Broad-band Match of Narrow-band Planar Array Antennas

Klaus Solbach and Maria Pardalopoulou
Universität Duisburg-Essen, Hochfrequenztechnik, Bismarckstrasse 81, D-47048 Duisburg
Tel. 0203/379-3286, Fax – 3498, Email hft@uni-duisburg.de

Abstract

Resonant planar array antennas are narrow-band in their impedance as well as gain. Increasing bandwidth requires reduction of number of elements in the resonant array, which often leads to a subdivision into smaller radiator modules which are fed by a corporate network. A method that improves the impedance bandwidth is presented which employs the separation of the resonant array of arbitrary number of elements into two equal halves and feeding by a 90° hybrid (directional coupler of 3 dB). The reflected waves from the two halves are redirected in the 90° hybrid to the fourth (isolated) port which may be terminated in a matched load. The 90° phase shift in one of the two antenna halves has to be corrected by a phase shifter plate in front of the radiating face in order to produce a plane wave at broadside direction. Resulting impedance match mainly depends on the symmetry of the antenna halves and the isolation, directivity and match of the hybrid coupler. An experimental demonstrator is presented which uses two linear 6-element waveguide slot arrays operating at X-band. Pattern degradation in far-off side lobes is recognized due to the dielectric plate.

1 Introduction

Many types of planar array antennas exhibit very narrow impedance match bandwidth, e.g., resonant slot array antennas /1/. Methods for improvement include double-tuning and reduction of number of elements per sub-array, which will increase the impedance match bandwidth as well as the gain- and pattern-bandwidth. However, many communication systems require extremely well matched antenna impedance over a broad frequency band, which is not necessarily combined with a requirement of flat gain and pattern variation with frequency. Such requirements may be owed to the sensitivity of high power amplifiers or the sensitivity of diplexer filters with respect to mismatch and in many instances, an expensive circulator / isolator may be necessary. In this presentation an alternative solution is presented which requires that the array antenna be divided in two symmetric halves and be fed via a 3 dB-directional coupler (90° hybrid). The basic idea is borrowed from RF amplifier techniques where two transistor amplifiers are combined using 3 dB-hybrids at input and output /2/.

2 Antenna Concept

The principle antenna concept due to /3/ can be understood from the design of the demonstrator set-up, Fig.1. The incident wave at the input port is divided into two equal size but 90° phase shifted waves at the two output ports of the coupler. These waves feed the two antenna symmetric halves and due to the phase shift in one signal relative to the other signal, the reflected waves from the antenna halves are coupled to the isolated forth port of the coupler which is terminated by a matched load. Thus, at the input port, the reflection coefficient will be very low across the complete frequency range of the coupler, independent of the antenna bandwidth as long as the two halves exhibit exactly the same impedance and the coupler exhibits good directivity and match on its own. The symmetry condition is critically dependent on the size of the array antenna: Due to mutual coupling, the reflection coefficient of the two halves will differ if they are fed at a phase offset even though they may be produced exactly symmetric. However, the mutual coupling decreases as the number of elements increases in a broadside array antenna such that this effect may be negligible in arrays of a few elements ( in the demonstrator antenna, we use 2 x 6 elements). The major problem is created by the phase shift from the coupler: The two antenna halves will radiate at a phase offset of exactly 90° due to the first pass through the directional coupler and this has to be compensated without introducing phase shift into the reflected waves between the antenna halves and the coupler. In Fig. 2, it is shown that the radiation phase of one of the two antenna halves can be shifted by employing a dielectric free space 90°-phase shift plate (quarter-wave plate).

3 Antenna Demonstrator

Such a phase shift plate was designed and optimised to yield very low reflection of the radiation wave in front of the array (plane wave) and give 90° of differential (relative to free space) phase shift at the same time, see Fig. 3. The plate design employs a two-sided quarter-wave impedance match section based on milled grooves in a solid dielectric material of \( \varepsilon_r = 3.35 \). The groove dimensions and the total thickness of the plate were optimised by modelling with Agilent-HFSS, resulting in a plate of about 0.5 \( \lambda_0 \) (16 mm) and very good match better than 40 dB over 5% bandwidth.
The demonstrator antenna was realized using two 6-element waveguide slot arrays of uniform broad-wall offset slots in WR-90 rectangular waveguide. The waveguides were terminated with short-circuits at one end and waveguide-to-coax transitions at the feeding end. Both transitions were connected to a ridged waveguide short-slot coupler by coaxial cables of equal length. The frequency band for both coupler and waveguide slot arrays was X-band, while the slot arrays exhibited a ~10 dB-bandwidth of 9.2 to 10.2 GHz and the coupler covered about 9 to 11 GHz with acceptable match and directivity.

The dielectric phase shifter plate was manufactured from Ultem-material (PEI with 30% micro-glass fibres) based on a scaled design with reference to Fig. 3 and with a width of 10 cm to cover the broad radiation from the linear slot array in the narrow dimension and of a length slightly more than the 6-element array length. Comparison of far field levels of a 6-element array with and without additional phase plate showed an insertion loss of less than 0.4 dB. The mounting height of the phase plate over the slot array contour was found to be critical: A minimum distance between slots and the lower surface of the phase plate of 8 mm had to be kept in order to minimize pattern degradation effects of increased far-off side lobes, see below.

The limited impedance bandwidth of a single 6-element slot array can be seen in Fig. 4, together with the resulting bandwidth of the matched antenna system: At lower frequencies, the input match degrades due to the limitations of the coupler, while at the higher end of the displayed frequency range a satisfactory match of around –20 dB is maintained. However, it must be warned that the gain bandwidth of the matched antenna system does not improve at the same time, since reflected power from the two halves of the antenna array is only kept away from the input port but is not at all reduced in magnitude.

Measuring the antenna patterns of the matched antenna (including the phase shift plate) exhibits a main beam at broadside and a sufficiently symmetric side lobe structure near the main beam and first side lobes at about –13 dB, Fig. 5. It is now interesting to compare these results to the patterns that are measured, when the two antenna halves are fed with equal phase using a Wilkinson power divider (but at narrow-band impedance match) so that the two halves radiate in phase and no correcting phase plate is needed, see Fig. 6: We find the main beam and first side lobes at the same position as in the first pattern but we realize that the side lobe level decays more steeply with the angle off broadside outside +/- 60°, as is to be expected from a uniform distribution slot array in the H-plane (slot-element-factor producing null at +/- 90°). In a third measurement the two antenna halves are fed by the directional coupler, but now the 90° phase correction is performed by mechanically elevating one of the antenna halves by a quarter wave (free space) so that the surface of the array is stepped at the centre: In Fig. 7, we realize that also this configuration produces pattern results with steeper decay of side lobes outside +/- 60°. The principle concept of this variant has been proposed earlier by Gotthard and presented in a Kathrein-company booklet /4/, where proposed application was in the field of broadcast antennas.

4 Discussion of Results

Considering the results of all three pattern measurements, it can be concluded that the degradation in the far-off side lobes, i.e. in the grazing angle range between +/- 90° and +/- 60°, in one part may be due to the diffraction effect of the dielectric plate: It is clear that under angles far-off the normal incidence angle (for which the plate was optimised in its match and phase shift properties), the plate will scatter and degrade the plane-wave spectrum of the array antenna, so that superposition of radiation contributions of the two halves tends to de-correlate with increasing angle off broadside. A second effect that seems to influence the pattern characteristics at far-off angles is the excitation of surface waves on the dielectric plate, an effect that is known to deteriorate side lobe performance in microstrip array antennas. As a conclusion to that, the design of the dielectric phase plate should be refined to make it more “transparent” at grazing angles of incidence.

On the other hand, the use of a mechanical displacement of one half against the other half of the array antenna may lead to a simple and low-cost realization without major pattern degradation. However, in practical planar array production techniques, the manufacture of a structure with a step in the surface contour may defy integration and increase cost so that the application of an “extra” dielectric plate may be more advantageous over-all.

5 Conclusion

A concept of broadening the impedance match bandwidth of planar array antennas is presented, based on the use of a 90° hybrid as a central power divider and correction of the phase shift by a dielectric quarter-wave plate. Using a demonstrator of 12 slot elements in a linear resonant array, it is shown that this approach can realize match which is mainly limited by the properties of the coupler. Pattern results are satisfactory with slight degradation seen for far-off side lobes.

References

Fig. 1 Feeding concept for increased impedance bandwidth

Fig. 2 Phase compensation of array antenna radiation by a dielectric plate

Fig. 3 Dielectric quarter-wave plate simulation results for plane wave incidence

Fig. 4 Reflection coefficient measured for a single 6-element array and for the complete antenna system (matched array antenna)
Fig. 5 Far field pattern of the matched antenna at 9.6 GHz; phase plate at 12 mm above the slot array surface

Fig. 6 Far field pattern of array with in-phase feed (without phase plate)

Fig. 7 Far field pattern of array with one array-halve shifted in position by a quarter wave length