Tunable Interface Electronics for HEMT based Sensor

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Abstract. The paper reports a tunable interface electronics for High Electron Mobility Transistors (HEMTs) based Field Effect Transistor (FET) sensor. The approach presented in the work can estimate both the 'on resistance' and drain current of the FET sensor while maintaining a constant drain-source voltage (V_{DS}). The interface electronics consist of a full Wilson current mirror with a floating voltage-controlled resistance which is controlled by the output of an integrator forming a closed-loop feedback control. The bias point for the sensor is set by the external voltage, V_{bias} and the difference between the sensor drain-source voltage, V_{DS} and V_{bias} is fed to the integrator as an error signal. The output of the integrator, V_c varies the tunable resistance which in turn varies the current in the current mirror branch. This current is mirrored to the sensor branch and continues to vary until the drain-source voltage, V_{DS} matches the applied external bias voltage, V_{bias}. At this point, the circuit is at the balanced state and the corresponding control voltage, V_c represents the sensor signal. The circuit is evaluated with SPICE simulation and experimentally verified using a prototype PCB. Experimental testing revealed that the circuit can work for a range of 200Ω to 2000Ω with an absolute relative error of less than $\pm 1\%$. The circuit can also be tuned for the desired working range and allows the user to apply external bias potential based on the sensor's requirement. The proposed circuit has great potential as a bio-chemical interface circuit for FET based sensors.

INTRODUCTION

Interest in Field Effect Transistor (FET) based devices as bio-chemical sensors was propelled with the introduction of open-gate ion-selective field-effect transistor by Bergveld [1]. The device combined the effect of a chemically sensitive membrane at the open gate area and the conduction channel between drain and source terminal of the FET underneath the gate. The resulting structure give rise to modulation of source-drain current (I_{DS}) of the FET. Though it was a breakthrough, extensive study of such devices revealed shortcomings such as thermal dependency, drift and hysteresis. Overcoming these issues, GaN/AlGaN high electron mobility transistors (HEMTs) based FET have been extremely popular for number of reasons. These devices are bio-compatible, chemically inert, stable at high temperature, inherently sensitive to ambient. Unlike conventional semiconductor FET, the channel formation is not dependent on the doping concentration but rely on two-dimensional electron gas (2DEG) located at the interface of the AlGaN and GaN hetero-structure [2, 3]. This 2DEG is formed due to the piezoelectric polarization of the strained AlGaN layer and the difference in the spontaneous polarization between AlGaN and GaN. Also, this high electron sheet carrier concentration channel is sensitive to the ambient [4, 5]. Due to these advantages, group III – nitride including GaN, AlN, InN and their alloys are increasingly used for next generation chemical and biological sensing platforms. The inherent property of the heterostructure device to form a polarization – induced 2DEG is an appealing feature to detect ions, impurities in liquid, bio molecules and polar liquids.

Seeing the promising possibility of these devices, a great deal of research has also been made to model the Al-GaN/GaN devices to comprehend its behavior [6]. Close study of the device reveals that the drain-source current (I_{DS}) is a coupled function of gate-source voltage (V_{GS}) and drain-source voltage (V_{DS}) represented mathematically as:

$$I_{DS}(V_{GS}, V_{DS}) = f(V_{GS})g(V_{DS}) \tag{1}$$

While FET devices are typically characterized by 'on resistance' or drain current (IDS) variation ratio with respect to the analyte concentration, the working of the device is ensured by its interface circuit to implement a precise biasing. For ultra-low analyte concentration, such as proteins, bio-markers, impurities and heavy metals in liquid, a precise and stable interface circuit is highly desirable.

As the sensor design field progresses, the need for novel interface circuits exclusive to HEMT based sensors has also increased. Although, HEMT based sensors have clear advantages, system design based on these sensors are still not reported. One of the contributing factors is the fact that these sensors have a high base/offset current with