MICROSTRIP ARRAY ANTENNA

Ing. Jiří ŠPAČEK, Doctoral Degree Programme (1)
Dept. of Radio Electronics, FEEC, BUT
E-mail: xspace07@stud.feec.vutbr.cz

Supervised by: Dr. Miroslav Kasal

ABSTRACT

Microstrip array antenna for 1.5 GHz band is described in this paper. The array antenna consists of three serial connected rectangle microstrip radiators, working in a state of resonance. The interconnection of radiators is realized by a section of microstrip transmission line. For the bandwidth enhancement the rectangle parasitic microstrip elements are used.

1 INTRODUCTION

Simple microstrip resonator is created as a rectangle of conductor (usually thin copper plate) on high quality dielectric material. Parameters of each microstrip antenna are very strongly dependent on its geometric dimensions. Simple rectangular microstrip radiator has quite good impedance bandwidth, but it has wide major lobe in radiation pattern, too. An array antenna can be used for obtaining narrower major lobe in the radiation pattern. For basic microstrip array antenna, a narrow impedance bandwidth is typical. In this paper, an array antenna with narrow major lobe in radiation pattern and wide impedance bandwidth is presented.

The described microstrip array antenna is designed for 1.5 GHz band, linear polarization, good side lobes suppression, wide impedance bandwidth, and it is impedance matched to feeder with characteristic impedance $Z_{0F} = 50\ \Omega$.

2 ANTENNA DESIGN

The design is based on the classical serial microstrip array antenna. All the rectangular microstrip radiators in this array are excited by in-phase signal and work in state of resonance. So, between two radiators, whereas each radiator is ~λ/2 long, a transmission line ~λ/2 long must be present for in-phase feeding. The interconnection between radiators is created with the aid of a non-symmetric microstrip transmission line.

If the array antenna is used, the width of major lobe in radiation pattern is lower and the gain is bigger than in the case of a single radiator. Unfortunately, in this case the impedance bandwidth of array gets decreased. For better suppression of the side lobes, the amplitude distribution is applied. According to the array antenna theory, the feed signal amplitude is lower at outer radiators than at middle radiator. For the impedance bandwidth enhancement the parasitic microstrip elements are used. The parasitic elements decrease the factor of quality for each radiator. Consequently the array antenna impedance bandwidth is wider. Parasitic elements affect the side lobes in radiation pattern too, but their effect is small.

For the array antenna impedance-matching to the feeder characteristic impedance of 50 Ω, two quarter-wave transformers are used. According to the line theory, the electrical parameters of two serial connected quarter-wave transformers are slightly dependent on the frequency.

2.1 APPROXIMATE RADIATOR DIMENSIONS

Geometric dimensions of radiators are calculated by a complex procedure, described in [1]. In this paper only the summary of that computing procedure is presented. In first approximation, the length of any microstrip radiator L_{rxa} is given by

$$L_{\mathrm{rxa}} = \frac{c}{2 f_{\mathrm{r}} \sqrt{\varepsilon_{\mathrm{r}}}} - h \doteq 45.65\ \mathrm{mm}, \qquad (1)$$

where c is speed of light, f_r = 1.5 GHz is design frequency, ε_r = 4.2 is relative permittivity of FR4 substrate and h = 3.1 mm is thickness of dielectric plate. Following the procedure closely described in [1], which covers the effect of limited change the value of effective relative permittivity by changing the radiator geometric dimensions.

All radiators are designed with reference to the impedance for its parallel arrangement must be 96.6 Ω. This value is given by (2) responding to width of interconnecting microstrip line W_L = 1.5 mm. This width is good for manufacture. Simultaneously it is important to take into account the fact that the amplitude distribution is necessary for the side lobes suppression use. So, at outer radiators is the feed amplitude 80% compared to middle radiator. Then finally approximate dimensions of radiators are for middle radiator L_{rma} = 48.06 mm, W_{rma} = 43.38 mm and for outer radiator L_{roa} = 49.07 mm, W_{roa} = 27.07 mm.

