

# ON THE PATTERN CONTROL OF AN ANNULAR SLOT ANTENNA OPERATING IN ITS 'DC' MODE

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## ABSTRACT

Electrically-small antennas are well-known as being narrow-band structures. The addition of a tuning network not only allows these structures to work well across a wide band, but provides a degree of stability over the element's radiation pattern and polarisation. In this paper the radiation characteristics of an electrically-small annular slot operating in its 'DC' mode as a function of frequency are presented. It is shown that over the tuning range of the slot these radiation patterns remain relatively constant. Consideration is also given to the gain and efficiency variations of the slot over this range too.

## INTRODUCTION

With the ever decreasing size of the mobile terminal, coupled with the desire to use multiple elements at the handset to exploit channel capacity [1], provide link robustness [2, 3], and realise adaptive capabilities [4], the space available for the location of antennas is limited. As well as this size constraint there is much desire to produce a single terminal which is capable of operating well across a plethora of standards [5].

One way of meeting this space challenge is to reduce the size of the antenna such that it becomes electrically-small. However, it's well-known that in doing so its  $Q$  increases. This has the consequence of introducing a trade-off which must be made between bandwidth and efficiency [6].

If the element in question is a passive structure then this trade-off restricts operation of the element, but if a tuning mechanism can be added, it is then possible to cover a wide range of frequencies in narrowband intervals.

When compared to wideband passive structures i.e. [7–9], narrowband tuneable antennas have several advantages: their inherent narrow bandwidth will add some degree of filtering to the RF front-end; adaptive re-tuning techniques [10] have been researched which allow the element to counteract environmental de-tuning, thus improving the power throughput of the RF front-end; a degree of stability over the modes in the structure is possible which allows the radiation pattern and polarisation to be optimised.

This paper considers the radiation characteristics of an electrically-small annular slot antenna, operating in its 'DC' mode, as it is tuned in frequency. Results show that across this tuning range the radiation patterns remains relatively unchanged. Moreover, the ratio of Cross- to Co-polar excitation stays low with the level of power in the Cross-polar pattern remaining small; something which is crucial for schemes relying on polarisation diversity.

## ANNULAR SLOT ANTENNA

The introduction of a shorting pin between the central resonating element and ground causes an additional resonant mode (the 'DC' mode) to be excited well below the first natural resonance of the structure (i.e. the slot being one wavelength long). The radiation patterns produced by exciting this mode have been shown to be equivalent to that of a wire monopole, yet the bandwidth of the input response is much less [11].

Figure 1 illustrates the layout of the cavity backed annular slot. The dimensions of the element were as follows:  $W_f=2.6\text{mm}$ ,  $L_f=22.5\text{mm}$ ,  $R_s=9\text{mm}$ ,  $W_s=0.5\text{mm}$ ,  $L_c=60\text{mm}$  and  $H_z=1.59\text{mm}$ . It should be noted that  $W_s$  was chosen as 0.5mm for practical

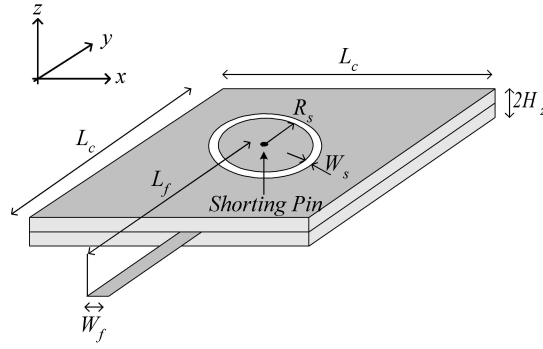


Figure 1. Layout of Annular Slot

Pattern	Directivity / dBi	$\frac{XP_{max}}{CP_{max}}$ /dB	Total Co-Polar Power / %
(a)	4.89	-15.90	98.4
(b)	5.97	-14.26	98.5
(c)	5.94	-13.11	98.8

TABLE 1

COMPARISON OF RADIATION PROPERTIES AS A FUNCTION OF FREQUENCY

fabrication reasons.

A method for electronically reconfiguring the antenna so that its input response could cover an entire operational bandwidth is to use a varactor diode shunted across the element's aperture. This technique was first reported by [12] and used to tune a narrow-band patch antenna across a 30% bandwidth. A similar technique was now applied to the annular slot.

