Development of a Cryogenic Transimpedance Amplifier for Fourier Transform Mass Spectrometry using GaAs High Electron Mobility Transistors

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An FTICRMS that can detect a single ion with unity charge can significantly enhance the capabilities in the analysis of complex cellular proteins. This limit of unit charge detection in FTICRMS can be achieved by improving the signal to noise ratio of the detection circuit and by cooling the circuit to cryogenic temperatures to reduce the thermal noise intrinsic to the circuit components[1]. The development of cryogenic-FTICRMS presents an opportunity to implement this idea as this design makes it feasible to establish a thermal conductive path to cool the FTICRMS detection electronics[2]. The primary detection circuit in an FTICRMS is a transimpedance amplifier (TIA) which converts the induced image current on the detection plates to a measurable voltage. The first stage of this amplifier, the preamplifier, is mounted on the ICR cell and is capable of operating at 4 Kelvin thus considerably reducing the thermal noise in its components.

The induced image current in an FTICRMS is of the order of few pA/charge. For example a single ion having unity charge, with *m/z* 1000 Da, in a 14 Tesla magnetic field rotating at half the radius of the ICR cell will induce 0.1 pA of current. Thus for the detection of this current using a 14 bit DAC having a dynamic range of 1 volt, a transimpedance gain (TIG) of $\sim 10^8\ \Omega$ is required. Moreover, the signal bandwidth of interest in typical FTICRMS experiments is around 1 MHz. Here we describe the development of such a low noise cryogenic TIA.

A transimpedance amplifier using commercially available Gallium Arsenide (GaAs) Metal Semiconductor Field Effect Transistor (MESFET) from Eudyna Inc. has been designed[3]. Active devices made from GaAs can function at cryogenic temperatures without carrier "freeze-out". The schematic showing one half of the differential TIA to be used as cryogenic-FTICRMS detection circuit is shown in Fig.1. The addition of bypass capacitors and low pass filters on the bias lines minimizes power line coupling and prevents high frequency instability of the transistor. Additionally for the high frequency stability of the MESFETs, the drain was terminated with a 1.2 pF capacitor in series with a 50 Ω load.

Small signal characterization of TIA was done at 77 Kelvin. Fig. 2. shows that the achievable transimpedance gain at 100 KHz increases, as the Q1 drain current increases. However, the allowable power dissipation in the single side of the preamplifier is limited to 50 mW in the cryogenic-FTICRMS design. Under this consideration the bias point of the Q1 was selected to be VDS = 1.5 volts and IDS = 13 mA. The mid band transimpedance gain is around 90 KΩ. A DC blocking capacitor was added at the drain of Q1 to prevent DC overload of the next stage which set the low frequency cut-off at around 23 KHz. The high frequency -3dB point is at approx. 1 MHz.

The functionality of the preamplifier was also tested in a 7 Tesla magnetic field with the channel of the FET at various angles to the magnetic field. It was expected that the FET characteristics would vary with the angle between the channel and magnetic field. The operating point of the FETs changed slightly. However, surprisingly, the gain-bandwidth of the preamplifier remains unchanged. Apparently the actual electron velocities in the channel are not sufficiently high to be affected by the magnetic field. The amplifier was also tested in a 14 T field with similar results.

The critical component of the detection circuit is the preamplifier which should have an equivalent input noise voltage significantly less than the signal. With a TIG of 90 kΩ in the preamplifier a 0.1 pA of current is amplified to approx. 1 μvolt. This μvolt of ion signal has to be amplified to 0.61 mvolts ($10/2^{14}$) before being fed to the DAC which requires a further gain of approx. 600. A low-noise differential JFET stage has been designed to be mounted on the 50 k shield of the superconducting magnet for this purpose.

