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

B. L. Beck[1]

[1]McKnight Brain Institute, University of Florida, Gainesville, FL, United States

Introduction: A key component of the MRI system is the Low Noise Amplifier (LNA), the first stage of amplification of the very small MRI signal. There is a unique implementation of the LNA for array imaging where the input is configured to a low, real impedance (<3Ω). This is accomplished with a series-shunt LC circuit, the reactances of which are equal [1]. An alternative, but 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 greater than 1 GHz. Operating frequencies for clinical MRI scanners are ≤ 128 MHz and small animal research systems in the range of 200-500 MHz. Consequently, critical design parameters are not available to the engineer. 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.

Methods: A GaAs FET (NE71300) was chosen for simulation using Orcad Capture 9.2. The circuit of Fig. 1a was used to extract the critical parameters Γ_{opt} and $NF_{min.}$ The DC bias point was Ids =10 mA, Vds =2 V, and Vgs =-0.5V. A series RL circuit was inserted on the input and R was fixed to a nominal value; i.e. 50 Ω. L was defined as a PARAMETER to vary its value. Noise Analysis was enabled to measure voltage at the node labeled Vout on the schematic. A Parametric Sweep was executed that varied L through a range of values while the 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 simulated and NFcomputed from [2],

$$F = V(inoise)^2 / 4kTR_s$$

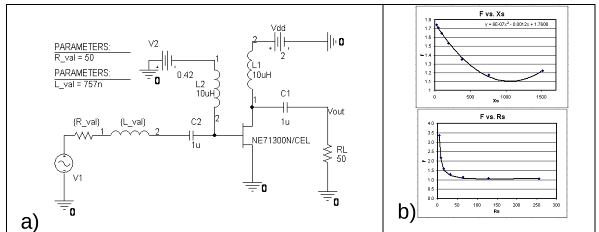
where k is Boltzman's constant, T temperature in Kelvin, R_s the source resistance. Note, X_s may be substituted for R_s. Fig. 1b shows the plots of F vs. X_s and F vs. R_s. Curve fitting was performed and the coefficients of the polynomials used to calculate the optimum impedance [3].

$$X_{opt} = -B/2A \qquad R_{opt} = \sqrt{(D/E)} \qquad Z_{opt} = R_{opt} + jX_{opt}$$

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 by,

$$\Gamma_{opt} = (Z_{opt} - Z_0) / (Z_{opt} + Z_0) \qquad NF_{min}=10*\log_{10} (F)$$

These steps were first performed at 2 GHz and extracted parameters compared to those published in data sheets so that accuracy of the procedure was verified. Then, the procedure was applied to 470 MHz (proton resonance at 11.1T). Having characterized the transistor, the Smith chart was used to choose matching components that transformed the source impedance to Γ_{opt} . Simulations were run with the chosen matching components and the circuit of Fig. 2a, keeping the DC bias point the same as that in noise parameter extraction circuit. The NF and Gain were measured from the frequency plots (Fig. 2b). Finally, simulations were run with seven LC pairs of equal reactance (the phased array input) and the NF and Gain measured.



Parameter	Measured	Data Sheet
Γ_{opt} 2 GHz	0.824 ∠ 32°	0.81 ∠ 37°
Γ_{opt} 470 MHz	0.986 ∠ 5.6°	NA

Fig 1. a) parameter extraction circuit, b) curve fitting

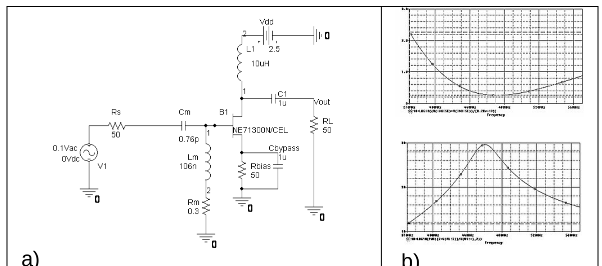


Fig 2. a)circuit with matching components, b) NF (top) and Gain plots at 470 MHz

Results: The extracted data for 2 GHz shown in Fig. 1 is equivalent to the data sheet value, indicating accuracy of the procedure and confidence in the 470 MHz extracted values. The plots of Fig. 2 show a minimum NF of 0.26 dB centered at 470 MHz and a maximum Gain of 28 dB slightly below 470 MHz. From Table 1, the NF for the transistor matched with equal reactance LC pairs starts at a high value decreases to a minimum, and then increases again as the reactance is increased. The Gain follows an inverse pattern, beginning low, traversing through a maximum and then decreasing. The minimum NF for the 72nH and 1.59 pF pair was not centered at 470 MHz, but a slight adjustment to the capacitor shifted the minimum NF point to 470 MHz and the NF was then 0.27 dB and the Gain 25.6 dB, very close to values demonstrated by the transistor matched to Γ_{opt}.

Matching Strategy	L (nH)	C (pF)	NF (dB)	Gain (dB)
Source impedance to Γ_{opt}	106	0.76	0.26	28.0
Equal reactance LC (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

Conclusion: Transistor data sheets do not list device parameters for frequencies used in MRI. Therefore, design and performance criteria such as optimum reflection coefficient, minimum noise figure, and maximum gain are unknown. In this work, a procedure to extract these important parameters was demonstrated. The extracted Γ_{opt} was used to choose matching components that yielded minimum NF and maximum Gain. The phased array input configuration was shown to yield many possible NF and Gain values, only one of which was close to that predicted from the Γ_{opt} match. With knowledge of extracted transistor parameters, input components were chosen that optimized NF and Gain. Many transistor models are available in PSPICE, or can be downloaded from device manufacturers, making the procedure outlined in this work widely applicable.

References

1. P.B. Roemer, W.A. Edelstein, C.E. Hayes, S.P Souza, O.M. Mueller. The NMR phased array. *Magn. Reson. Med.* 16, 192-225 (1990).
2. Guillermo Gonzalez, *Microwave Transistor Amplifiers.* Englewood Cliffs, NJ: Prentice-Hall, 1984.
3. J.T. Colvin. Package Interconnect and Substrate Effects on Silicon Bipolar LNAs Operating in the 2 to 6 GHZ Frequency Range. *Master's Thesis*, Department of Electrical and Computer Engineering, University of Florida, Gainesville, FL, 1998.

Acknowledgements

This work supported by the Advanced Magnetic Resonance and Spectroscopy (AMRIS) facility in the McKnight Brain Institute, Univ. of Florida, and the National High Magnetic Field Lab. Special thanks to Dr. K.K. O of the Dept. of Electrical and Computer Engineering, Univ. of Florida, for guidance.