

Study of a dipole antenna in the vicinity of lossless and lossy medium for on-body antenna analysis

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ABSTRACT

In this paper, a detailed study of a dipole antenna in the close proximity of lossy and lossless human modeled structure is discussed. The main goal of the analysis is that which factors should be taken into account to design better on-body antennas and highlight the challenges associated with these kind of antennas in the vicinity of the lossy and lossless medium as compared to free space designs. The analysis is based on dipole separation distance from the equivalent human body structure. The antenna is analyzed in terms of shift in the frequency, reflection coefficient variation, input impedance and gain of the antenna. This analysis is very beneficial in terms of designing on body antennas and reliable wireless wearable devices. A full wave EM solver is used to demonstrate this study.

CCS Concepts

• CCS → Hardware → Communication hardware, interfaces and storage → Wireless devices

• CCS → Human-centered computing → Ubiquitous and mobile computing → Ubiquitous and mobile devices → Personal digital assistants

Keywords

Dipole antenna, reflection coefficient, On-body antenna, lossless medium, lossy medium, layered structure, body area communication, wearable antenna.

1. INTRODUCTION

From last few decades body area networks (BANs) have gained a lot of interest due their attracting applications in health monitoring system, military, sports and entertainment [1-4]. The development of reliable wireless wearable devices is rapidly growing. In these wearable systems, the position of the antenna with respect to the human body plays a vital role for in-body and on-body communication. Antenna designing for body area communication is much challenging as compared to free space antennas. It requires proper consideration of the permittivity of the surrounding material and how much the wave is slowed down and

shortened [5]. In reality the human biological tissue is lossy so it should also be taken into account for the performance analysis of body area antennas..

In this paper, a detailed study of a half wave dipole antenna in the proximity of the human body is investigated. The human body is modeled with equivalent average tissue characteristics. Initially the analysis is based on high permittivity material excluding the losses simplify the problem by giving an insight that how the waves are slowed down and how shortened wavelengths affect the performance of the antenna. Moreover, taking into consideration the losses gives a clearer analysis of the performance of the wearable antennas used for body area communication. In this study, different dipole antenna characteristics such as reflection coefficient, gain patterns, and input impedance are analyzed with various separation of the antenna with respect to lossless and lossy human body tissue. A full EM wave solver FEKO is used to demonstrate the different cases of the study.

2. In the vicinity of lossless medium

The simulation setup in FEKO environment is shown in Figure 1. The dipole is a half wavelength dipole at the designed frequency of 7 GHz. The dipole is analyzed at a height of h from the infinite half space dielectric medium having permittivity equivalent to the average value of lossless human body tissue.

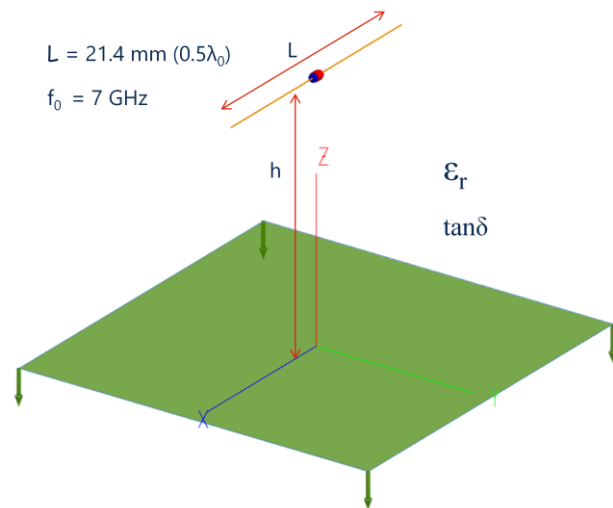


Figure 1. Dipole in the vicinity of lossless half space homogeneous dielectric medium with equivalent body tissue permittivity.

Table 1. Different cases of dipole antenna in the vicinity of lossless and lossy medium.