2.2 APPROXIMATE LINE DIMENSIONS

The width of lines between radiators must be quite large for good manufacturing and simultaneously quite less for low radiation from this section and consequently low losses too. Optimal width for interconnecting lines is W_L = 1.5 mm. The value of characteristic impedance for that line is given in [2] by

$$Z_{0\mathrm{L}} = \frac{120\pi}{\sqrt{\varepsilon_{\mathrm{eff\,r}}}} \frac{h}{W_{\mathrm{Leff}}} = 96.6\ \Omega, \qquad (2)$$

where ε_{effr} = 2.94 is effective value of relative permittivity, h = 3.1 mm is thickness of dielectric plate and W_{Leff} = 7.06 is effective width of microstrip line with W_L = 1.5 mm for substrate FR4.

Length of interconnecting lines is given by formula (3), which is presented in [1].

$$L_{\mathrm{L}} = \frac{\lambda_{\mathrm{g\,L}}}{2} - 1.5\left(\frac{\Delta L_{\mathrm{roa}} + \Delta L_{\mathrm{rma}}}{2}\right) = 55.87\ \mathrm{mm}. \qquad (3)$$

Here λ_{gL} = 116.66 mm is wavelength of electromagnetic wave for frequency f = 1.5 GHz on microstrip line with W_L = 1.5 mm for the used substrate. ΔL_{ro} and ΔL_{rm} are coefficients, which cover the effect of edge field scattering on microstrip radiators.

For the array antenna impedance matching to feeder characteristic impedance Z_{0F} = 50 Ω, two quarter-wave transformers are used. Array antenna has input impedance Z_{INA} = 96.6 Ω. Consequently the impedance between both quarter-wave transformers is [1]

$$Z_{BT} = \sqrt{Z_{0F} Z_{INA}} = 65.5\,\Omega \qquad (4)$$

and characteristic impedance of both quarter-wave transformers according to [3] are Z_{0T1} = 59.0 Ω and Z_{0T2} = 82.0 Ω.

2.3 APPROXIMATE PARASITIC ELEMENT DIMENSIONS

According to [2], the parasitic element created along each radiator is approximately as long as the affected radiator. Therefore the approximate length of all parasitic elements is L_{Pa} = 48.5 mm.

Approximately, the width of parasitic elements [4] is given by

$$W_{Pa} = \frac{\lambda_{gP}}{4} = 25.32\text{ mm}, \qquad (5)$$

where λ_{gP} = 101.27 mm is wavelength of electromagnetic wave for frequency f = 1.5 GHz on microstrip line with width $W = L_{Pa}$ = 48.5 mm for used substrate. Approximately, the location for each parasitic element [4] is given by

$$j_{Pxa} = 4h = 12.40\text{ mm}. \qquad (6)$$

The shape of the designed antenna is shown in figure 1.

3 ANTENNA OPTIMIZATION

An optimization processor integrated in the Zeland IE3D electromagnetic simulator is used for optimization. The shape of array antenna with approximate dimensions, given in section 2 above, was drawn using this tool.

