# A Discussion on the Optimum Operating Frequency of an Implant

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**Abstract:** *Antenna design for implant communications is a well-established research area standardised under the specification of Medical Device Radiocommunications Service (MedRadio) by US Federal Communications Commission (FCC) and Medical Implant Communication Service/ Medical Data Service (MICS/MEDS) by European Telecommunications Standards Institute (ETSI). Here the operating frequencies proposed in these standards are challenged. A tuneable cavity backed meandered slot antenna is designed and analysed in a sphere of muscle tissue and the efficiency of the antenna at different depths is observed. The behaviour of the Poynting Vector depending on the frequency of operation is associated with these efficiency figures.*

## 1. Introduction

MedRadio spectrum frequency allows operation in the 401-406 MHz range. Application specific bands in the 413-457 MHz range are also available for Medical Micropower Networks (MMNs). In addition, in 2012, FCC incorporated Medical Body Area Networks MBAN into MedRadio which covers 2360-2400 MHz band [1]. Therefore the majority of work on Implantable antennas has been done in these two frequency bands: 401-406 MHz and 2.4 GHz. Note that there have been limited investigations on unlicensed Ultra-wide Band (UWB) in the 3.5-4.5 GHz range [2] and in the Wireless Medical Telemetry Services (WMTS) band in the 1.395-1.400 GHz range [3].

Within the body, path loss increases with the operating frequency hence MedRadio choses a comparatively lower band. This together with the size limitation of the devices due to the nature of the application leads to the choice of Electrically Small Antennas (ESA). ESAs are typically inefficient however the efficiency becomes a greater issue once the nearfield of the antenna is exposed to lossy body tissues.

Here we investigate the trade-off between the antenna efficiency and the path loss within the lossy tissues through a cavity backed meandered slot antenna. The slot is tuned to various frequencies between 1 GHz and 3.5 GHz while its size is kept constant. The efficiency figures for the different variations of the antenna is calculated for the depths between 20 mm to 60 mm. Finally the emission is plotted against the depth and the frequency which sheds a light on the optimum choice of design parameters in implantable antenna design.

## 2. Tuneable Cavity Backed Meandered Slot Antenna

An implantable ESA is designed with an overall size of 12 mm x 12 mm x 1 mm using a finite element method solver, Ansys HFSS. The antenna is tuned in two ways: by changing the length of the radiator and by dielectric loading. In the first method, the length of the slot is changed between 50 mm and 90 mm while the cavity size is kept constant as seen in Figure 1. This change provides a frequency coverage from approximately 1 GHz to 3 GHz as seen in Figure 2.

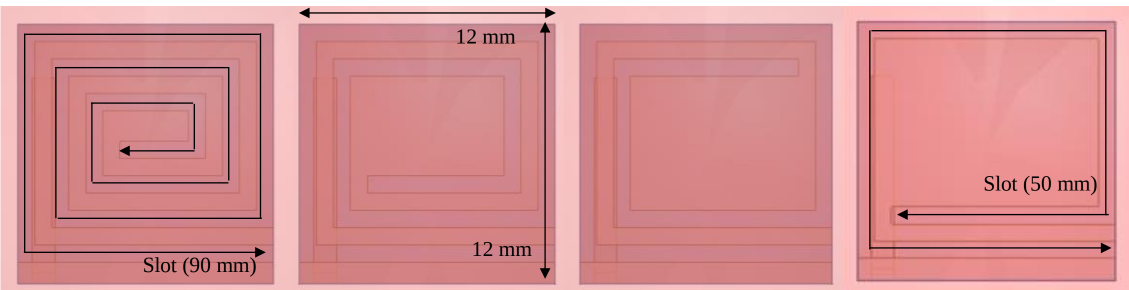


Figure 1 Implantable cavity backed meandered slot antenna (12 mm x 12 mm x 1 mm): the slot length is changed between 90 mm and 50 mm from left to right.

In the second method, the relative permittivity of the loading is varied. The antenna is fed with a stripline sandwiched between the cavity walls. Note that as the loading changes, the stripline width should also be changed so that the characteristic impedance is tuned to 50 Ω. The matching for both methods can be further optimized by parametrizing the length and the position of the stripline. For the emission calculations the variation in the reflection coefficient is compensated for.

