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# The Effect of Antenna Spacing on Active S-Parameters in Planar Array Antennas

**Emirhan Aydin**
Samsung Electronics Turkey

**Ramiz Erdem Aykac**
Samsung Electronics Turkey

**Abstract**: In wireless communication systems, an RF signal generated by a transmitter is sent into free space and eventually picked up by a receiver. An antenna radiation pattern can be defined as the directional function that characterizes the relative power distribution radiated by an antenna. it is more advantageous to restrict the direction in which signals are sent or received. This requires a steerable antenna. This is referred to as antenna directivity. Directivity refers to the ability of an antenna to transmit or receive signals over a narrow range of horizontal directions. In other words, the physical orientation of the antenna gives it a highly directional response or directivity curve. A directional antenna eliminates interference from other signals received in all directions other than the direction of the desired signal. Directional antennas provide great efficiency of power transmission because the transmitter power can be focused into a narrow beam directed toward the station of interest. The combination of two or more antennas used together is known as an antenna array. Although an array need not contain identical radiating elements, most arrays prefer identical elements such as dipoles, horn antennas or parabolic dish antennas. Antenna arrays provide high directivity, narrow beams, low side apertures, steerable beams and shaped antenna patterns starting from very simple antenna elements. In this study, a series of simulations are performed by varying the inter-antenna distances and the effects of the inter-antenna distance on the S-parameters of planar antenna arrays are investigated at 3GHz center frequency, which will be mostly available for 5G NR applications in the future.

**Keywords:** Planar antenna array, Antenna gain, Antenna directivity, S-parameters, Millimeter-wave antenna

## Introduction

In wireless communication systems, an RF signal generated by a transmitter is sent into free space and eventually picked up by a receiver. An antenna can be defined a transducer that converts a guided wave into an electromagnetic wave propagating on a transmission line. Antennas are made in a variety of shapes and sizes and are frequently used in radio and television broadcasting and reception, radio-wave communication systems, cell phones, radar systems and anti-collision car sensors, among many other applications.

The radiation and impedance characteristics of an antenna are governed by its shape, size and material properties. The dimensions of an antenna are usually defined in terms of the wavelength (λ) of the transmitted or received wave. The length of the antenna depends on the center operating frequency. Antennas have the most effective radiation pattern when their length is directly related to the wavelength of the transmitted signal. Most antennas are defined by a length in terms of a wavelength.

An antenna radiation pattern can be defined as the directional function that characterizes the relative power distribution radiated by an antenna. A direction independent antenna is a hypothetical antenna that radiates the same in all directions and is often used as a reference radiation pattern when describing the radiation characteristics of real antennas. In many types of communication systems, it is desirable to use antennas with omnidirectional characteristics, i.e. antennas that can send messages in any direction and receive them in any direction. In others, it is more advantageous to restrict the direction in which signals are sent or received. This requires a steerable antenna. This is referred to as antenna directivity.

