60 GHz band radial line slot array antenna fed by rectangular waveguide

Y. Kim, J. Lee, H. Chae, J. Park, S.-C. Kim and S. Nam

A single-layered radial line slot array (SL-RLSA) antenna etched on a substrate and fed by a rectangular waveguide is presented in the 60 GHz band. The design curves are obtained by an efficient electromagnetic coupling analysis using Ewald sum technique and Shanks' transformation. The antenna has rectangular waveguide feed structure using a rectangular waveguide-to-radial line transition. The prototype antenna of 10 cm diameter was tested and the gain of 30 dBi was measured at 60 GHz.

Introduction: High-gain planar antennas are important elements in wireless LANs and collision avoidance radar systems in the millimetre-wave band. The RLSA antenna was proposed as a candidate for these requirements with high efficiency. Since the analysis model, from which the information about coupling through slots can be obtained, and design procedures have been well developed already in the 12 GHz band [1], several types of RLSA antennas have been designed easily [2]. But, in the coupling analysis of these RLSAs, the efficiency from the viewpoint of numerical analysis has not been emphasised, so there is a practical difficulty in convergence behaviour in the evaluation of the Green's functions. Also, the use of coaxial cable with a coaxial-to-radial line transition as a feed structure in existing RLSA antennas made these antennas more lossy, expensive, and difficult to handle in the millimetre-wave band. This Letter summarises the proposed efficient method of analysing the slot coupling and proposes a new planar feeding method suitable for the 60 GHz band. Fig. 1 shows the structure of prototype antenna to be designed.

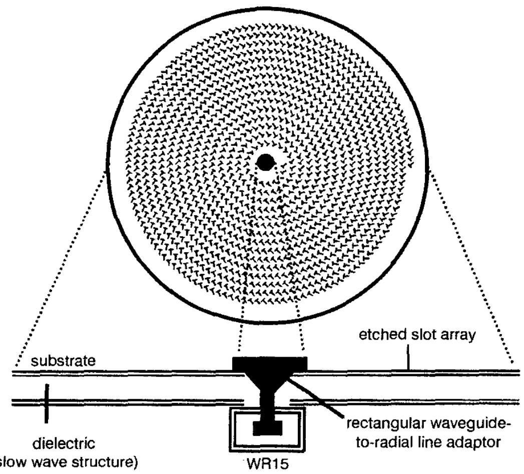

Fig. 1 *SL-RLSA antenna with proposed adaptor*

Summary of efficient analysis of coupling: The slot coupling characteristics should be analysed in RLSA for its design. The previous analysis [1] used a waveguide model with a periodic boundary condition on its narrow walls and periodically-arranged slots on its wide wall. The magnetic field integral equation and two dyadic Green's functions for each region are derived and the method of moments is used. For the rectangular waveguide region, the Green's function is a two dimensional series, which is quite slowly convergent. In our analysis, the Green's function is expanded in terms of an image series. The series is the superposition of the free-space periodic Green's functions, which can be efficiently calculated using the Ewald sum technique [3–5]. As a result, exponential convergence is achieved by increasing the number of summation terms. Similarly, some method of acceleration is required for the effective calculation of the free-space Green's function series in the half space region. We used Shanks' transformation which transforms the sequence of partial sums of slowly convergent infinite series into the new one which converges quickly toward the exact value [6]. In addition to the accelerations of the two Green's functions, two different kinds of basis function, the entire domain basis function and the sub-domain one, are used together to maximise the efficiency of numerical analysis and to extract singularities. That is to say, in filling the impedance matrix in the method of moments, the non-self term is calculated using the entire basis function expansion of magnetic current because there are no singularities. But, since entire basis functions cannot be used for the self-term due to the difficulties in extracting singularities, the current is expanded using the roof-top basis functions through the piecewise linear approximation of the entire domain basis function. With the help of this sub-domain basis function, we can use the well-known analytical integral formulas in computing the part related to singularities and numerical integrations in computing the other part, respectively. It can be shown that the proposed analysis method leads to a reduction in computational effort and time with better accuracy. Fig. 2 shows the coupling characteristics of the slots etched on the substrate.

