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Analysis and RF Test Drive of an Overhauser Sensor for Geomagnetic Field Measurements

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Abstract. A co-axial cavity type overhauser sensor for geomagnetic field measurement has been analyzed. The cavity with free radical solution has inductance of 32 nH. A Radio Frequency (RF) matching network has been designed to couple the RF power at proton polarization frequency of 40 MHz. The tuned circuit has quality factor of 150. The required voltage for the geomagnetic field measurement, which is less than 50 V has achieved at RF input power of less than 2 watts at 40 MHz.

INTRODUCTION

The geomagnetic field measure has wider application in oil exploration, mineral detection, defense applications, navigation, and also to find ground water resources. In view of its various application sensors like proton magnetometer, optical sensor, overhauser sensor are of recent interests in the geomagnetic field measurement [1]. The overhauser sensor uses the dynamic nuclear polarization (DNP) effect to enhance the proton polarization of free radical sample. The DNP effect was 1st discovered by Overhauser in 1953 [2]. After this, several authors have made the Overhauser sensors and coupled the RF signal and tested the geo magnetic field, But the circuit equivalent of sensor and matching network details are unavailable. The paper presents the detailed analysis of sensor and its matching network design. It also presents the results of RF test drive.

PRINCIPLE OF OPERATION

Under the ambient geomagnetic field, the free electrons in the free radical solution undergo electron spin resonance (ESR), when the solution is irradiated with RF source of same resonance frequency. Due to dynamic nuclear polarization the electron spins are coupled to the proton spins and this cross coupling improves the proton polarization. The magnitude of the proton polarization will be increased. This increase in proton polarization results in increase of the free induction decay signal, which is measure of geomagnetic field. It improves the signal to noise ration of the sensor. So, it enables the improved sensitivity and resolution of the overhauser sensor. The DNP effect is shown in Fig 1. Fig. 1 (a) shows the proton polarization under geomagnetic field which is same direction as the earth magnetic field. When solution is irradiated with RF, the magnitude of the vector is increases due to DNP effect as shown in Fig.1 (b). when RF is switched OFF and DC pulse is ON, the proto polarization vector M is aligned with the plane of precession as shown in Fig. 1 (c). Finally, when the DC pulse is OFF, the protons undergo precession around the earth magnetic field axis. During the time of precession, the FID signal is generated and frequency of which is a measure of earth's magnetic field. The relation between the FID signal and M_p, decay time, and angle of M_p w.r.t to axis is given in equation 1. Amplitude of decay signal $V(t)$ is proportional to Lamour frequency ω, and magnitude of polarization vector M_p, and sine of the angle of polarization vector Θ.

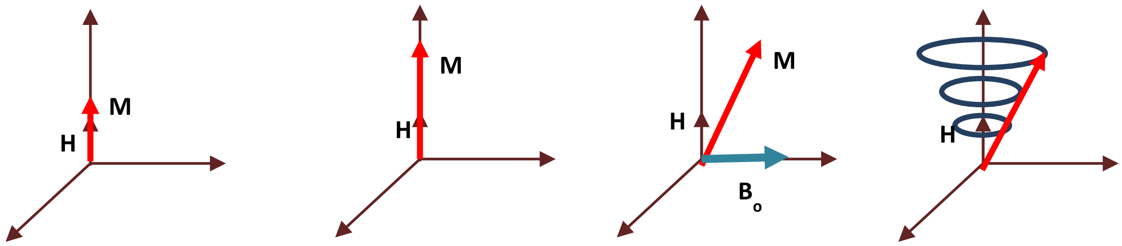


FIGURE 1. Proton precession process (a) No RF or DC, (b) Enhance M due to RF, (c) rotation of M due to DC field in y direction, and (d) proton precession under geomagnetic field.

$$V(t) = c \times M_p \times \omega \times sin^2\theta \times e^{-t/T} sin\,\omega t \tag{1}$$

