AntennaMagus
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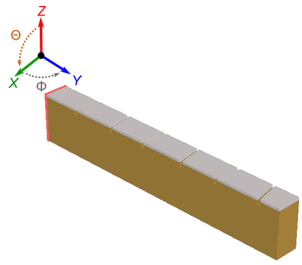
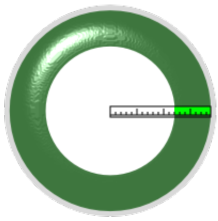
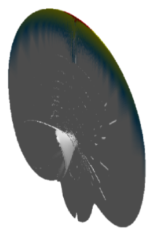
Linear resonant waveguide slot array with narrow-wall slots





Large (> λ/2)



Highly directed fan

Quick Summary

Quantity	Typical	Minimum	Maximum
Polarisation	Linear	-	-
Radiation pattern	Broadside fan beam	-	-
Gain	18 dBi	9 dBi	24 dBi
Performance bandwidth	3 %	1 %	6 %
Complexity	Medium	-	-
Balun	None required	-	-
Beamwidth	30 °	1.7 °	45 °
SLL (Side-lobe level)	-20 dB	-	-

Background

Waveguide slot arrays are typically used at microwave frequencies and are particularly popular for radar applications. They are robust, low-loss and able to withstand high powers. Linear arrays, which produce fan beams, can be used to create a single pencil beam by arraying a number of them together or using them as feeds for a parabolic cylindrical reflector.

Linear waveguide arrays generally fall into one two fundamental categories, namely resonant and travelling-wave. In the latter case, the magnitude of the wave launched from the feed decays towards the load where the little remaining power is absorbed by a matched load. The coupling between the travelling wave and the radiating slots is increased towards the load such that the radiation intensity from the second half of the array is comparable to that from the first half. The slots are spaced such that there is a progressive phase shift between slots, resulting in a fan beam which squints off broadside and scans with frequency. In addition, the antenna is well matched over a reasonably wide bandwidth and the bandwidth does not degrade with increasing array length.

The array designed here is of the resonant type. Because the waveguide is terminated by a short circuit, a standing wave is formed within the guide with identical field maxima at the centres of the slot. The phase of the radiation of each slot is identical at the centre frequency, resulting in a broadside beam. The performance bandwidth is usually narrower than that of travelling wave design.

One of the attractive features of a waveguide slot, is the ease with which the coupling between the slot and the waveguide transmission line can be varied. Slot types include longitudinal broad-wall, rotated broad-wall and rotated narrow-wall (used here).

Linear arrays of edge slots (narrow-wall) may be combined to form planar arrays, which are attractive when beam shaping in the H-plane is desired. [Elliot]

Physical Description

The antenna consists of a length of waveguide which is terminated by metal plate. Narrow-wall slots extending at varying depths into the waveguide are cut into the narrow wall, effectively wrapping around and invading both broad walls to achieve resonant length. [Elliiot] Each slot has its own slant angle and corresponding depth.

Feed Method

The antenna is fed with a waveguide feed or a coaxial-to-waveguide transition.

Operation Mechanism

The antenna can be viewed in terms of an equivalent circuit mode, where the waveguide sections between adjacent slot centres are transmission lines and the slots are lossy resonant elements in shunt with the transmission line. At the resonant frequency of the slots (which is chosen to be the same as the centre frequency), the slot admittance is almost purely real and can be represented by a conductance, G. This slot conductance, and hence the coupling to the waveguide field, increases as the slot angle is increased.

With the short circuit at the end of the waveguide placed at n/4 λ_g beyond the centre of the last slot (where λ_g is the wavelength in the waveguide and n = 1, 3, 5...), the short circuit appears as an open circuit in shunt with the last slot and thus has no effect on the antenna input admittance at the centre frequency. Because each shunt element is $\lambda_g/2$ apart along the transmission line, the input admittance as seen at the first slot is simply the sum of all the slot conductances. In addition, this spacing ensures that the slot excitations are in phase, making the antenna radiate at broadside.

