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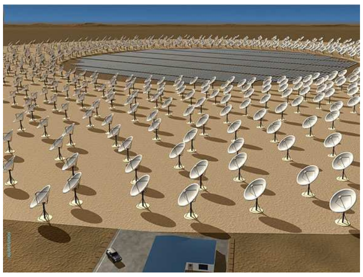
ESTIMATION OF COUPLED NOISE IN LOW NOISE PHASED ARRAY ANTENNAS

INTRODUCTION

There is currently a great deal of interest in the use of phased array receivers for radio astronomy projects like the Square Kilometer Array (SKA). At frequencies above a few hundred MHz it is vital to obtain very low noise temperature performance from such phased arrays in order for them to be practical as radio astronomy receivers. One aspect of the system noise for these arrays that has received much attention is the coupled noise between antenna elements: noise emanating from the input of a low noise amplifier that is coupled into adjacent antennas [1].

This work looks at the coupled noise from the point of view of noise waves emanating from the input of each LNA, considering theory to evaluate these noise levels from the knowledge of the four noise parameters. It is based on the fundamental principles of noisy networks.



THEORY

The theory is based on the wave representation of noise in linear two-ports [2], as shown in Fig. 1. The noise powers delivered to the terminations in a 1-Hz bandwidth and the correlation power are given in terms of the noise and S-parameters of the two-port as [2]:

$$\overline{|c_1|^2} = kT_{min}\left(|S_{11}|^2-1\right)+\frac{4kT_0R_n}{Z_0}\cdot\frac{|1-S_{11}\Gamma_{opt}|^2}{|1+\Gamma_{opt}|^2}$$

$$\overline{|c_2|^2}=|S_{21}|^2\left(kT_{min}+\frac{4kT_0R_n}{Z_0}\cdot\frac{|\Gamma_{opt}|^2}{|1+\Gamma_{opt}|^2}\right)$$

$$\overline{c_1c_2^*}=\frac{4kT_0R_n}{Z_0}\cdot\frac{-S_{21}^*\Gamma_{opt}^*}{|1+\Gamma_{opt}|^2}+\frac{S_{11}}{S_{21}}\overline{|c_2|^2}$$

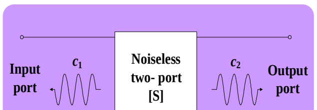


Fig. 1. Wedge representation of a linear noisy two-port [2]

$$\begin{pmatrix} b_1-c_1 \\ b_2-c_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

T_{min} = minimum noise temperature, T_0 = 290K, Γ_{opt} = optimum noise reflection coefficient, R_n = noise resistance.

EXPERIMENTAL ARRANGEMENT

To measure the effective temperature of the reverse noise wave, the DUT is connected in a reverse manner, and the NFM is set to display noise power ratio in dB, relative to 290K. Thus,

Power ratio displayed (dB)
= 10 log(T_d/290)

where T_d (in K) is the temperature associated with the unknown power spectral density.

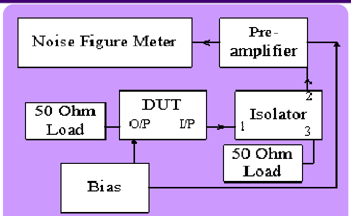


Fig. 2. Experimental set-up for the determination of effective temperature of the reverse noise wave emanating from the DUT

Tuner measurements are used to determine the DUT noise parameters.

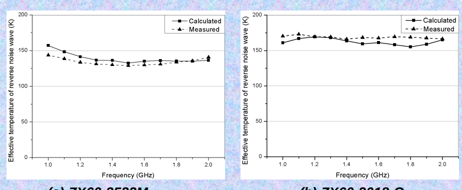
References: [1] R. Maaskant and E. E. M. Woestenburg, "Applying the active antenna impedance to achieve noise match in receiving array antennas," in *IEEE Antennas and Propagation Society International Symposium*, Honolulu, Hawaii USA, Jun. 2007, pp. 5889-5892.

[2] S. W. Wedge and D. B. Rutledge, "Wave techniques for noise modeling and measurement," *IEEE Trans. Microw. Theory Tech.*, vol. 40, pp. 2004-2012, Nov. 1992.

[3] S. Bhaumik and D. George, "SKA LNA Technologies and Topologies," presented in Wide Field Astronomy & Technology for the Square Kilometre Array, Chateau de Limelette, Belgium, Nov. 2009.

RESULTS

The theory has been validate by measurements on two COTS packaged Minicircuits amplifiers: the ZX60-2522M and ZX60-3018-G. Results of measured effective temperature of the reverse noise wave for these show excellent agreement with calculated values, as shown in Fig. 3 a-b. This validates the theoretical approach.



(a) ZX60-2522M *(b) ZX60-3018-G*

Fig. 3. Comparison of calculated and measured effective temperatures of the reverse noise waves

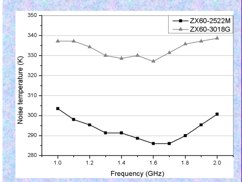
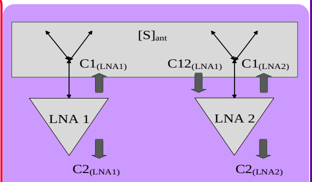


Fig. 4. Noise temperatures of the two amplifiers

APPLICATION TO SKA

The principle is applied to the SKA phased array environment in a three-step process:

1. An LNA designed for the SKA application is considered, for which the measured noise parameters are available.
2. The temperature C1 associated with the reverse noise wave is then calculated for this LNA.
3. A previously-used antenna S-parameter [1] set is used to determine the maximum amount of noise that will be coupled into an adjacent antenna in an example two-element array system, as shown in Fig. 5.



$$[S]_{ant}=\begin{bmatrix} 0.166-0.123j & 0.272+0.219j \\ 0.272+0.219j & 0.166-0.123j \end{bmatrix}$$

Fig. 5. A two-element array to illustrate the noise coupling

For step 1, single-ended LNA designed by the SKA team at ASTRON, reported in [3] is selected, due to the following reasons:

a) The design is based on Avago Technology's GaAs pHEMT device, ATF54143, a popular choices in SKA LNA designs.

b) It exhibits a noise temperature value of 35 K over 1 – 1.6 GHz. Such values have been achieved by more than one team in the SKA frequency range.

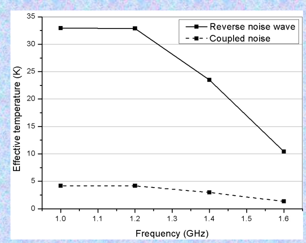


Fig. 6. Effective temperatures of the reverse noise wave and the coupled noise for an example SKA LNA

Fig. 6 indicate calculated values of the effective temperature of the reverse noise wave is below 33 K for the frequency of operation, and coupled noise the order of a few K for SKA LNAs. The noise resistance R_n is also an important factor in this calculation.

CONCLUSIONS

1. Results from the noise wave analysis suggest that the coupled noise contribution to system noise temperature in SKA phased array receivers should be quite small.
2. The theoretical approach can be used to determine the level of noise emanating from the input of any noisy two-port, and can be effectively used by phased array system designers.

For further details about this work, please refer to [4].

[4] M. Roy and D. George, "Estimation of Coupled Noise in Low Noise Phased Array Antennas," *IEEE Trans. Ant & Prop.* , vol. 59, no. 6, pp. 1846-1854, Jun. 2011.

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