Research report

Cutting-edge technology in wireless transmission -

New generation microwave solutions

Student name: Tibor HERMAN

Nowadays small range radio modules need to consume as little power as possible to have a long battery lifetime while maintaining their best range and small form factor. To keep manufacturing and operational costs low these devices should be flexible in terms of usability. This means they have to be able to use different frequency bands. For such devices the careful design of cheap, small, but highly efficient antennas is an important phase.

As this topic is currently a cutting-edge technology, in my research summary I discuss my work about small antennas. I did a lot of reading about the design of these antennas before designing one myself. I got to know about basic antenna properties, measurement techniques, the types and design aspects of small range antennas. After studying, I designed, built and measured an antenna which can operate in the sub-GHz ISM bands.

Introduction

Small antennas are used more and more often in wider ranges of applications of pocket sized gadgets, and yet there is still more to discover. These antennas are usually modified types of rectangular shapes because of the box's dimensions.

During the design of such antennas, the designer has to take into account the effect of the human body, known as hand effect, the efficiency of the antenna in and out of pocket, and that it should use as few matching components as possible.

Though the efficiency of loop antennas is not too high, the usability is quite impressive. After the earlier use of the 150 and 250 MHz bands, manufacturers started to use these structures in the 400 and 900 MHz bands as well, because with the increase of frequency, grows the efficiency of the antenna. Unfortunately surroundings also have more effect on the antenna with this change, which asks for trade-offs.

In practice the loop element consist of a thin wire or plate. Both solutions are easy to make, cheap and strong and has many advantages over other structures. The problem lies within the degrading effect of the surroundings. With the increasing frequency, the effect of the electrical components grows. This has to be dealt with during the design of the antenna.

Design and simulation

My goas was to design and measure a dual band antenna for the 434 MHz and 868 MHz bands. I used the microwave simulation application, called Sonnet to simulate the structure of the antenna. I started the design with the help of an application note about small antennas. The recommended geometry was valid for a single band, 434 MHz antenna, so I redesigned it to be dual band.

First, I designed the two antenna structures separately, then simulated their impedances, and later I united their geometries. For the 434 MHz band the geometry can be seen on Figure 1. The sizes of the antenna are taken from the AN421 document, from Silicon Laboratories. The antenna is a thin plate loop, with a capacitive resonance element at its input, which represent the internal capacitance of the radio that drives the antenna. This is a variable capacitance which allows it to be a tunable resonant circuit. For the best efficiency the input impedance (Z11) has to be tuned so that the structure resonates at the desired frequency. As the parallel capacitance and the frequency is known, the inductance of the antenna can be given with the use of the well-known Thomson-formula:

$$L = \frac{1}{(2\pi f)^2 C_{pa}} = 66.25\,nH$$

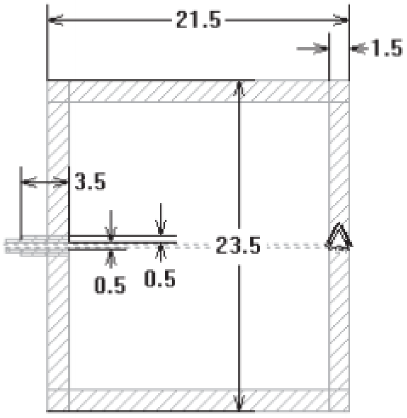
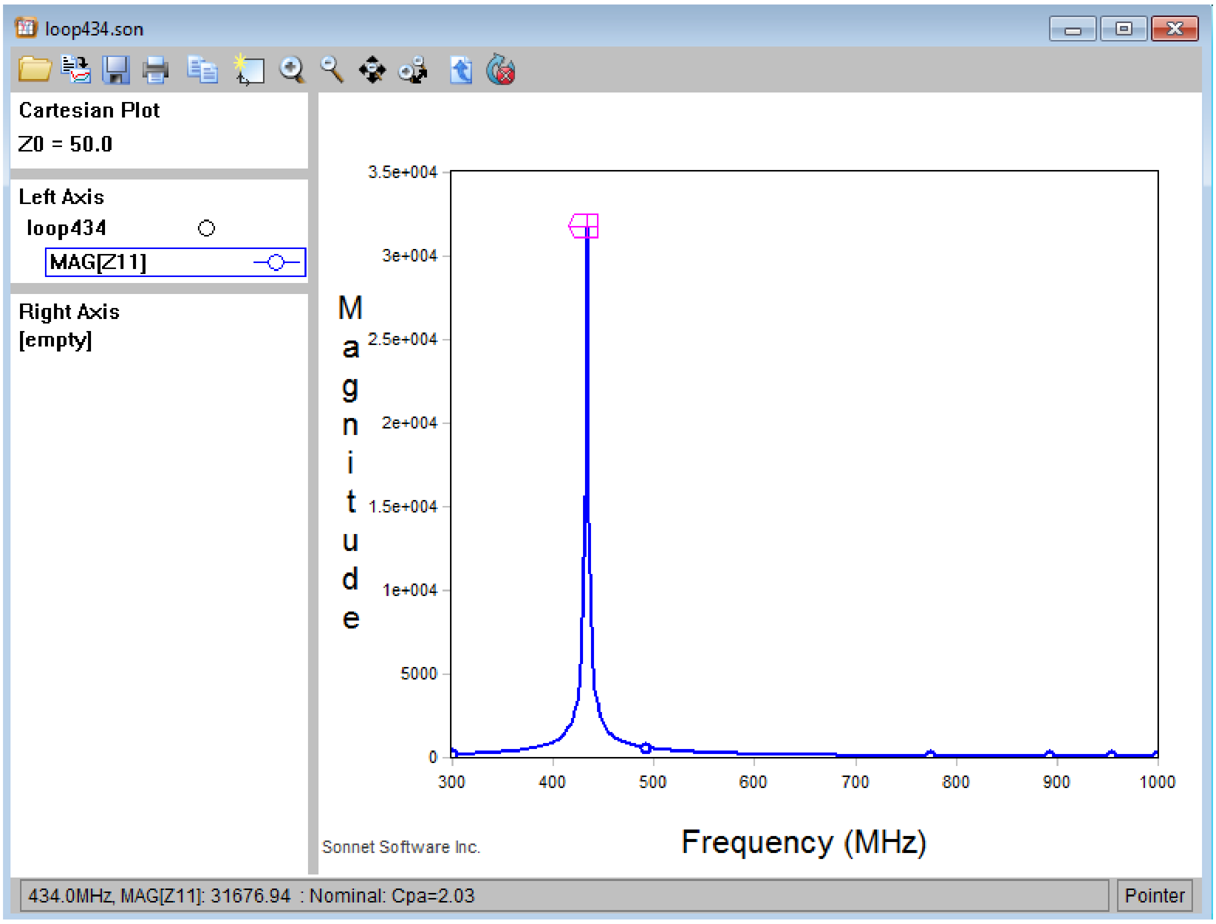


