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A Feeding Network with Chebyshev Distribution for Designing Low Sidelobe Level Antenna Arrays

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Abstract

This paper proposes a feeding network to gain low sidelobe levels for microstrip linear antenna arrays. The procedure to design a feeding network using Chebyshev weighting method will be proposed and presented. As ademonstration, a feeding network for 8×1 elements linear array with Chebyshev distribution weights (preset sidelobelevel of -25 dB) has been designed. The unequal T-junction power dividers have been applied in designing the feedingnetwork to guarantee the output powers the same as Chebyshev weights. The obtained results of the amplitudes ateach output port have been validated with theory data. The phases of output signals are almost equal at all ports. Thearray factor of simulated excitation coefficients has been given and compared with that from theory. It is observedthat the sidelobe level can be reduced to -22 dB. The proposed feeding network, therefore, can be a good candidatefor constructing a low sidelobe level linear antenna arrays.

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1. Introduction

In the recent years, microstrip antennas are commonly used in modern wireless systems due to possessing a number of advantages such as light weight, low cost, easy fabrication and integration into PCB circuits. However, they still have limitations, among which low gain is one of these drawbacks. Though this can be alleviated by combining single patches into arrays, it will generate high sidelobe level (SLL) that wastes the energy in undesirable directions and can be interfered by other signals. Therefore, designing arrays with low SLL has always captured a great attention of designers and researchers. Among several ways to reduce SLL of the array antenna, amplitude weighting method is the most effective and efficient one.

There are some common amplitude weighting methods, which are Binomial, Chebyshev, and Taylor [1]. Of three methods, Binomial can help eliminate minor lobes and have no sidelobes, but it is not preferable for large arrays due to high variations in weights [2]. Taylor produces a pattern whose inner minor lobes are maintained at constant level [2]. Whereas Dolph- Tschebyshev (Chebyshev) array provides optimum beamwidth for a specified SLL [1, 2]. Among three methods, Chebyshev arrays can provide better directivity with lower SLL [3]. These methods are used mostly in digital beamforming, but occasionally used directly in antenna design. In microstrip antenna arrays, the amplitude weight distributions can be obtained by designing a

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feeding network that has powers at output ports proportional to the coefficients of the above distributions.

In the literature, there are several publications involved the study and design of feeding network with amplitude weight tappers. A number of series feeding networks have been proposed in [3-9]. The design of feeding network for an aperture coupled microstrips antenna array with low sidelobe and backlobe has been studied in [4]. Though the feed designed for 25×1 aperture linear array can help to acquire low SLL (-20.9 dB), the authors did not mention the distribution to be used. In [5, 6], two novel feeding networks were designed for 5×1 elements linear arrays. Sidelobe suppression (-16 dB in [5], and -20 dB in [6]) has been given by using Dolph Chebyshev power distribution. Sidelobe reduction to -20 dB has also been obtained by using Chebyshev amplitude weight feeding network in [7]. Several Chebyshev feeding networks for 8×1 linear arrays have been presented in [8-10]. However, those proposals are difficult to fabricate due to the complex structure of the feed (2-3 layers) that may cause high fabrication tolerance.

Corporate feed networks for the performance of low SLL have also been introduced in [10-13]. The work in [11] presented a feed network based on Binomial weight distribution and Wilkinson power dividers with circular polarization for vehicular communications. However, the SLL was only reduced to -18 dB as the effect of complex structure of the feed and resistors in Wilkinson power dividers. A. Wahid has proposed a 8×4 planar array with Dolph-Tchebysheff distribution in [12, 13]. This array could provide a low SLL of -22 dB in E-plane, but it was about -14 dB in H-plane.