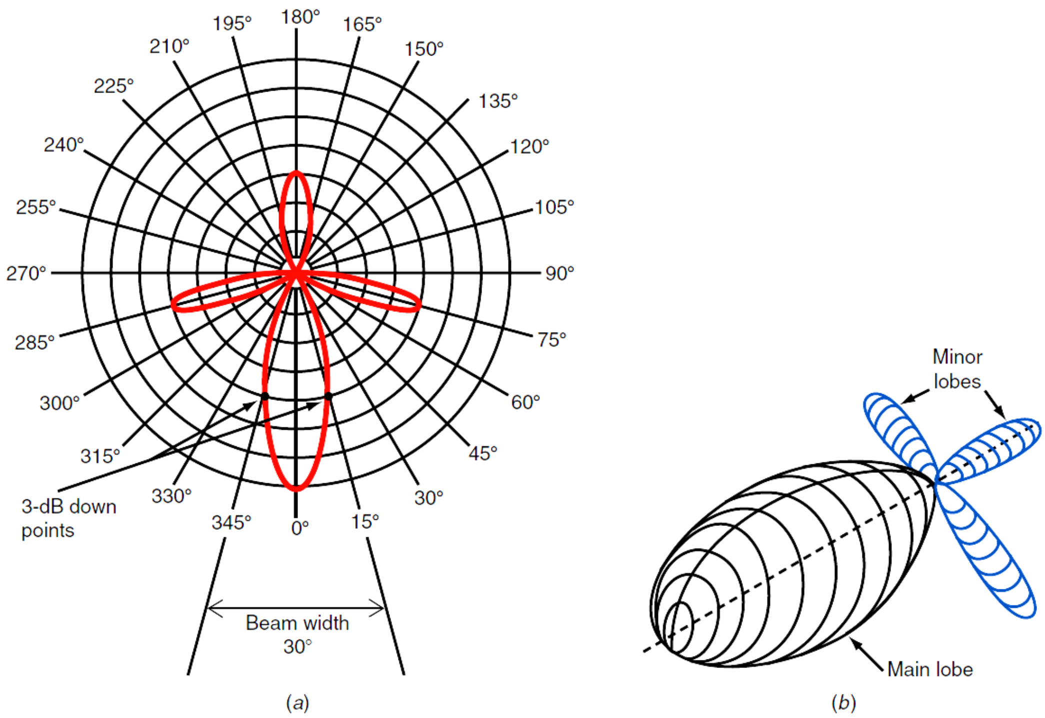


Figure 1. (a) Horizontal radiation pattern. (b) Three-dimensional radiation pattern.

Directivity refers to the ability of an antenna to transmit or receive signals over a narrow range of horizontal directions. In other words, the physical orientation of the antenna gives it a highly directional response or directivity curve. A directional antenna eliminates interference from other signals received in all directions other than the direction of the desired signal. Directional antennas provide great efficiency of power transmission because the transmitter power can be focused into a narrow beam directed toward the station of interest (R. S. Elliott, 1963). Antennas can be designed to be unidirectional; unidirectional antennas send or receive signals in one direction only. A three-dimensional version of the horizontal radiation pattern shown in (Figure 1 (a)) is given in (Figure (b)) (Principles of Electronic Communication Systems, 2014; Aksimsek, 2021)

Figure 1 shows the directivity pattern of a highly directional antenna. The larger loop represents the main response curve for the antenna. Maximum radiation or reception is in the direction of 0°. The three smaller patterns or loops going off in different directions from the main larger pattern are called minor lobes. When using a highly directional antenna, all the transmitted power is focused in one direction. Because the power is concentrated in a small beam, the effect is as if the antenna amplifies the transmitted signal. The directivity causes the antenna to show gain, a form of amplification, because it focuses the power (Tai, 1964). Since an antenna can focus energy in a single direction, the amount of power radiated is significantly higher than the power output of the transmitter. The power gain of an antenna can be expressed as the ratio of the power transmitted $P_{trans}$ to the input power of the antenna $P_{in}$ and expressed in decibels (Principles of Electronic Communication Systems, 2014).

$$\mathrm{dB} = 10 \log \frac{P_{\mathrm{trans}}}{P_{\mathrm{in}}} \tag{1}$$

To create an antenna with directivity and gain, two or more antenna elements are combined to form an array. In this paper, we aimed to design an antenna array with different distance between them to see distance effect on active S-parameters and radiation pattern.

## Antenna Arrays

The combination of two or more antennas used together is known as an antenna array. Although an array need not contain identical radiating elements, most arrays prefer identical elements such as dipoles, horn antennas or parabolic dish antennas. Antenna arrays provide high directivity, narrow beams, low side apertures, steerable beams and shaped antenna patterns starting from very simple antenna elements. Antenna arrays are used to direct radiated power to a desired angular sector. The number, geometrical arrangement and relative amplitude and phase of the array elements depend on the angular pattern to be achieved. Once an array has been designed to focus in a particular direction, changing the relative phases of the array elements (called steering or scanning) to steer it in another direction makes the solution of the problem a simpler matter.