Figure 1. Loop element dimensions in mm for 434 MHz



434.0MHz, MAG[Z11]: 31676.94 : Nominal: Cpa=2.03

Figure 2. Impedance of the loop element as the function of frequency

The geometry of the loop for 868 MHz is of course smaller, as can be seen on Figure 3.

Again, using the Thomson-formula, the impedance can be given:

$$L = \frac{1}{(2\pi f)^2 C_{pa}} = 12.83\ nH$$

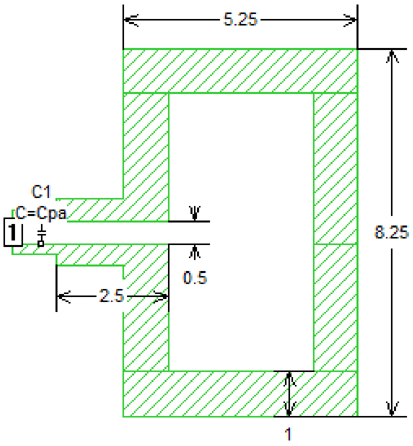
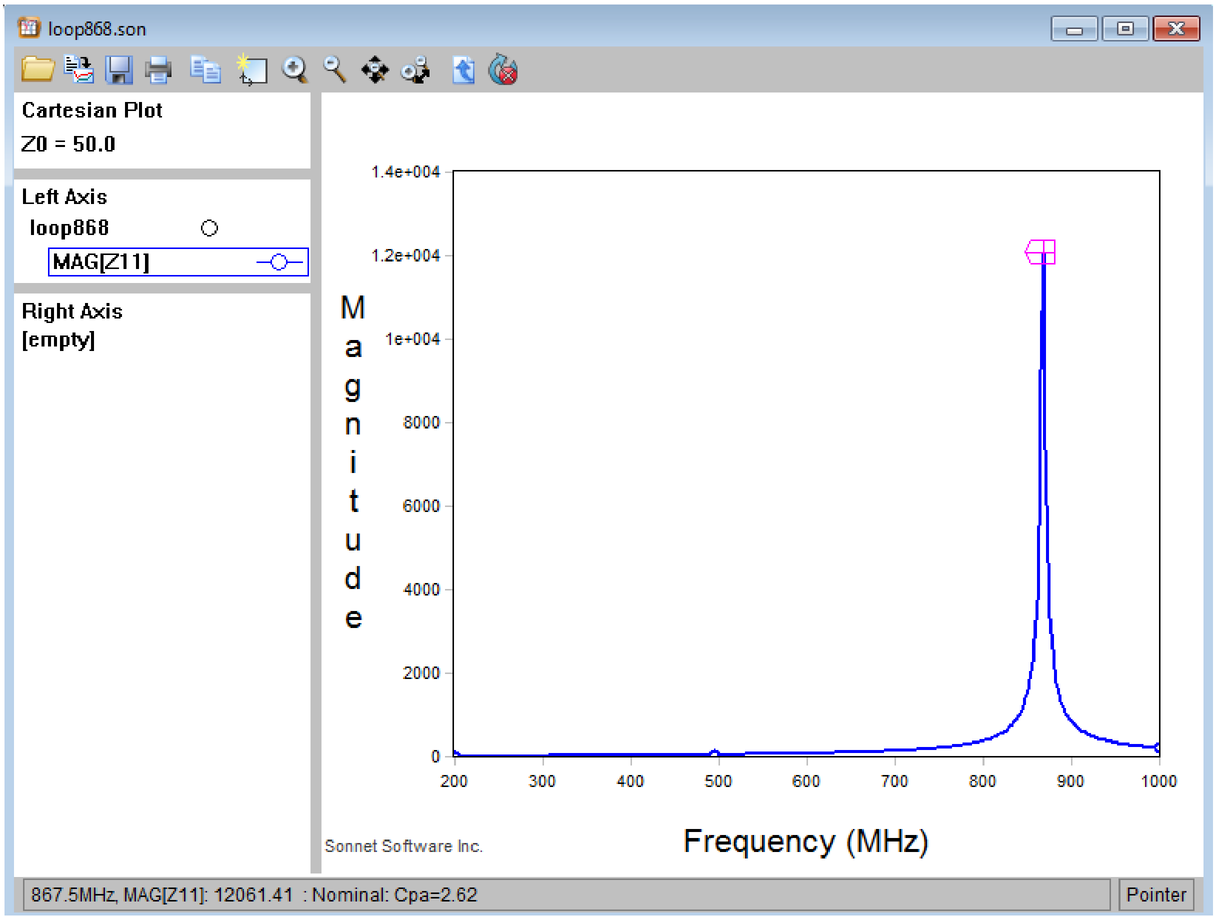