Number	Permittivity (ϵ_r)	$\tan\delta$	Separation distance (h)
Case 1	50	0	$1 \rightarrow \lambda$
Case 2	50	0	$1 \rightarrow 3 \text{ mm}$
Case 3	$1 \rightarrow 4$	0	0
Case 4	$1 \rightarrow 45$	0	0
Case 5	$1 \rightarrow 45$	0	1 mm
Case 6	5	$0 \rightarrow 0.1$	0
Case 7	5	$0 \rightarrow 0.1$	1 mm

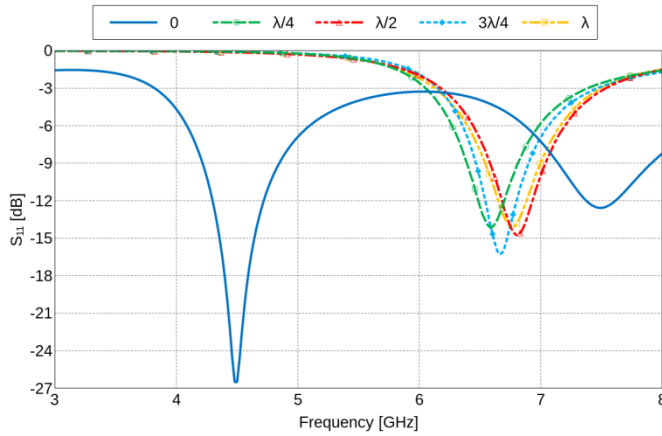


Figure 2. Simulated reflection coefficient results for case 1.

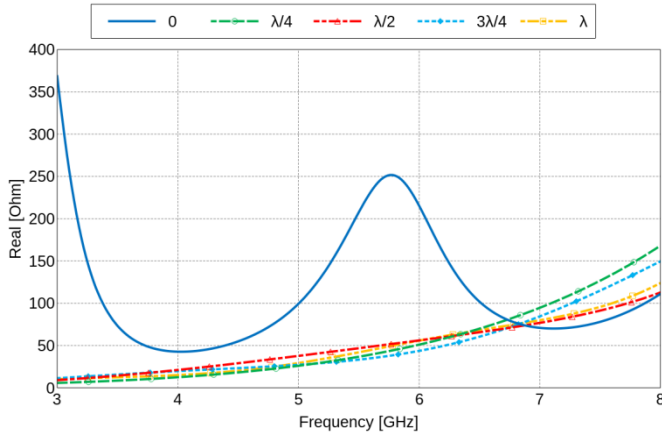


Figure 3. Simulated real part of input impedance results for case 1.

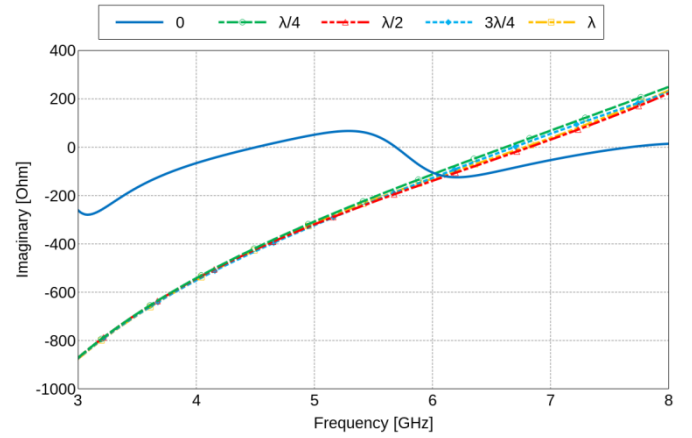


Figure 4. Simulated imaginary part of input impedance results for case 1.

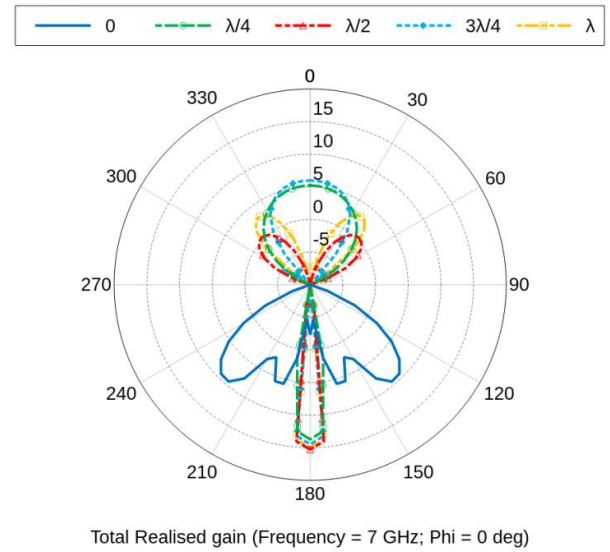


Figure 5. Simulated realized gain pattern results for case 1.