The most basic characteristic of an array is that the relative displacement of the antenna elements relative to each other provides relative phase shifts in the radiation vectors (Cheng, 1971). This can then be added constructively in some directions or destructively in others. This is a direct consequence of the translational phase shift property of Fourier transforms. Collinear antennas usually consist of two or more half-wave dipoles mounted end to end (Figure 2). With this configuration, the individual antenna signals combine, producing a more focused beam (Principles of Electronic Communication Systems, 2014; Yang et al.,2016).

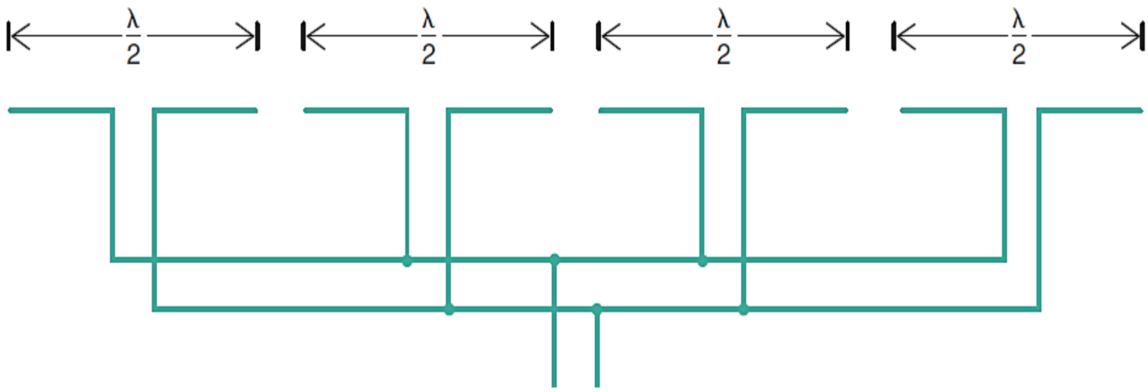


Figure 2. Collinear antenna array

Antenna arrays are generally used for the following purposes:

- To increase the overall directivity of the antenna at the operating frequency
- To achieve maximum radiation in the desired directions and a low side lobe level due to this radiation
- Optimizing the SNR value of the communication system for the desired ranges
- Blocking radiation to unwanted areas

The radiation pattern of an antenna array:

- Depending on the types of antennas
- Distance between antennas used in the array
- Phase difference between the antennas used in the array
- Feed amplitudes of the antennas used in the array
- How the antennas are arranged in the array in question

varies depending on the parameters of the array. In this study, the effect of the distance between the antennas in the array on the directivity and active S-parameters of the array will be investigated.

## Method

### Design Preparation

In order to investigate the effect of the distance between the antennas on the antenna radiation pattern, three different use cases were simulated. By this way, we planned to have an observation on the radiation pattern. Within the scope of the study, each array structure was implemented using the CST Studio Suite program for the following 3 different cases.

**Distance Based Use Cases**

Within the scope of this study, we simulated below cases:

- A planar antenna array consisting of 5 antennas spaced λ/2 apart in the X-axis and 6 antennas spaced λ/3 apart in the Y-axis
- A planar antenna array consisting of 5 antennas spaced at a distance of λ/2 in the X-axis and 6 antennas spaced at a distance of λ/2 in the Y-axis
- A planar antenna array consisting of 5 antennas spaced at a distance of λ/2 in the X-axis and 6 antennas spaced at a distance of 2λ/3 in the Y-axis

*Design Results for a Planar Antenna Array Consisting of 5 Antennas Placed at a Distance of λ/2 in the X-axis and 6 Antennas Placed at a Distance of λ/3 in the Y-axis (Case-I)*

For the 3 GHz operating frequency, the wavelength value to be used was calculated as λ = 102.5 mm using the equation λ = c/f, taking into account the impedance matching margin of 4.5%. Since the effect of distance on the array will be analyzed in this study, all antennas are fed with the same feed amplitude and no phase difference is defined between the antennas. The distance between the antennas placed on the X and Y axes were calculated as λ/2 = 51.25 mm for the X axis and λ/3 = 34.17 mm for the Y axis, shown in Figure 3.

