Noise Figure and Gain Comparison of GaAs and SiGe Semiconductors at High B_0 Field Strength

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Purpose

To compare MRI preamplifiers utilizing Gallium Arsenide (GaAs) and Silicon Germanium (SiGe) semiconductors in terms of noise figure (NF) and available gain as strength and orientation of the main magnetic field (B_0) changes.

Methods

A noise figure measurement system[1] was used to measure NFs of two sets of array coil preamplifiers at 200.1 MHz: Microwave Technology (MwT) MPH200281 GaAs MRI preamplifiers, and self-built SiGe preamps utilizing a BGB707L7ESD (Infineon, USA) first stage and a SGA-4286 (RFMD, USA) second stage. The B_0 field strength was varied between 0 T and 9.4 T by moving each preamp along the axis of a 9.4 T magnet bore. Preamp orientation was chosen to cause the greatest NF and gain degradation. Scattering (S) parameters were measured at ten field strengths. The noise figure was then measured using the Y-factor method[3] and a calibrated noise source (NW1M500-6-CS, NoiseWave, USA) with 6.56 dB excess noise ratio (ENR). The ENR was corrected for the attenuation of the long coaxial cable.[4] The noise figure was calculated from the Y-factor using corrections for second stage noise[3] and available gain (which utilized S-parameters measured previously).[4]

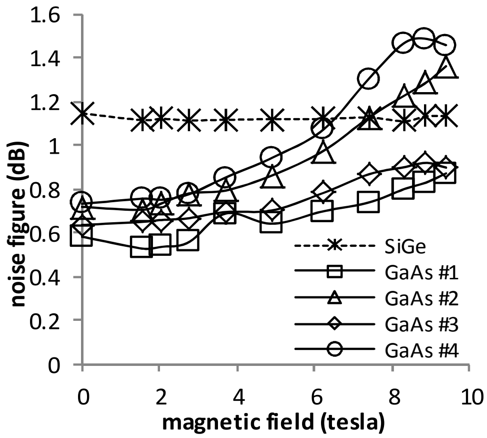

Figure 1: Noise figure variation as a function of B_0 for all GaAs preamps oriented perpendicularly to B_0 and one representative SiGe sample

Results

The greatest variation in S-parameters was measured when the MwT preamplifier was perpendicular to the B_0 field, corresponding to a decrease in gain and increase in NF (Figures 1 and 2). At 9.4 T, gain was reduced by 4.5 dB and NF increased by 0.28 dB (preamps 1 and 3) and 0.69 dB (preamps 2 and 4) relative to zero field. In the other orientations changes in gain were less than 0.1 dB. In contrast, the SiGe device exhibited no measurable change in S-parameters (or gain), nor NF, as B_0 was varied and board orientation altered. Reflection coefficient (S_{11}) varied minimally for both GaAs and SiGe devices.

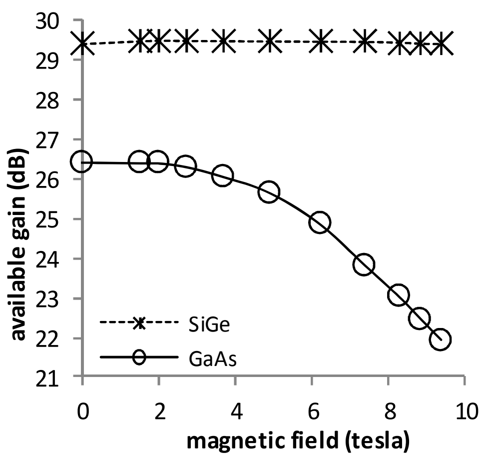

Figure 2: Available Gain (calculated from S-parameters) as a function of B_0 for one representative preamplifier from each group

Discussion

Noise figure and available gain of GaAs field-effect-type preamps are most affected by the B_0 field due to the semiconductor's high electron mobility and channel length.[5] However, it is unclear why GaAs preamps with a lower baseline noise figure also displayed a smaller increase in NF. The immunity of SiGe bipolar-type devices to the B_0 field is attributed to their thin base dimension.[2] Although baseline NF was higher for this un-optimized self-built SiGe preamp, a carefully-designed version[2] could prove ideal for situations in which optimal amplifier orientation cannot be ensured, e.g., in high-density arrays.[6] Due to limitations of matching components and layouts, realistic NFs achievable in preamps with SiGe transistors are expected to be similar to those achievable using GaAs transistors, i.e., in the 0.5 dB range even though NFs of isolated GaAs devices can be lower (e.g., 0.1 dB for the GaAs ATF-35143 (Avago, USA) and 0.4 dB for the SiGe BFP740 (Infineon, USA)).

Conclusion

Our results confirm that high magnetic fields can cause degradation in both NF and gain for GaAs semiconductor devices. The present measurements indicate that a SiGe preamplifier will retain optimal performance, even at fields beyond 9.4 T, regardless of orientation relative to B_0.

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References

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