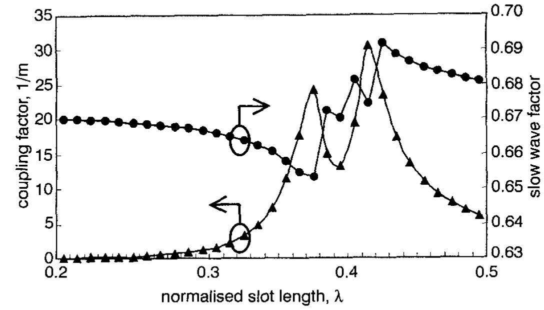

Fig. 2 *Coupling characteristics of slots*

—●— coupling factor
—▲— slow wave factor

Design of rectangular waveguide feeder: In the usual RLSA antenna, the power is fed by the coaxial feed at the centre of the radial waveguide [2]. However, this type of feed cannot be easily used in the millimetre-wave band because coaxial cable is lossy, and the adaptors are expensive and fragile in that band. Therefore, most millimetre-wave transceivers have their input/output ports with standard rectangular waveguides. For these reasons, the commonly used coaxial-to-waveguide transition was applied directly to a rectangular waveguide-to-radial line transition. The mechanism of power transfer by our adaptor is as follows. First, the input power is coupled from the rectangular waveguide to the upper substrate. Next, the coupled power is gradually changed into a radially outward travelling wave by the inclined shape of the adaptor and finally radiates through slots. The optimum dimensions of the adaptor were determined using commercial field simulators assuming the absence of an etched slot array. The structure of the proposed transition was already shown in Fig. 1.

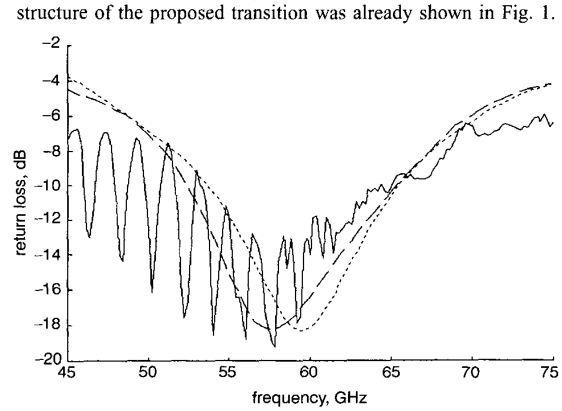

Fig. 3 *Reflection of feeder*

––– simulation HFSS
.... simulation microwave studio
—— measurement

Results: A prototype RLSA antenna with a new feed structure was fabricated and tested. We used a substrate on which the pattern of slots was chemically etched for ease of manufacture contrary to the conventional type of RLSA. The measured reflection in Fig. 3 shows satisfactory return loss of about −14 dB around 60 GHz. The ripple in Fig. 3 is due to the existence of etched slots that cannot be considered in simulations. Fig. 4 shows the measured far-field radiation pattern (−20° to +20° only). The beam pattern is reasonably symmetrical and reveals the first side lobe level of −18 dB and the 3 dB beam width of ~4–5°. Also, the axial ratio is about 1.3 and high-gain of 30 dBi is measured.

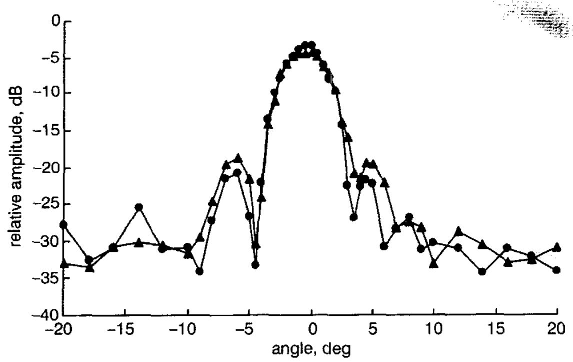

Fig. 4 *Measured antenna radiation pattern (LHCP)*
—●— vertical
—▲— horizontal

Conclusions: We have presented the design of an RLSA antenna etched on a substrate which is fed by a rectangular waveguide at 60 GHz. By using two different kinds of accelerating techniques and exploiting two different kinds of basis function, the coupling characteristics of the slot array were analysed exactly and rapidly. We replaced the coaxial feeder with the rectangular waveguide by using the simple adaptor in the feed structure, which has less loss and can be easily connected to most millimetre-wave transceivers. The proposed antenna showed good performance.

