Determinants of receiver sensitivity –

What are the keys to better weak signal receive performance?

One of the greatest advances we have seen in the last few years has been the application of Digital Signal Processing. Joe Taylor (K1JT) has developed digital processing software, (JT44 and WSJT) that have allowed modestly equipped stations to expand their capabilities to degrees previously only dreamed about.

World wide activity has reached unprecedented levels in the fields of VHF/UHF low signal communications. EME communications have now been achieved by relatively small stations without the use CW. Two Meter meteor scatter communications are now a relatively simple process that does not require anything more than sound card in your shack computer interfaced to your "5*0 watt multi mode rice box*".

All of this is very exciting and thanks to Joe (K1JT) and others, the new techniques have breathed fresh air into the weak signal VHF communication facet of our hobby.

However … as a French Amateur commented on a reflector recently …
"Too many Amateurs are striving to find the latest software that will give them a 0.1dB advantage instead of first optimizing their existing equipment to its best potential".

This struck a chord with me and in conversations with those new to the modes it seemed that some of the fundamentals of achieving better weak signal performance have been forgotten or ignored whilst down loading the latest software. The keyboard is greater than the soldering iron or at least easier to use these days! A lot of us are attracted by this approach. The number of high power EME stations as well as CW/SSB activity has decreased noticeably in the last 2 years. It is now easier to communicate with modest installations and thus avoid the requirement of large antennae, high power and the wrath of your neighbours,

This talk and software demonstration, concentrates upon what are the *fundamental keys to better weak signal performance* and how you can achieve significant improvement that will complement that latest software you are running. If you think you performance is outstanding now then if you follow the basic steps and understand what you are trying to achieve and why, then you will benefit significantly. *In most cases your improvement will be greater than what you may have already achieved by software!*

Now to the key elements that determine our ability to communicate and those that form the base line below which limit this ability. Please refer to my software *EMECalc.exe* (Receiver Performance) that enables you to change and display the effects of all the parameters that are to be described below.

In the simplest form we have to address two basic issues. Noise and Losses.

Noise.

The noise component comprises of two main elements.

External to the receiving system and *receiver internal generated noise.*

The *external noise* can also be subdivided into two categories

Man made noise.

Amateurs are well aware of the problems that modern living have impacted upon the noise floor and there is little one can do, in most suburban situations, to reduce it to a point where it is not a limiting factor. Highly directional antennae, polarization choice, good noise blankers will always help but Murphy predicts that the signal you wish to work will always be below the level of the "birdie" generated from next door and precisely the frequency and in the direction of interest!

Stellar or galactic back ground noise (including ground noise).

Ground noise ideally will be your limiting factor in terrestrial communications. Noise from the other sources can go un-noticed by many VHF and UHF operators. Why ? Because their receiver performance is far from optimum. Even the most modest system should be able to hear Sun noise (on both 2 meters and 70cms) when using small yagis. If you can't hear this noise then you have room to improve your system!

Noise is related to temperature. At this point it is best to clarify what is commonly referred to as *antennae temperature*. It is not the physical temperature of the antennae sitting in the Sun (viz 32c) but the temperature of the object which the antennae is facing. This temperature also includes contributing noise from side lobes (in yagis) or spill over and feed thru in the case of dishes. The performance of an antennae can also be defined as its Gain/temperature. Hence a high performance low temperature antennae is one with maximum forward gain, minimum back and side lobes. For this reason Radio Astronomers or deep Space communication systems and all others seeking to achieve the lowest possible *antennae temperature* will most likely use a Cassegrain reflector feed system and also under illuminate the reflector. In this way the feed is not pointing at the ground (rear of the antennae) and thus "seeing" ground noise and the "unused" surface area of the antennae will provide additional noise immunity through reduced rear lobe pick up. Typically ground temperature is referred to 290 degrees Kelvin or 17 degrees Celsius. Noise sources are referred to in °K. The power of the noise source or Flux Density is also referred to in Jansky (Jy). The latter is the terminology used by Radio Astronomers ton categorize noise source magnitudes. For the purpose of this article I will use °K. Preamplifiers can be described as have Noise Figure in dB or can also be described as having a noise temperature of °K. Both are directly related mathematically by the formulae: NF in dB =10*log10((T+290)/290) where T is in °Kelvin. Thus a preamp with a Noise figure of 2.8dB has a noise temperature of 288.6 °K.