In order to provide a large tuning range using a varactor diode, a large capacitance-to-voltage,  $\frac{C}{V}$ , ratio is required together with small parasitic affects. The Alpha Industries SMV1763-079 Hyperabrupt Junction varactor diode was used since it provides quite a large  $\frac{C}{V}$  ratio together with low parasitics.

The varactor was connected in a reverse biased configuration between the shorting pin and ground. Provision for a DC bias was made through a series 22nH RFC. The tuning circuitry was enclosed in a small RF can of brass shim. Using this configuration a tuning range of 28% was measured from 1.920GHz to 2.550GHz [13].

## VARIATION IN RADIATION PATTERNS WITH FREQUENCY

The annular slot described in the previous section was mounted in an anechoic chamber and its full 3-D radiation patterns measured as a function of frequency. Three of these patterns are shown, Figure 2(a), Figure 2(b) and Figure 2(c) which approximately represent the beginning (1.920GHz), middle (2.195GHz) and end (2.495GHz) of the tuneable range respectively.

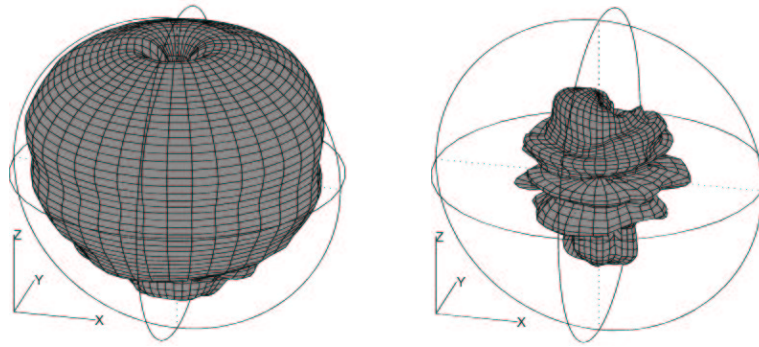
For each of the patterns the maximum level of Directivity, ratio of maximum Cross- to Co-polarisation power ( $\frac{XP_{max}}{CP_{max}}$ ), and maximum Co-polar power were calculated and are shown in Table 1. As can be seen from the patterns (Figure 2) and statistics (Table 1), there is little change in the amount of power split between the polarisations as a function of frequency. There is, however, a slight widening of the null in the Co-polar pattern ( $z$ -direction), which is most probably due to the excitement of an additional, higher-order mode. Consequently the level of  $\frac{XP_{max}}{CP_{max}}$  decreases slightly, but is always better than -13dB.

In order to determine efficiency,  $\eta$ , of the antenna across its tuning range, its gain,  $G$ , was measured at the same bias conditions as the patterns using the method outlined in [14]. Figure 3(a) shows these results. Using these values together with the values of directivity,  $D$ , in Table 1, the efficiency was calculated using the relationship in Equation 1 and is shown in Figure 3(b).

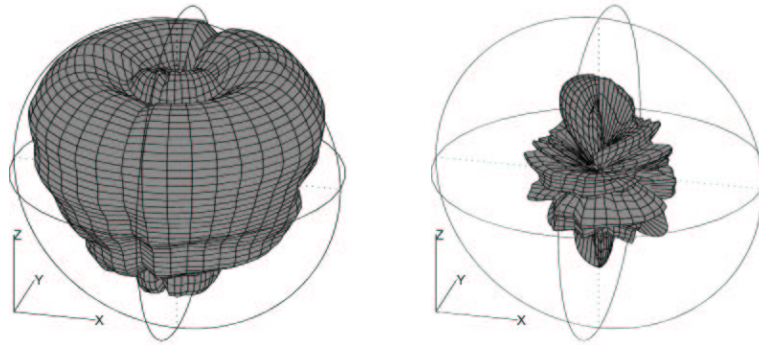
$$\eta = \frac{G}{D} \quad (1)$$

From the radiation patterns in Figure 2, it is clear that there is little change in the overall shape of the beam as bias voltage is varied. It is therefore reasonable that the directivity would remain fairly constant across this range, which from Figure 3(a) is indeed the case.

