# Extending the frequency limits of non-contact acoustic generation

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***Abstract*: This work focuses on the GHz frequency limit of the Magnetic Acoustic Resonator Sensor, and how the instrumentation can be modified to support a unique function: the acoustic spectroscopy of interfacial biological films. The optimization route we chose, involved careful characterization of the spiral coil in terms of its S22 reflectivity, and electrical characterisation of the transmission line linking it to our MARS detector. Two specific problems were identified with this method: the tendency for the larger coil to experience parasitic behaviour and the presence of quarter wave reflections in short sections of twisted wire feeder. We found both of these effects compromised high frequency performance.**

## I. INTRODUCTION

This work aims to identify the factors that limit the performance of the Magnetic Acoustic Resonator Sensor (MARS): This system can operate at multiple frequencies up to 1GHz and provide opportunities for wireless and non-invasive biosensor application that complement the conventional Quartz Crystal Microbalance device [1, 2]. It uses a 5mm spiral coil to create an electromagnetic field that instigates shear wave vibrations in a quartz disc contacting a fluid sample.

It is based on contact acoustic sensors that have played a central role in biological sensing, either as a surface acoustic wave devices or quartz crystal Microbalances (QCM). So far, their main contribution has been the provision of a frequency, which changes whenever the environment surrounding the element changes; normally within the interfacial region just above the surface of the device. This is approximately 15 nm thick for 100 MHz devices and defines a very small sensing volume above the device surface. In operation this region normally defines a sample which changes if viscosity or viscoelastic alters, which in turn influences the acoustics and allows detection. The key disadvantages of the contact mode is the need to isolate the electrodes from chemical reagents, otherwise it will not function. Also the information obtained from complex biological films tends to be limited in contact mode, due to the narrow range of frequencies that can be used to probe the film.

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To address both these issues, we have developed the Magnetic Acoustic Resonators Sensor (MARS) which operates at a multiple frequencies, and can function without wired electrodes. We have demonstrated multiple frequency measurements from 1MHz up to 1.1GHz at Q factors exceeding $10^4$ [3]. But at specific frequencies the signal to noise was degraded substantially, so the spectrum was obscured in this region. In addition there appeared to be a frequency turning point, where the signal would decline. We have suggested the coil's parasitic capacitance across each turn, is responsible for the limiting frequency.

In this present paper we seek to identify the cause of the degradation, so we can increase MARS' frequency limit and extend operating frequency range.

## II. EQUIPMENT & METHODS

We characterised the coil's reflection coefficient, via the Smith chart display of the network analyser and then compared it to the acoustic spectrum obtained with the MARS detector. The main focus was to establish the cause of the 650MHz cut-off point [3], limiting the operating frequency.

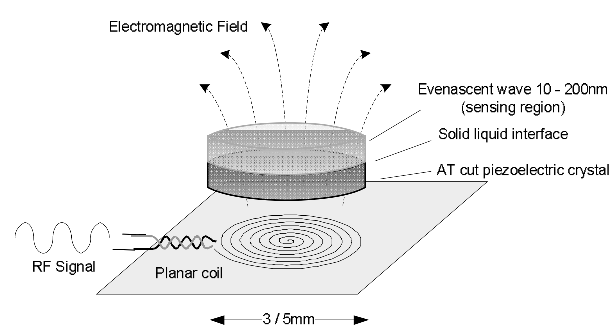


Figure 1. A non-contact transducer based on a spiral coil

### A. *Network analyser*

Smith charts for the spiral coils were obtained by connecting the two terminals of the spiral coil to an Agilent 8753ES network analyzer instrument set to measure the S22 reflection parameter. To ensure the same electrical environment as the working MARS instrument, the spiral coil was sited in its normal position on the instrument's metallic base. The collection of these Smith charts helps to define the complete electrical properties of the spiral coils as a function of frequency, so the coils likely contribution to the final MARS signal can be obtained.

### B. *MARS detector*

The MARS system is based on a E8254 signal generator that inputs a FM modulated signal into a spiral coil wound from 85um enameled copper wire, which in turn is coupled via a fixed length of transmission line, which avoids the need for tuning. The field of the spiral coil couples to a 0.25mm thick quartz disc, which instigates vibrational modes via the converse piezoelectric effect. This in turn generates a radiative signal on vibration, which couples back into the spiral coil. The net result is as an impedance dip, which can be captured via a custom made AM Detector based on an EG&G 7265 lock- in amplifier, for subsequent display on a PC. Further details of the system are discussed elsewhere.

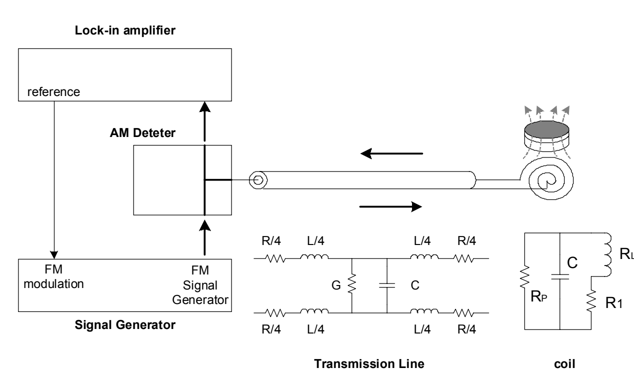


Figure 2. Wideband MARS detection system

## III. RESULTS AND DISCUSSION

The focus of the experimental work was to define the electrical behaviour of two coils, and then to recognise the how the geometry of the coil impacts on MARS spectra. This involved looking for patterns in the S22 reflection measurements of the two coils, the impedance character of the coaxial line and the resulting acoustic spectra.

### A. *Coil S parameters*

We tested the behaviour of the 5mm coil, by connecting it to the S22 input of the network analyser. Figure 3 shows the electrical characteristics of the 5mm coil as presented on the instrument's Smith chart. Following the points clockwise on the chart, starting at 30 kHz, we can see successive points forming a spiral line on the chart, where the coil responds either inductively on the top side of the chart, to capacitively on the lower part, so the signal line alternates between these regions as frequency increases. All looks to be regular predictable, except for three small loops or twists in the curves between 400 and 600 MHz. These deviations are indicative of parasitic resonances. Then, beyond 635 MHz and on to 1 GHz, reflectivity begins to fall, with the signal line moving to the centre. This change in RF reflectivity indicates the coils electrical properties are beginning to change significantly.

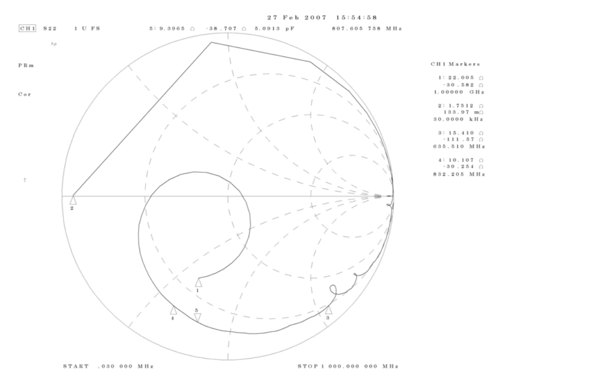

Figure 3. S22 measurment for a 5mm diameter spiral coil.

Moving to the 3 mm coil (Figure 4) the corresponding Smith chart looks similar in form, but with distinct differences: First the region between 400 and 600 MHz has two parasitic resonances at different locations. Their shape suggests they are not as significant as the 5 mm coil. The other difference is the magnitude of the reflection, which doesn't change significantly up to 1GHz. This suggests the impedance of the 3mm coil is more stable and uniform than the larger coil.

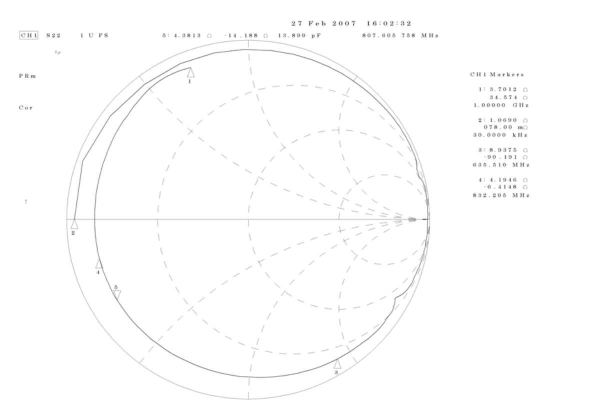

Figure 4. S22 measurment for a 3mm diameter spiral

### B. *Coaxial cable*

The other important component that determines the acoustic amplitude of the MARS system, is the cable. It joins the coil to the detector and has resonance behaviour that supports wideband operation. From our previous study it can be seen and the length of cable determines the separation of the acoustic peaks, as the line alternates between high and low impedance, forming a backcloth to the acoustic data. The expression for the line impedance is given by

$$Z = Z_0 \left( \frac{(Z_R/Z_0) + Tanh[\gamma d]}{1 + (Z_R/Z_0) Tanh[\gamma d]} \right) \quad (1)$$

where $\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$ and $Z_0 = \sqrt{(R + j\omega L)/(G + j\omega C)}$, and d is the length of the line and shown to fit our experimental data when R=0.1Ω, L=0.23µH, C=55pF and G=$10^{-9}$.

### *C. Acoustic response*

We now consider the coil and cable characteristics, with respect to the acoustic signals that emerge from the MARS system. The figure 5 shows the amplitude of the acoustic response of the 5mm coil as a function of frequency. The first point to note is that the response is not identical to the previous spiral coil we described earlier [3]. Clearly winding and connection differences, must be present. With this in mind we analyse the relative height of the peaks and find differences occur at 400 MHz where a substantial peak occurs, possibly related to a parasitic. Then at 550 MHz and beyond, the signal falls substantially, and doesn't recover, except a few minor resonances up to 1.1 GHz. Overall, there is a phase where the coil operates, and another where the signal falls substantially beyond 600 MHz..

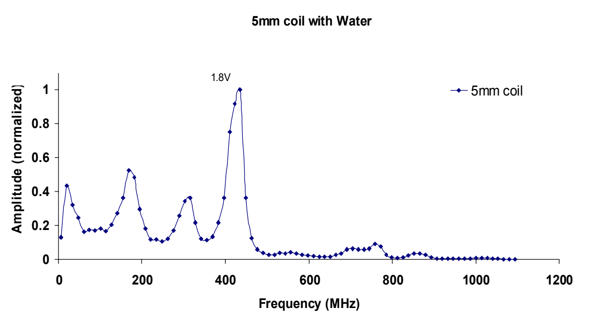


Figure 5. Variation in acoustic signal with 5mm coil

Moving to the 3 mm coil (Figure 6), all peaks below 500 MHz, except in the first resonance, match the peak frequencies of the 5 mm coil up to a similar dip at 600 MHz. However there is a much improved higher frequency response compared to the 5 mm coil.

If we compare the network parameter S22 data (Figure 3 & 4) with these acoustic plots (Figure 5 & 6), we find frequency regions that are related: For the 5 mm coil, the region where the acoustic signal falls significantly corresponds to reduced reflectivity zone on the Smith Chart, where the impedance seems to be dominated by parasitics. Whereas the 3 mm coil continues to operate in this zone, with a regular behaviour, that follows on from the low frequency acoustic spectrum.

The key feature appears to be the absence of signals at 650 MHz, for both the large and smaller coils. Clearly this region is not related to the coil, as previously surmised in our early paper. Instead, this zone suggests reflections are occurring in the system from a quarter wave line, effectively shortening the output. The calculated length of the quarter wave component is approximately 0.05 meters, which corresponds to the length of the short enameled copper wire that bridges the coil and panel connector. We believe it is this component that is corrupting the true wideband character of the system.

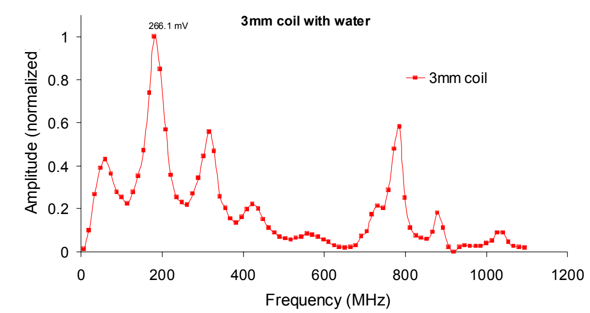


Figure 6. Variation in acoustic signal with 3mm coil

## IV. CONCLUSION

We identified two key improvements that will increase the high- frequency response of MARS. Part of the solution is to use a small spiral coil. The other related to reflections in short lengths of twisted wire feeder - an issue that became obvious when two different coils shared the same spectral depression at 650 MHz. Hence our action to increase the operating frequency of MARS, will involve two steps: Making spiral coils with diameters smaller than 3mm and connecting the coaxial transmission line to the coil with a strip line section.

These steps will not only raise the operating frequency of MARS, as desired, but also expose other parameters that may be limiting performance. With these incremental extensions to the bandwidth, we will soon be able to access more detailed interfacial spectra or 'fingerprints' of adsorbed biomolecules. Although interfacial slip and relaxation process are not understood, these steps will provide instrumentation that can support the development of a new theory, so we can finally relate the spectra to the interfacial chemistry.

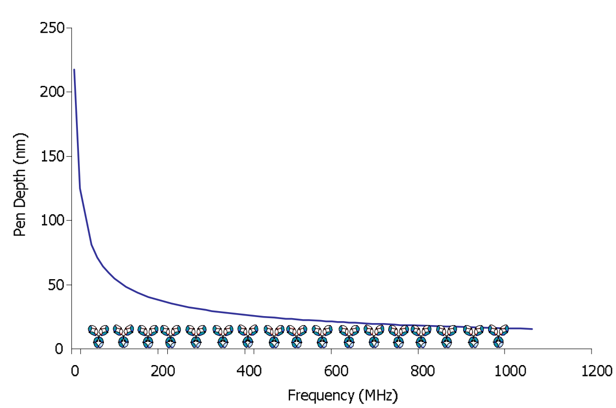


Figure 7. Variation in the penetration depth as a function of frequency

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