Losses

Some losses can be masked or "designed out of the equation" however all losses between the antennae source and the first stage of the receiver will be additive and detrimental to the *Receiver System Sensitivity.* This comprises the noise figure of the receiver front end plus the losses between it and the antennae. In a typical Amateur system (without a preamp at the feed of the antennae) it would most likely consist of many metres of coax, two or more connectors, and a change over or isolation relay for those running an amplifier. In this case all of these losses are added and will form a significant degradation on your stations performance ability.
As an example consider the following typical 2 Meter Station.

	dB	Equivalent in °K
Typical Transceiver Noise figure	2.8	262.6
20 metres of 9913 coax.	0.98	73.4
Return loss of 1:5 1.	0.18	12.3
4 x PL239 connectors	0.2	13.7
Change over relay	0.01	6.8
Total of Losses	4.16 dB	466.4 °K

In the above example the *Receiver System Sensitivity* equates to 466 °K

Now we will add a low noise preamplifier right at the antennae feed.

	dB	Equivalent in °K
LNA Nf	0.25	17.2
Antennae to LNA	0.01	6.8
* Return loss of 1:5 1.	(0.18)	(12.3)
4 x PL239 connectors	0.2	13.7
Change over relay	0.01	6.8
Total of Losses	0.47 dB	33.1 °K
Typical Transceiver Noise figure	2.8	288.6
20 metres of 9913 coax.	0.98	73.4
Return loss of 1:5 1.	0.18	12.3
2 x PL239 connectors	0.32	23.0

* The LNA return loss may generally be neglected as the LNA Nf reflects the overall loss. Some LNA designs can have a significant input return loss but their overall Nf can be quite low and it is this figure that is predominate.

Providing the gain of the LNA exceeds the losses between it and the receiver the above losses are in consequential. To determine the actual degradation in *Receiver System Performance* the following formulae is applied to calculate the *Receiver Noise Temperature*:

RxTk = T1*(L1-1)+(N1*L1) +T2*(L1/G1)*(L2-1)+N2*(L1*L2/G1)

where

RxTk = Receiver Noise Temperature in °K.
T1 & T2 =290 °K
L1 = total of losses between Antennae and LNA in °K
L2 = total losses between LNA and the Receiver in °K

In the above example (with a LNA at the feed) the *Receiver System Sensitivity* equates to 33.1 °K or a improvement in Noise Figure of 3.69 dB.
You have more than doubled the size of your array!

Although improvement is most significant unfortunately there is the matter of noise to contend with and here we come to appreciate the meaning of *Receiver System Temperature* which determines your ability to utilize your *Receiver System Sensitivity* .

Receiver System Temperature is your *Receiver System Sensitivity* plus your *Antenna temperature*. The latter is a combination of the Sky temperature plus ground noise contributed by your front, back and side lobes. Sky temperature varies depending upon where in the sky you are pointing but in the case of 144 MHz the lowest Sky temperature you will see (Aquarius) is about 250 °K. If you happen to pointing at the Sun or Sagittarius for example your Sky Temperature will soar to thousands of degrees. Those who have marginal EME Stations are well aware of the consequences of Sky noise and they schedule their activities to correspond to periods of adequate separation of the Moon from such noise sources and at elevations that minimizes ground noise. In the case of terrestrial communications where we are beaming at the horizon *ground noise becomes ultimately our limiting factor* as it will always be present and our system will be required to discern between it and our wanted signal. As has been demonstrated even a modest pre amp will be lower than the contributing effects of ground noise. (290°K)

As a consequence of the dreaded but un-avoidable ground noise our *Receiver System Temperature* will “bring us down to Earth” of what can be achieved. Typically at 144 MHz, with a single DL6WU design Yagi, the combination of side and back lobes plus the forward lobe will equate to a minimum noise temperature of about 480 °K. Given this our *Receiver System Temperature is* about 510°K with the LNA and about 830°K without the LNA.

It thus becomes clear that the *achievable* *Receiver System Sensitivity* is over shadowed by the *Receiver System Temperature* as a result of external noise. Notably it is our own ground noise that is generally our prime limiting factor for terrestrial communications. However once we look skywards the *achievable* *Receiver System Sensitivity* can generally be realized.

What have we achieved by installing a LNA? Earlier we saw a 3.69 dB improvement in *Receiver System Sensitivity* but with the addition of noise (Ground and Sky) this figure has been reduced to 1.78 dB. In other words, although the *Receiver System Sensitivity* has been *improved* by 3.69 dB the *Receiver System Temperature* has only realized a 1.78 dB improvement.

It is worth remembering that, for those contemplating EME, achievable *Receiver System Temperature* is a key factor. The minimum sky temperature on 144 MHz is about 250°k but this falls to about 15°k at 70 cms and about 10°k at 23 cms. Although effective aperture varies inversely with frequency (144MHz / 432MHz = 9dB) the lower sky temperature will provide an advantage over the loss!

I have provided an option in the software that enables you to simulate antennae temperature to that of the temperature of a resistor. It can be seen by changing the frequency of operation and choosing the default Sky temperature how dramatic external noise effects your system capability. It is thus possible to measure relative levels by employing a Y factor measurement, by either knowing the temperature of a noise source or using the hot/cold method of a resistor. (refer to Y factor calculations in Two Station EME calculations of this software for predicted levels)

In conclusion … a some what *down to Earth* thought!
A 0.2dB noise figure 144 MHz pre amplifier is achievable with today's devices and construction techniques. *Unfortunately one has to leave this galaxy to utilize its full potential for terrestrial communications!*

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