In this work, a feeding network with Chebyshev distribution (only one layer) for designing low SLL microstrip antenna arrays will be proposed. The step by step in design process will be presented. A Chebyshev feeding network for a 8×1 linear antenna array with preset SLL of -25 dB has been designed as a demonstration of the procedure. In order to get the output power at each port proportional to Chebyshev weights, unequal T junction power dividers have been used. The obtained results indicate that the amplitude of output signal at each port is proportional to the coefficient of the Chebyshev weights. The phases of signals at each port are also in phase with each other. The array factor of simulated excitation coefficients has been given and compared with that from theory. It is observed that the sidelobe level can be reduced to -22 dB.

2. Dolph-chebyshev’sdistribution

Chebyshev tapered distribution, a well-known amplitude weight method, can help to set SLL to a specified value. This work can be done by mapping the array factor to Chebyshev polynomial [13]. The array factor (AF) of a linear array as given in [14] is written as:

$$AF(\theta) = \sum_{n=0}^{N-1} u_n e^{j\beta d n \cos(\theta)} = \sum_{n=0}^{N-1} \left(z - e^{j\psi_n}\right) \quad (1)$$

Table 1. Chebyshev amplitude weights for 8×1 linear array with the inter-element spacing = 0.5λ (SLL = -25 dB)

Element No. (n)	1	2	3	4	5	6	7	8
Normalized amplitude (u_n)	0.378	0.584	0.842	1	1	0.842	0.584	0.378
Amplitude distribution (dB)	-11.7	-9.82	-8.32	- 7.49	-7.49	-8.32	-9.82	-11.7

where: u_n is amplitude weight excited at each port, β is the wave number, d is the element spacing, θ is scanning angle, $\psi_n = \beta dn\cos(\theta)$.

A Chebyshev polynomial $T_m(x)$ of m^{th} order and an independent variable x is an orthogonal polynomial and can be represented by:

$$T_m(x) = \begin{cases} \cos(m\cos^{-1}x) & -1 \le x \le 1 \\ \cosh(m\cosh^{-1}x) & |x| > 1 \end{cases} \quad (2)$$

It can be observed that when $-1 \le x \le 1$, these polynomials oscillate as a cosine function. However, outside that range, they quickly rise or decrease as the cosh function. Assuming that the maximum SLL is 1.0, it will equal to the height of the ripples of the Chebyshev polynomial as$-1 \le x \le 1$. An N element array corresponds to a Chebyshev polynomial of order $N-1$. The main lobe of the array factor can be mapped to the peak value of the Chebyshev polynomial by the equation below:

$$T_{N-1}(x_{mb}) = 10^{s/20} \quad (3)$$

where: s is the SLL (in dB), x_{mb} is the position of main lobe.

Then, setting (3) equal to (2) results in the main lobe at:

$$x_{mb} = \cosh\left[\frac{\cosh^{-1}(10^{s/20})}{N-1}\right] \quad (4)$$

Next, zeros of the polynomial are mapped to NULLs of the array factor followed by the equation:

$$x_n = \cos\left[\frac{\pi(n-0.5)}{N-1}\right] = x_{mb}\cos\left(\frac{\psi_n}{2}\right) \quad (5)$$

By using the expression $z_k = e^{j\psi k}$, the weights u_k can be found by substituting phases and x_{mb} to the AF. As a demonstration, the Chebyshev amplitude weights for 8×1 linear array with preset SLL of -25 dB are calculated and given in the Table 1. Figure 1 gives the normalized radiation pattern of 8×1 linear array with Chebyshev weights (SLL reduced to -25 dB) assuming that isotropic elements are used.

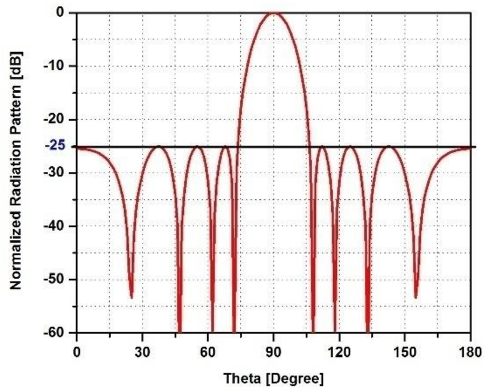

Figure 1. Normalized radiation pattern of 8×1 linear array with SLL suppressed to -25 dB (element spacing = 0.5λ).

3. Feedingnetworkdesign

3.1. T-junction power divider

As the weight coefficients have been defined, the next step is to design a feeding network that has amplitude outputs proportional to the obtained weights. In order to do that, unequal T-junction dividers have been used in this work. A typical unequal T-junction power divider is shown in Figure 2.

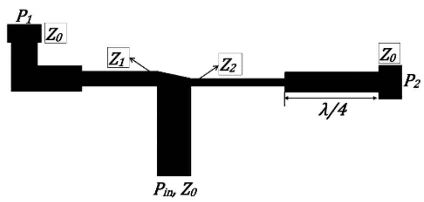

Figure 2. An unequal T-junction power divider.

Assuming that the input voltage is V_0, and the transmission line used is lossless, the relationship between input and output power will be:

$$P_{out} = P_1 + P_2 = P_{in} \quad (6)$$

where: $P_{in} = \frac{V_0^2}{2Z_0}$, $P_1 = \frac{V_0^2}{2Z_1}$, $P_2 = \frac{V_0^2}{2Z_2}$. The relation between two outputs and the input can be given by:

$$P_1 = aP_{in}$$
$$P_2 = (1-a)P_{in} \quad 0 < a < 1 \qquad (7)$$

Solving the above equations, the impedances at each output port of the divider can be obtained as

$$Z_1 = \frac{Z_0}{a}$$
$$Z_2 = \frac{Z_0}{1-a} \qquad (8)$$

Therefore, if the output powers are given, the impedance at each output port of the divider will be easily determined. In order to facilitate the simulation and futher division, it is necessary to transfer the impedance at each output port back to input impedance. Therefore, the $\lambda/4$ transformer, which defines the resonant frequency of the feed, is used to transfer the impedance (Z_1, Z_2) to the input impedance, while maintaining the expected output powers.

3.2. Chebyshevfeeding network

Based on the Chebyshev weights and T-junction power divider design method, the feeding network for 8×1 linear array has been designed on Rogers RT/Duroid 5870tm substrate (thickness of 1.575 mm and the permitivity of 2.33) as given in Figure 3.

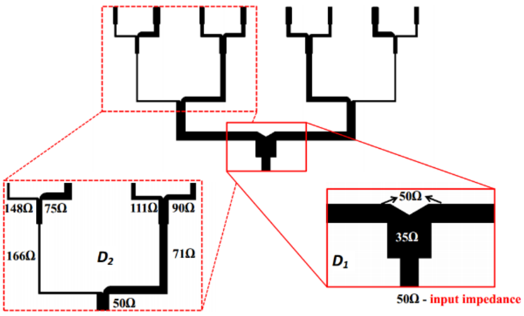

Figure 3. The proposed Chebyshev feeding network.

It is observed that the Chebyshev coefficients are symmetrical at the center. Therefore, with even number of elements, an equal T-junction power divider, D_1, has been designed to ensure that two sides are identical. The combination of dividers, D_2, is calculated and designed in order to match the first four weights of Chebyshev distribution. After that, the divider, D_2 is mirrored at the center of the divider D_1 to get the full feeding network. Each port has been designed with uniform spacing to ensure that the output signals are in phase. The simulation results of this feed will be given specifically in the next section.

4. Simulationresults and discussions

The proposed feeding network has been simulated in CST Microwave Studio. Some simulated results have been exported and compared with the theory. Figure 4 presents the simulation results of S-parameters of the feeding network (detailed data are summarized in Table 1).

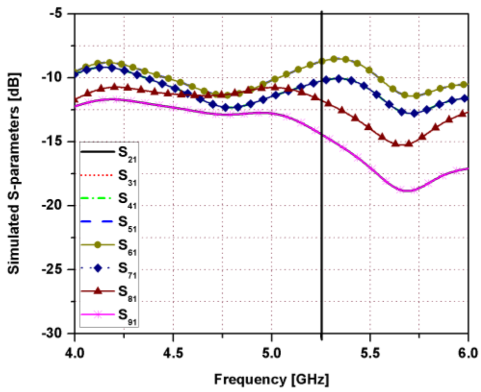

Figure 4. The simulated S-parameters of the feeding network.

