THE DESIGN OF ACTIVE RECEIVING ANTENNAS FOR BROADBAND LOW-NOISE OPERATION

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ABSTRACT

This paper describes an approach to matching a broad band antenna to an integrated amplifier with the objective of minimising the noise figure over the frequency range of interest while maintaining a useful overall gain. The method makes use of the known input impedance of the antenna and the impedance required at the amplifier input for minimum noise figure to design a constrained impedance matching network that best matches the two requirements. An example is given for a log periodic antenna.

INTRODUCTION

Traditionally, low noise amplifiers and antennas have been designed to operate into a known reference impedance. The design of each component is usually undertaken independently. For integrated antennas where the first amplifier is connected directly at the antenna terminals without the benefit of any further impedance transformation this usually results in less than optimum noise performance. In applications such as radio astronomy where the noise performance is critical, cryogenically cooled amplifiers have been used to reduce the system noise temperature [1]. A reduction of the physical temperature from 300 K to 20 K has been shown to reduce the noise temperature of the amplifier by a factor of approximately 4.5 [1]. For large focal plane arrays or other feed systems, however, cooling is a costly solution, and as a consequence other methods that minimize the noise figure of the system are desirable. The problem is exacerbated where a broad band design is required, and both the antenna and the amplifier impedance characteristics are complex functions of frequency.

Some attention has been given in the literature to the noise performance of active receiving antennas (see for example [2]). However, practical methods for the broad band design of active receiving antennas, and the characterization of the performance of such antennas, do not appear to have been presented. Moreover, with increasing access to modest cost MMIC fabrication, application-specific design of the amplifier circuit can be undertaken to increase the number of parameters available to optimize the active antenna.

This paper describes a conjunction of the design processes for an antenna matching network and a low noise amplifier input circuit. The design objective is to minimize the noise figure of the resulting integrated antenna over a useful frequency range. It is also possible to concurrently ensure that useable gain is still obtained over that frequency range. The approach can be extended to arrays of antenna elements by including the mutual coupling in the evaluation of the impedance presented to the amplifier.

METHOD

The design of an antenna element usually involves attempting to provide a feed point impedance equal to some known, real, system impedance. A broad band design often results in some compromises, but the requirement to approximate this system impedance is seldom departed from due to the need for a well defined interface to the transmission line connecting the antenna to the electronic circuits that feed it. For an integrated antenna, the direct connection of the amplifier to the feed port of the antenna removes the need for a defined system impedance, and an arbitrary choice can be made in the design. In practice this system impedance may remain undefined if the circuit of Figure 1(a) is employed, and an impedance matching network can be designed to transform the antenna feed point impedance to the impedance required at the input to the amplifier by minimizing:

$$L\{\Gamma'_a(f) - \Gamma_s(f)\} \tag{1}$$

over the frequency range $f = f_1 \mathrm{K}\ f_2$, where Γ'_a is the reflection coefficient of the antenna seen through the impedance matching network, Γ_s is the source reflection coefficient required to be seen from the amplifier input terminals, and *L* is the cost function used in the optimization to minimize the error between the desired match and that obtained in the implementation.

In order to minimize the noise figure of the integrated antenna, the primary design objective is to transform the antenna impedance so that the antenna presents an input impedance to the amplifier corresponding to the so called "optimum noise impedance", requiring that, in equation (1),

$$\Gamma_s(f) = \Gamma_{\mathrm{opt}}(f) \tag{2}$$

where Γ_{opt} is the reflection coefficient corresponding to the optimum noise impedance. The design objective of (1) is illustrated by the arrow in Figure 1(b). This is usually not equivalent to conjugate matching for maximum power transfer, and some compromise between optimum noise and maximum power transfer must be made. Where a broad band design is required, this objective has to be met across the frequency range of interest.

If the tools and skills exist to do so, the method also offers the opportunity to design the antenna and the impedance matching network together to facilitate this impedance transformation to the input of the active device. An added degree of freedom is provided in this case through the control of the reflection coefficient at the antenna terminals, Γ_a, in the design process.

The method therefore takes a known antenna feed point impedance as the source impedance and the required amplifier input impedance as the load impedance of a matching network and uses an iterative approach to optimize the noise figure of the amplifier. Additional optimization constraints can be used to ensure that reasonable gain is maintained. Furthermore, the impedance matching network itself must be constrained to be realizable in the technology used to implement the integrated antenna, and must itself be low loss so as not to compromise the noise figure. Many methods are available for this optimization procedure [3,4]. In the following example a gradient optimizer was used to start the process, and a pattern search algorithm with adaptive and independent step size for each variable used to refine the design.