Table 1 shows different cases of the study. Initial five cases are related to lossless infinite half space medium and last two cases are related to lossy medium. In case 1, the dipole height is varied in terms of λ with respect to the plane of dielectric substrate. Figure 2 shows the reflection coefficient results of the dipole with different separation distances from the surface of the medium for case 1. As dipole gets closer, the resonant frequency shifts to lower frequencies. A significant resonance shift is observed when the dipole becomes in contact with the medium. Figure 3 and Figure 4 show the real and imaginary part of the input impedance of the dipole, respectively, with different separation heights from the surface of the lossless medium. In the case of full contact with the body, the imaginary values of dipole input impedance show multiple resonances due to shortening effect. Figure 5 shows the gain pattern of the dipole antenna. In the free space it is observed that patterns are showing constructive interference when the height is $\lambda/4$ and $3\lambda/4$ and destructive interference are observed when it is $\lambda/2$ and λ . Due to shortening effect in the medium much of the dipole gain is reduced and distributed among the side lobes.

As the dipole gets far away from the body surface the gain of the dipole shows an increasing pattern.

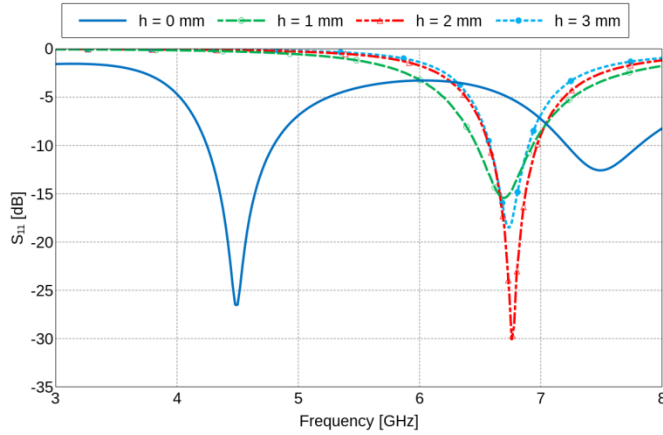


Figure 6. Simulated reflection coefficient results for case 2.

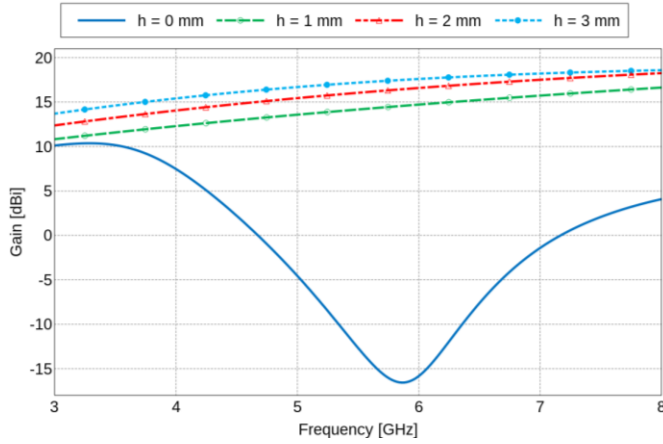


Figure 7. Simulated gain of dipole antenna for case 2.