Figure 3. Dimensions of the loop element for 868 MHz



loop868.son

Cartesian Plot
Z0 = 50.0

Left Axis
loop868 ○
MAG[Z11]

Right Axis
[empty]

867.5MHz, MAG[Z11]: 12061.41 : Nominal: Cpa=2.62

Figure 4. Impedance of the loop element for 868 MHz as the function of frequency

The schematic diagram of the power amplifier of a differential output radio can be seen on Figure 5. The parallel capacitance bank can be controlled with FETs.

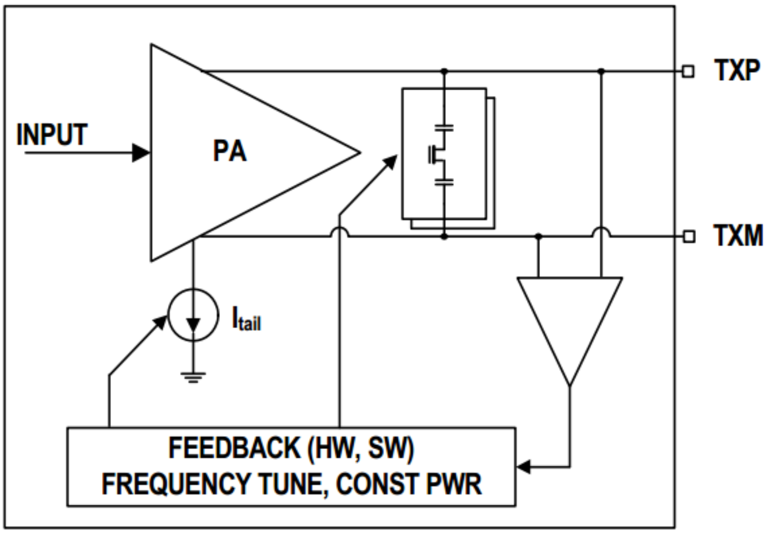


Figure 5. Schematic diagram of a differential output radio

Since the output of the power amplifier is a current generator, the maximum voltage amplitude can be achieved by an approximately 400 Ohm termination, because the supply voltage is 3.3 V. If the impedance is greater than this value, the antenna will generate unwanted harmonics, which need to be filtered as per the applicable laws. Because of this the goal is to approximate the impedance from underneath. This can be achieved by a serial capacitance in the loop, which seems easy to do, but when we add a second loop, parasitic capacitances and mutual inductance will be a problem.

The other restriction during the design is that the capacitance bank of the radio module is finite. It can be set from 0 pF to 10 pF, so the two resonant frequencies have to be achieved with tuning the capacitance in this range. Ideally the cap bank should have 2 and 8 pF capacitance at the operating frequencies. This is required because 868 MHz is the harmonic of 434 MHz, and we want to eliminate harmonics as much as possible and the laws restrict the power emitted on harmonic frequencies. Hence when the antenna resonates on the 434 MHz band, it should be mismatched on 868 MHz

To achieve the desired frequency, I needed to find an optimal geometry. Multiple structures were tested, until the final was found. First, I tried merging the two loops together, which proved useless because of parasitic capacitances. Both the resonant frequency and the impedance were far from the ideal values. I also tried placing the smaller loop inside the large, so that they do not have mutual sides, but this was also a failure, in terms of tenability. I was not able to tune the antenna to the desired frequencies.

The final solution was found in the geometry shown on Figure 6. This structure has two serial and two parallel resonances, as the impedance diagram shows. This is because of the geometry. For me, the parallel resonance is the interesting one, because its impedance is more controllable and is closer to the impedance of the power amplifier. The serial resonance is determined mainly by the serial capacitance, so it doesn’t vary the resonance significantly. Because of this, I started tuning the impedance first. According to the simulation results, the serial resonance is below the parallel resonance, so I kept it in mind while tuning the antenna. It also shows that the final design meets my requirements regarding the resonant frequency, the impedance and the two parallel capacitance values at resonance as shown on Figures 7 and 8. The tuning capacitance tunes the antenna to

868 MHz from 434 MHz with 8 pF difference, which is the value I wanted. The final impedance tuning capacitance values are as follows:

- Small loop Ctop2 = 0.8 pF
- Large loop Ctop = 0.8 pF

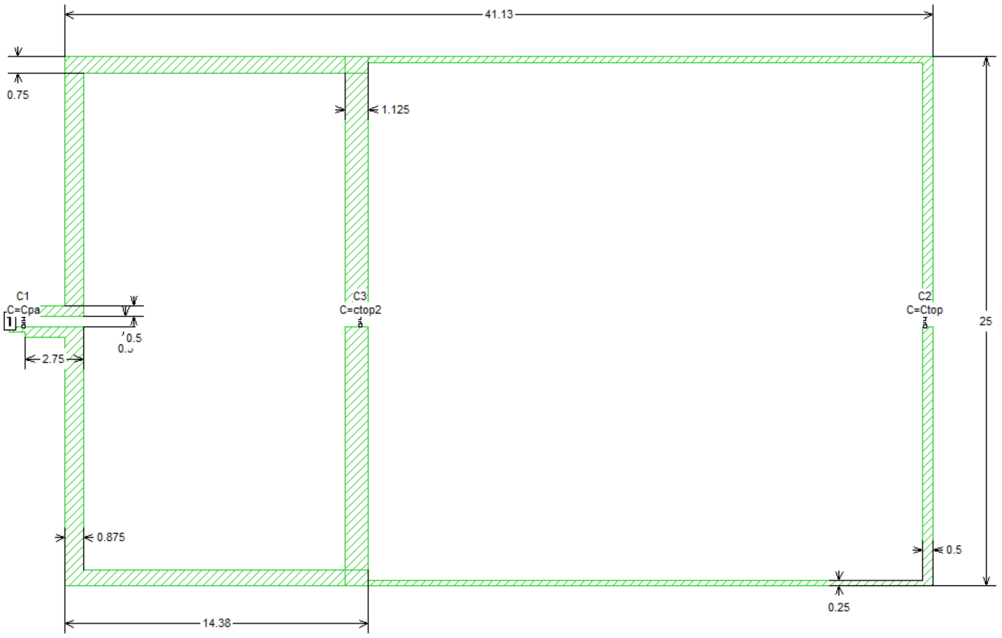
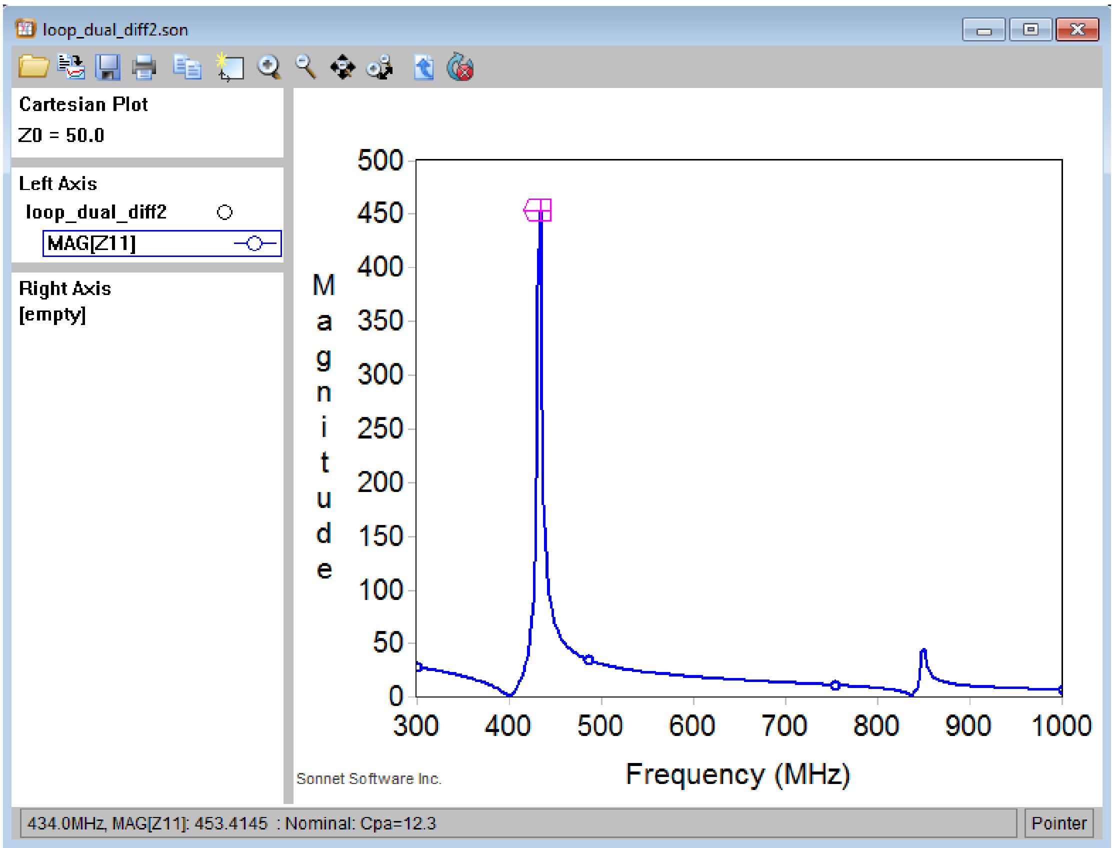