EXAMPLE

To demonstrate how the method can be used in the design of an active receiving antenna for broad band operation with respect to the noise figure specification, a log periodic antenna having known input impedance characteristics [5] is matched to an off-the-shelf ATF-10136 low-noise Gallium Arsenide FET amplifier. The minimum noise figure that can be achieved with this amplifier is approximately 0.45 dB. The log periodic antenna has a reference impedance of 130 ohms and is connected to a microstrip circuit by means of a 1:1 balun. A reference design that matches the log periodic to the 50 ohm reference impedance of the microstrip circuit achieves a noise figure of approximately 1.6 dB across the frequency range 2.5 to 4 GHz.

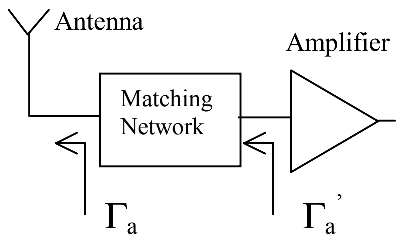
By using the method described in this paper, the simple microstrip matching network shown in Figure 2 was designed. The design includes models for tee junctions, end effects, and via holes. The noise performance of the antenna and FET combination, with its optimized matching network, is illustrated in Figure 3, where it is shown that a noise figure less than 1 dB is achieved across the frequency range of interest. The transformed antenna impedance $\Gamma'_a(f)$ for the optimized noise figure is shown in Figure 1(b). The corresponding gain of the amplifier across the frequency range is 14 ± 1 dB, which is within 1 dB of the gain that would be achieved by including a constraint to maximize the gain in the optimization. Some additional gain compensation would be feasible by means of an output matching network, but this was not undertaken in this design.

CONCLUDING REMARKS

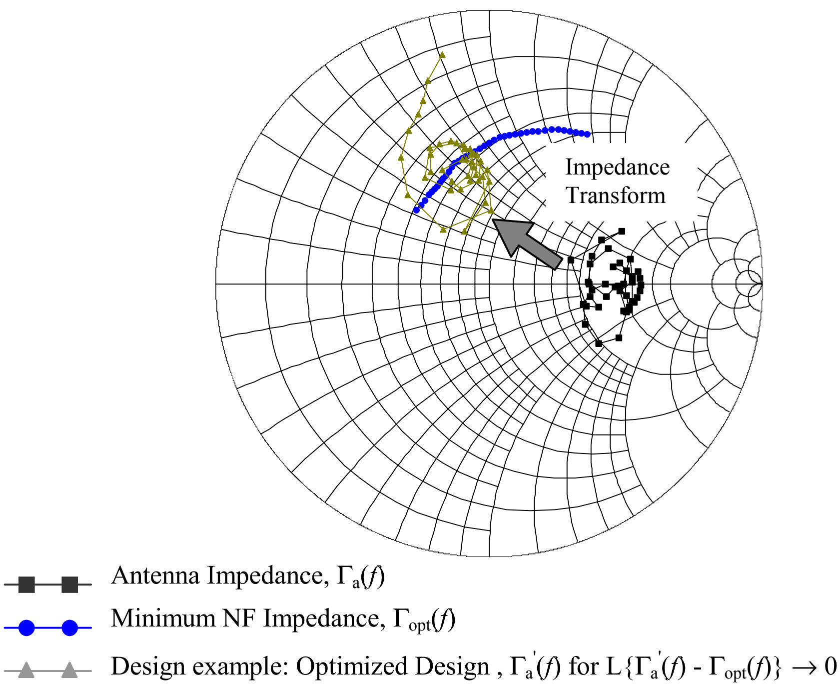
A method has been demonstrated for designing broad band low noise integrated antennas for receiver systems. At low microwave frequencies, improving the noise match by design of a suitable broad band impedance transforming network can yield a low noise performance for an integrated antenna or an array close to the optimum noise performance of the amplifier.

REFERENCES

1. Weinreb S., "Low-Noise Cooled GASFET Amplifiers", IEEE Transactions on Microwave Theory and Techniques" Vol. MTT-28, No. 10, 1980.
2. Rohde, U.L., Whitaker, J. and Bucher, T.T.N., "Communications Receivers", Second Edition, Chapter 4, New York: McGraw Hill, 1996.
3. Maas, S.A. and Nichols, A., "C/NL2 for Windows: Linear and Nonlinear Microwave Circuit Analysis and Optimization", Boston: Artech House, 1994.
4. Eagleware Corporation, "Genesis 7.0", 4772 Stone Drive, Tucker, GA 30084, USA. http://www.eagleware.com, 1999.
5. Smith, C.E., editor, "Log Periodic Antenna Design Handbook", Ohio: Smith Electronics Incorporated, 1996.



(a)



(b)

Figure 1: (a) block diagram of active antenna system with impedance matching, (b) Smith Chart representation of impedance matching objective, and impedance matching results for the example in this paper.

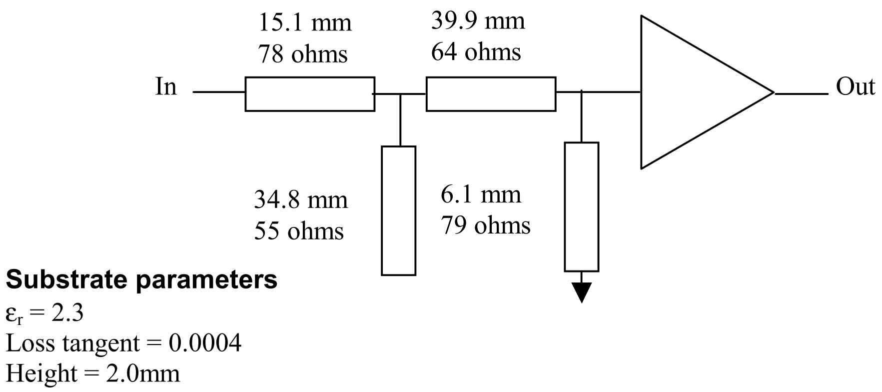


Figure 2: Microstrip matching network for broad band realization of optimum noise figure for the example in this paper.

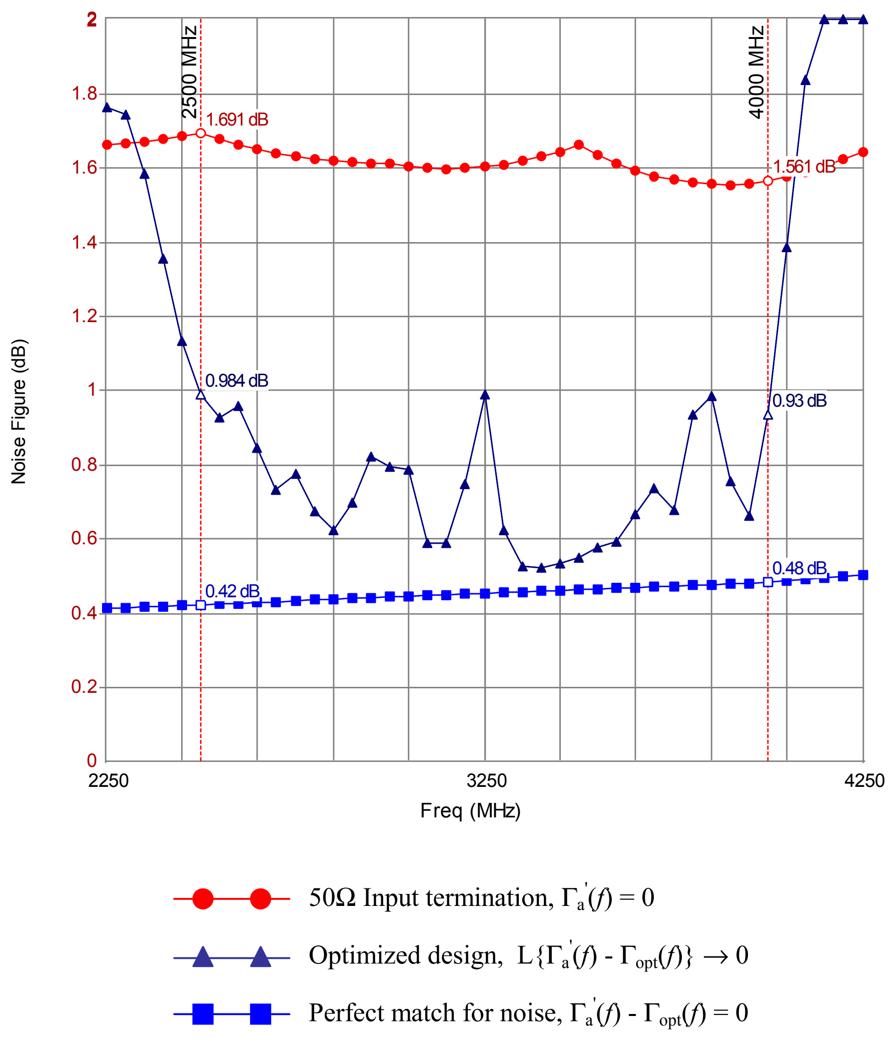


Figure 3: Noise figure for the integrated antenna in the example in this paper compared with the minimum noise figure achievable with the ATF-10136 FET.