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Enhanced Stripline Scanning Array

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ABSTRACT

Previous work demonstrating the successful beam scanning of a 3 element array, with integral low bias strength ferrite phase shifters, is extended here to show significant improvement by implementing the structure as symmetrical stripline. The maximum beam scan angle is increased by 30% over that of the microstrip array.

INTRODUCTION

Steerable antenna arrays offer the facility of both beam scanning and adaptive spatial diversity which makes the development of such squinting arrays desirable providing they are physically small and cost effective. Vehicle cruise control radar represents one application for beam scanning (approximately ±15°) while vehicle mounted mobile communications antennas could provide another application. Beam squinting can be accomplished by applying a static magnetic bias field to microstrip circuitry containing ferrite inserts within a dielectric substrate [1,2] or by using Electric fields in conjunction with Ferroelectric materials [3]. Biased ferrite devices are often avoided for battery supplied mobile systems as large drive currents are necessary to achieve significant phase shifts. However, it has been demonstrated that the requirement for a strong controllable magnetic field is removed by biasing the ferrite close to a region of resonance, [4]. This letter presents a method of utilizing ferrite substrates that require only a relatively small field change to steer the beam.

In this work a static magnetic field was applied to bias the ferrite at the threshold of the magnetic absorption region where the effective permeability presented by the ferrite becomes negative and propagating modes are cut off, [4]. The steep phase progression associated with this phenomenon ensures that only small bias variations are needed to produce significant changes in the ferrite tensor permeability. A microstrip line traversing such a region of ferrite will experience large changes in electrical length for relatively small alterations in the applied magnetic field (in the order of 1° per Oersted) before the ferrite attenuation increases by 3dB.

Earlier work, [5], demonstrated the above principle using a corporate feed 3 element array with identical phase shifters providing positive and negative shifts around a central reference element. The antenna elements and all of the feed layout except for the phase shifters were printed onto dielectric with $\varepsilon_r = 2.33$. Transtech G350 YIG Ferrite tiles were then inserted into the dielectric to provide a hybrid substrate. The limitation of the ferromagnetic material to certain regions prevented any unwanted frequency tuning of the antenna elements or spurious mismatches arising in the feed. The array functioned as expected and achieved beam steering of ±30° for an applied field change of around 40Oe. However, there were several problems associated with implementing the array as a microstrip structure. Firstly the phase shifters were problematic to design requiring many trials before the correct physical length was produced. In conjunction with the previous point, great care had to be taken in the placement of the magnetic bias magnets below the substrate and results were difficult to reproduce. These problems were closely associated with uncertainties about the magnetic field distribution which would be strongly divergent for a microstrip system as the ferrites could only be magnetised from below. All modelling and analysis of the magnetised ferrites had assumed that the only existing internal field components were normal to the large surfaces of the ferrite tile and also that the field intensity was constant across the tile. The divergent nature of the field prevented these assumptions from being true. A further limitation of the microstrip array was the strength of the permanent magnets required to provide static biasing near to the absorption resonance point. Permanent magnetisations of 3.5 kG were needed to provide ferrite internal field densities in the order of 2.6 kG, which necessitated the use of expensive high strength permanent magnets. Additionally microstrip antenna feeds require screening to prevent spurious radiation degrading the radiation patterns. All of the above considerations could be addressed by implementing the system in stripline rather than microstrip. In this case the ferrites could be biased symmetrically from above and beneath to provide a uniform field density which would be normally directed to the ferrite tile surfaces.

STRIPLINE ARRAY

A demonstrator system has been implemented where two complimentary phase shifters are driven by small bias field shifts from an electromagnet wound round a permanent magnetic core, Fig.1. The feed coupled electromagnetically to 3 square loop antennas in the upper ground plane. All the structures in this paper were designed to operate at 7.8GHz.