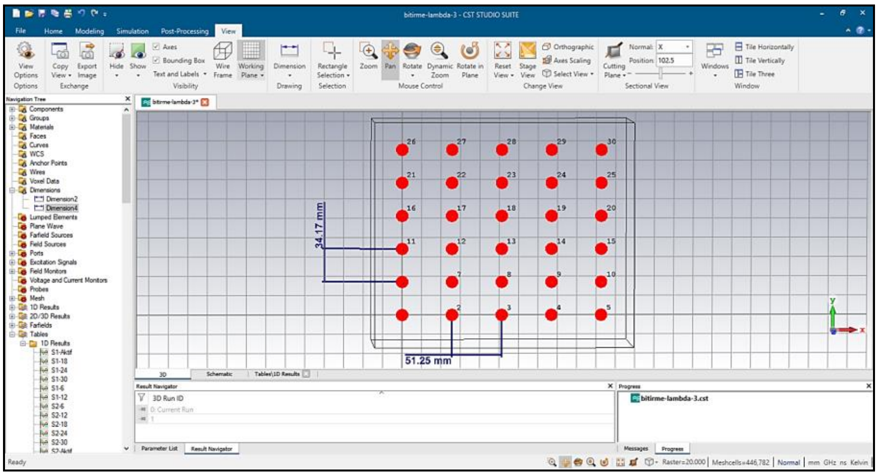

Figure 3. Antenna array design for case-I

Since the array in question is a planar structure, there is a symmetry. Therefore, it will be sufficient to take into account one of the elements with the same radiation in the calculations. In the following simulations, calculations will be made only for one of the symmetric array elements as shown in Table 1.

Table 1. Symmetric antenna matrix

| Located antenna elements on antenna array | |
|---|---|
| 1 | 30 |
| 2 | 29 |
| 3 | 28 |
| 4 | 27 |
| 5 | 26 |
| 6 | 25 |
| 7 | 24 |
| 8 | 23 |
| 9 | 22 |
| 10 | 21 |
| 11 | 20 |
| 12 | 19 |
| 13 | 18 |
| 14 | 17 |
| 15 | 16 |

The results of the active S-parameters obtained for the planar antenna array we have designed are shown in (Figure 4). It was observed that this design has a directivity of approximately -7.36 dB at the operating frequency. In the Figure 5, we can see the overall radiation pattern of the simulation was obtained. Based on this pattern, it is observed that the maximum radiation gain is low and therefore no effective directionality can be achieved.

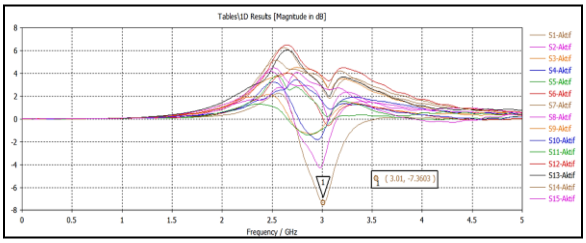


Figure 4. Active S-parameter result for case-I

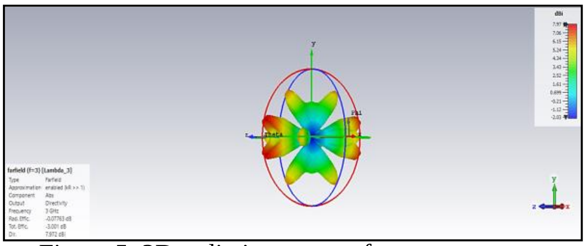

Figure 5. 3D radiation pattern for case-ı

*Design Results for a Planar Antenna Array Consisting of 5 Antennas Placed at a Distance of λ/2 in the X-axis and 6 Antennas Placed at a Distance of λ/2 in the Y-axis (Case-II)*

