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WHOLE BODY L-BAND RESONATOR WITH A WIDE RANGE FREQUENCY TUNING USING PIEZO ACTUATOR

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Measurements by present *in vivo* L-band EPR often are enhanced by using whole body resonators, but use of such resonators are connected with several challenging problems. One is the relatively large change in the resonator frequency caused by voluntary and involuntary movements of the animal. To overcome this, we designed a loop gap resonator (600 and/or 1200 MHz) with a metal plate that is a part of the resonators capacitor that can be displaced by a piezo bender. We have used a recently developed multilayer, low voltage non-magnetic piezo bender, that bends up to 0.5 mm, which is sufficient to change the resonant frequency by about 15 MHz. With the use of an automatic frequency control (AFC) system, this tuning range is sufficient to keep the resonant frequency constant and to compensate for the effects caused by the movements of the investigated object. A step motor is used as the base of the mechanical part of the matching adjustment

INTRODUCTION

The development of *in vivo* ESR Low- Frequency spectroscopy as a powerful and versatile method depends on solving several practical problems. One of the most critical challenges for this technique is animal motion, which can cause mismatching and detuning of the resonator, resulting in distortions or complete loss of the signal.

To keep the resonant frequency and matching constant, automatic frequency control (AFC) and matching control (AMC), can be used. Automatic tuning and matching circuits that use varactor diodes, piezoelectric transducers, or electromchanical transducers have been utilized. Each approach has benefits and deficiencies. The advantage of the varactors based system is fast response of AFC circuitry. On the other hand, varactors are sensitive to the magnetic field modulation and special shielding is needed. Also, use of varactor diodes when AFC and AMC is used can generate second harmonics when the power is greater than 100 mW.

The resonant frequency also can be changed by mechanical movement of a capacitor plate that is a part of the resonant structure. Hyde at al. (Hyde, Rilling, Jesmanowicz & Kneeland, 1989) have used a piezoelectric bimorph disk to adjust the tuning capacitor of the nuclear magnetic resonance (NMR) surface coil. A similar system has been used by McCallum et al. (McCallum & Resmer, 1999) where the piezoelectric disk actuator was used to change the capacity of the coupling capacitor of a low frequency EPR spectrometer.

Recently a new multilayer bender actuators became commercially available (Physik Instrumente GmBH&Co., Waldbron, Germany). The positioning range of these multilayer benders are an order of magnitude larger than the previous design. Since these benders are made of nonmagnetic materials and also employ low operating voltage (60 Vmax.), they are very convenient to construct voltage controlled variable capacitors. The larger displacement available enable the design of a control system that is smaller and therefore less sensitive to audio noise. As a result the spectrometer's sensitivity can be improved.

TECHNICAL DESCRIPTION

Resonator design

We used a bridge loop gap resonator (BLGR) whose structure was supported by a quartz tube of 30mm diameter. The schematic diagram of the resonator is on Fig. 1. The resonant frequency can be adjusted either by changing the dimensions of capacitors plates or by varying the distance between the capacitor plate and the loop. We have used teflon tape to fix the loop and the capacitor copper plates (20 mm wide stripes). We adjusted the resonator frequency by changing the distance between the plates and the loop.

