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 ($\Gamma_{\text{opt}}$) of the transistor, producing minimum noise figure ($\text{NF}_{\text{min}}$). 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 $\Gamma_{\text{opt}}$ and $\text{NF}_{\text{min}}$ 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 $\Gamma_{\text{opt}}$ and $\text{NF}_{\text{min}}$. The DC bias point was Ids = 10 mA, Vds = -2 V, and Vgs = -0.5 V. 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(noise) were extracted from the Output File for the range of R and L values simulated and NFcomputed from [2],

$$F = \frac{V_{\text{noise}}^2}{4kTR_s}$$

where k is Boltzman’s constant, T temperature in Kelvin, R_s the source resistance. Note, $X_{\text{opt}}$ may be substituted for $R_{\text{opt}}$. Fig. 1b shows the plots of F vs. X_c and F vs. R_L. Curve fitting was performed and the coefficients of the polynomials used to calculate the optimum impedance [3].

$$X_{\text{opt}} = \frac{B}{2A} \quad R_{\text{opt}} = \sqrt{\frac{D}{E}} \quad Z_{\text{opt}} = R_{\text{opt}} + jX_{\text{opt}}$$

Finally, $Z_{\text{opt}}$ was converted to the minimum reflection coefficient, $\Gamma_{\text{opt}}$ , and the minimum F was extracted from Fig. 1 to calculate the minimum NF by

$$\Gamma_{\text{opt}} = \frac{(Z_{\text{opt}} - Z_0)}{(Z_{\text{opt}} + Z_0)} \quad \text{NF}_{\text{min}} = \frac{1}{10}\log_{10}(F)$$

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 $\Gamma_{\text{opt}}$. 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.

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 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...