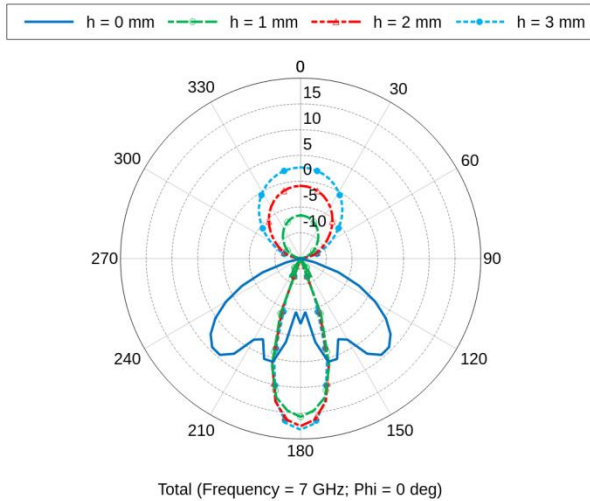


Figure 8. Simulated gain of dipole antenna for case 2.

In case 2, the permittivity is kept same, however, the separation distance is varied in a smaller step near the surface of the lossless medium. Figure 6, Figure 7 and Figure 8 show the reflection coefficient, gain and gain pattern of the dipole antenna with

different distance near the surface of the body. Even near to the surface the antenna resonance frequency shifts only too much when the dipole is in the direct contact with the surface. The side lobes start to form when the antenna is directly connected to the surface and gain starts to increase as it starts to move away from the surface.

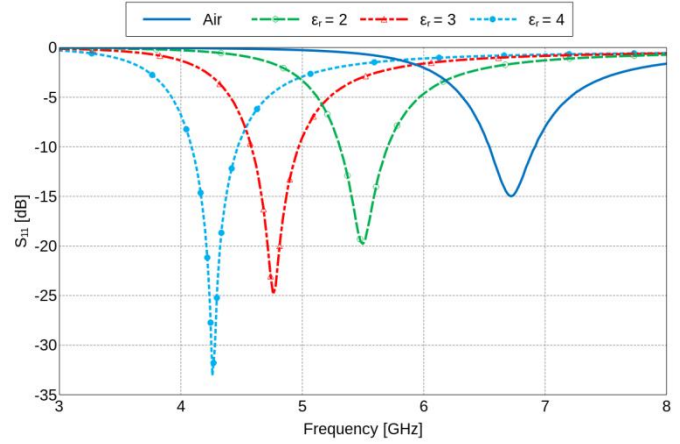


Figure 9. Simulated reflection coefficient of dipole antenna for case 3.

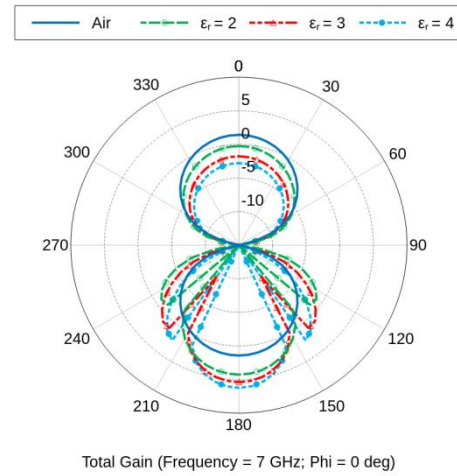


Figure 10. Simulated gain of dipole antenna for case 3.

In case 3, the dipole is in contact with the lossless half space homogeneous dielectric medium whose permittivity is varied from 1 to 4 and its influence was observed on the performance of the antenna in terms of shift in the frequency, gain, and impedance, respectively. Figure 9 shows result of this case that as the permittivity value is increasing, the resonance frequency of antenna shifts to lower frequency due to wave shortening effect. The effect of permittivity variance on the gain of the dipole antenna is shown in Figure 10, which implies an increasing gain inside the medium as the permittivity value is increasing.

Moreover, in case 4 and case 5 the relative permittivity was varied from free space to 45 and a comparison was made between the dipole being direct contact with the surface and dipole at a distance of 1 mm from the surface. Figure 11 and Figure 12 show the reflection coefficient results of the two cases, respectively. In case of direct contact the shift in the reflection is more prominent at different values of relative permittivity, however, in case of 1 mm distance from the surface the shift is insignificant. Figure 13 and Figure 14 show the simulated gain pattern of the dipole in direct contact and 1 mm away from the surface, respectively. In case of direct contact, as the permittivity is increasing the side lobes starts to form more prominently in the medium. Whereas in the case of 1 mm distance from the surface the main lobe is preserved inside the medium and its directivity increases more as value of relative permittivity is increased.