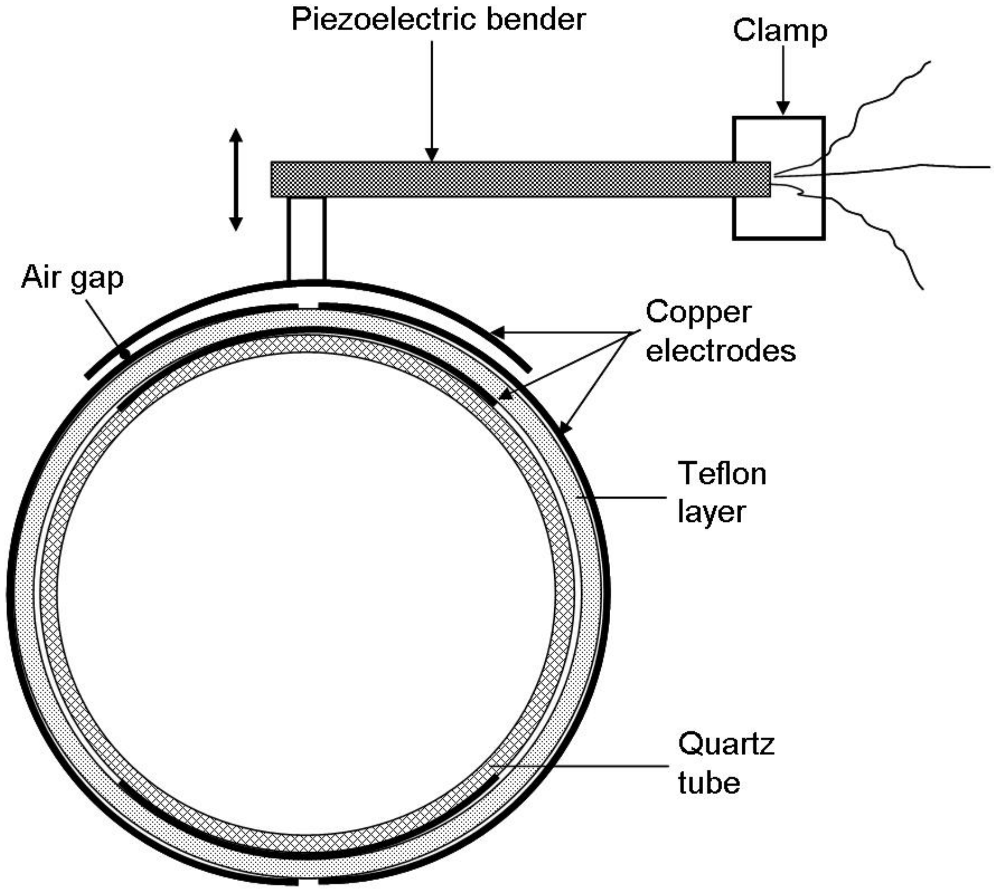

Fig. 1. Schematic of a piezo-controlled whole body resonator

One of the bridge capacitor plates was split into two parts. One half was fixed by teflon tape while the second part was left free and mechanically coupled with a piezoelectric bender. By splitting the electrode plate we could change the distance of one half of the plate sufficiently to change the resonant frequency (up to 15 MHz) for the operation of the AFC system. Since the second half of the capacitor is fixed, the whole cavity structure is less sensitive to microphonics, improving the spectrometer's signal to noise ratio.

Piezoelectric control and measurements

The new generation of multilayer piezoelectric benders have a range of movement up to 2 mm and can be operated with low voltages (60 V max). We have used the smallest model (PL-122.251), which has a displacement up to 0.5 mm. The 25 mm long bender is clamped at one side and fixed to the aluminum housing of the whole body cavity, while the second side is mechanically coupled to the mobile part of the resonant capacitor by a 14 mm long quartz tube. This electrode was made from 0.1 mm thick phosbronze plate with a round shape to fit the curvature of the quartz cavity body. All of the plates of the resonator structure were silver plated. Changes to the resonant frequency by moving the electrode can be done in two ways: by mechanical repositioning of the piezobender and electrode position to provide a coarse adjustment, and electromechanically by changing the voltage applied to the piezobender. Fig. 2 shows the dependence of the resonant frequency on control voltage with the empty resonator (graph 2A) and loaded with mouse (2B). We can see, that there is some hysteresis, which has been observed previously (McCallum & Resmer, 1999).