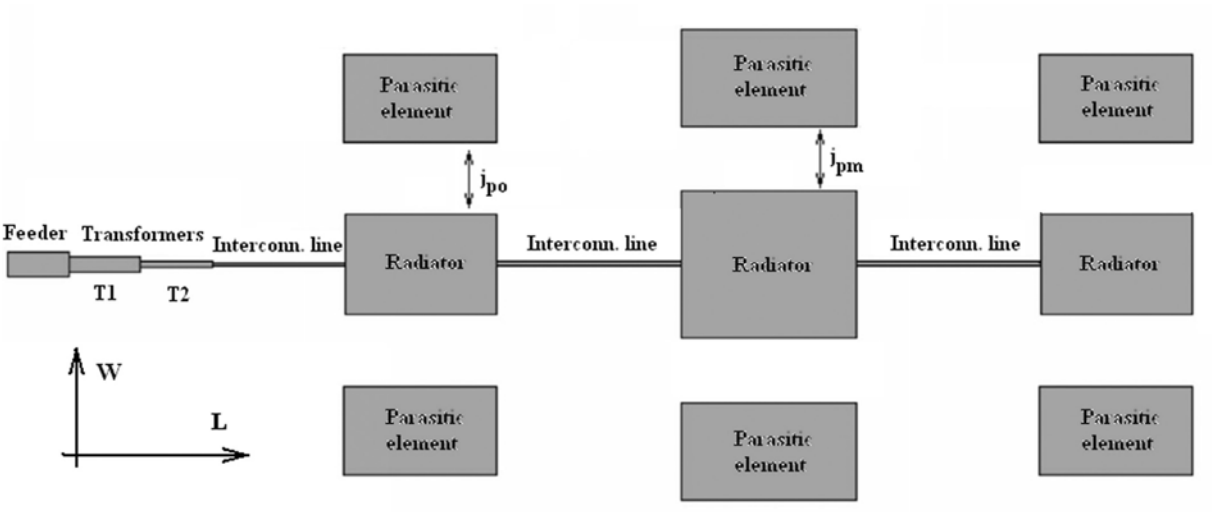

Fig. 1: *The Shape of Designed Array Antenna*

All the dimensions of antenna shape given in section 2 are optimized with the genetic algorithm method. Most important parameters of optimization algorithm settings are:

- Number of generations 1496.
- Population size 36.
- Mutation rate 0.15.

Optimization goals are:

- At frequencies f = (1.45; 1.50; 1.55) GHz should be VSWR < 2.
- At frequency f = 1.50 GHz should be $\mathrm{Re}\{s_{11}\} = \mathrm{Im}\{s_{11}\} = 0$.

So, the required impedance bandwidth is BW = 100 MHz and best impedance matching for frequency f = 1.5 GHz is necessary too.

The results of optimization are presented in table I. In this table "Int. Line" means interconnecting line between radiators and "Int. Line TA" means interconnecting line between transformers and array antenna, as shown in Figure 1.

Part	**Width *W* [mm]**	**Length *L* [mm]**	**Part**	**Width *W* [mm]**	**Length *L* [mm]**
Feeder	5.87	14.28	Rad. Outer	26.40	49.20
Transf. T1	3.60	28.79	Paras. Mid.	26.87	42.07
Transf. T2	3.21	31.19	Paras. Out.	25.98	45.91
Inter. Line	0.60	56.10	**Parasitic**	**Distance to radiator *j* [mm]**	
Int. Line TA	1.37	57.45	Outer	12.91	
Rad. Middle	39.10	48.17	Middle	15.10	

Tab. 1: *Dimensions of Optimized Array Antenna Shape*

4 ANTENNA CONSTRUCTION

Array antenna is manufactured on FR4 dielectric substrate with thickness h = 3.1 mm, and the value of relative permittivity is ε_r = 4.2. For obtaining the thickness h = 3.1 mm must be two dielectric plates with thickness h_1 = 1.5 mm glued together with polyester resin as shown in Figure 2. The big thickness of substrate is suitable for impedance bandwidth enhancement.

For antenna feeding, the SMA connector is used.

