduced a little unwanted noise to our consideration, and this due to inherent noise mainly in the input circuit of the amplifier.

It is common for engineers who design low noise amplifiers to quote this unwanted noise in decibels of noise figure. However, we can quickly convert this quotation to Kelvin temperature increase by consultation of the chart in figure 2. As an example, if we use an amplifier with a noise figure of .5 dB, we see that we must add about 35.5 K to the system noise. The only way we may conceivably improve the signal to noise ratio at this critical circuit juncture is to do as the professionals do, and pump out as much of this amplifier noise as is possible with a costly cryogenic unit. Without such a measure, we must be reconciled to live with it

System Noise Temperature

Happily, as we progress through the successive modular amplifier stages of the rest of the receiver, we need not continue to add in their Kelvin noise temperature contributions as simple sums. We have something very beneficial going for us, and this is *stage gain*. In any practical radio astronomy receiver, the entire system noise temperature is pretty well determined by the first three stages. (In this case perhaps by two cascaded LNA amplifiers and a gain producing L/O mixer.) The noise temperature contribution of a very high gain IF.