Patch Antenna Arrays And Feeding Networks

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***Abstract* - This paper presents a summary of most common feeding configurations used for patch antenna arrays. Some of the most crucial formulas are provided to perform preliminary antenna array design.**

I. Introduction

Most common patch antenna array feeding network configurations are:

- Series-fed patch arrays
- Corporate-fed patch arrays
- Series-parallel patch arrays

Patch radiators may be fed with equal phases and amplitudes, or with different phases and/or amplitudes. Varying phase and/or amplitude distribution over entire patch array allows to control antena pattern beam direction and shape.

II. Feeding Network Configurations

A. True series-fed patch arrays

In true series-fed arrays radiating elements are part of feeding network (Fig.1, a). Weighting for true series-fed arrays may be realized by varying width and height of individual patch radiators, and by varying shape of feeding networks[7]. To obtain in-phase feeding patches are serially connected with half-wavelength microstrip lines, which results in radiation pattern with main lobe perpendicular to the plane of the array. If interconnection line length differs from 180°, beam direction deviation occurs. For straight feeding lines patch element spacing is constrained by substrate relative dielectric constant **Er**, operating frequency **F** and feeding line characteristic impedance **Z**. These values result in particular wavelength **λ** for feeding lines. Thus, series-fed array may be used as frequency beam-steering antenna array. When used as sub-array in series-parallel antennas, deviation of dielectric constant **Er** may result in antenna pattern degradation, as sub-array beams steered in opposite directions.

In series-fed patch arrangement balanced feeding structure may be used [4], which may improve some of antenna characteristics.

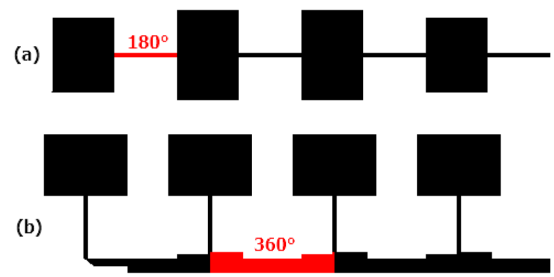

Fig.1 Series-fed patch arrays

B. T-Junction based series-fed patch arrays

T-junction based series-fed array feeding networks are built of T-junction power dividers connected in series (Fig.1, b). It is most common configuration used for commercial microwave Doppler sensor antennas. Desired weighting is obtained by varying T-junction power divider port impedance's distribution. Microstrip line length between T-junctions provides 360° phase shift, so all patches are fed with equal phase. Using different feedings for odd and even patches allows to obtain in-phase feeding with 180° interconnections. Patch element spacing is constrained similar to true series-fed patch arrays. Arbitrary element spacing may be obtained by introducing additional phasing lines at the cost of reduced bandwidth.

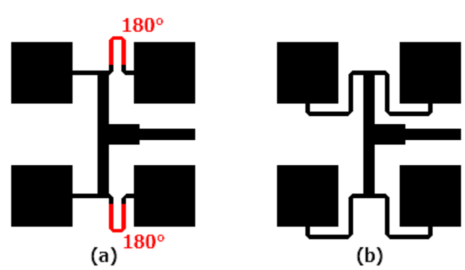

Fig.2 Corporate-fed patch array: (a) with reduced feeding network length, (b) conventional design

C. Corporate-fed patch arrays

Corporate feeding network provides in-phase feeding of patch radiators (Fig.2, b). In-phase feeding is obtained even for large deviations of substrate **Er** and operating frequency **F**. Thus, corporate fed array beam direction may be maintained for a wide frequency range, which is only limited by bandwidths of T-junction interconnections and used patch radiators. Increased feed-network length compared to series-fed networks results in larger spurious radiation, larger losses, and degrades radiation pattern quality. One way of improving antenna array characteristics is to use combined corporate-series-fed array [1]. Feed-network spurious radiation also may be significantly reduced by isolating radiating patches from feeding network. This may be realized using aperture coupling through common ground plane on a four-layer dielectric substrate (Fig.3):

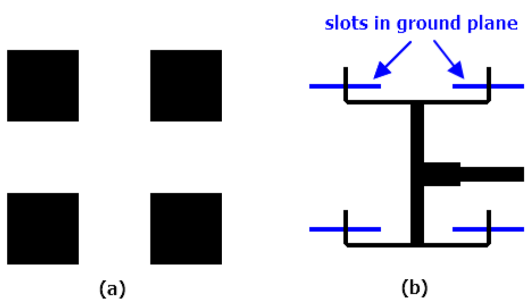

Fig.3 Corporate-fed array with aperture coupling: (a) patches plane, (b) feeding network plane with slots

Multi-layer SIW (substrate integrated waveguide) power dividers may be used to form compact corporate feeding networks [3]. Ultra-wide bandwidth corporate fed arrays may be built using SIW corporate feeding networks in conjunction with aperture-coupled patches.