Figure 6. Dual-band loop geometry and dimensions



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434.0MHz, MAG[Z11]: 453.4145  : Nominal: Cpa=12.3
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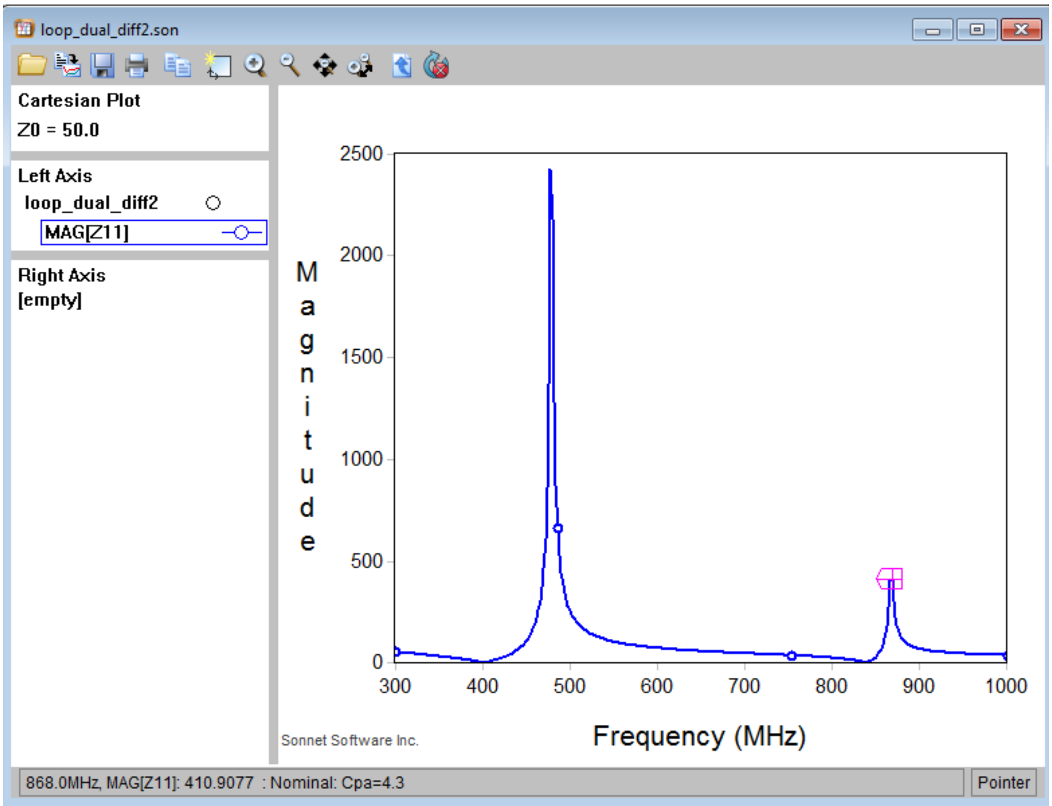
Figure 7. Loop impedance at 434 MHz



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868.0MHz, MAG[Z11]: 410.9077  : Nominal: Cpa=4.3
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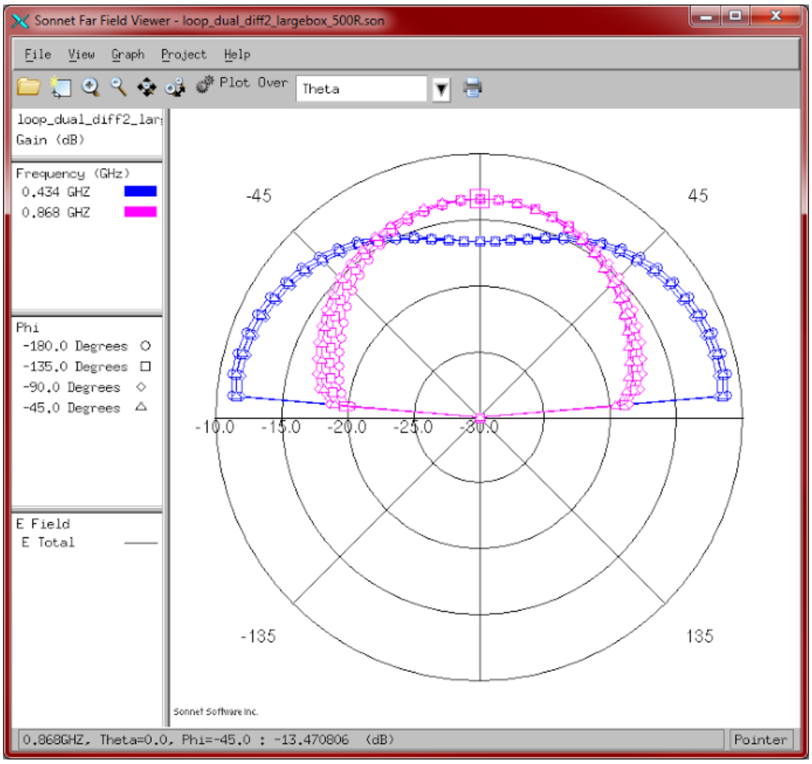
Figure 8. Loop impedance at 868MHz

The gain of the antenna was simulated in Sonnet as well, which proved that this property is limited for small antennas. Figure 9 shows that its maximum value is around -11 to -14 dB.



0.868GHZ, Theta=0.0, Phi=-45.0 : -13.470806 (dB)

Figure 9. Simulated far field pattern

Impedance measurements

The antenna impedance was measures with the help of a vector network analyzer, in dual port mode. The measured S-parameters needed to be converted to single port differential S-parameters, which can be done with the help of Microwave Office. This application is a microwave circuit designer and simulation software. The measurement method can be seen on Figure 10.