STRIPLINE PHASE SHIFTER RESULTS

A test jig of a single phase shifter based on the structure outlined in Fig.1 was created and an investigation was carried out into the performance of symmetrical biasing over the asymmetrical case. Initially the magnetic field was applied from only beneath the lower ground plane with a single magnet, as for microstrip structures. The stripline structure was then biased symmetrically from above and beneath. The phase of S_{21} for the stripline structure was measured on a Wiltron 360 Network Analyser and is presented in Figs.2a and b as polar plots of $|S_{21}|$ against $\angle S_{21}$. The operating frequency of 7.8GHz is marked. Figure 2a shows the phase of S_{21} for two bias fields applied by a single magnet, while Fig.2b presents the same data for a symmetrically biased 2 magnet configuration. The reproducibility problem for the single magnet bias is clearly visible from a comparison between the figures. The symmetrically biased ferrite produces a much more monotonic variation of phase with applied field, with none of the resonances present that can be observed in Fig.2a for the asymmetrical case. Figure 2 shows that just 20 Gauss caused a phase shift of 20° for the symmetric bias compared to 73 G which was necessary for a 10° change in the asymmetric case. The significantly smaller magnetisation required for the 2 magnets than for the single magnet device was due to the non-divergent nature of the field between the poles. The double magnets provided average field densities of 1.49 kG each while 2.59 kG was required from the single magnet case. The insertion loss in each case increased by about 1.8dB.

ARRAY PATTERNS

A complete stripline array was constructed with 3 radiating square loop antenna elements and two phase shifters. The loop side dimensions and slot width were 12.5mm and 1.0mm respectively and the ground plane sides were 120mm and 110mm. The dielectric substrate was RT Duroid 5870 which has a relative permittivity of 2.33. The total height of the stripline substrate was approximately 1.6mm. The array was designed such that a zero bias caused a broadside beam with zero squint. The results of applying positive and negative drive currents to the electromagnet coils are displayed in Fig.3. It can be seen that the current polarity determines the direction of squint and that a current magnitude of 2.5A is sufficient to steer the beam out to ±20°. The zero bias pattern has been normalised while the relative magnitudes of the three beams have been maintained. The patterns have been compared with an array factor simulation which indicated a phase shift of ±75° has been achieved.

CONCLUSION

The steering of a 3 element stripline array has been demonstrated. The phase shifter operation has been improved over an original microstrip design by implementation as a symmetrical stripline structure. The array beam was squinted over 40° without significant degradation or attenuation in the radiation pattern. Power dissipation was about 12W. This could be provided by a vehicle battery. The magnetic field divergence was significantly reduced within the ferrite meaning more easily characterizable fields could be provided by smaller permanent magnets. The feasibility of providing magnetically controlled beam steering with small and practical field levels has been demonstrated.