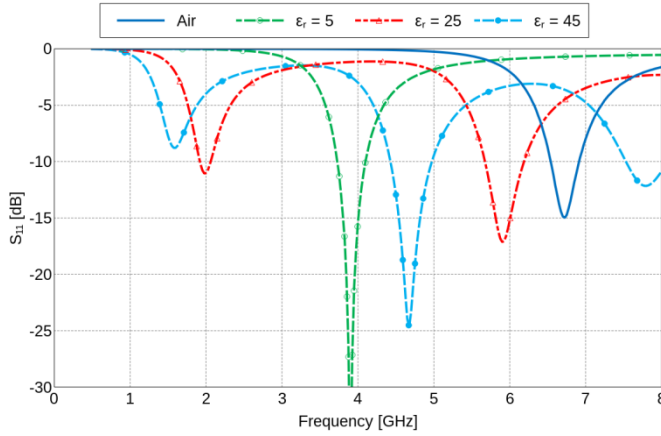


Figure 11. Simulated reflection coefficient of the dipole antenna for case 4.

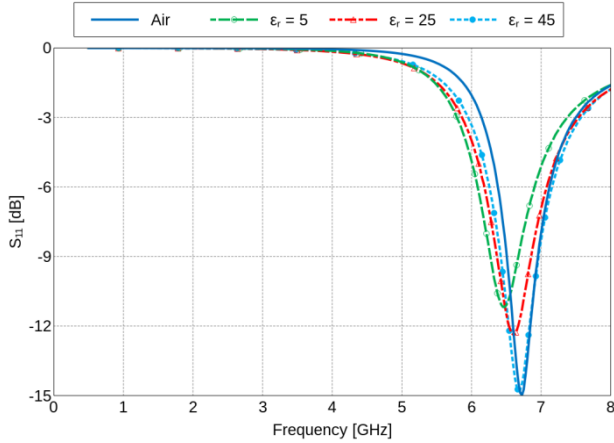


Figure 12. Simulated reflection coefficient of the dipole antenna for case 5.

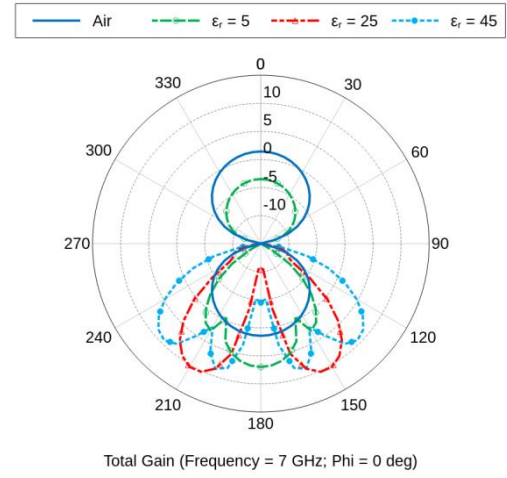


Figure 13. Simulated gain of the dipole antenna for case 4.

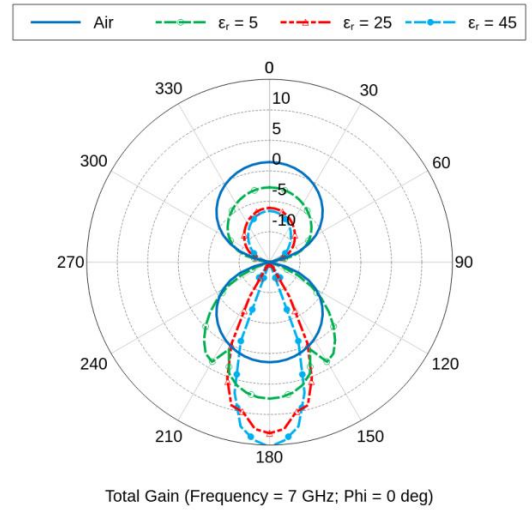


Figure 14. Simulated gain of the dipole antenna for case 5.

