FABRICATION OF A THIN FILM LOW NOISE AMLIFIER FOR USE IN HIGH SPEED COMMUNICATION DEVICES USING SPUTTER TECHNIQUE

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ABSTRACT

The analysis and design of a new low noise two stage amplifier based on single and double stub-matched networks, which matches 50 ohms circuit to low input resistance (~10ohms) components is described. The single-stub is able to match any load impedance (as long as it has a nonzero real part) to a transmission line, but it requires a variable length of line between the load and the stub. In this case, the double-stub tuner, which uses two tuning stubs in fixed position are used. The scattering parameters of transistor amplifier are introduced including calculations of power gain, noise figure and stability. The scattering parameters represent any arbitrary N-port passive network under an impedance reference system, and can be obtained from measurements. The practical realisation and the structure of the amplifier (analysed in terms of the Touchstone-variables) are investigated. The bias networks are included in the analysis with a view to observing their influence on the overall noise figure. The results are used in the preliminary evaluation of the performance enhancement of a low noise satellite receiver amplifier. This work forms a general basis for the investigation of stub-matched networks for use in low noise satellite receiver system.

I. INTRODUCTION

Due to an increasing number of communication intelligent systems working at microwave frequencies in recent years, the need to amplify such signal is increasing rapidly. Microwave amplifier fall into three general categories, having:

a) *low noise figure,*
b) *relatively high gain,* and
c) *relatively high output power.*

In receiver applications, it is often required to have preamplifier with a noise figure as low as possible, since the first stage of receiver front end has the dominant effect on the noise performance of the overall system. Generally there is a trade off between the minimum noise figure and maximum gain for an amplifier. The receivers used in a satellite system usually consists of bandpass filters followed by a preamplifier which often utilizes a GaAs FET for its low noise characteristics. The required signal from the dish antenna is usually of the order of -128dBm (0.1 μV) which must be amplified before further processing can take place[2].The specification considered for the amplifier in this study, requires noise level of less then 1dB with an associated gain of 10dB which could only be achieved by using GaAs - FET's. In order to transmit signal at microwave frequencies, suitable transmission media are needed[4]. For maximum microwave frequency power transmission, it is desirable that the load be matched to the characteristic line so that the standing -wave ratio on the line is as close to unity. Reflectionless matching of transmission line can be achieved by using stubs to tune out reactance or suspectance at the correct position on the line. Where the line is connected in series with the main line, it is best to work with impedance and reactances. For parallel connection, on the other hand, it is best to work with admittances or susceptances[3]. Appropriately a matching circuits can be fabricated by utilizing established techniques, since lumped elements are not required [4]. Stub-matched MIC's have the advantage of ease of manufacture over most transmission media in terms of the requirements of post fabrication trimming if needed, using relatively small area of substrate customizing of all parallel stubs. However in some cases especially for frequencies above 10GHz the geometry's of the strips become very small and therefore, the accuracy of the manufacturing system must be high. A better solution with respect to broad band matching is the use of ETL (exponential transmission lines)[3].Current contact moralization is done in vacuum chambers. The choice of particular vacuum system depends on specific deposition needs. It consist of mechanical pump, called a rotary pump, which brings the vacuum system from atmospheric pressure to about 10^{-2}mbar (10 to 0.1Pa or 7.5 x 10^{-2} to 7.5 x 10^{-4} torr.) An oil diffusion pump, backed up the roughing pump, can bring the pressure down to 10^{-6}mbar and with the help of a liquid nitrogen trap to as low as10^{-7}mbar. The liquid nitrogen trap is important for minimizing the oil contamination streaming into the main working chamber. A sputter-ion pump is capable of bring in the pressure down to 10^{-9}mbar. Sputter-ion pumps are used in vacuum system where oil contamination must be avoided (e.g. Molecular-beam expitaxial).Figure 1a shows a schematic view of a deposition system.

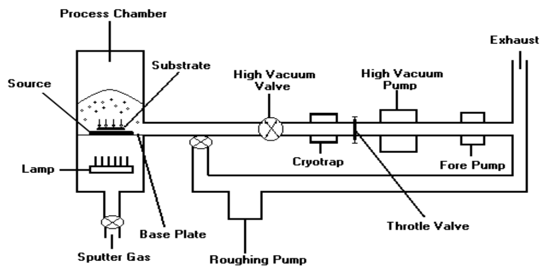

Figure 1. Sputtering equipment for preparation of thin film superconducting microstrips

The chamber is a bell jar a stainless steel cylindrical vessel closed at the top sealed at base by a gasket. A rotary pump evaluates starting at atmospheric pressure the chamber. This rotary pump brings the appropriate system pressure when the chamber is opened to a high-vacuum pumping system that continues to reduce the pressure of the process chamber. This high-vacuum pumping system brings the chamber to a low pressure that is tolerable for the deposition process. This is considered the working or base pressure. In our case for the gold evaporation is 5.7 x10^{-6}mbar. During the film deposition sputter system operates with about 1 Pascal argon pressure. Control of conductive film is very important because of film thinner than desired can cause excess current density and failure during operation and also difficulties in etching.

Design and Results of LNA

The continuous development of semiconductor materials has resulted in the design of transistors suitable for frequencies up to 40GHz with either very low noise figure (0.4-3dB dependent on the frequency range) or an high output power (several watts). The FET for example is an outstanding low noise device because it produces very little noise, this is especially important near the front end of receiver. Because the performance of less than 1dB of noise and an associated gain of 10dB can only be achieved by using GaAs-FET's it was decided to design a microwave amplifier using FET. Secondly, in order to transmit signals at microwave frequencies suitable transmission media are needed. It can clearly be seen that stub matched MIC's have the advantage of ease of manufacture (such as trimming if needed, relatively small area of substrate material and all of parallel stubs used are open circuits) over most transmission media. A better solution with respect to broad band matching is the use of exponential transmission lines (ETL). However in some cases especially for frequencies above 10GHz the geometry's of the strips become very small and therefore, the accuracy of the manufacturing system must be high.
An impedance matching network is the most extensively used circuit element in design of microwave devices using microstrip circuits. Almost all impedance matching networks can be grouped under two categories, impedance transformers and filters. For the design of narrow band amplifiers the impedance transformers are more relevant. Microwave circuits require impedance matching of complex loads with reactive elements. In order to fulfill the matched condition the so called conjugate complex matching has to be performed. In other words the complex output impedance of the input matching network must be conjugate complex of the input impedance of the following stage. The stub matching network consists of parallel stubs, either open or short circuits, separated by series of transmission lines. Both open and short circuit stubs may be designed to act either as a capacitor or inductor depending on their electrical length. The stub acts as matching element for the imaginary part and the series of transmission line matches the real part of the load impedance. Double stub matching is needed in cases where it is impracticable to place a single stub physically in an ideal location. These techniques are easy to perform where the desired impedance matching of a complex load is achieved over narrow bandwidth. For this realization of this project (bandwidth 1%) this matching technique was mostly chosen in preference to other methods because of its ease of manufacture, a matching circuit frequently used is quarter wavelength transformer, it consists of a transmission line characteristic impedance Z_T and an electrical length of $\lambda/4$. The impedance of the line is given by:

$$Z_{in} - Z_o - (Z^2_T - Z_L) \qquad (1)$$

The configuration is shown in figure 2

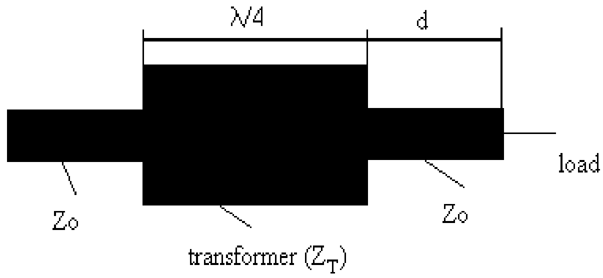

Figure 2: The quarter wavelength transformer

The single quarter wavelength transformer may be extended to multisection quarter wavelength transformers, which than can be used to match real impedances over wide bandwidths. However these multisection transformers occupy relatively large area of substrate material. Therefore the use of these circuits is avoided for the realization of the LNA. A better solution with respect to broad band matching is the use of a tapered line, which can be seen in figure3. The cross-section dimensions of the transmission line changes gradually from a lower to a higher characteristics impedance.

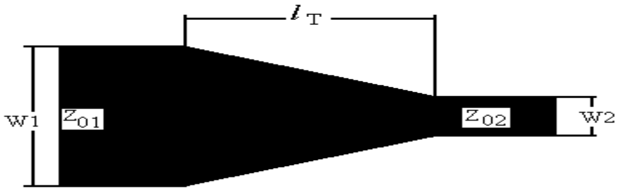

Figure 3. The tapered microstrip line

The manner in which the characteristic impedance of the taper changes, described in taper e.g. exponential hyperbolic and parabolic, are commonly used types. Exponential transmission lines have the simplest geometries and can match real impedances in terms of minimum reflection coefficients.
The amplifier to be designed is characterized by very low noise figure therefore the impedance matching is done to achieve an operating point of minimum noise figure rather than provide maximum transducer gain. For this purpose the input reflection coefficient for optimum noise figure of the FET is given. The inputs of FET's are to be matched for optimum noise figure rather then maximum power gain. The second stage is added in order to increase the overall gain amplifier, both stages use similar reflection coefficient for optimum noise figure Γ_{sopt} =0.9e and scattering parameters as follows:

$$S_{11} = 0.90e^{-j14°}$$
$$S_{12} = 3.24e^{-j54°}$$
$$S_{21} = 0.03e^{-j72°}$$
$$S_{22} = 0.50e^{-j19°}$$

Using equation :

$$\Gamma_{LOPT} = S_{22}+\{(S_{12}\, S_{21}\, \Gamma_{sopt})/(1-S_{11}\Gamma_{sopt})\} \qquad (2)$$

gives $\Gamma_{LOPT} = 0.7025e^{-j88.6°}$

Γ_{LOPT} is the associated output reflection coefficient for optimum noise. Using the reflection coefficient the input and output impedance hence the input matching has to match 50 ohms input impedance to 144.041Ω +j52.028Ω interstage 17.35Ω -j48.15Ω to 144.041Ω + j52.028Ω and the output matching network 17.35Ω-j48.15Ω to the 50Ω output. Assuming ideal matching conditions for optimum noise figure the transducer gain gives the value G=30.5=14.8dB per stage and the overall gain 29.6dB.
Those the theoretical noise figure of two stage amplifier is F_{min1} =F_{min2} =0.6dB therefore F=0.618dB. The FET's used for the realization of the amplifier are not conditionally stable. In order to guarantee operation without oscillation the unstable regions have to plotted onto Smith Chart, load and source impedance must be avoided these regions as described previously. Connecting a resistor parallel to the gate of each FET stabilizes the FET.
This technique is called input loading technique and decreases the magnitude of S_{11} in connection with slight change of its angle $S_{11} = 0.98e^{-j24°}$. The equation

$$Y = \{(1-\Gamma)/(1+\Gamma)\} \qquad (3)$$

Provides Y_{in} = 0.015 +0.225j, and the 220Ω stub adds 0.0045 and normalized to 50Ω line Y_{in} is :

$$Y_{in} = 0.015 + (0.0045 \times 50) +0.225j$$
$$Y_{in} = 0.242 +0.225j$$

So $S_{11} = 0.638e^{-j27°}$ and the new stability factor K=2.33. This shows that FET may be connected to every possible passive source load without occurrence of oscillations due to value of K factor being greater than 1. An important choice is a substrate material for frequency up to 2GHz, alumina material satisfies both the frequency response and the cost of the design.Two different line widths are used: 50Ω lines for impedance transformers and 120Ω for bias network, the line width may be given by:

Stub	Length
L1	24.253 mm
L2	29.061 mm
L3	1.892 mm
L4	12.975 mm
L5	10.504 mm
L6	16.426 mm
L7	19.530 mm
L8	19.166 mm
L9	12.893 mm
L10	27.599 mm
L11	25.280 mm

Table 1. Dimensions of the microstrip lines

Z_o	w/h	H	w
50 Ω	2.402	1.51 mm	3.784 mm
120Ω	0.326	1.517 mm	0.514 mm

Table 2 Specific line widths

The networks of two different types: gate-bias and drain bias networks with R1=56 Ω, R2=220Ω,C=4700pF for gate bias are added. The condition for optimum biasing are given by V_{GS} ≈0.6V and current I=2.72mA leading to a voltage V=-0.752V must be applied to a point in order to define gate-source voltage –0.6V. The low input must provide a short circuit for microwave frequency (Xc – 0.5Πfc –0.026Ω) and blocks additional feeding of microwave signals from the bias network. The drain bias with R=110Ω and C=4700pF with conditions V_{DS} =-3V and I_{DS} =-10mA thus giving the voltage across R 1.1V, in order to match 4.1V should be applied. To avoid a flowing and lead to a voltage across the matching network we applied dc-blocking capacitors.