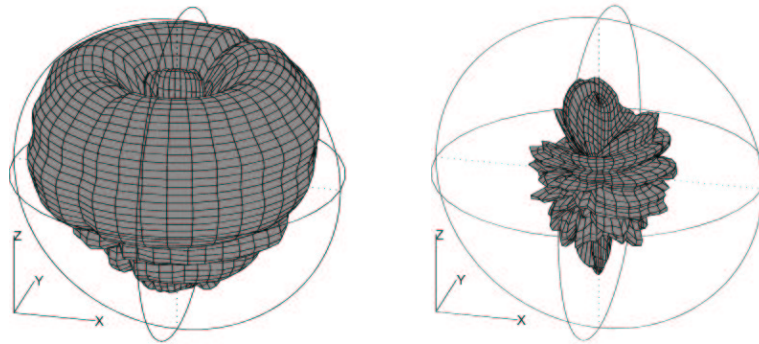
For low bias voltages the gain is less than unity (0dBi), and efficiency is under 27%. As bias voltage is increased so too does



(a) 1.920GHz Co- and Cross-polar

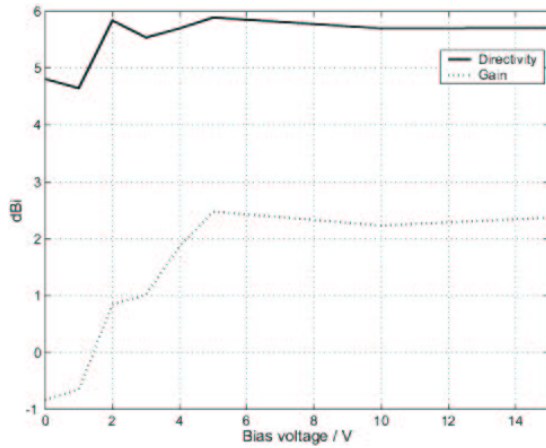


(b) 2.195GHz Co- and Cross-polar

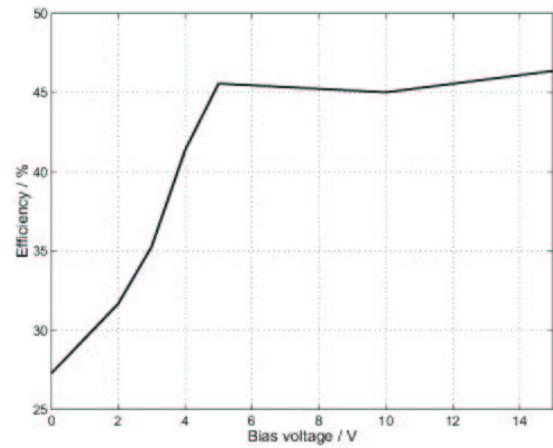


(c) 2.495GHz Co- and Cross-polar

Figure 2. 3-D Radiation Patterns for Annular Slot. dB scale, -40dB at centre



(a) Variation in Gain and Efficiency with Bias Voltage



(b) Variation in Efficiency with Reverse Bias Voltage

Figure 3.

gain and efficiency, flattening out at around 2.5dBi and 45%, Figure 3(a) and Figure 3(b) respectively.

Considering the change in resonant frequency with bias voltage it is clear that in the varactor's non-linear region, where the greatest change in resonance is exhibited, the lowest gain, and as directivity is constant, lowest efficiency too is observed. Conversely, in the varactor's linear region where the change in resonance is small, the gain and efficiency are relatively constant. This is in agreement with previous work [13] which suggested that the majority of the losses are attributed to varactor diode losses. Through utilisation of more efficient tuning technology, such as MEMS, it's envisaged that not only may the overall tuning range be increased, but the losses of the systems will be much less thus yielding a much higher system efficiency.

## CONCLUSIONS

This paper has presented the results of a pattern analysis as a function of frequency for an electrically-small annular slot operating in its 'DC' mode.

Although the annular slot's directivity changed with frequency, the overall shape of its pattern remained fairly constant across this range. Furthermore, the ratio of ( $\frac{X P_{max}}{C P_{max}}$ ) remained low across the whole range, and the amount of power in the Co-polar pattern remained high.

This suggests that through using a tuning device in an annular slot, it is possible to stability the modes in the structure, and therefore have control over the radiation patterns and power split between the polarisations.

Consideration has been given to the gain and efficiency of the annular slot at various bias conditions. It has been shown that in the device's non-linear region, where the tuning is greatest the losses are large and result in a low system efficiency. The opposite is true of the linear region. It's envisaged that through using a more efficient tuning technique, such as MEMS, system efficiency will be improved and a larger tuning range may be realised.

## ACKNOWLEDGEMENTS

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