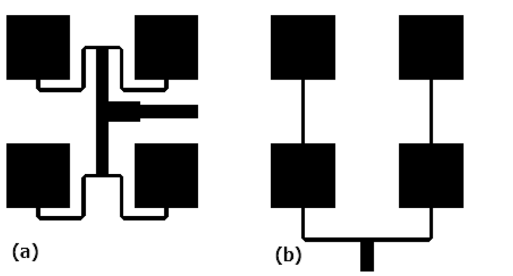

Fig.4 Corporate-fed and parallel-fed patch arrays

D. Series-parallel patch arrays

Series-parallel patch array feeding network (Fig.4, b) provides reduced length compared to corporate-fed networks (Fig.4, a). This results in reduced feeding network spurious radiation and losses [2]. Different configurations exploiting series-fed configuration advantages may be implemented, such as series-fed active antennas connected into corporate-fed network.

III. Patch Antenna Element Spacing

Patch element spacing is usually equal and chosen in range from $\lambda/2$ to λ of operating frequency free-space wavelength, resulting in different 3dB beam widths and side lobe levels. For spacing greater than λ grating lobes may be used to form dual-beam antennas [5] Unequal spacing of patch elements may be used [6] to obtain desired radiation patterns. Radiating element spacing may be analyzed using array factor formulas for planar array. For 4-element linear patch array AF may be written as:

```
fld(t,p,dx,dy)=F(t,p,0*dx,0)+F(t,p,1*dx,0)
+F(t,p,2*dx,0) + F(t,p,3*dx,0) ;
```
(1)

where

```
F(theta,phi,x,y)=Exp(i*2*Pi*x*Sin(theta)*Cos(phi))
*Exp(i*2*Pi*y*Sin(theta)*Sin(phi));
```
(2)

theta, phi – direction angles in horizontal and vertical planes, dx, dy – radiating element spacing in horizontal and vertical direction.

And plot for **0.5*λ**, **0.75*λ** and **λ** radiating element spacing using following commands:

```
Plot(20*Log10(Abs(fld(x,0,0.5,1))),xMin=-90,xMax=90);
Plot(20*Log10(Abs(fld(x,0,0.75,1))),xMin=-90,xMax=90);
Plot(20*Log10(Abs(fld(x,0,1,1))),xMin=-90,xMax=90);
```
(3)

Formulas and commands provided in **SpeqMath** software syntax (http://www.speqmath.com/) for convenience.