As can be seen from Figure 4 and Table 1, the simulated amplitudes obtained at each port are uniform in pairs ($S_{21} = S_{91} = -13.72$ dB, $S_{31} = S_{81} = -11.27$ dB, $S_{41} = S_{71} = -10.58$ dB, and $S_{51} = S_{61} = -9.1$ dB), which are similar to the characteristic of Chebyshev weights as presented in Table 1. The simulated amplitudes of output signals have also been compared to the calculated weights from theory as shown in Figure 6. It is clear that the simulated and measured lines are quite uniform. The discrepancy between two lines is caused by the losses of the transimission line, which are not considered in theory.

Table 2. Simulated S-parameters of the proposed feeding network at 5.25 GHz

S-parameter	S_{21}	S_{31}	S_{41}	S_{51}	S_{61}	S_{71}	S_{81}	S_{91}
Value (dB)	-13.72	-11.27	-10.58	-9.12	-9.12	-10.58	-11.27	-13.72

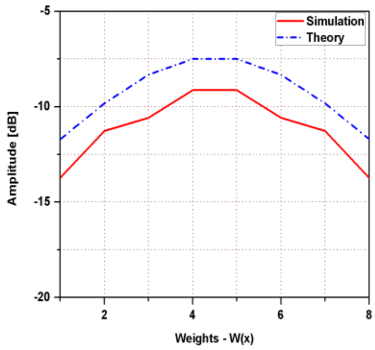

Figure 5. Comparison of amplitude distribution between simulation (solid line) and theory (dotted line).

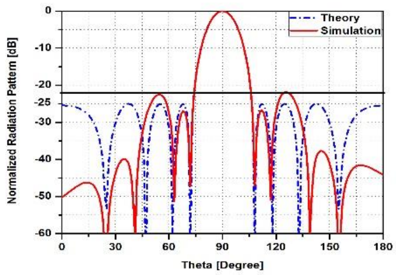

Figure 7. Comparison between the normalized radiation pattern of simulated and theoretical antenna arrays.

In the theory [1], Chebyshev weighting method only impacts the amplitude but the phase of the output signals. Therefore, in order to ensure that the simulated results meet well with the theory, the phase should be in phase at all output ports of the feeding network. As can be seen in Figure 7, the phases at all ports are equal to each other. The simulated normalized radiation pattern has been compared to that of theory as shown in Figure 8. It is clear that the linear array with simulated excitation coefficients has the SLL of -22 dB. Therefore, the proposed feeding network is appropriate to be combined in the 8×1 linear array to have SLL preset at -22 dB.

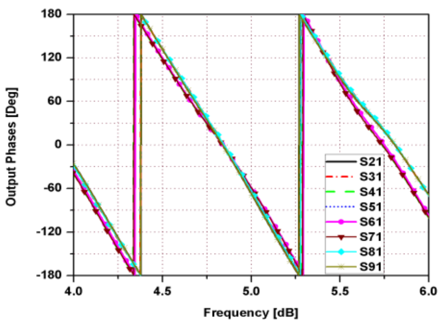

Figure 6. The output phases at each port.

5. Conclusions

In this paper, a Chebyshev distribution based feeding network for designing low SLL microstrip antenna arrays has been proposed. The detailed design procedure and calculation have been presented. A feeding network for 8×1 linear antenna array with Chebyshev weigths (preset SLL of -25 dB) has been designed and simulated as a demonstration. The results show that the output power at each port is proportional to the weights generated using Chebyshev weighting distribution method as required in Table 1. The phases are also in phase at all ports. This feeding network can be used to construct a linear array antenna, which has sidelobe level suppressed to -22 dB.

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