A Method for Designing Unequal Power Divider for Implementing Antenna Array Excitations

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Abstract. In this paper, a method for designing a feeding network to obtain a low peak sidelobe pattern of an 8*1 linear antenna array is proposed. The optimized element weights were first obtained using genetic algorithm. Then two different networks based on equal and unequal power dividers are designed for the linear antenna arrays. In an equal power divider structure, the power is divided equally into all branches of the network to reach the final ports, while in the unequal structure; the division is only made equal in some branches and unequal in other branches to build an unequal power divider. In the two methods, the design process is based on two stages, the first stage uses a T-junction power divider, and the second stage a Wilkinson power divider is used. In an equal power divider, T-junction and Wilkinson divide the power equally, while in the case of an unequal power divider the T-junction divider is only unequal. In the two designs, the feeding network is designed according to the following specifications: the substrate (FR-4 with $\varepsilon_r=4.3$) and ground dimensions are 440.4mm x 103.8mm x 1.6 mm and 440.4mm x 103.8mm x 0.035mm respectively, and at a resonant frequency of 2.36 GHz. The simulation results showed the effectiveness of the designed power dividers that to be used as a feeding network in the linear antenna arrays.

Keywords: Peak sidelobe pattern, equal power divider, unequal power divider, T-junction divider, Wilkinson power divider.

1. Introduction

Many modern communication applications, such as 5G wireless communications, satellites and radar require an antenna array with unique radiation characteristics such as high directivity and low sidelobe level. Reducing the high sidelobes is essential to suppress the interfering signals and maintaining the overall system performance at acceptable level of the output signal to noise plus interference ratio especially in the severe noisy environments that polluted with many signals which resulted in a very crowded spectrum. For instance, the tracking applications, require a low sidelobe to avoid the interfering from the other tracked targets [1]. The highest permissible limit for the sidelobe level is -13.2 dB in the uniformly excited feeding array (i.e., amplitude and phase excitations are ones and zeros respectively) [2]. However, this level is relatively high and it is not sufficient to avoid the interfering signals in the modern communication systems. Thus, this level should be reduced as much as possible. This can be achieved through unequal amplitude element excitations where it has maximum value at the centre of the array and gradually decaying at the edges of the array. The implementation of such taper in practice is most difficult task especially for large array sizes. This
taper can be effectively configured by combining the unequal Wilkinson power divider and the T-junction power divider so that the output powers of each port is satisfying the required value of the amplitude element excitation.

Usually, in the equal power divider, the power is entered from a specific port, then it is divided into two or more ports, each of them carrying the same value of amplitude and all the ports are matched using a λ/4 transformer. The use of the equal power divider achieves uniform amplitude distribution on the array elements. Its array pattern has a peak sidelobe at -13.2 dB as mentioned before. In order to design a specific taper and then implement it practically, an optimization algorithm is first used to optimize the array amplitudes under some desired constraints such as the required side lobe level and undistorted beam width [3-8]. Then, the amplitudes of the optimized elements are implemented by using unequal T-junction power divider and Wilkinson power divider. The difference between equal and unequal power divider is through the power distribution of the port. In case of equal, the distribution is even, while in the case of unequal it is uneven [9].

Generally, there are several methods to reduce the sidelobes, and they can be divided into two parts, the first is based on optimizing the excitation of all elements using deterministic polynomials such as Dolph and Taylor [10-11]. The second method is based on the modification of the array excitation of some elements that located at the edges of the linear array [12-13]. In [14] the effect of amplitude errors, which is most important factor in practice, was investigated. The difference between the first and the second approaches is in the used strategy of designing the power divider. The first strategy requires a completely different design from the conventional equal power divider because the output of each port is different from the other, thus requires different calculations of impedances for each path of the output port. As for the second strategy, it is possible to rely on some port impedance paths whose output is of equal power, therefore this design is hybrid and requires fewer attenuators than the design in the first strategy.

Recently, many of the works in the literature have been concerned with reducing the level of sidelobes in the printed antenna array by relying on power divider methods such as parallel (or corporate) and series [15-17]. An innovative aperture printed array was introduced in [18], the array contained 100 microstrips distributed in two rows, each row of 50 elements with a distance of 0.15 between any two elements. In this case, the sidelobe level was found to be -20.9 dB. However, the size of the designed whole array was very large while the achieved reduction in the level of the sidelobe was not very low. In [19], Saputra and others introduced a novel feeding network to excite the elements at X-band with Dolph’s distribution. The design was operating at a frequency of 9.3GHz and gave off -19.4dB. In [20], a lower sidelobe was obtained using an evolutionary algorithm to synthesis an array of 10 elements, after which a series feeding network was designed to excite the elements.

In this paper, a method for designing and implementing a specific taper (i.e., non-uniform amplitude excitations) that results in low side lobe level in the array pattern is presented. Two design strategies are introduced for the feeding networks of the linear array elements. The first strategy includes the use of the equal T-junction and Wilkinson power divider which is totally different from the conventional corporate equal power divider, whereas the second strategy includes the use of unequal power divider that realize the optimized amplitude excitations. The two designs are being built on a Microstrips board using CST 2019 version at the following specifications: 2.38 GHz frequency, FR4 substrate.