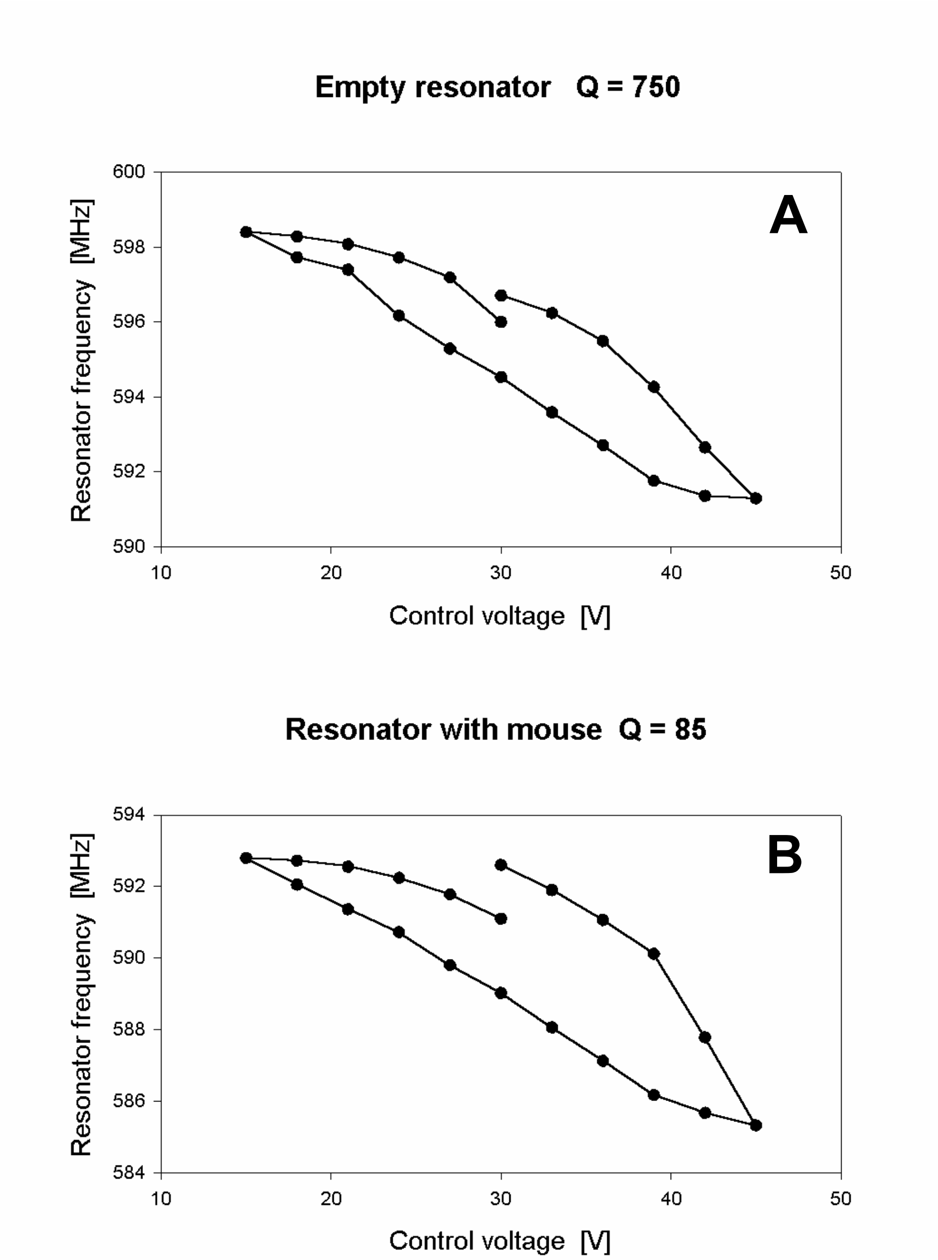

Fig. 2. Resonant frequency dependence on control voltage: A: empty resonator; B: loaded (with mouse)

MATCHING CONTROL

The bridge loop whole body resonator we have designed is equipped with magnetic type of coupling. To reduce the influence of coupling adjustment on the resonator frequency, a flexible impedance transformer was used connecting the coupling loop to the transmission line (Hirata, Walczak & Swartz, 1997).

By changing the distance between the resonant structure and the single turn loop, we can vary the coupling and match the cavity to a RF source. Very often a simple screw is used to change the distance. This can be inconvenient, however, so we have used a step motor controlled movement of the coupling coil. Fig. 3 shows the schematic of the whole system. Since a standard step motor can rotate in 0.9 degree steps and using a 6.3 mm diameter motor shaft, we achieved translational shifts of 50 microns. Changing the coupling loop position and measuring the reflected power from the cavity with a detector diode, we obtained the

