A Novel Waveguide Radiator Array Element for Metallized Plastics Antenna Technology

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Abstract

In a project aimed at the development of electrically large array antennas for millimetre-wave communications to be produced in metallized plastics technology, novel array elements have been developed. The design allows a ridged waveguide feed to radiate through a resonant slot into a vertical open waveguide which is rotated in its axis in order to produce radiation from its aperture with 45°-twisted linear polarisation. Coupling slots in the ridged waveguide broad wall are aligned on the centre line and are coupled to the waveguide mode by small pins at alternating sides of the slots. In order to compensate the pin capacitance, a small indentation is applied to the ridge beneath the pin. This complex radiator design was developed using modelling and simulation in Agilent HFSS and the design was verified by a 10-element subarray produced in milled metal technology before a 32 x 20 – element full array was produced in plastics injection moulding technology.

1 Introduction

In a project (BMBF-Verbundvorhaben „Adaptive Kommunikations-Module, aKoM“, led by DaimlerChrysler / Ulm, now part of EADS) aimed at the advancement of design- and production-technologies for millimetre wave modules on the basis of metallized plastics, a concept was created for an electrically large 37 – 39.5 GHz flat antenna for point-to-point communications, see Fig. 1: With the goal of creating a design suitable for low-cost plastics technology and starting from experience learned in predecessor programs, it was decided to go for a planar array antenna with integration of radiators and feed networks in three layers of metallized plastics which are bonded together. The array architecture employs two symmetric halves of 32 rows each of 10 open waveguide radiators (total array: 32x20 elements) and the rows are fed at their centres through a corporate feed network placed in a layer below. Row- and column distribution networks provide uniform distribution so that a maximum gain can be realized. The goal of lowest possible loss favoured rectangular waveguide, but in order to provide enough space between parallel waveguides as interface area for reliable bonding of the plastic layers, both the radiator-rows and the feed network employ ridged waveguide of only half-wavelength width. In order that the antenna can provide highest possible gain and low sidelobes at the same time, it is necessary to exploit the inter-cardinal sidelobes in stead of the cardinal plane patterns (in the planes of rows and columns). This leads to the array mounted under a 45° tilt angle and requires that the radiator elements provide equally tilted linear polarization to realize vertical polarized radiation from the antenna system. The sum of all these requirements and constructional conditions made it impossible to employ a conventional slot radiator design, and made a “custom”- design necessary.

Fig.1 Antenna system using metallized plastic

2 Design of Radiating Element

The concept for the radiator rows employs resonant array architecture (centre-fed, short-circuited at both ends) and radiating elements, Fig.2, based on slots in the broad wall of the row-waveguides coupling into open-ended sections of vertical rectangular waveguide which are tilted under a twist angle of 45°. Since the complete antenna is mounted under 45°, linear polarized radiation is created and the cardinal sidelobe planes (in the planes of rows and columns) appear tilted +/-45°, so that low azimuth sidelobes are achieved even though using uniform amplitude distribution over the array. The design of the radiating element had to take into account constructional limitations due to plastics technology, resulting in slots placed on the centre line of the row waveguide. Due to symmetric current flow on the broad wall with flow direction coinciding with
the slot axis, such slots will not couple unless they are excited by additional means, some of which are discussed in /1/. Our concept employs a small post at one side of the half-wavelength slot combined with an indentation in the waveguide ridge below in order to compensate the post reactance and keep the slot a real impedance at resonance. The vertically branching waveguide section above each slot acts as a polarization twist and impedance transformer at the same time. This means that the reflection coefficient of the open-end is transformed to the slot plane through the waveguide section and is further transformed through the slot into the feeding ridged waveguide. The minimum length of the waveguide section is on the order of a half-wavelength to guaranty cross-polarization below 20 dB. Compatible with design rules for precise production of the radiator plastics layer, additional length could be used to tune the over-all radiator element for a bandwidth compatible with the requirements. Of particular concern was the open-end radiator reflection coefficient including the mutual coupling in the large array: As an approximation for an average element within the array, an infinite array was assumed and the reflection coefficient was calculated from a virtual waveguide simulator which was created under Agilent HFSS, see Fig.3, employing electric and magnetic walls (note that in real waveguide simulators only electric walls can be used so that proper broadside radiation condition cannot be simulated). Due to the 45° tilt angle of the open-ended waveguides, the rectangular apertures appear aligned in parallel but offset; the simulator was designed such that the smallest possible cross section of the array between proper symmetry planes was modelled resulting in just a quarter of two neighbouring radiator apertures (dashed line in Fig.3). The reflection coefficient for the excitation of only one of the two aperture ports was combined with the transmission coefficient between the two ports, which is equivalent to the reflection coefficient for the even-mode excitation of the two radiating apertures, while the simulator waveguide was terminated in a matched load. This leads to the reflection coefficient of each of the radiators in a uniform infinite array, Fig.4, which is found to be a special case of the “multimode simulator technique” due to /2/.

Fig. 2 Waveguide radiator array element

Fig. 3 Radiating aperture grid and virtual waveguide simulator

3 Array Design

Mutual coupling of neighbouring radiator elements inside the ridged waveguide region as well as coupling to a T-junction at the centre of 10-element rows was investigated also by modelling in HFSS: As an example, Fig.5 shows the model of the ridged waveguide T-junction with the feeding point at port 1 and two radiator elements at each side. Electromagnetic field simulation results from HFSS

Fig. 4 Comparison of reflection coefficients for isolated element and infinite array element
in the form of a five-port scattering matrix were transferred to a network analysis tool (Agilent ADS) where ridged waveguide ports 2 and 3 are terminated in matched loads and the radiating aperture ports 4 and 5 are terminated by the infinite array reflection coefficient. In this way we were able to step-up our model of the antenna array without too large electromagnetic models but still being able to include mutual coupling effects and higher-order mode effects inside the waveguide structures.

The design of the complete 10-element subarray was done on the basis of mixed electromagnetic- and network-simulation. Before producing the expensive injection moulding tool the design was verified by a scaled model at X-band produced in milled metal technology, see Fig. 6. Results of (input) port 1-reflection coefficient show good agreement between simulation and measurement, Fig. 7.

**Fig. 5** Model of ridged waveguide T-junction with two radiating elements

![Fig. 5 Model of ridged waveguide T-junction with two radiating elements](image1)

**Fig. 6** Scaled model 10-element radiator sub-array

![Fig. 6 Scaled model 10-element radiator sub-array](image2)

**Fig. 7** Measured and simulated input reflection coefficient of 10-element subarray

![Fig. 7 Measured and simulated input reflection coefficient of 10-element subarray](image3)

4 Conclusion

The development of a novel waveguide radiator element was presented which complies with very special requirements of metallized plastics production. Several features of the element are unusual and would be very difficult to fabricate in milled metal technology. Thus, theoretical results and design rules have not been available for the design so that all steps had to be solved fresh from the start. It was found that a commercial e.m. simulator together with a network simulator is sufficient to serve in the design process.

**References**

/1/ J.Green, H.Shnitkin, P.Bertalan,”Asymmetric Ridge Waveguide Radiating Element for a Scanned planar Array”, IEEE Trans.AP, August 1990, 1161-1165

/2/ A.Derneryd, J.Gustincic,”The Interpolation of General Active Array Impedance from Multielement Simulators”, IEEE Trans.AP, January 1979, 68-71