2. Architecture of the Designed Array

2.1 The 8:1 Equal Power divider

In a conventional equal power divider, the power is evenly divided among the ports that division out from the input port. In the case of a 2:1 power divider, the division is simple, especially in terms of matching, but by increasing the division branches leads to the further complexity of the feeding network and the problem of difficulty achieving the required matching appears.

In this section, the design of an equal power splitter is presented. The design is based on a T-Junction splitter with an equal Wilkinson splitter. The main advantage of this method is to deliver the impedance of 50 ohms to the point where Wilkinson is used, so that each port is integrated into an optimized Wilkinson dual port network. Thus, we can achieve a division of a power equally and
appropriately. Finally, we can achieve the equal and matched power division. In the next two subsections, the method of designing an equal power divider, which consists of two stages (T-junction and Wilkinson), is explained.

**Equal T-junction Power divider**

Since the weights are equal (i.e., amplitude and phase excitations are ones and zeros respectively) in the uniform antenna array, the T-junction design has an output amplitude proportional to the uniform weights. Figure 1 shows an equal T-junction power divider. It is possible to find a relationship between the two power outputs $P_A$ and $P_B$ and the input power $P_{input}$ depending on the following equations:

1. $P_A = \alpha P_{input}$
2. $P_B = (1 - \alpha) P_{input}$

Where $0 < \alpha > 1$ The impedances are also calculated at each output port of the divider as follows:

3. $Z_A = Z_o / \alpha$
4. $Z_B = Z_o / (1 - \alpha)$

The $\alpha$ value decides the ratio of divided power at each output port. In the case of antenna arrays of uniform weights, the value of $\alpha = 0.5$ is chosen considering that the power division is equal. In order to simplify the feeding network for a future splitting (i.e., increasing the port branches), it is necessary to transfer the impedance in each output port to the input impedance. Therefore, a $\lambda/4$ transformer is usually used by which the resonant frequency of the feeding is determined in order to transfer the impedances ($Z_A$ and $Z_B$) to the input impedance while maintaining the output power of each port.

**Equal Wilkinson power divider**

Equal Wilkinson power divider is the second stage in building an optimized integrated feeding network. In the case of the conventional equal Wilkinson power divider shown in [16], the calculation of impedances is easy, but by increasing the output ports, the complexity increases. A Wilkinson splitter can be constructed of an equal power divider in the form of a microstrip line as shown in Figure 2.
The method of dividing the power between any two of the eight ports depends on setting a certain ratio of the power flow in any port, therefore, the equations shown in [17] can be used in the installation of the power divider as follows:

\[ K^2 = \frac{P_A}{P_B} \] (5)

\[ Z_{CB} = Z_0 \sqrt{\frac{1+K^2}{K^2}} \] (6)

\[ Z_{0\alpha} = K^2 Z_{0\beta} = Z_0 \sqrt{K(1+K^2)} \] (7)

\[ R_W = Z_0 \left( K + \frac{1}{K} \right) \] (8)

Here, a Wilkinson splitter is constructed by setting the value of \( k = 1 \), meaning that the ports have the same values of power.

2.2 The 8:1 Side Unequal Power divider
In this section, the methods used in the equal case are used to construct the unequal combination. The power outputs are changed to the ports located at the edges of the feeding network to achieve the desired peak sidelobe pattern level.

Unequal T-junction power divider
Since the weights of the elements in the array are predetermined using the theoretical methods. Designing a feeding network with an amplitude output proportional to the weights obtained from the optimization is achieved. In order to do this, an unequal T-junction divider is used as an initial step. Figure 3 represents an unequal T-junction power divider. Equations (1 to 4) are used in the calculations of the power values and impedances in the output of each port, with taking into account the control of the \( \alpha \) value through which the unequal division is made.

![Figure 3. Unequal T-junction power divider structure](image)

A side unequal power divider design includes several steps. As the design process of an unequal divider is implemented with three stages which are equal and unequal power dividers (the first and third stages are equal and the second is unequal). In the first and third stages, each port passes a power of -3dB, while the second stage, each port passes a power according to the designer at the value required to be designed. According to calculations and measurements, there are two important factors for developing an unequal power divider, the width of the strip line and the isolation resistance between the lines.

3. Simulation Results and Discussions
To validate the performance of the proposed power dividers, equal and unequal power feeding networks were designed and selected to be used in an 8*1 linear antenna array using CST Microwave
Studio with the following specifications: frequency of 2.36 GHz, substrate of FR-4 (\(\varepsilon_r = 4.3\)) with dimensions of (440.4 x 103.8 x 1.6) mm\(^3\) and ground of (440.4 x 103.8 x 0.035) mm\(^3\). Simulation results for the two designs are exported and compared with the theoretical proposed results. As for the equal power divider, the excitations of the elements in the array need equal weights, thus, figure 4 shows the proposed uniform design. Table 1 shows the transmission line width dimensions of the parameters used in this design. The transmission line width equation shown in [18] has been adopted in calculating the transmission line width for our designs.