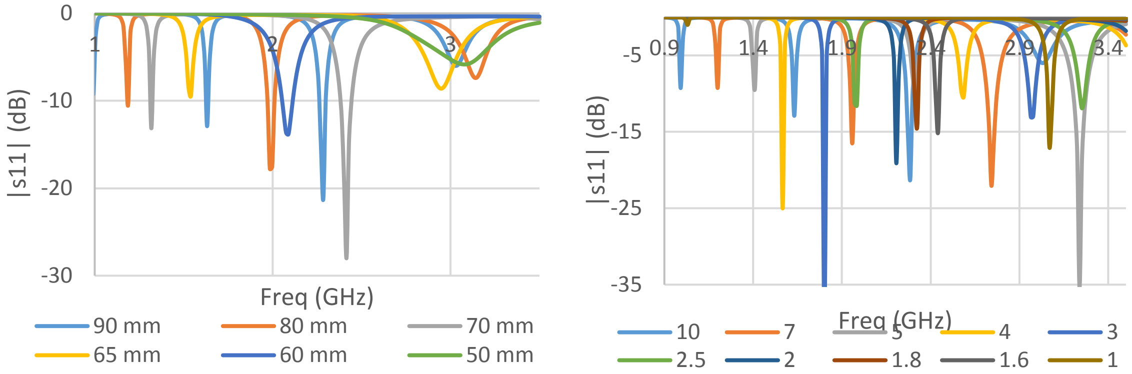


Figure 2 The frequency response of the cavity backed meandered slot antenna as the slot length is changed (left), and as the relative permittivity is changed from 1 to 10 (right).

## 3. The Efficiency of the AUT

In order to find the optimum frequency of operation at a certain depth for the implantable antenna, simulations have been performed using a muscle tissue sphere of frequency dependent properties with a radii r, where 20 mm $\leq r \leq 60$ mm.

Wideband simulations were performed over the frequency band of interest for each set of antennas tuned at various frequency points to investigate the radiation efficiency of the implanted antenna. Considering that the radiation efficiency is not dependent on the antenna mismatch, the results seen in Figure 3 and Figure 4 for each antenna plotted against frequency are comparable to each other.

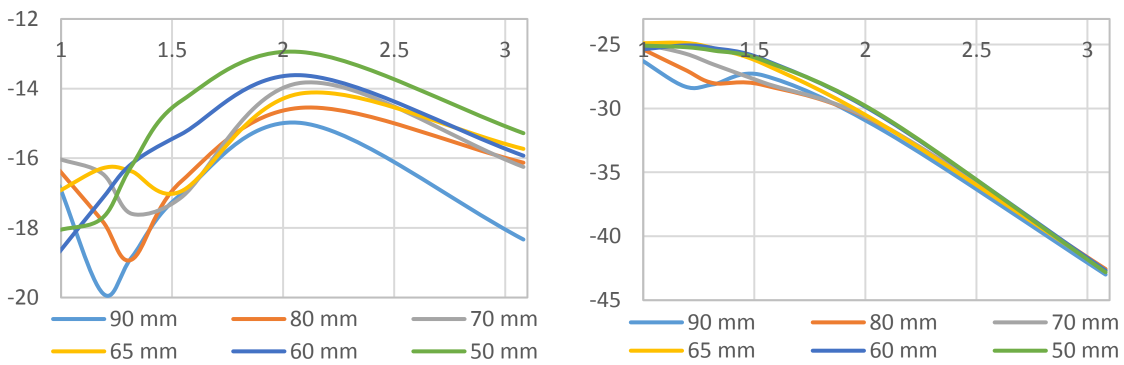


Figure 3 Radiation efficiencies of the antenna set tuned with slot resizing merged into 20 mm and 80mm radius of muscle spheres

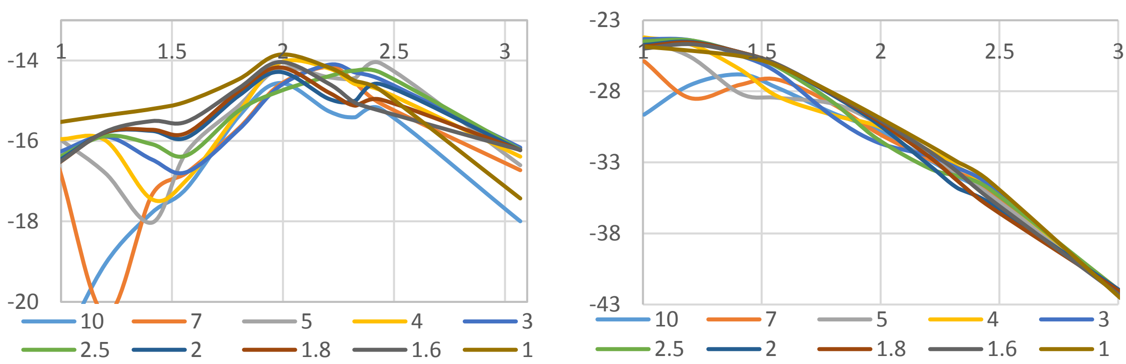


Figure 4 Radiation efficiencies of the antenna set tuned with dielectric loading merged into 20 mm and 80 mm radius of muscle spheres