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Figure 1

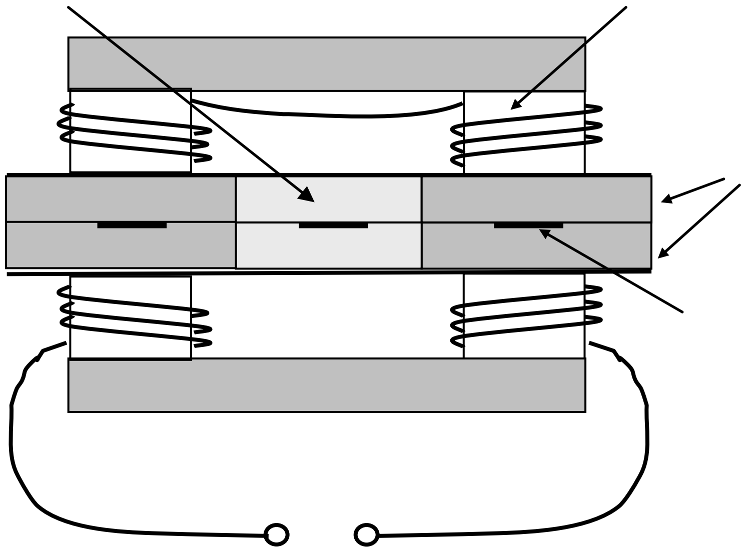

Figure 2a

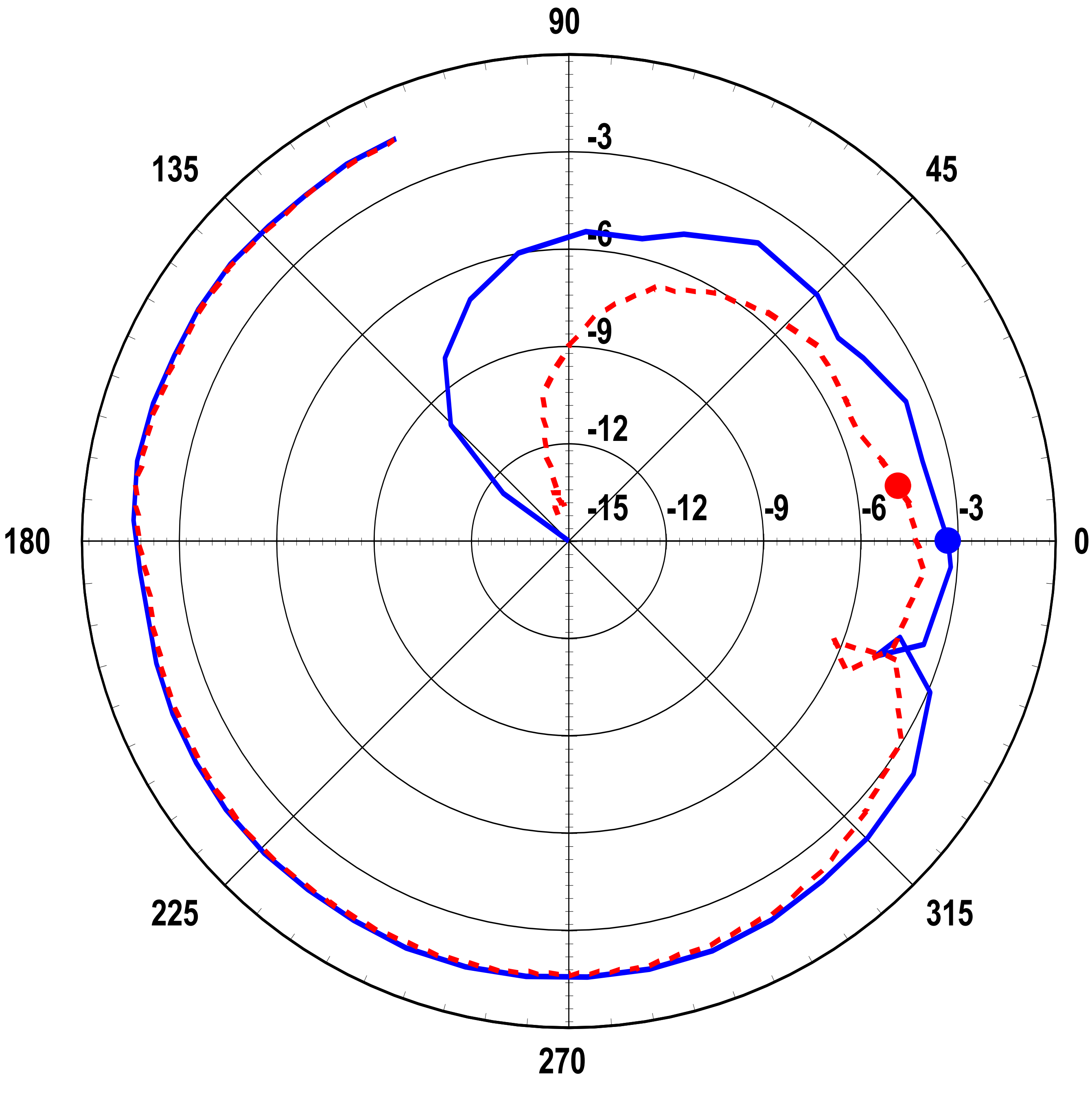

Figure 2b

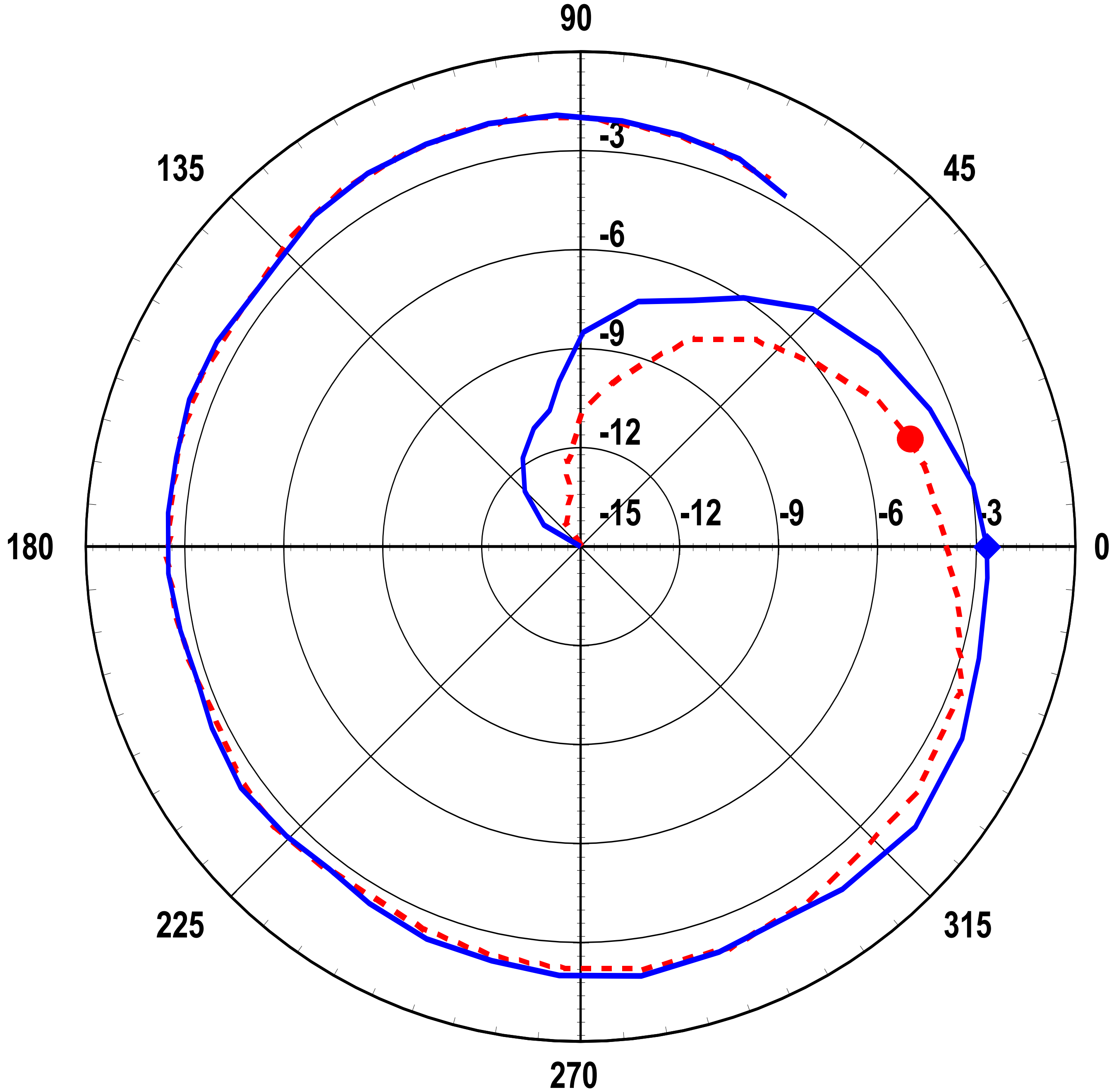

Figure 3

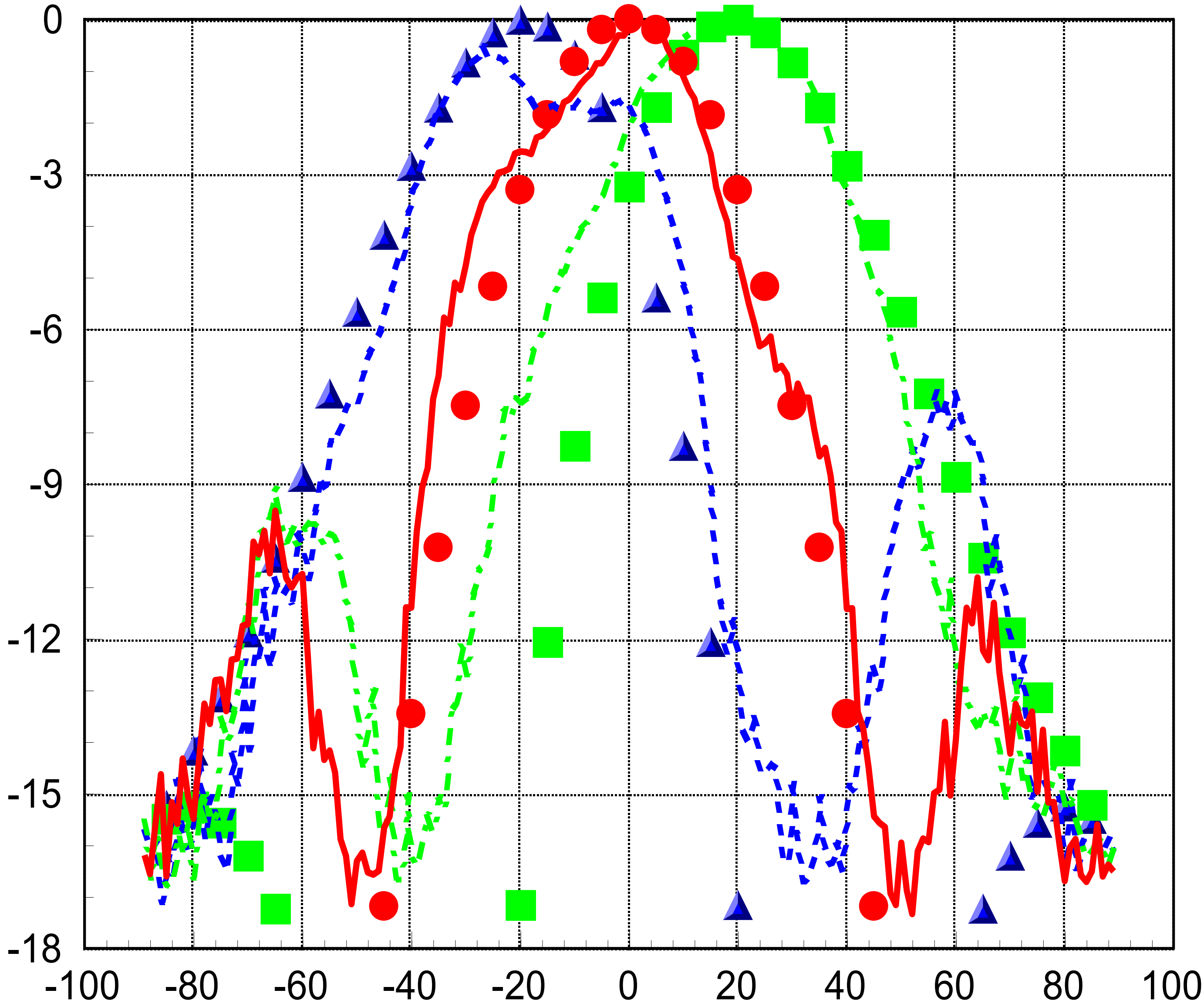

Figure Captions