![Figure 4](image)

**Figure 4.** Complete structure of equal power divider

| Transmission line width | F1 | F2 | F3 | F4 | F5 | F6 | F7 |
|-------------------------|----|----|----|----|----|----|----|
| Value (mm)              | 3.1| 1.6| 3.1| 2.4| 3.1| 3.1| 3.1|

As for unequal feeding network, figure 5 shows the design of an unequal power divider for an 8*1 linear array. Table 2 shows the dimensions of the parameters. Table 3 shows the values of the optimized weights of the elements in the array, on the basis of which an unequal feeding network was designed.

![Figure 5](image)

**Figure 5.** Complete structure of unequal power divider

| Transmission line width | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 |
|-------------------------|----|----|----|----|----|----|----|----|----|-----|
| Value (mm)              | 3.1| 1.6| 3.1| 2.4| 3.1| 0.67| 3.2| 3   | 3.1| 2.3 |
It is observed through this structure that the elements in the centre of the array will be fed with equal powers as in the case of the first design. As for the elements on the sides, there is a need to design an unequal power divider in order to achieve the required perturbed weights depending on the unequal T-junction divider as well as the Wilkinson divider. In order to achieve an unequal power division, the value of the power ratio in the F4 branch is chosen with $P_4=0.25 P_3$ and the power in the F7 branch with $P_7=0.75 P_3$ (i.e., $3/4$ of the power in the F7 branch compared to the F4 branch). Thus, the new powers are divided according to the next divisions, down to the end of the ports. In addition, the ports located at the edges of the feeding network that feeds the side elements will have less powers than the elements located in the centre.

Figure 6 shows the results of the $S_{11}$ parameter for the proposed unequal power divider at 2.36 GHz, while Figure 7 shows the results of the $S_{21}$ and $S_{41}$. It is evident from Figure 5 that the branches fed with the same value of power will have the same values of $S$-parameters, meaning that the power parameter of the branches leading to the side elements carries the same amount of power as well as the centre branches. Therefore, $S_{21}=S_{31}=S_{81}=S_{91}$ (the side ports) and $S_{41}=S_{51}=S_{61}=S_{71}$ (the centre ports). Table 4 shows the comparison of the theoretical element weights with the $S$-parameters results for each output port. It can be seen from this table the convergence of simulation results with the results of the assumed weights.

| Element No. (n) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|-----------------|---|---|---|---|---|---|---|---|
| Normalized amplitude ($u_n$) | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 0.5 | 0.5 |

Table 3 Amplitude weights for 8×1 linear array with the inter-element spacing = 0.5λ (SLL = -20 dB)

Figure 6. Simulated $S_{11}$ for unequal power divider
Finally, figure 8 shows the results of a comparison between the patterns in the case of equal and unequal divider output powers with theoretical pattern and how the unequal power divider was achieved in reducing the peak sidelobe pattern. It is clear that the simulated and assumed lines are completely homogeneous, and any difference between the patterns is a result of transmission line losses, which is not considered theoretically.

**Figure 7.** Simulated S-parameters for unequal power divider

**Table 4** Comparison between assumed optimized weights and simulated S-parameters of the proposed unequal power splitter

| S-parameter | $S_{21}$ | $S_{31}$ | $S_{41}$ | $S_{51}$ | $S_{61}$ | $S_{71}$ | $S_{81}$ | $S_{91}$ |
|-------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Value (dB)  | -13.82   | -13.82   | -7.75    | -7.75    | -7.75    | -7.75    | -13.82   | -13.82   |
| Value       | 0.204    | 0.204    | 0.41     | 0.41     | 0.41     | 0.41     | 0.204    | 0.204    |
| Normalized S-parameter value | 0.497 | 0.497 | 1 | 1 | 1 | 1 | 0.497 | 0.497 |
| Normalized amplitude ($u_a$) | 0.5 | 0.5 | 1 | 1 | 1 | 1 | 0.5 | 0.5 |

Finally, figure 8 shows the results of a comparison between the patterns in the case of equal and unequal divider output powers with theoretical pattern and how the unequal power divider was achieved in reducing the peak sidelobe pattern. It is clear that the simulated and assumed lines are completely homogeneous, and any difference between the patterns is a result of transmission line losses, which is not considered theoretically.

**Figure 8** Comparison between the normalized theoretical and
4. Conclusion
In this paper, a method for designing the feeding network according to a specific weight distribution was implemented. The design considers a linear array that consists of 8 antenna elements in form of rectangular microstrips. The designed array was found to reduce the peak sidelobe pattern to -20dB with compared to the reference value -13.23 dB. Two methods have been proposed to fulfill the requirement of uniform and non-uniform linear antenna array weights by designing an equal and unequal power divider based on a T-junction power divider (equal and unequal) with an equal Wilkinson power divider. Simulation results showed that the output power in each port is proportional to the proposed weights resulting from the theoretical calculations, as shown in Table 4. Through these results, it has been proven that this array is a good candidate for applications such as point-to-point communication and a tracking system that requires low sidelobes.

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