3. In the vicinity of lossy medium

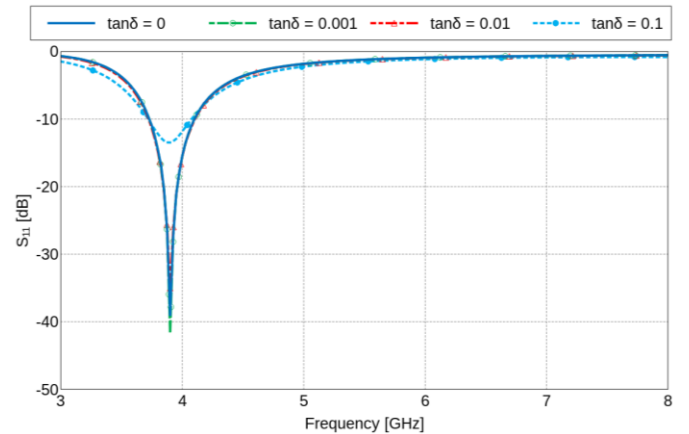


Figure 15. Simulated reflection coefficient of the dipole antenna for case 6.

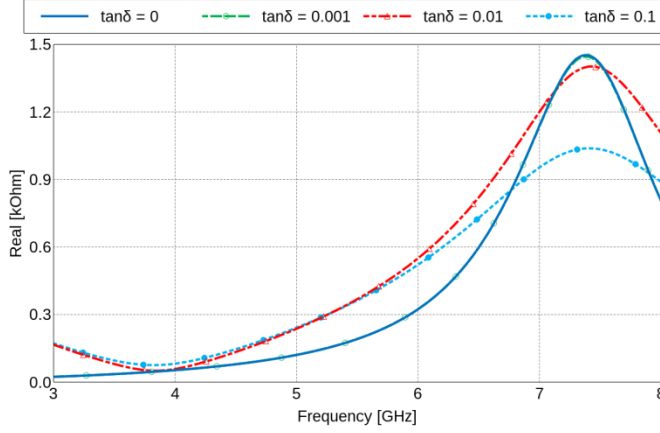


Figure 16. Simulated real part of the input impedance of the dipole antenna for case 6.

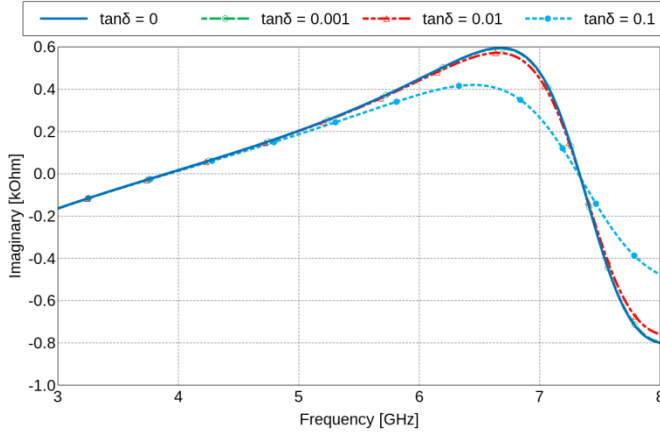


Figure 17. Simulated imaginary part of the input impedance of the dipole antenna for case 6.

In the previous section, all the results were without losses. In reality, the human body is lossy medium. In this part, losses are introduced in the medium and its different impacts on the antenna are analyzed. Table 1 highlights case 6 and case 7 which are associated with the losses of the medium. And it shows the ϵ_r is kept constant with the value of 5 and $\tan\delta$ is varied from 0 to 0.1 to account for the losses. Figure 16 shows the reflection coefficient results of the dipole antenna in direct contact with the lossy medium. In case of direct contact, the losses influence the matching of the antenna and bandwidth is increased a little bit, however, it doesn't shift the resonance frequency of the antenna. Figure 17 and Figure 18 show the results of real and imaginary part of the input impedance of the dipole antenna in direct contact with the lossy medium, the results show a decrease in the maximum value of real and imaginary part of the impedance with the increasing $\tan\delta$ values, however, the zero crossing of the reactance values are not influenced by the loss. Figure 19 shows the reflection coefficient of the dipole at a 1 mm distance from the surface of the lossy medium. The lossy medium has no impact on the results if the dipole is kept at a distance from the surface. And

Figure 19 and Figure 20 show that results are nearly equal for the real and imaginary part of the dipole antenna kept at a distance of 1 mm from the lossy medium. Which implies an isolation layer between the antenna and lossy medium could sustain the performance of the antenna in body area communication.