Figure 1:
Stripline array cross-section showing phase shifters.

Figure 2:
Measured S_{21} for asymmetrical and symmetrical biasing, $|S_{21}|$ polar axis; $\angle S_{21}$ radial axis.

(a) lower magnet only

2.585kG

2.658kG

(b) upper and lower magnets

1.493kG per magnet

1.513kG per magnet

Figure 3:
Array radiation patterns.

-2.5A drive current

-75° simulated phase gradient

0A drive current

0° simulated phase gradient

+2.5A drive current

+75° simulated phase gradient

Figure 1 with text:

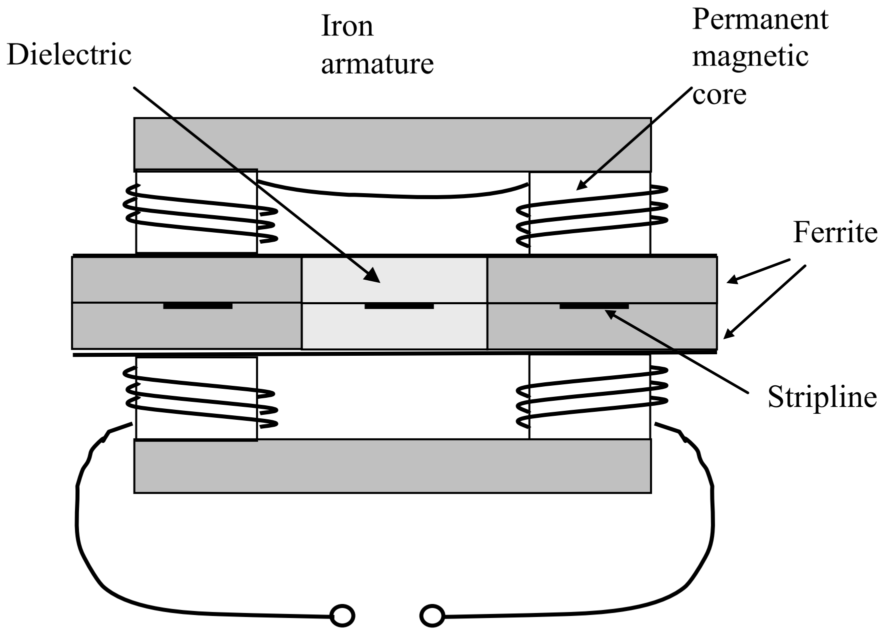

Figure 3 with text: