Noise Parameter Extraction in the Design of Low Noise Amplifiers (LNA) for MRI

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Introduction

A key component of the MRI system is the Low Noise Amplifier (LNA). A well established engineering method for the design of a LNA is to choose matching components that transform the source impedance to the optimum reflection coefficient (Γ_{opt}) of the transistor, producing minimum noise figure (NF_{min}). The necessary parameters to perform this transformation are given on manufacturer data sheets, typically for frequencies much greater than those used in MRI. The work describes a technique to extract Γ_{opt} and NF_{min} from simulation and utilize them to design an optimized LNA. This design is compared to a LNA that uses the typical MRI array matching scheme of equal reactances in the input circuit.

Experimental

The NE71300 GaAs FET was simulated (Pspice) to extract critical parameters (Γ_{opt} and NF_{min}). A series RL circuit was put on the FET input and R fixed to a nominal value. A Parametric Sweep was executed that varied L while Noise Analysis was performed. An identical process was followed for R, but with L given the value yielding the lowest Noise Factor, F, from the preceding run. The values of V_{inoise} were extracted from the Output File for the range of R and L values and NF computed from [2]; $F=V_{inoise}^2 / 4kTR_s$. Note, X_s may be substituted for R_s. Fig. 1 shows plots of F vs. X_s and F vs. R_s. Excel was used for curve fitting and the coefficients of the polynomials used to calculate the optimum impedance [3]: $X_{opt} = -B/2A$, $R_{opt} = \sqrt{(D/E)}$, $Z_{opt} = R_{opt} + jX_{op}$. Finally, Z_{opt} was converted to the minimum reflection coefficient, Γ_{opt}, and the minimum F was extracted from Fig. 1 to calculate the minimum NF: $\Gamma_{opt} = (Z_{opt} - Z_0) / (Z_{opt} + Z_0)$, $NF_{min}=10*\log_{10}(F)$. These steps were first performed at 2 GHz and extracted parameters compared to those on data sheets to verify accuracy of the procedure. Then, the procedure was applied to 470 MHz (1H at 11.1T magnet in AMRIS). Having characterized the transistor, the Smith chart was used to choose LC matching components to transform the source impedance to Γ_{opt}. NF and Gain were measured from the simulated frequency plots. Finally, simulations were run with seven LC pairs of equal reactance (the phased array input).

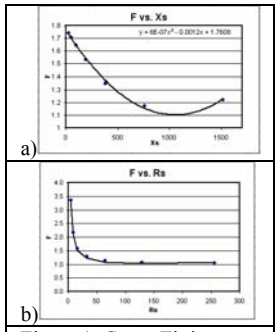

Figure 1. Curve Fitting
a) F vs. Xs, b) F vs. Rs

Results and Discussion

The extracted data for 2 GHz was equivalent to the data sheet (Measured $\Gamma opt=0.824 \angle 32°$, Data Sheet $\Gamma opt=0.81 \angle 37°$), indicating accuracy of the procedure and confidence in the 470 MHz extracted values ($\Gamma opt=0.986 \angle 5.6°$). Table 1 shows simulated NF and Gain values for the two matching schemes. The best NF and Gain is achieved when the extracted parameter procedure given above was followed.

Matching Strategy	L (nH)	C (pF)	NF (dB)	Gain (dB)
Matching to Γopt	106	0.76	0.26	28.0
Random LC pairs of equal reactance (phased array input)	36	3.19	0.66	17.8
	54	2.12	0.37	20.3
	72	1.59	0.33	20.4
	90	1.27	0.37	19.3
	108	1.06	0.47	18.1
	126	0.91	0.59	16.9
	144	0.80	0.73	15.7

Table 1. NF and Gain for different matching components, 470MHz

Conclusions

Critical device parameters necessary for optimum MRI LNA design are not listed on data sheets. This work demonstrates a procedure to extract these important parameters. The extracted parameters were used to design an LNA that yielded optimum NF and Gain. The phased array input configuration was shown to yield many possible NF and Gain values.

Acknowledgements

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References

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