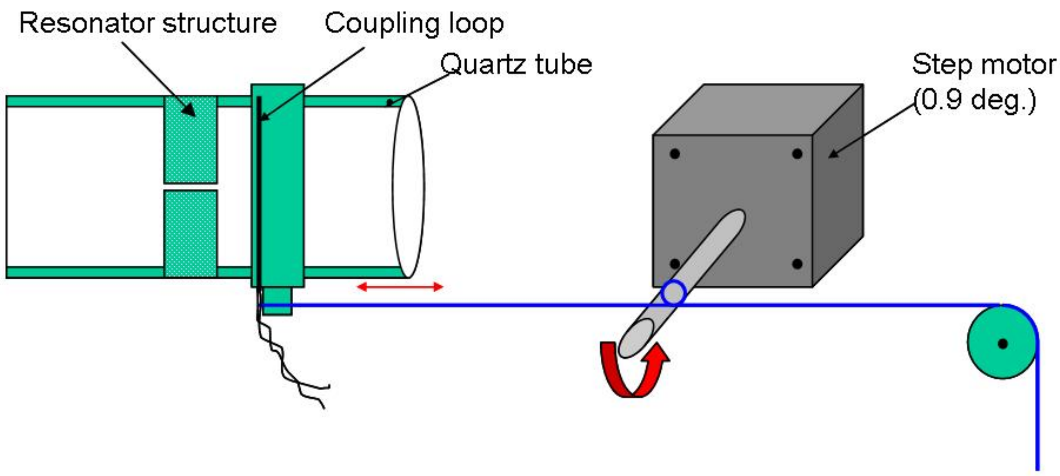

Fig 3.: Schematic of coupling loop control using step motor.

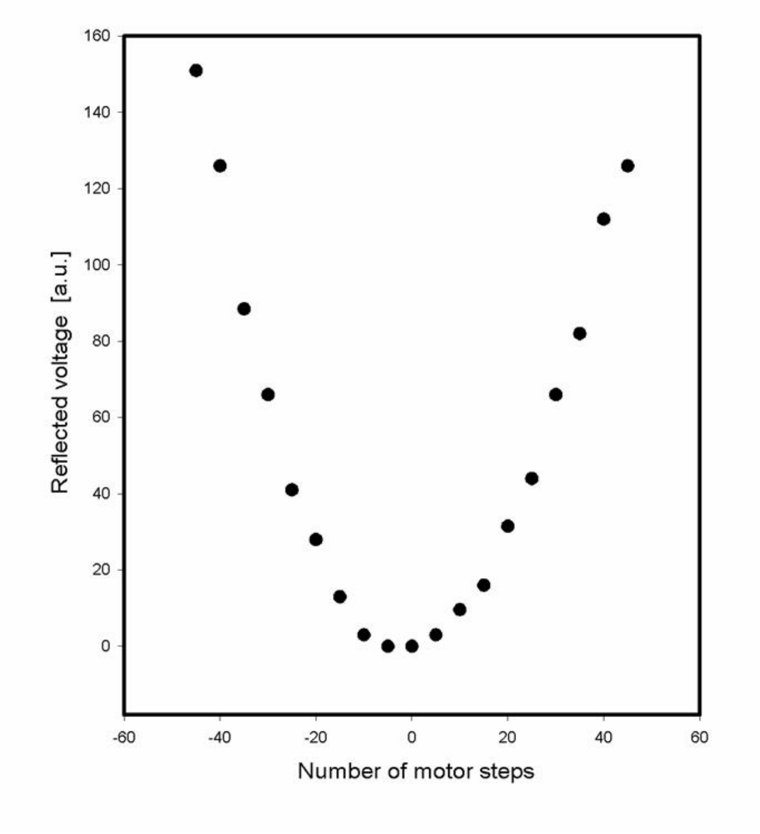

Fig. 4. Resonator coupling vs number of motor steps. At zero position coupling is critical, by rotating in one or another direction we can under or over couple the cavity to the RF source.

dependence on resonator coupling shown on Fig. 4. The change in coupling from under coupled to over coupled was achieved with 90 steps, that correspond to 4.5 mm of total coil movement. It should be noted that the small step motor used (Type 4H4018L0502, Nanotec, Munchen, Ge) could change the direction of rotation quite fast, so a frequency of several Hertz could be achieved. We believe that this is fast enough to use ACC control electronics, with which most of the animal movements could be compensated. This is the subject of our ongoing investigation.

CONCLUSIONS

The availability of a new generation of piezo benders offers the possibility for construction of improved automatic frequency and coupling controls of resonators. We have used a piezo bender with up to 0.5 mm displacement range to control the resonant frequency of a 600-650 MHz whole body resonator. The resonator resonance frequency change of 15 MHz that was obtained is sufficient for AFC electronic control.

In addition to the resonator frequency change that is caused by movements of animals, the coupling also is effected. We have introduced a step motor control that moves a single turn coupling loop to match the resonator and RF source. We believe that this proposed step motor controlled matching adjustment will be fast enough to use ACC electronics.

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