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References

1 HIROKAWA, J., ANDO, M., and GOTO, N.: 'Analysis of slot coupling in a radial line slot antenna for DBS reception', *IEE Proc. H, Microw. Antennas Propag.*, 1990, **137**, (5), pp. 249–254
2 TAKAHASHI, M., TAKADA, J., ANDO, M., and GOTO, N.: 'A slot design for uniform aperture field distribution in single-layered radial line slot antennas', *IEEE Trans. Antennas Propag.*, 1991, **39**, (7), pp. 954–959
3 JORGENSON, R.E., and MITTRA, R.: 'Efficient calculation of the free-space period Green's function', *IEEE Trans. Antennas Propag.*, 1990, **38**, pp. 633–642
4 JORDAN, K.E., RICHTER, G.R., and SHENG, P.: 'An efficient numerical evaluation of the Green's function for the Helmholtz operator on periodic structures', *J. Comput. Phys.*, 1986, pp. 222–235
5 PARK, M.J.: 'A study on the efficient analysis of shielded and periodic microwave structures using Ewald Sum Technique'. Ph.D. dissertation, Seoul National Univ., Korea, 1998
6 BLUME, S., and KREBS, V.: 'Numerical evaluation of dyadic diffraction coefficients and bistatic radar cross sections for a perfectly conducting semi-infinite elliptic cone', *IEEE Trans. Antennas Propag.*, 1998, **46**, (3), pp. 414–424

Multi-disk radiating structure with flat-topped element pattern for planar array antenna

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The results of numerical simulation and experimental modelling of a multi-disk slowing structure excited by a two-dimensional planar array antenna of circular waveguides are presented. The geometrical parameters of the array structure with the flat-topped element pattern, required to suppress the array grating lobes when beam scanning, are also determined.

Introduction: With advances in radio systems, the requirements relating to the side lobe level of the antennas have become increasingly stringent. The quest for cost reductions of phased array systems gives rise to the use of array antennas with fewer elements and with lattices that cause grating lobes within the antenna radiation pattern. An effective means of suppressing the grating lobes is to form a flat-topped element pattern [1, 2]. Phased array antennas with a flat-topped element pattern and a limited field of view can be created by various methods [2] such as multi-port networks, protruding-dielectric elements, quasi-optical networks of overlapped sub-arrays. The work described here concentrated on a multi-disk slowing structure, proposed in [3]. In contrast to other variants, this structure has a simpler construction and permits the realisation of beam scanning in a sufficiently wide conical sector similar to dielectric rods. The performance of the disk structures is stable up to the millimetre-wave band. Alternatively, the performance of dielectric rod structures is critical with respect to variations in the dielectric materials. In addition, at low frequency bands, such as the *S*-band and *X*-band, the disk structures on thin films decrease the overall array weight compared with heavy dielectric rods.

The similar slow-wave strip structure excited by parallel plate waveguides with TEM mode was theoretically analysed in [4] for the one-dimensional array.

In this Letter, the optimal geometrical parameters of two-dimensional multi-disk structures are suggested, and the simulation and experimental results of an antenna fabricated on a Ka-band breadboard are shown.

Numerical simulation: The array geometry of a model for the numerical analysis is shown in Fig. 1. The array is a periodic structure whose elements are arranged at the nodes of a triangular lattice with spacing d_x. Each array element is an input semi-infinite circular waveguide of diameter $2a_0$, and a radiating cylindrical section of diameter $2a$ and length h, with both sections having a common axis. The radiating section connects to a common infinite flange. Above each radiating circular waveguide, N infinitely thin disks are arranged. Each disk is characterised by its radius, r, and its height above the waveguide, z_i. Any waveguide walls, flanges and disks of the structure are assumed to be perfect conductors.

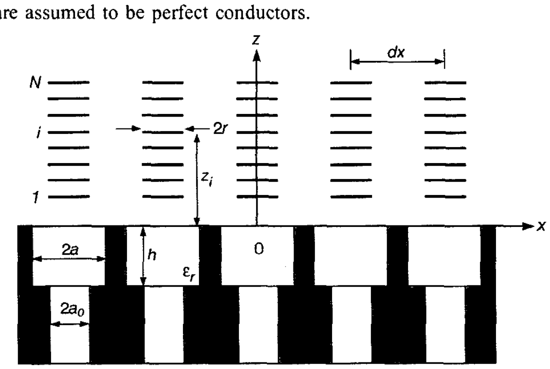

Fig. 1 *Array geometry*

We also assume that the input waveguides are excited by the eigenmodes of identical amplitudes while the phases change linearly along the main axes, with the phase steps corresponding to the array's specified main beam direction.