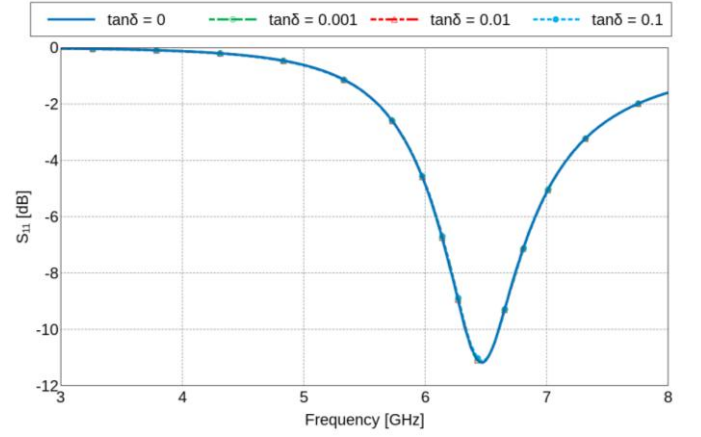


Figure 18. Simulated reflection coefficient of dipole antenna for case 7.

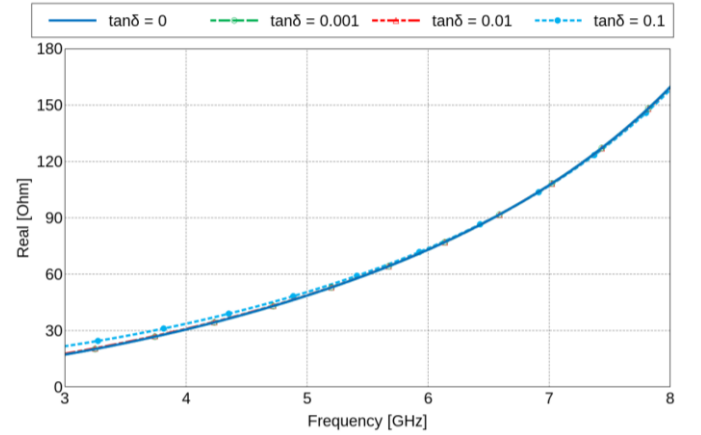


Figure 19. Simulated real part of the input impedance of the dipole antenna for case 7.

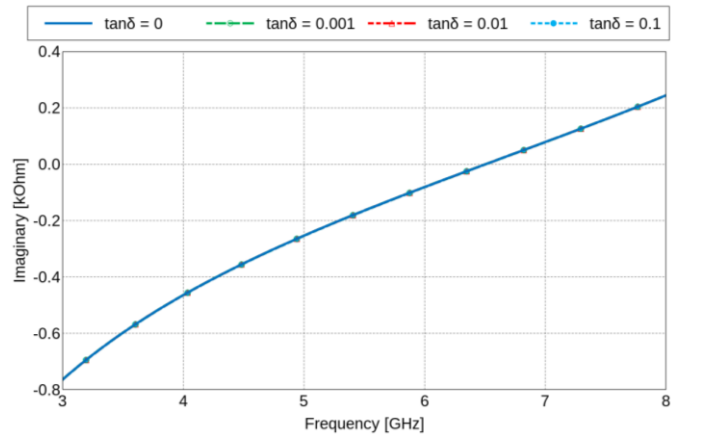


Figure 20. Simulated imaginary part of the input impedance of the dipole antenna case 7.