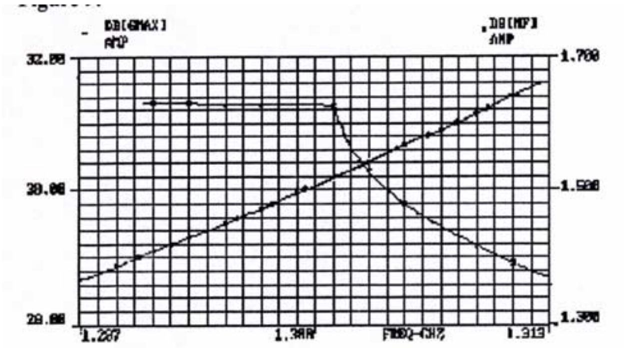

Figure 4 Output characteristics over 1.287GHz to 1.313GHz

The structure of amplifier is analyzed in terms of the Touchstone variables. The bias networks are included in analysis in order to observe their influence on the overall noise figure of the amplifier as seen in figure 4, the gain and the noise figure of the amplifier is :

NF_{max}=1.36dB
G_{min} =31.33dB

The result refers to a frequency band ranging from 1.287 to 1.313 GHz (2%) and the value of Gmin is the maximum value available from the amplifier. However the amplifier is designed for optimum noise figure leading to considerable lower gain values. Calculations including power loss due to mismatch at the transistor input give a gain of 29.6dB.

To achieve the better results the comparison of the exponential transmission lines with the stub matching microstrips in Fig 5a and 5b. we show the direct TDR measurement results of microstrip lines with the physical shape. For one line, impedance changes sharp, these causes the width of line to be larger impedance changes than elsewhere. Figure 5a shows that –7.5% reflection occurs at point's b and c due to the lowered characteristic impedance at the changes. For the other line the impedance changes are exponential to produce constant line width, which is shown on Figure 5b, it should be noted that an inductive reflection does occur at the end of the line due to the inductance of the resistors,(Resistor leads should be kept short to minimize termination inductance).

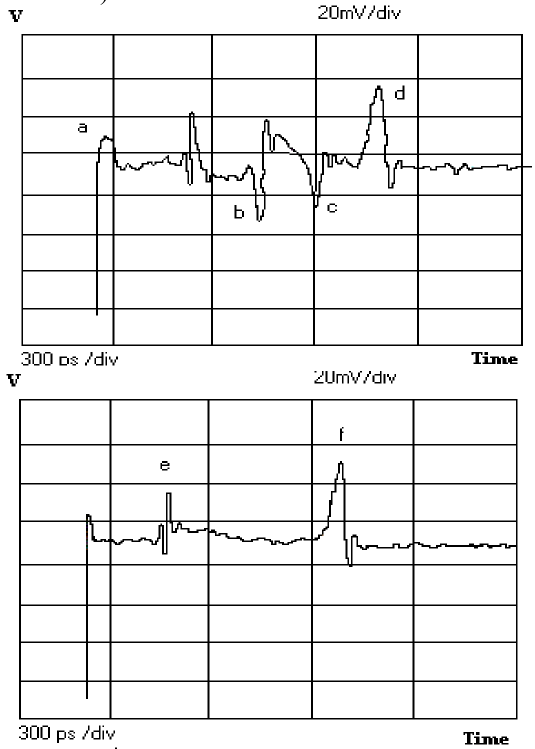

Figure 5. Reflection caused by transmission line shape (a)linear and (b) Exponential

We have shown how high speed digital circuits can be designed with a minimum reflection taking into consideration strong relationship between microstrip shape and the time domain reflectometry. The use of exponential transmission lines, which acts as impedance matching is shown to bring improvements and enables unusually low impedance to be reached with large bandwidth which in principles shows the use of ETL in high speed PIN photodiode applications.

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