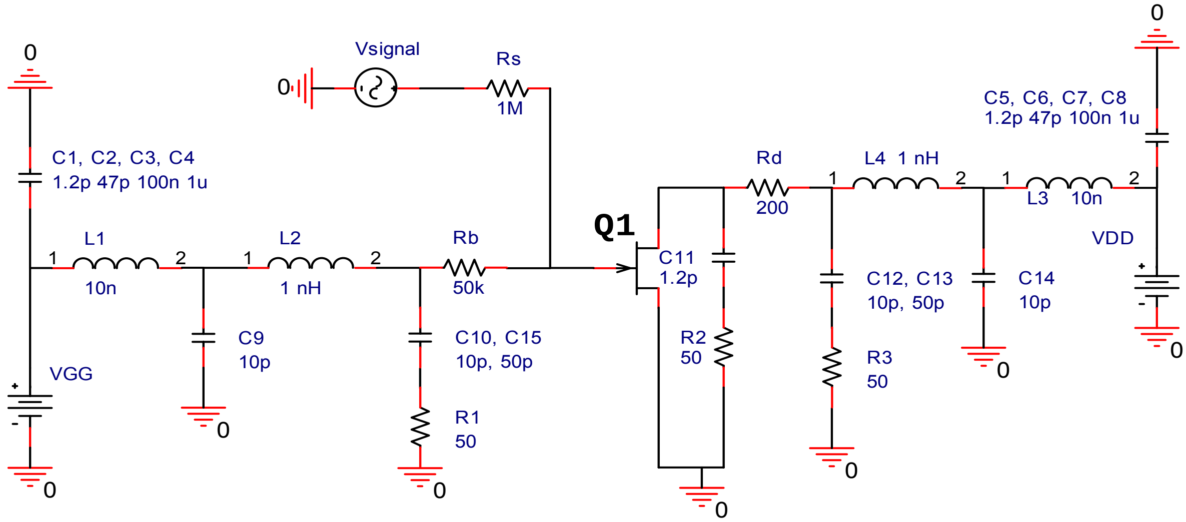

Figure 1. **Circuit Schematic of Cryogenic Transimpedance Preamplifier**

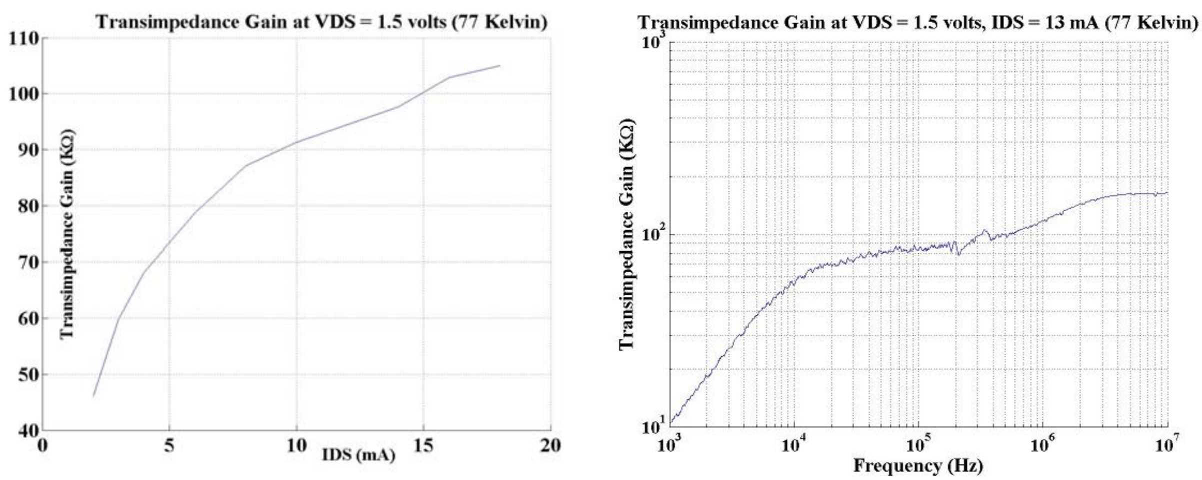

Figure 2. **Characteristics Plots of the Preamplifier.**

Acknowledgements: This work was sponsored by NIH/NCRR P41RR10888, by NIH/NHLBI N01HV28178, by MDS-Sciex, and by the ACS Petroleum Research Fund.

References:

1. Anderson, G. A., Bruce; J. E. et al. “Low Noise ICR Detection Electronics.” *43rd Annual Conference of the American Society for Mass Spectrometry*, **1995**.

2. O’Connor, P.B. “Considerations for the design of a Fourier Transform mass spectrometer in the 4.2 k cold bore of a superconducting magnet," *Rapid Commun. Mass Spectrom.*, **2002**, 16, 1160-1167.

3. FSU01LG (GaAs MESFETs) from Eudyna Inc. (formerly Fujitsu Compound Semiconductor).