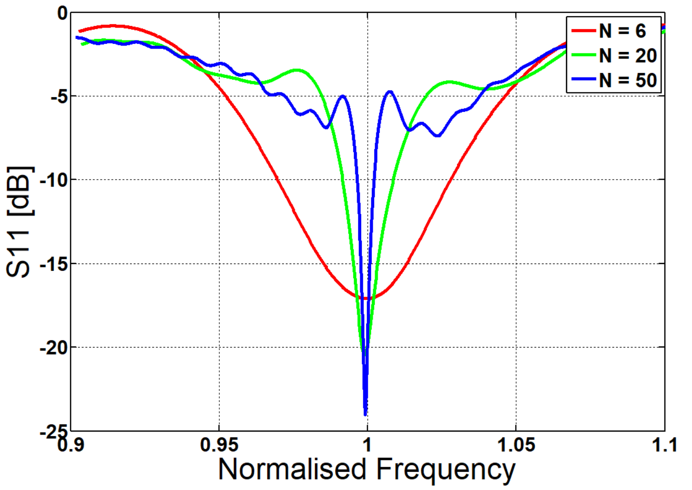
Performance

The antenna produces a fan beam in the plane of the waveguide cross-section, with a maximum at broadside. The bandwidth is rather narrow, in terms of impedance and pattern quality.

The plots shown below are for a 6, 20 and 50 element arrays which were designed to have a Villeneuve excitation distribution.

Impedance Characteristics

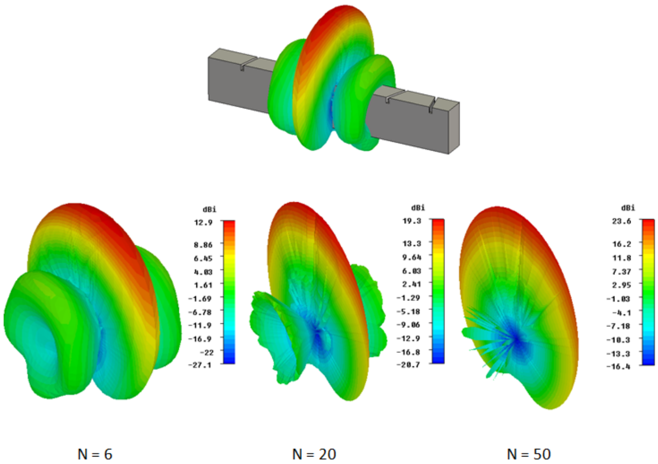
At the centre frequency, the slot conductances simply add together at the feed port, allowing an extremely good match to be obtained. However, the short circuit termination only transforms to an open circuit at the first slot, at the centre frequency. How rapidly the phase of this reflection changes with frequency is determined by the length of waveguide from the first slot to the termination. This phase error becomes increasingly severe with array length, and for larger arrays, the impedance bandwidth is primarily determined by the length of waveguide. For small arrays, the bandwidth may be limited by the bandwidth of the individual slots. This increases with slot width.