4. In the vicinity of lossless and lossy layered medium

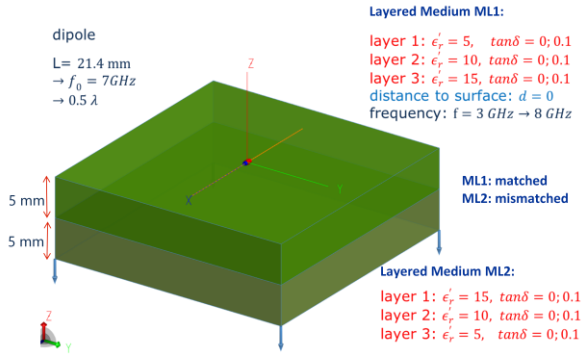


Figure 21. Dipole in the direct contact with the lossless and lossy multilayer dielectric medium.

In this section, different characteristics of the dipole antenna are analyzed when it is kept in contact with the lossy and lossless layered structure. The layered structure is shown in Figure 21. The structure consist of three layers, in the first case layer 1, layer 2 and layer 3 are assigned with the relative permittivity of 5, 10 and 15, respectively and named as multilayer 1 (ML1). In the second case the multilayer named as multilayer 2 (ML2), the permittivities of layers were reversed such that layer 1, layer 2 and layer 3 are assigned with the relative permittivity of 15, 10, and 5, respectively. The simulated gain pattern results in Figure 22 show that in case of lossless ML1, the inside radiation is having high gain and main lobe is maintained, whereas in case of ML2 the gain is reduced and side lobes start to appear. In case of lossy ML1 and ML2 the inside gain deteriorates a lot in both of the cases. Figure 23 shows the gain of the antenna at different frequency values for the lossless case. In lossless ML1 the gain is nearly constant at different frequencies, however, in case of lossless ML2 the dipole gain drops tremendously at higher frequencies.

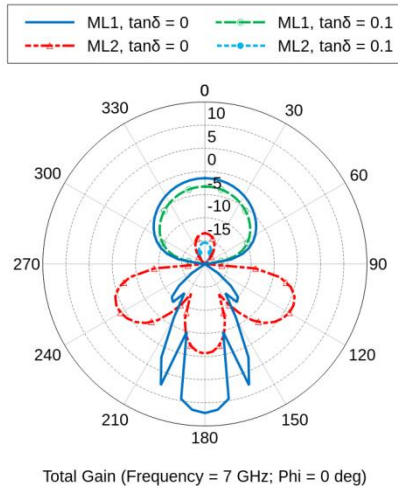


Figure 22. Simulated gain pattern of the dipole antenna in contact with the lossy and lossless layered half space dielectric medium with different tangent loss values.

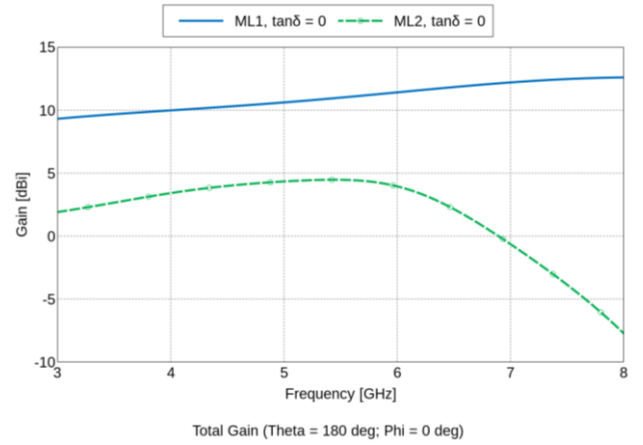


Figure 23. Simulated gain of the dipole antenna in contact with the lossless layered half space dielectric medium.

5. Conclusion

Different dipole cases in the close proximity of lossless and lossy medium are analyzed in depth. A matching condition was observed in lossless multilayer case when the dipole is in direct contact with the medium. The losses deteriorate the matching conditions of the dipole, but have negligible effect on the resonance frequency of the antenna. In order to maintain a good performance of the antenna for outside body communication, the body antenna must be isolated from the human body. The study is very beneficial in designing on body antennas.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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