The antenna is expected to have lower efficiency values towards the extremities of the spectrum because of the dominance of small electrical size at lower frequencies and the high material loss at higher frequencies. The near-field region boundary of an ESA can be approximated with Eqn (1) [4]. For the frequency range considered here R changes from 47 mm to 16 mm. In Figure 3 and Figure 4, it can be observed that once the whole nearfield is merged into the muscle then the efficiency has a clear negative slope. Analytically this should happen at 2.3 GHz and 1.2 GHz for 20 mm and 40 mm radii respectively and this agrees with the simulations.

$$R < \frac{\lambda}{2\pi} \tag{1}$$

## 3. Emission at Its Best

In order to visualize the trade-off between the radiation efficiency of the antenna and the path loss, the maximum value of the Poynting Vector at depths from 20 mm to 80 mm has been recorded. These values are normalized according to the maximum emitted power at that certain depth. Finally the power levels are plotted against frequency and depth as seen in Figure 5. Both techniques applied to tune the resonant frequency generate agreeing results. It is advised that depending on the position of the implant in the human body and the body composition of the human, the implant antenna should be personalized to operate in the most efficient way possible. Same analysis can be repeated for different tissues.

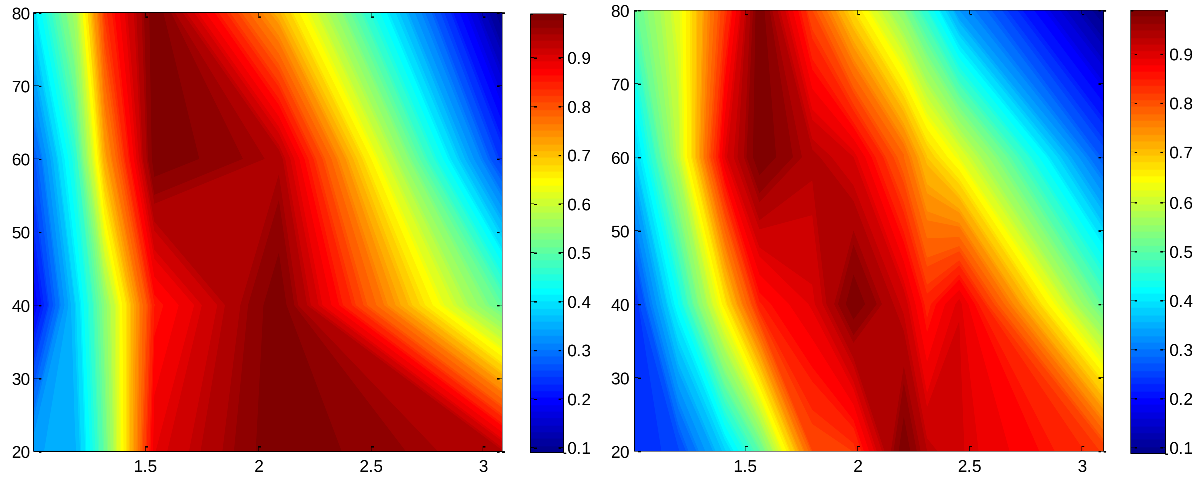


Figure 5 Normalized Maximum Poynting vector values plotted against depth and frequency, frequency of operation is changed by slot resizing and dielectric loading

## 4. Conclusion

Here the optimum frequency of an implanted device was shown to be dependent on the depth of the implant. It was observed that the losses in the nearfield of the antenna are dominant for Gigahertz frequencies up to 80 mm depth. Once the antenna's nearfield is completely merged into the muscle tissue, efficiency degrades monotonically. The competition between the radiation efficiency of the antenna and the path loss was demonstrated with an emission test. It can be concluded that a reconfigurable implanted device would operate best considering the fact that human body decomposition is constantly changing as well as the depth of a particular implant from patient to patient.

## References

[1] *Medical Device Radiocommunications Service (MedRadio)*, FCC 47 C.F.R. Part 95. Available https://www.fcc.gov/general/medical-device-radiocommunications-service-medradio

[2] P. A. Floor et al., "In-Body to On-Body Ultrawideband Propagation Model Derived From Measurements in Living Animals," in IEEE Journal of Biomedical and Health Informatics, vol. 19, no. 3, pp. 938-948, May 2015.

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[4] Antenna Theory: Analysis and Design, John Wiley & Sons, Inc., 2016(4th ed.).