# An Integrated Negative Resistance Current Amplifier to Enhance the Sensitivity of a Weakly Coupled Local Detector

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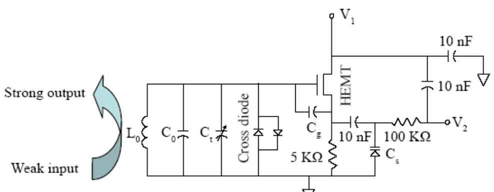
**Target Audience:**
RF Engineers, MR physicists.

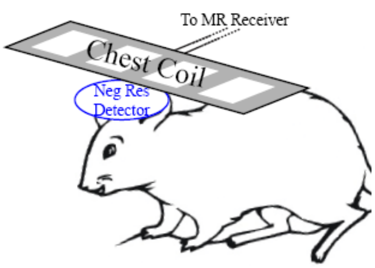
**Purpose:**
In an ordinary MR detector, weak signals are amplified after the circuit is impedance matched via capacitive coupling. When inductive coupling is used in implantable detectors[1], however, it is advantageous to amplify signals directly on the coil to reduce the sensitivity loss from signal transmission. Previously, on-coil amplification was implemented using parametric frequency mixing with an externally provided pumping signal[2-3]. Here, we demonstrate that the feedback effect in a transistor can also be utilized to amplify signal currents *in situ*, as if a negative resistance was connected in parallel with the *LC* resonator. Because there is no multi band frequency mixing involved, current amplification using transistor feedback does not mix noise into the signal pass-band. Such negative resistance detector can be used to enhance the local detection sensitivity when inductively coupled with much larger receiver coils, even though the transmission efficiency of inductive coupling is small.



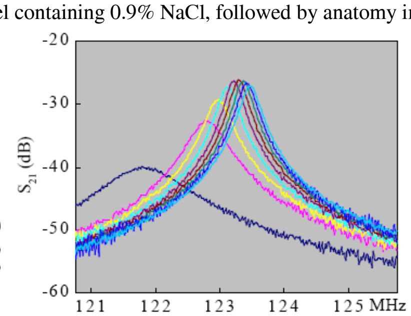
(Fig. 1)

**Methods:**
Fig. 1 is the circuit diagram of the negative resistance detector. The *LC* circuit of the sample coil is placed in parallel with the gate of the transistor. $L_0$ (24 nH) is an 11 mm single turn detection inductor printed on G10 substrate. The parallel capacitor $C_0$ (62 pF) is chosen to resonate the sample coil slightly above the Larmor frequency at 3T (123.24 MHz). Precise frequency adjustment for the initial setup is controlled by the trim capacitor $C_t$ (Johanson 9702-2). The cross diodes (BAT15-04W) connected in parallel to $C_0$ can passively detune the *LC* resonator during RF excitation. The HEMT transistor (ATF-34143) is connected in the common source configuration with its drain incrementally grounded with a 10 nF capacitor and biased with an adjustable voltage ($V_1$). Under saturation condition, the transistor is operating at a bias current of 0.11 mA, which is controlled by the source resistance (5 kΩ). Current feedback transforms the source capacitance $C_s$ into negative resistance on the gate. Efficient amplification occurs when the negative resistance is close enough to the positive resistance of the *LC* resonator. The magnitude of the negative resistance is dependent upon the gate capacitance $C_g$, the transconductance $g_m$ and the source capacitance $C_s$. To adjust the value of negative resistance, a second bias voltage $V_2$ is used to adjust the voltage on the source varactor (BBY57-02W) via a 100 kΩ resistor. All MR experiments were performed on a 3T Skyra (Siemens) clinical scanner. The negative resistance detector was placed on top of the sample to receive and amplify MR signals. A Siemens 8-element phased array chest coil was positioned immediately above the detector to relay amplified signals into the scanner interface (Fig. 2). Phantom images were first acquired on an agarose gel containing 0.9% NaCl, followed by anatomy images acquired on a mouse head.

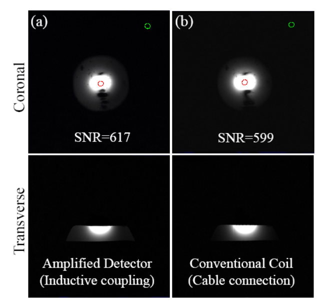
**Results:**



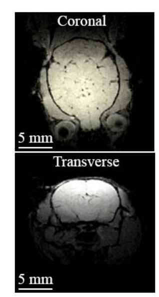
(Fig. 2)



(Fig. 3)



(Fig. 4)



(Fig. 5)

Fig. 3 shows the $S_{12}$ transmission curves of the negative resistance detector measured with a double pick-up loop connected to an E5061A network analyzer. The left most curve was measured without bias voltage. The remaining curves from left to right correspond to $V_1$ = 0.8 V and $V_2$ = 0 V, 0.5 V, 1 V, 1.5 V, 2 V, 2.5 V, 3 V, 3.5 V respectively. The relative height of each curve with respect to the peak position of the reference curve reflects the gain. When $V_2$ = 2 V, the brown curve has the highest gain at 14 dB and a bandwidth of 258 kHz. This bandwidth is sufficient for most MRI experiments. Fig. 4a shows phantom images obtained by the negative resistance detector that is inductively coupled to a human chest coil. When compared to images acquired by a conventional surface coil with direct cable connection (Fig. 4b), the negative resistance detector has similar detection profiles but slightly better sensitivity. Since the noise factor of the preamp in front of the scanner interface adaptor was measured to be 0.9 dB, the noise factor of the negative resistance detector should not exceed 0.9 dB in order to maintain comparable sensitivity after signal transmission through weak inductive coupling. Fig. 5 shows the coronal and transverse images of a mouse head acquired on a 3T Siemens scanner. Owing to the superior sensitivity of the local detector and the *in situ* amplification for signal transmission, it was possible to obtain images with 0.3 mm slice thickness and 156 x 156 $\mu m^2$ in-plane resolution and observe micro vascular structures in a mouse head.

**Discussion:**
A negative resistance amplifier can be directly attached to the *LC* resonator without the need for impedance matching. It can operate at very low bias current without sacrificing its low noise performance. When the negative resistance detector is used in conjunction with commercially available coils of much larger dimension, there is increased inductive coupling efficiency due to the increased gain. High resolution local images with small coils and low resolution global images from the larger standard clinical coils can be obtained with the same setup, without the need to reconfigure the scanner interface.

**Conclusion:**
A low power amplifier based on transistor feedback is integrated with MR detector to enhance the local detection sensitivity. When proper power harvesting schemes are developed, such an integrated amplification scheme can find important applications in interventional detectors as well.

**Reference:**
1. Schnall MD, Lenkinski RE, Pollack HM, et al. Prostate - Mr Imaging with an Endorectal Surface Coil. *Radiology* 1989; 172:570-574.
2. Syms RRA, Solymar L, Young IR. Three-frequency parametric amplification in magneto-inductive ring resonators. Metamaterials 2008; 2:122-134.
3. Qian C, Murphy-Boesch J, Dodd S, Koretsky A. Sensitivity enhancement of remotely coupled NMR detectors using wirelessly powered parametric amplification, *Magn. Reson. Med.* 2012; 68: 989-996.