For 3 GHz operating frequency, the wavelength value to be used was calculated as λ = 102.5 mm using the equation λ = c/f, taking into account the impedance matching margin of 4.5%. The distance between the antennas placed on the X and Y axes were calculated as λ/2 = 51.25 mm for the X axis and λ/2 = 51.25 mm for the Y axis, shown in Figure 6.

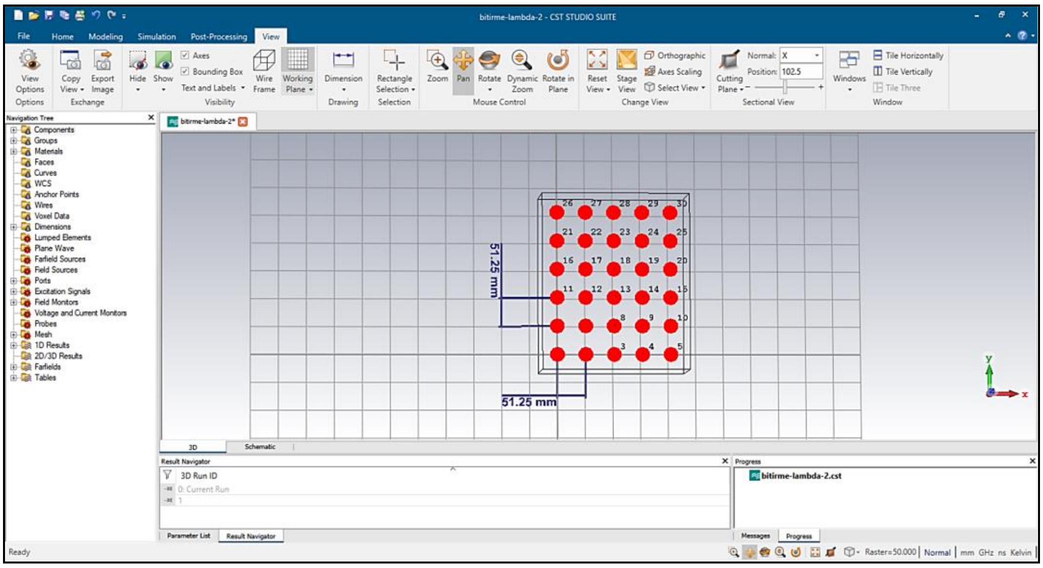


Figure 6. Antenna array design for case-II

The active S-parameters obtained for a planar antenna array consisting of 5 antennas spaced λ/2 apart in the X-axis and 6 antennas spaced λ/2 apart in the Y-axis were shown in (Figure 7). The design has directivity of approximately -8.97 dB at the operating frequency. Compared to Case-I, the gain and directivity of the designed antenna array were increased due to same distance between the antennas, as shown in Figure 8.

