STUDENT PROJECT

ARRAY OF MICROSTRIP PATCH ANTENNAS

Antennas

1. INTRODUCTION

Microstrip antennas are not only used as single elements but are very popular in arrays. Arrays can be used to synthesize a required pattern that cannot be achieved with a single element. [Balanis]. The two dimensional nature of planar arrays results in versatile structures, which are able to provide specified radiation patterns with low side lobes. Applications include, among others, tracking and search radars, altimeters, remote sensing, terrestrial and aerospace communication systems. Due to their low weight and profile, microstrip patch arrays, are suitable for numerous microwave and millimeter wave applications, or when flush mounted, conformal arrays are needed. The linear array is formed by placing rectangular patch elements along a line, in this case N by 1 where N is a power of 2 (result of exponentiation with as base the number two and as exponent the integer n). A microstrip corporate feed network is included.

Single elements of the microstrip patch array are fed by quarter wave microstrip transformer lines connected to the patch. These quarter wave transformers feeding the patch elements match the patch input impedance to an impedance which is practically realizable using microstrip lines. The N by 1 microstrip array may be fed using a number of techniques. The single-layer microstrip array, as used here, is fed by a corporate network with the feed lines printed on the same side of the substrate as the patch elements. The four co-polarized patches of this antenna are fed from a single feed point. Mitered sections may be used on 90 degree corners as well as on T-junctions to reduce mismatch due to reflections from discontinuities. Quarter wave transformers have been added before each T-junction to allow some degree of impedance matching.

Ohmic and dielectric losses in the feed network, as well as parasitic radiation from the feed network, result in limitations on the efficiency of the antenna. The use of low loss tangent dielectrics counteracts some of these loss mechanisms. The operation of this antenna may be explained using patch antenna theory, combined with some general array theory. The single patch can be seen as a resonant cavity [Balanis] with radiating slots at each end of the patch. The fringing fields act to extend the effective length of the patch, with the result that the length of the half-wave patch is less than a half wavelength in the dielectric medium. Although simple array theory does not take mutual coupling effects into account, which may be significant for microstrip patches, it may be used to obtain a first order approximation of the resulting array pattern. The total field of the array is determined by the vector addition of the fields radiated by the individual elements, assuming that the current in each element is the same as that of the isolated element.

2. DESIGN GUIDELINES

The design of a N by 1 patch array combines the design of the individual patch element with the design of the microstrip feed network. The dimensions of a single resonant patch are constrained by the substrate parameters, while the characteristic impedance of the feed lines is dictated by realisation considerations. For example, for characteristic impedances significantly higher than say 100Ω, the line widths might become too narrow for etching, depending on the substrate height and relative permittivity. Conversely, if the port input resistance is chosen too low, the line widths might be unacceptably wide.

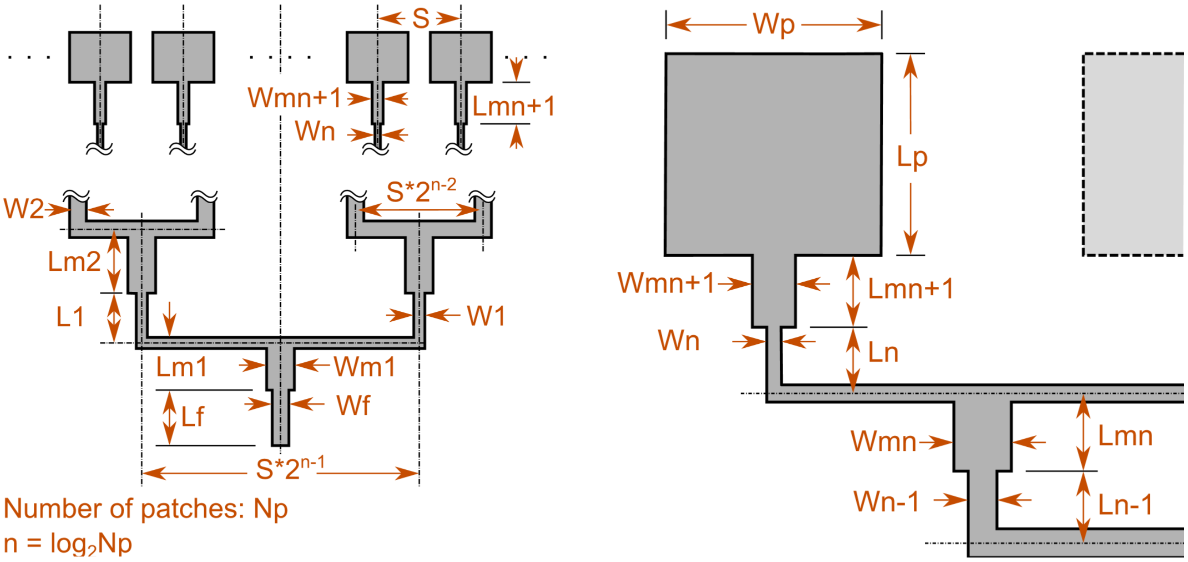

Figure 1. Array of microstrip patch antennas, (left) top view, and (right) detailed patch view.

Figure 2. Array of microstrip patch antennas, side view.