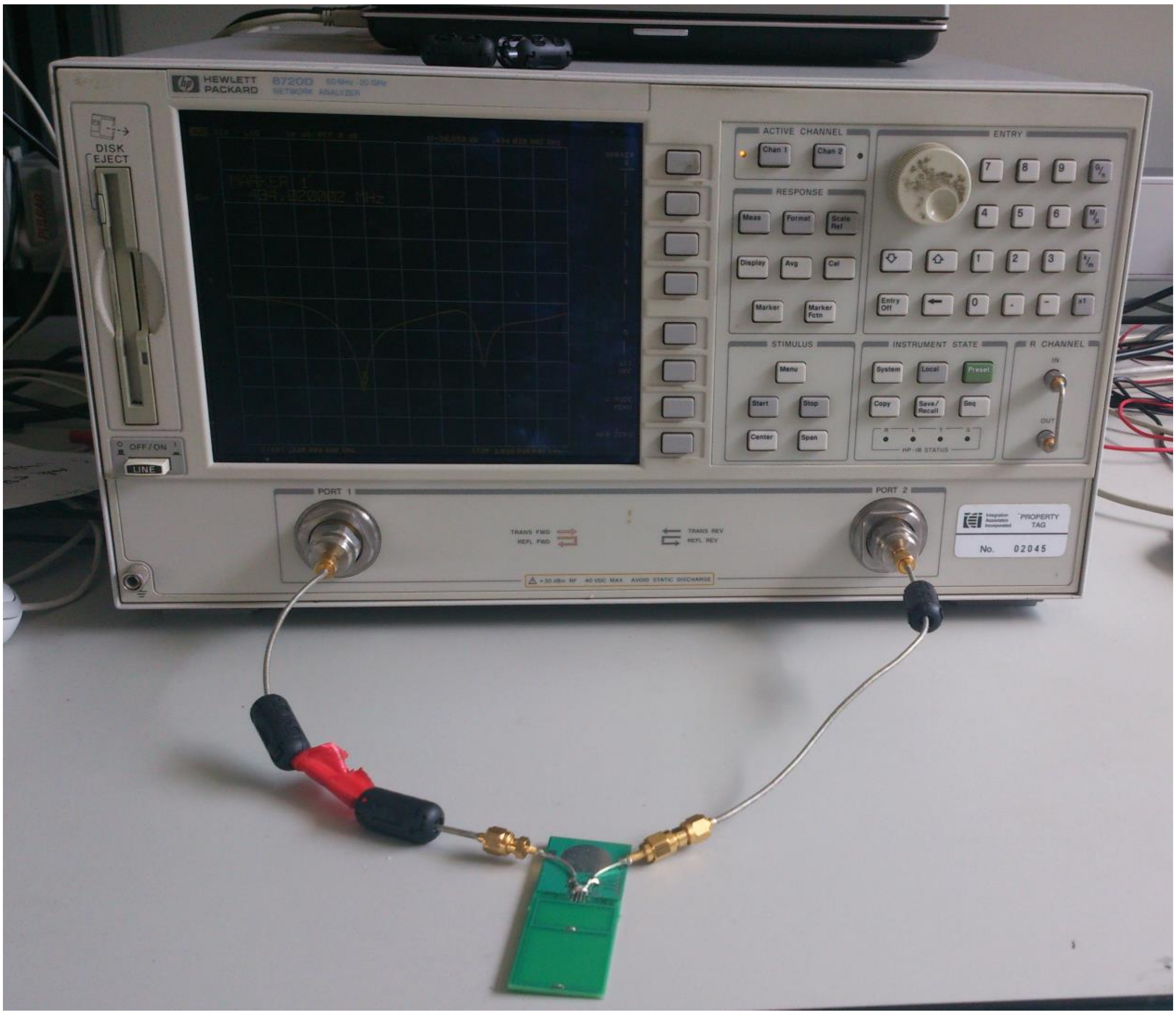


Figure 10. Measurement method

To display the differential impedance in MWO, I created an equivalent circuit, which included the source, a balun and the measurements, which the application treats as a dual pole element, this way the antenna can be simulated in differential mode as shown on Figure 11.