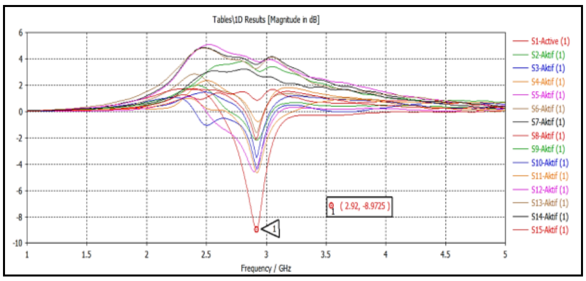


Figure 7. Active S-parameter result for case-II

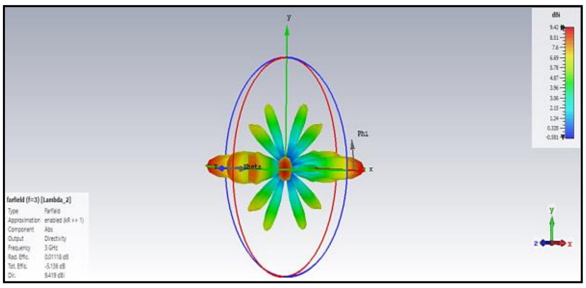

Figure 8. 3D radiation pattern for case-II

*Design Results for a Planar Antenna Array Consisting of 5 Antennas Placed at a Distance of λ/2 in the X-axis and 6 Antennas Placed at a Distance of 2λ/3 in the Y-axis (Case-III)*

For 3 GHz operating frequency, the wavelength value to be used was calculated as $\lambda$ = 102.5 mm using the equation $\lambda = c/f$, taking into account the impedance matching margin of 4.5%. The distance between the antennas placed on the X and Y axes were calculated as $\lambda/2$ = 51.25 mm for the X axis and $2\lambda/3$ = 68.33 mm for the Y axis, shown in Figure 9.

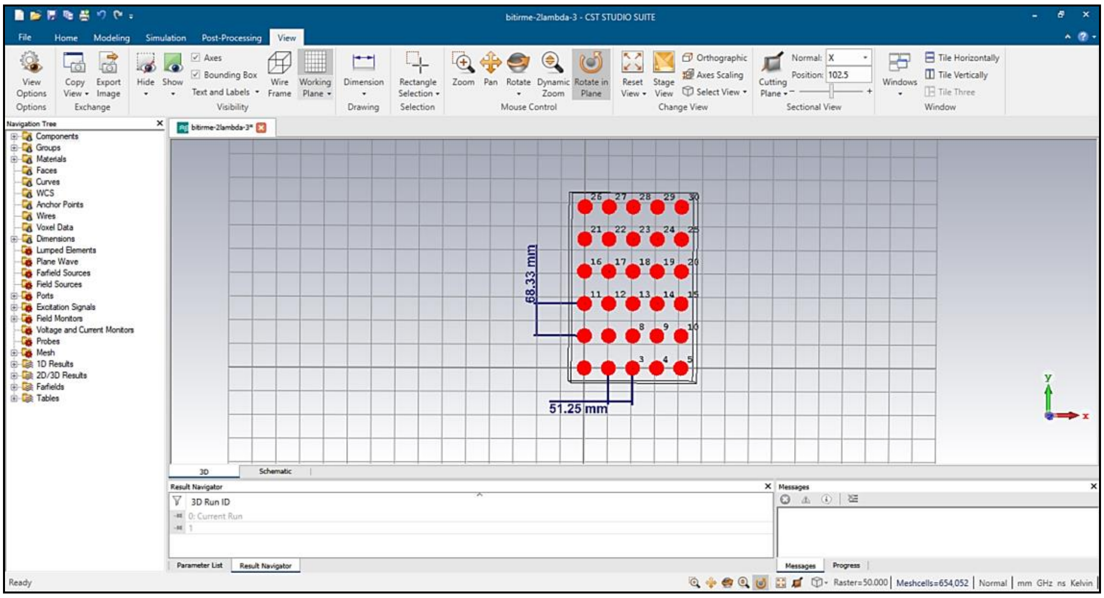


Figure 9. Antenna array design for case-III

The active S-parameters obtained for a planar antenna array consisting of 5 antennas spaced λ/2 apart in the X-axis and 6 antennas spaced 2λ/3 apart in the Y-axis were shown in (Figure 9). The design has a directivity of approximately -7.90 dB at the operating frequency (Figure 10). Compared to Case-II, the gain and directivity of the designed antenna array were decreased due to the different distance between the antennas. In the Figure 11, we can see the overall radiation pattern of the simulation was obtained. Based on this pattern, it is observed that the maximum radiation gain is low and therefore no effective directionality can be achieved.