RF ANALYSIS OF OVERHAUSER CAVITY

The resonant cavity for proton polarization can be any of shapes being used in the RF and Microwave application like rectangular, cylindrical, spherical or a coaxial type. These cavities can be of fundamental mode or higher order mode. The minimum length of the cavity is at least one-fourth of the guide wavelength of the cavity. Since, the proton polarization occurs at 40 MHz, the sizes of the 1st three types are large and cannot be practicable. The coaxial resonator with capacitive loading can result the smaller size of the cavity. At 40 MHz the length of the quarter wave resonator is 1.875 mtr, which is large. A capacitive loaded and an inductive cavity full-fill the requirements of compact size for mobile geomagnetic field measurements. Construction of a typical coaxial cavity is shown in Fig 2. It consists of a thin glass annular cylindrical cavity in which a free radical solution is filled. The annular bottle's outer surfaces are jacketed with a thin conducting silver foil. One end of the foils is left open for RF drive signal and another end are short circuited. Overall it works as coaxial line with short circuited at one end. The solution works as dielectric filling between both inner and outer conductors. The geometry has been simulated in CST microwave studio. The dielectric constant ε is 32.7. The simulated inductance of the cavity is 36 nH. The H-field pattern of the cavity is shown in Fig. 3.

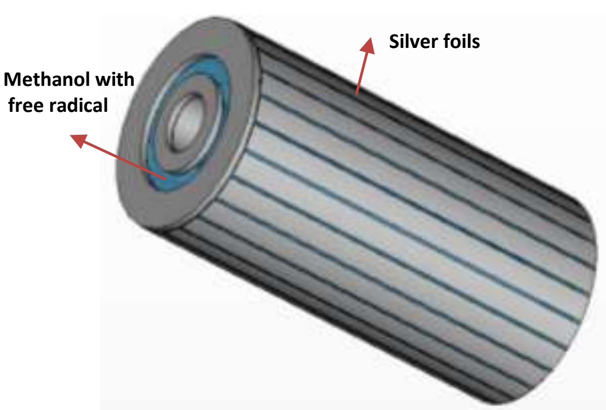


FIGURE 2. Geometry of the Overhauser cavity

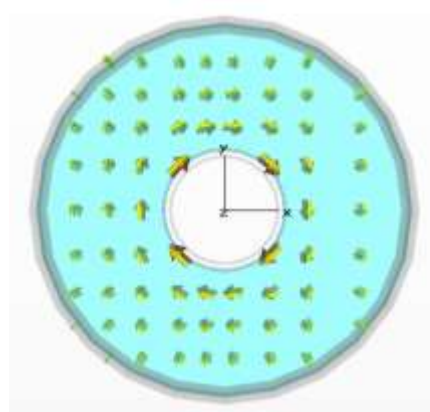


FIGURE 3. H-field inside the cavity

DESIGN OF IMPEDANCE MATCING NETWORK

The inductance of the Overhauser cavity is measured using the vector network analyzer (VNA). The measured input impedance of the sensor is shown in Fig. 4. The sensor has inductance of 40.4 nH at 40 MHz. It includes an approximate inductance of connector of 3.7 nH. To resonate and impedance match the cavity with a 50-ohm source resistance, an L-type matching network with two capacitors has been designed. The topology of the matching network is shown in Fig. 5.