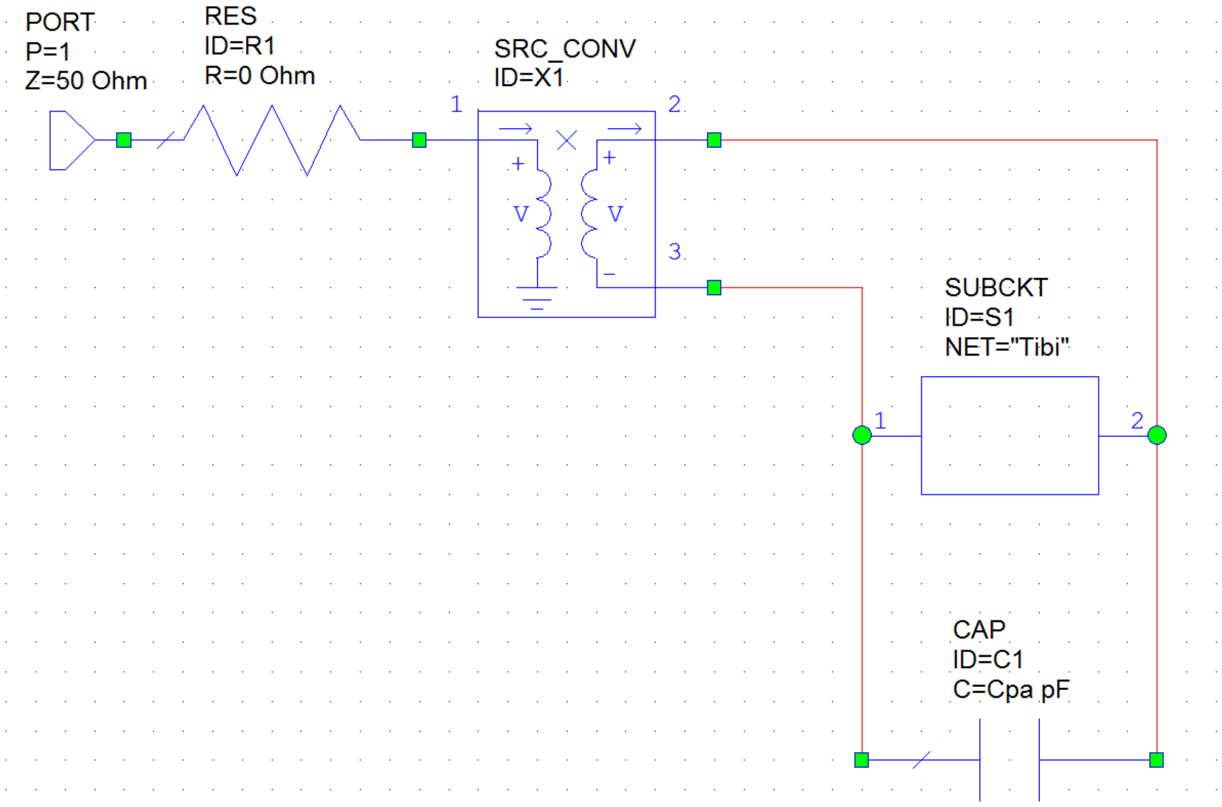


Figure 11. The equivalent circuit of the antenna and the source

The measured impedances can be seen on Figures 13-14. The measurement was carried out with the following capacitances: Ct=0.8pF, Ct2=1pF. The diagram shows the measurements compared to a model, which I designed in MWO as well. The discrete circuit shown on Figure 12 shows a quite similar resonant frequency network, although the impedance is a bit different. The capacitances Ct and Ct2 in the model are within error range of manufacturing technology compared to the measurement results. The measurement shows that the impedance at 434 MHz is higher than the simulated value, which results in worse emission properties. The tuning capacitance is 7.11 pF.

Figure 14 shows the measurements if the antenna is tuned to 868 MHz. This time the impedance is closer to the simulation results. The capacitance bank’s value is 4.21 pF.

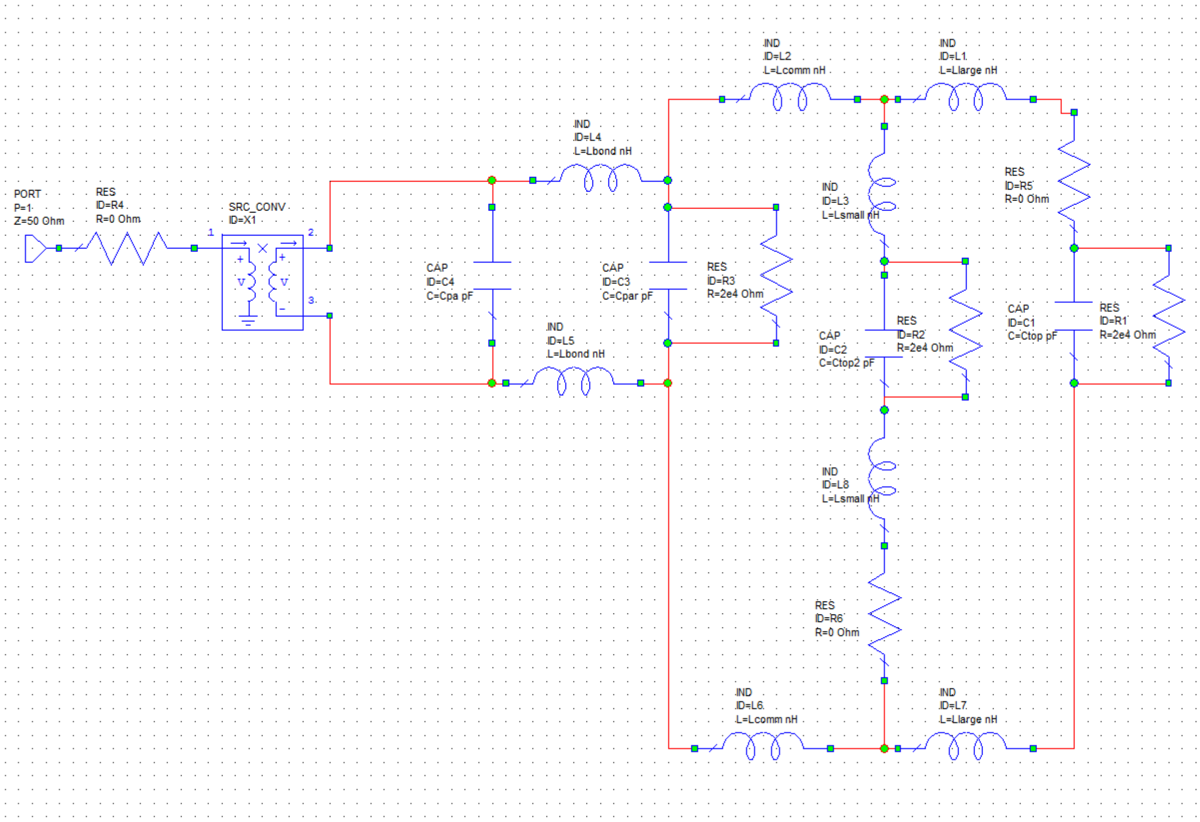
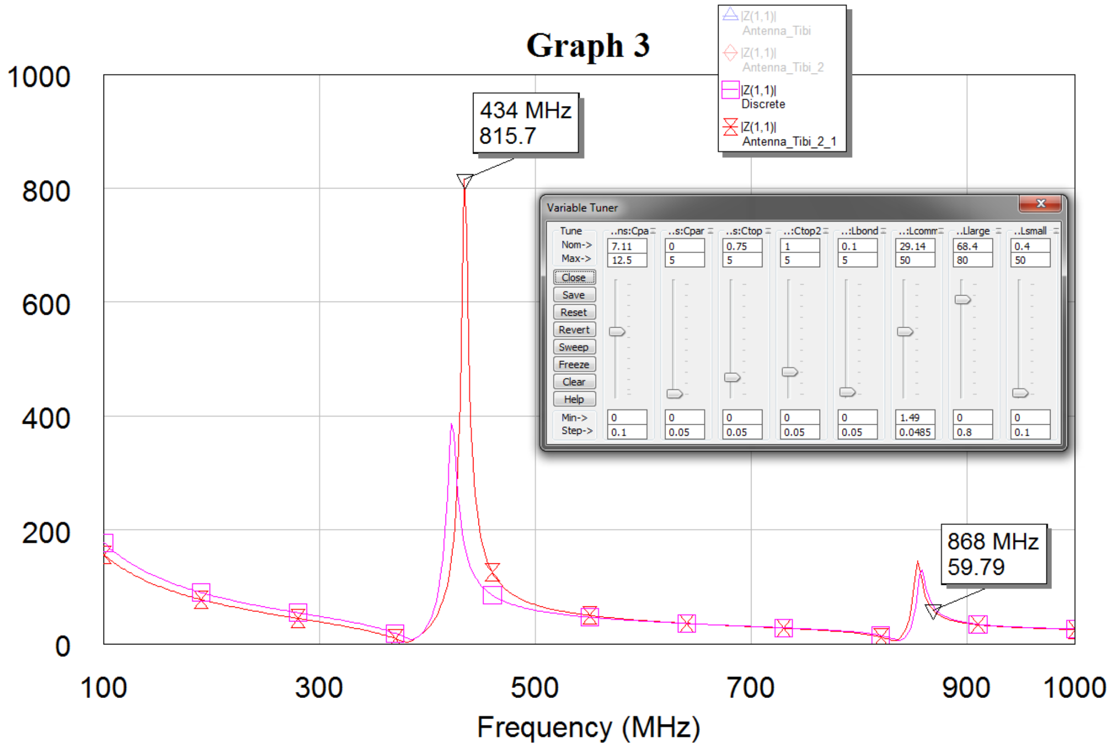
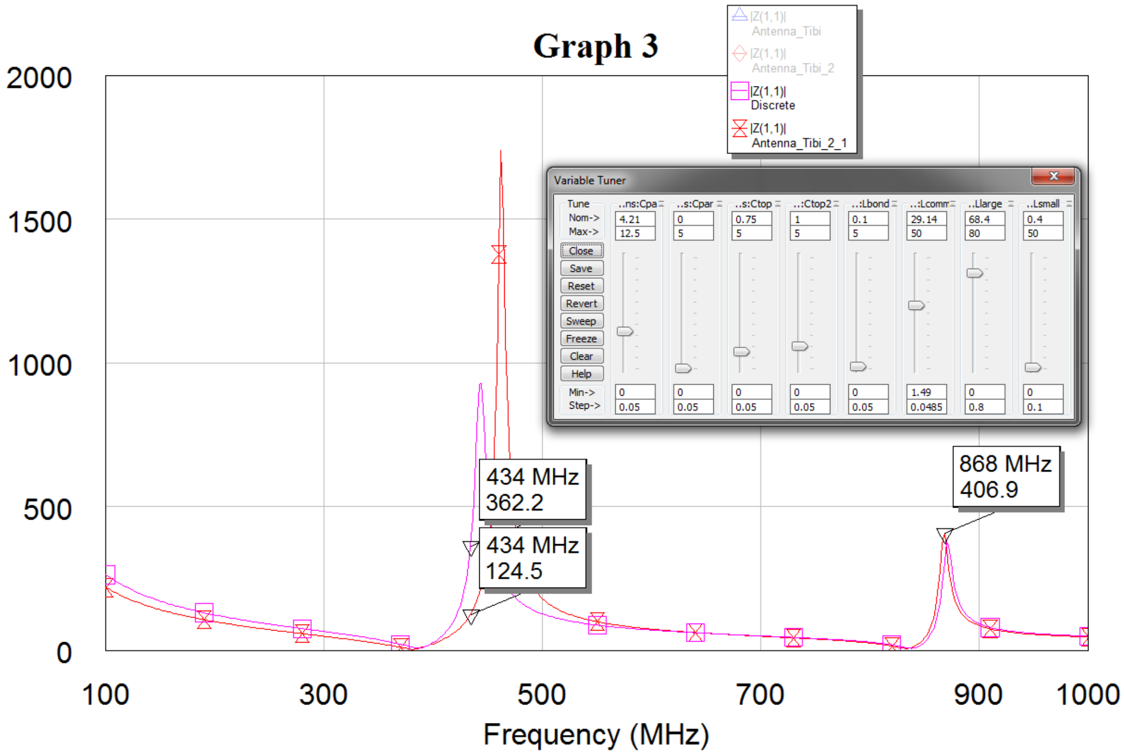