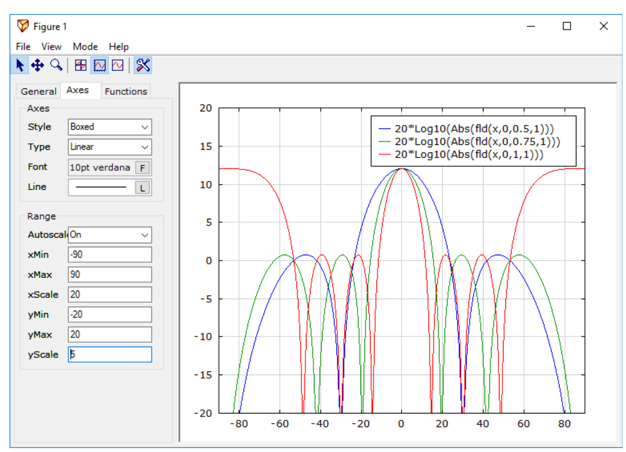

Fig.5 Radiation patterns for different element spacing

IV. Amplitude Weighting Of Array Elements

Amplitude weighting is often used to reduce side lobe level of the antenna [8,9]. Also it may be used to perform beam-steering without phase shifters [10]. Equal amplitude distribution is easily may be obtained in corporate feeding networks, because signal to each radiating element travels the same distance through microstrip power dividing network. For series feeding arrays equal amplitude distribution is obtained using tapered feeding line. For 4-element linear patch array equal amplitude distribution is obtained when each patch receives ¼ of power fed to antenna input. Impedance values for each port of microstrip T-junctions may be calculated using following formulas (SpeqMath syntax):

```
P=1/4; ' initial value of p

' --- first T-junction ---
p=p/(1-p);
z1_1=z2*p/(1+p)
z3_1=z1_1*(1+p)
z1q_1=Sqrt(zx*z1_1)
z3q_1=Sqrt(zx*z3_1)

' --- second T-junction ---
p=p/(1-p) ' using p value from first t-junction
z1_2=z2*p/(1+p)
z3_2=z1_2*(1+p)
z1q_2=Sqrt(zx*z1_2)
z3q_2=Sqrt(zx*z3_2)

' --- third T-junction ---
p=p/(1-p) ' using p value from second t-junction
z1_3=z2*p/(1+p)
z3_3=z1_3*(1+p)
z1q_3=Sqrt(zx*z1_3)
z3q_3=Sqrt(zx*z3_3)
```

(4)

Where **z1_n**, **z3_n** – "virtual "impedances at T-junction,
z1q_n, **z2**, **z3q_n** – T-junction port impedances,
z2 – patch antenna input impedance,
zx – impedance of main feeding line.
Table 1 provides results for zx=50 Ohm and z2=120 Ohm:

Table 1. Impedances For Power Dividing Network

T-Junction	Port 1	Port2	port3
Port-1	30 Ohm	120 Ohm	40 Ohm
Port-2	40 Ohm	120 Ohm	60 Ohm
Port-3	60 Ohm	120 Ohm	120 Ohm

Because very-high or very-low characteristic impedance will results in very-thin or very-wide physical dimension of microstrip line widths, it may be difficult or impossible to realize such lines. To avoid such problem virtual impedances are implemented at port 1 and port 3 of T-junction power divider using quarterwave transformers [11]. Table 2 provides calculated results of **z1q_n**, **z2**, **z3q_n**:

Table 2. Port Impedances After Transformation

T-Junction	Port 1	Port2	port3
Port-1	39 Ohm	120 Ohm	45 Ohm
Port-2	45 Ohm	120 Ohm	55 Ohm
Port-3	55 Ohm	120 Ohm	78 Ohm

For higher patch input impedances **z2** quarterwave transformation technique can be applied to port two also, but will require fixed feeding line length in multiples of **0.25*λ**.

V. Experimental Evaluation

Series-Parallel patch array was designed using formulas (1-5) and used in experimental design shown on Fig.6:

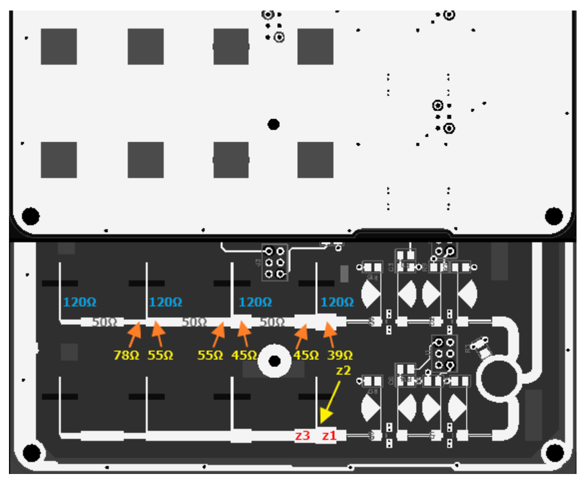

Fig.6 Experimental design with series-fed antenna array: aperture coupled 4x2 patch array (top), feeding network and FET resistive mixers with LNAs (bottom).

Evaluation of experimental design confirmed low side lobe levels and widened 3dB main lobe width for patch element spacing close to **0.25*λ**, which may be useful for phase monopulse transmitting and/or receiving antenna arrays.

VI. Conclusion

Most common feeding configurations of patch antennas was presented. Different feeding arrangements have their own advantages and disadvantages. By combining feeding networks of different type it is possible to obtain unique characteristics of radiation pattern.

Formulas for calculating array factor and amplitude weighting was used to design experimental prototype incorporating series-fed patch array antenna and proven to be reliable during experimental evaluation.

Further research will be conducted regarding circularly polarized antenna arrays as well as substrate integrated waveguide anatenna arrays, and more in-depth analysis of conventional microstrip feeding networks.

References

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1) 15 November 2017

2) 21 Match 2018: changed Fig.4 caption