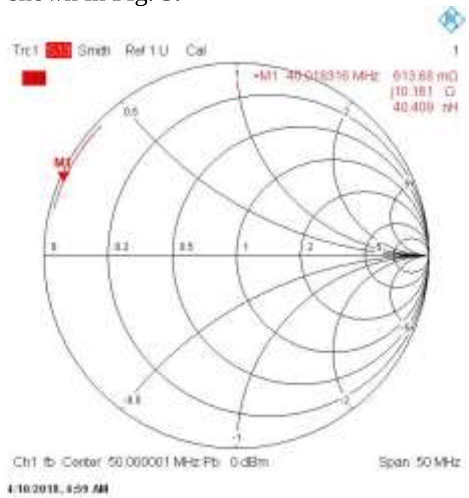


FIGURE 4. Mesured input impedance of sensor

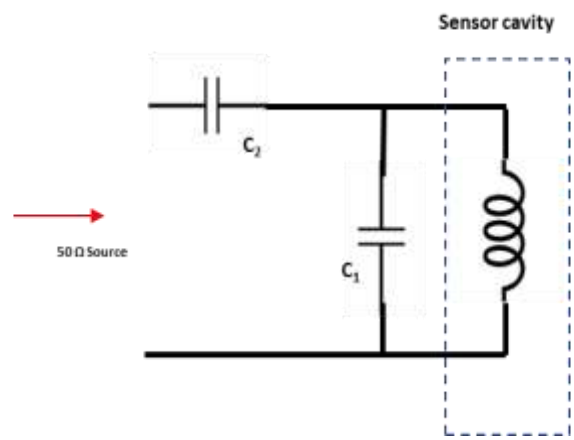
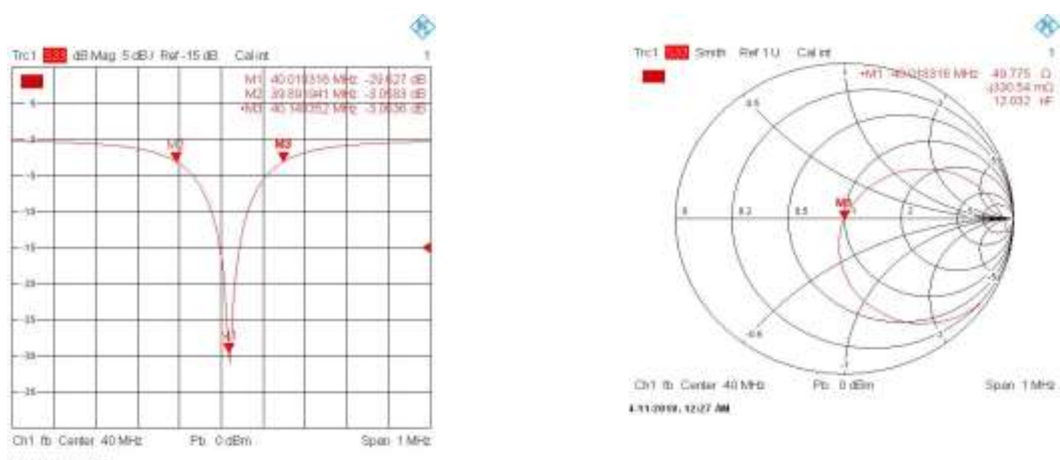


FIGURE 5. Matching Network

RF TEST DRIVE OF CAVITY

After matching the cavity to 50-ohm source at 40 MHz, it has been tested in the RF measurement set-up. The measurement set-up is shown in Fig.6. It consists of a signal generator, drive amplifier, an RF power meter, and oscilloscope. The sensor has been driven up to 3.27 W and the voltage developed has been recorded. The Table 1 shows the RF power versus voltage across the sensor.



(a) (b)

FIGURE 6. (a) Input return loss, and (b) impedance of sensor after matching.

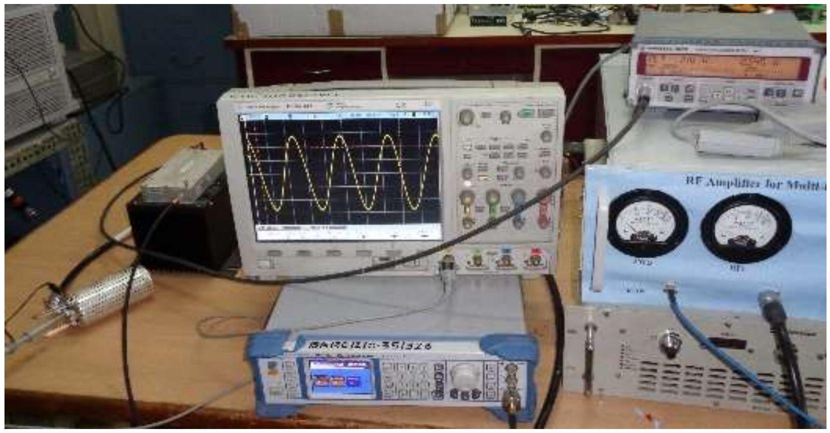


FIGURE 7. RF Measurement set-up of Overhauser sensor.

TABLE 1. RF power versus voltage across the cavity terminals.

RF Forward Power (W)	Reflected Power (W)	Voltage across cavity (V)
0.57	0.11	13
1.17	0.22	19.6
1.63	0.3	23.2
2.2	0.4	27
2.7	0.53	33
3.27	0.66	36

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