Figure 12. The discrete model of the antenna



Tune	..ns:Cpa	..s:Cpar	..s:Ctop	..:Ctop2	..:Lbond	..:Lcomm	..Llarge	..Lsmall
Nom->	7.11	0	0.75	1	0.1	29.14	68.4	0.4
Max->	12.5	5	5	5	5	50	80	50
Min->	0	0	0	0	0	1.49	0	0
Step->	0.1	0.05	0.05	0.05	0.05	0.0485	0.8	0.1

Figure 13. The measured impedance at 434 MHz



Tune	..ns:Cpa	..s:Cpar	..s:Ctop	..:Ctop2	..:Lbond	..:Lcomm	..Llarge	..Lsmall
Nom->	4.21	0	0.75	1	0.1	29.14	68.4	0.4
Max->	12.5	5	5	5	5	50	80	50
Min->	0	0	0	0	0	1.49	0	0
Step->	0.05	0.05	0.05	0.05	0.05	0.0485	0.8	0.1

Figure 14. The measured impedance at 868 MHz

Summary

In this report I did a research on small antennas as a cutting-edge technology in microwave transmission and learned the design aspects of the development of such structures. I focused on loop antennas, because these are less sensitive to the effects of the human body. I designed, simulated and measured the characteristics of a dual band loop antenna, and found that the simulated values are not far from the real life measurement results. These result can be used in further developments, for example compensating the next design.

Tibor Herman

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