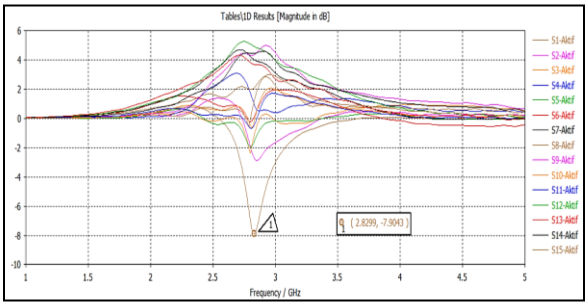


Figure 10. Active S-parameter result for case-III

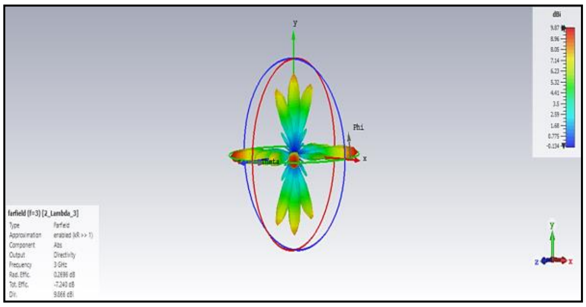

Figure 11. 3D radiation pattern for case-III

## Results and Discussion

The simulation results obtained are summarized in Table 2 below. As a result of this work, we observed that:

- The best results are obtained for the planar antenna array designed using half-wave dipole antennas
- The distance between the antenna elements needs to be same for both x-axis and y-axis to reach maximum directivity for λ/2 dipole antennas, as shown in Figure 12 with green plot, also can be seen on Table 2
- The antenna gains increased based on the distance, it is very important for antenna performance, the higher gain means the more directional antenna-narrower beam-width
- The 3D radiation pattern could not effectively provide directionality as the effect

Table 2. Result matrix

| Dx-distance | Dy-distance | Gain (dB) |
|---|---|---|
| λ/2 | λ/3 | -7.36 |
| λ/2 | λ/2 | -8.97 |
| λ/2 | 2λ/3 | -7.9 |

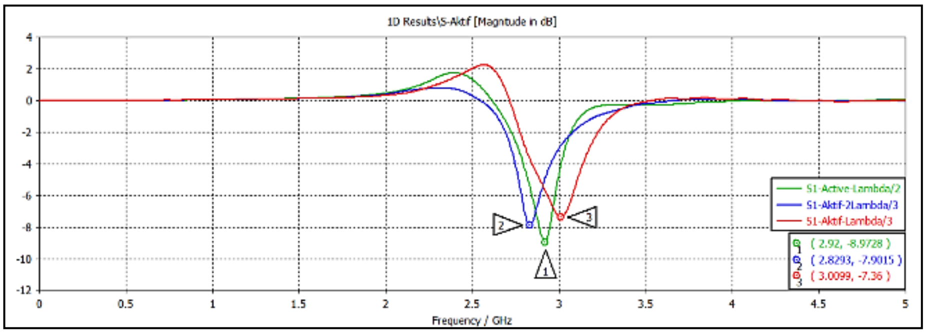


Figure 12. Compare active S-parameter results

## Conclusion

This study has shown that the distances between antennas to be used in high performance antenna designs depend on the wavelength of the antennas to be used. Correct antenna distance selection for high frequency antennas will have a direct impact on the gain of the system to be designed. The use of antenna arrays is expected to increase with 5G NR technology. As a result of the meaningful data and outputs provided, this study is intended to be a reference for future studies.

## Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

## Acknowledgements or Notes

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## Author Information

**Emirhan Aydın**
Samsung Electronics Turkey
Cerkezkoy, Tekirdag, Turkey
Contact e-mail: *e.aydin@samsung.com*

**Ramiz Erdem Aykac**
Samsung Electronics Turkey
Cerkezkoy, Tekirdag, Turkey

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