If no specific substrate is required for the design, parameters should be set at typical commercial values – e.g. relative permittivity ~2.2 with the substrate height ~5% of the wavelength in the medium. However, for microstrip arrays with coplanar feed networks the choice of substrate relative permittivity is a compromise between the often conflicting requirements of patch bandwidth (low permittivity and thick substrate) and tightly bound, non-radiating quasi-TEM guided waves in the corporate feed (high permittivity and low substrate height).

- The length of the patches may be changed to shift the resonances, or centre frequencies of the individual elements. The resonant input resistance of a single patch can be decreased by increasing the width of the patch. This is acceptable as long as the ratio of W_p/L_p does not exceed 2 because the aperture efficiency of a single patch begins to drop, as W_p/L_p increases beyond 2 [Balanis]. A better way to tune the input resistance is to use an inset feed, instead of the edge feed for the patches.
- To increase bandwidth, increase the substrate height and/or decrease the substrate permittivity (this will also affect resonant frequency and the impedance matching).
- The overall input impedance may be controlled sufficiently by adjusting the width (and length) of the input matching section of the corporate feed network.

Note: Antennas on very thin substrates have high copper-losses, while thicker and higher permittivity substrates may lead to performance degradation due to surface waves.

3. PROJECT PREPARATION

Given: Target frequency f_0 (e.g. 900 MHz or 2400 MHz).

Fixed parameters: Substrate parameters ε_r, $tan\delta$, H. The substrate should be FR4. Thickness ≈ 0.8 mm.

Output: $|S_{11}|$, input impedance Z_{in}, radiation efficiency/gain, resonance frequency f_r, radiation pattern.

STEP 1 – SINGLE PATCH ELEMENT

Task:

- Using the patch formula, calculate the patch dimensions W_p and L_p for the target frequency f_0.
- Simulate a single element and extract $|S_{11}|$ and gain.

Questions:

- What is the approximate relation between L_p and λ_{eff}?
- If ε_r increases, how do the patch dimensions and resonance frequency change?
- Explain how substrate thickness H affects bandwidth.

STEP 2 – FEED LINE AND SINGLE ELEMENT MATCHING

Task:

- Connect the patch to a 50 Ω source using a microstrip feed of length L_f and width W_f.
- Adjust L_f and W_f to achieve $|S_{11}| < -10$ dB.
- Optimize feed location (L_{m1}, W_{m1}) according to the figures.

Questions:

- How does W_f affect the input impedance?
- Why can varying L_f act like adding a series reactance (capacitive or inductive)?
- Identify the optimum feed position from your $|S_{11}|$ curve.

STEP 3 – TWO-ELEMENT ARRAY

Task:

- Design two identical patches and connect them through an equal power divider (L_{m1}, W_{m1}).
- Choose center-to-center spacing $S \approx 0.5\lambda_0$.
- Keep both feed lines phase equal (symmetrical layout).

Questions:

- Explain the effect of S on side-lobe level.
- If one feed line has 180° phase shift, how will the pattern change?
- What should be the power ratio between the two outputs of the divider?

STEP 4 – FOUR-ELEMENT FEED NETWORK

Task:

- Extend the 1→2 divider to a 1→4 network following the binary corporate feed layout.

- Design each branch width according to impedance transformation (for 1→2 split, each branch ≈ $2Z_0$).
- Adjust lengths (L_{m1}, L_{m2}, etc.) to maintain equal electrical phase.

Questions:

- What is the phase-equality condition for a corporate network?
- If one branch has 5° phase error, what is the impact on gain and beam direction?
- Why must line width vary at each division stage?

STEP 5 – FULL ARRAY INTEGRATION

Task:

- Simulate the complete four-element array. Extract $|S_{11}|$, gain, and radiation pattern.
- Vary element spacing S to observe side-lobe changes.
- Apply minor matching on each branch if needed to improve $|S_{11}|$.

Questions:

- How much higher is the array gain compared to a single patch?
- Why is the gain increase less than the theoretical 6 dB (due to feed losses)?
- Compare bandwidth ($|S_{11}|$ <–10 dB) of array vs. single patch.

STEP 6 – PHASE AND BEAM STEERING ANALYSIS

Task:

- Apply differential phase shifts between element feeds and observe beam direction.
- Plot main beam angle versus applied phase difference.

Questions:

- Derive the relation between main-beam angle and phase difference.
- What happens if element spacing exceeds 0.5λ (grating lobes)?
- How can controlled phase shifts be used for beam steering?

4. FINAL EVALUATION

Acceptance criteria:

$|S_{11}| < -10$ dB across the band, efficiency > 60 %, gain ≥ 10 dBi, dimensions within design limits.

Deliverables: Final geometry table (L_p, W_p, L_f, W_f, L_{m1}, L_{m2}, S, W_1, W_2). Plots: $|S_{11}|$, gain, and radiation pattern. Comparison of simulated and theoretical results. Written answers to all step questions in a report format

5. REFERENCES

[1] C. A. Balanis, Antenna Theory: Analysis and Design, 3rd Edition. Hoboken, NJ: Wiley-Blackwell, 2005.
[2] A. K. Skrivervik, ‘Rayonnement et antennes: notes du cours’, EPFL.