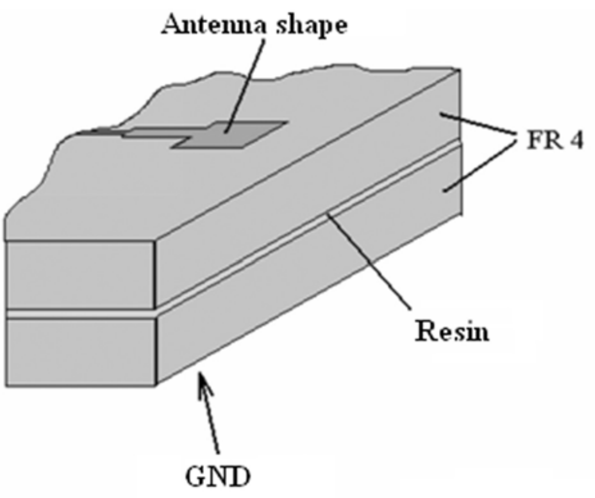

Fig. 2: *Two Glued Dielectric Plates*

5 MEASUREMENTS AND COMPARISON TO SIMULATION RESULTS

The measured radiation pattern for *E* plane compared to simulation results is presented in figure 3. For constructed antenna the major lobe width $2\Theta_E = 30^o$. Side lobe suppression is better than 14.5 dB.

Parameters of constructed array antenna are measured. The measured radiation pattern for *H* plane compared to the simulation results is presented in figure 4. For the constructed antenna the major lobe width $2\Theta_H = 75^o$.

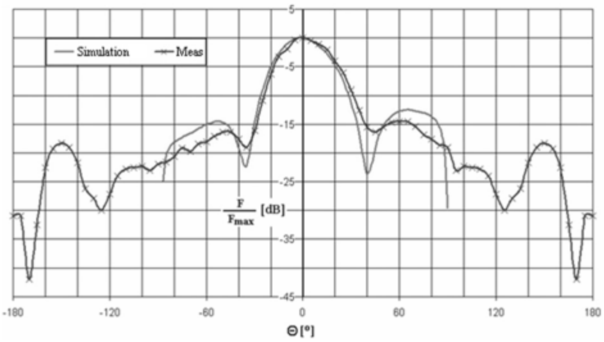

Fig. 3: *The Patterns for E Plane*

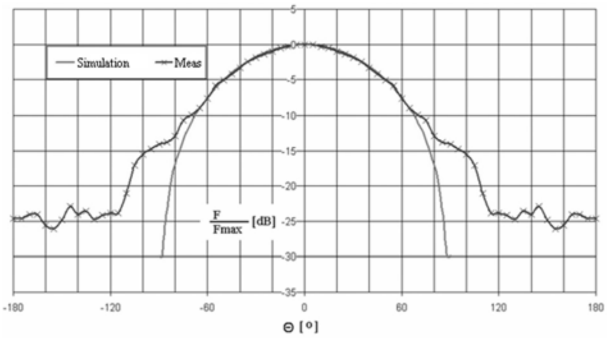

Fig. 4: *The Patterns for H Plane*

The constructed array antenna has impedance bandwidth *BW*(VSWR<2) = 67.5 MHz. The best impedance matching is for constructed array antenna at frequency $f = 1.505$ GHz, where $VSWR = 1.08$.

ACKNOWLEDGEMENTS

This paper has been supported by the technical intention MSM 0021630513 „Elektronické komunikační systémy a technologie nových generací (ELCOM)” (“Advanced Electronic Communication systems and technologies (ELCOM)”) and by PhD. grant project GAČR č. 102/03/H109 “Metody, struktury a komponenty elektronické bezdrátové komunikace“ (“Methods, structures and components of electronic wireless communication“).

REFERENCES

[1] Špaček, J.: Mikropásková anténní řada pro pásmo 1,5 GHz, Diploma thesis, Brno, FEKT VUT v Brně, 2004

[2] Svačina, J., Hanus, S.: Vysokofrekvenční a mikrovlnná technika – Přednášky, Skripta FEKT VUT v Brně, MJ Servis s.r.o. 2002

[3] Nováček, Z., Raida, Z., Černohorský, D.: Elektromagnetické vlny a vedení, Skripta FEKT VUT v Brně, Vutium 1999

[4] Sainati, R.: CAD of Microstrip Antennas for Wireless Applications, Artech House, Boston 1996