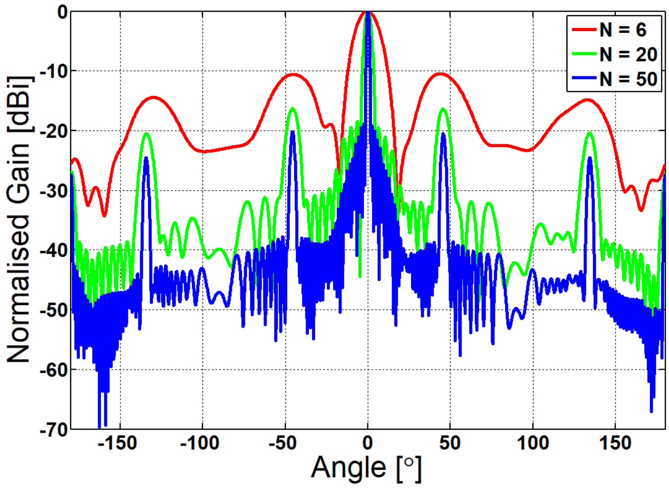
Typical reflection coefficient

Radiation Characteristics

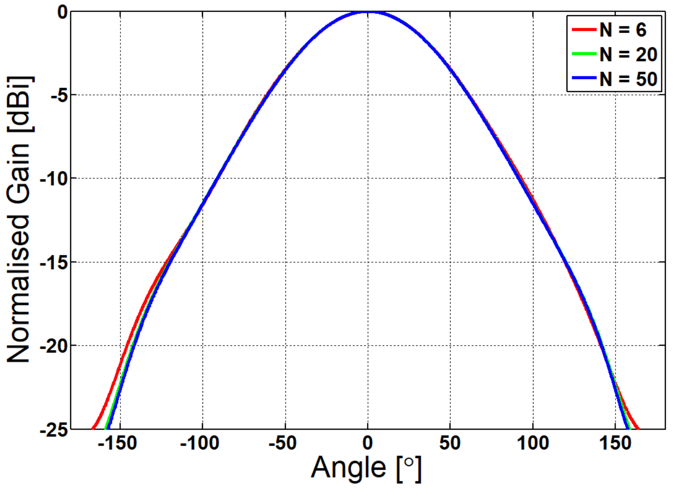
The array narrows the beam along the length of the waveguide, forming a fan beam with a maximum at broadside. As with the impedance, the radiation pattern degrades rapidly with frequency about the design frequency, especially for longer arrays.



Total 3D gain at the centre frequency for different numbers of slots using a Villeneuve distribution.



Typical radiation pattern in the plane of the narrow wall of the waveguide.



Typical radiation pattern in the plane perpendicular to the waveguide axis.

References

R. S. Elliott, Antenna Theory and Design, Revised edition, Wiley, 2003, pp. 89-99 and 397-414.

R.S. Elliot, “The Design of Waveguide-fed Slot Arrays”, Ch.12 in Antenna Handbook, Y.T. Lo (Ed.) and S.W. Lee (Ed.), Van Nostrand Reinhold, 1993.

B.N Das and J. Ramakrishna, “Resonant Conductance of Inclined Slots in the Narrow Wall of a Rectangular Waveguide”, IEEE Transactions on Antennas and Propagation, Vol. AP-32, No. 7, July 1984, pp. 759-761

Model Information (FEKO)

Model 1

Model using infinitely thin plates.

This model uses infinitely thin PEC sheets and is fed using a waveguide port. If a large number of slots is used, the model may take a long time to simulate.

Model Information (CST Studio Suite)

Model 1

Model optimised for the transient solver.

This model uses finite thickness PEC layers and is fed using a waveguide port. It has been set up for use with the transient solver.

Model Validation

The simulated radiation pattern was validated with respect to the theoretical array factor used to design the array. The reflection coefficient was validated with respect to a theoretical transmission-line model with ideal slot conductances. The simulated radiation pattern and reflection coefficients using the various codes were validated with respect to one another.

Each export model has been validated to give the expected results for several parameter variations in the design space.

Magus Analysis

The internal performance estimation uses the radiation pattern of a single typical slot in an array to calculate the radiation pattern. The input impedance, while displaying the correct trend, is calculated using an ideal network and hence will only be accurate at the design frequency. Typically estimated bandwidths are slightly wider than those achieved with the physical structure.

Design Guidelines

The design of this antenna hinges on having an accurate model of the slot behaviour in a resonant array environment, i.e. the resonant lengths and conductance values for different slot angles. When these dependences are known, it is possible to calculate the slot angles and slot depths from the desired conductance values. Existing design curves from Das et Al. were used in the design of this antenna.

- Keep the waveguide slots spaced at half the wavelength in the guide.
- Ensure that the distance between the last slot and the waveguide short circuit is an odd multiple of a quarter wavelength in the waveguide, i.e. $\lambda g/4$, $3\lambda g/4$, $5\lambda g/4$ etc.
- To increase the coupling between the slot and the waveguide (thus increasing the slot's conductance), increase the slot angle and adjust the respective slot depth to maintain resonance.
- To increase the bandwidth, decrease the number of slots in the array or consider using a travelling wave design. If very few slots are used, increasing the slot width may help.