Identifying the Principal Axes of a Birefringent Material by Polarisation Classification

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A novel use of a 'Rotary Polariser Quasi-Optical System' to locate the principal axes of a birifringent material is presented. It will be demonstrated that by examination of the ellipticity of the beam, one can determine the orientation of such principle axes and hence optimize the performance of Faraday Rotators.

Introduction

A material is said to exhibit birefringence [1] if two orthogonal axes exist which have different indices of refraction. These materials are sometimes referred to as being 'Optically Anisotropic'. Hence, the path-length traversed by a beam or the amount of refraction that is incurred upon it, is dependent on its orientation to these axes. The birefringence phenomena, has been exploited in the design of quarter-wave plate devices [2]. This is were it is arranged for the incident linear polarised wave to bisect the two orthogonal principle axes such that one of its orthogonal components propagates along one principle axis and the other along the the second principle axis. The length of the material is arranged such that one of the orthogonal components of the (E) vector travels ($\pi/2$) radians further. Hence, the beam exits circularly polarised.

Magnetic materials can also be birefringent. However, birefringence can sometimes serve to hinder the performance of a non-reciprocal magnetic device such as a Faraday Rotator[2]. The birifringent nature of the material can incur an ellipticity upon the beam and hence reduce the isolation[2] of the device. The reverse isolation of the device can also become reduced, since the amount of rotation is dependent upon the orientation of the beam. If one can determine the location of the principle axes, it can be arranged to machine the material such that the input beam rotates through one of the principle planes. This serves to minimise the ellipticity on the beam in the forward direction and hence maximise the device's isolation. However, the tradeoff comes when the beam passes through in the reverse direction and suffers maximum ellipticity[2]. The magnetic materials we employ to manufacture Faraday Rotators are of the Barium or Strontium Hexaferrite type with ‘Magneto-plumbite’ structure (BaM and SrM)[7,8]. These are all hexagonal in structure, thus are anisotropic and birefringent. Therefore, a test to locate the principle axes would prove beneficial in the optimization a Faraday Rotator's performance.

Locating the principle axes by Ellipticity Measurement

If one considers a material to be birefringent, then it possesses two principle axes (P1) and (P2) with respective indices of refraction (n_1) and (n_2). These principle axes are orthogonal to one another. If one inputs a linear polarised beam (E) along one of the two principle axes then its orthogonal components (E1) and (E2) will be inclined at 45° to both (P1) and (P2). This will result in (E1) and (E2) traversing the same relative path-length. Hence, the beam will remain linear upon exiting the material. Furthermore, a power meter will detect the loss associated to the particular principle axis. If the (E) vector is inclined at some arbitrary angle (θ) to the principle axis (P1), then the path-lengths traversed by each of the orthogonal components (E1) and (E2) will be proportional to the sum of the component resolved along both axes. This will result in the orthogonal components traversing different path-lengths and hence an ellipticity will be imposed on the beam. When the (E) vector is input such that it bisects (P1) and (P2) the ellipticity (ε) defined in [5] as the (minimum power/maximum power where if ε = 0 → Linear, ε = 1 → Circular, 1 < ε < 0 → Elliptical polarisation) will be largest and also a ratio of the refractive indices of (P1) and (P2). Therefore, when ε = 0 → Locate a Principle Axes and the largest ε → Locates the ratio of the refractive indices of (P1) and (P2). Since, the principle axes are fixed due to the intrinsic structure of a material it was possible to use an unmagnetised sample to locate them and hence avoid rotational effects if it were magnetised. The experiments undertaken were performed using the 'Rotary Polariser Quasi-Optical[6] System', detailed in [5]. The only change to the main setup in [5] was the incorporation of a manual rotary polariser instead of the horizontal polariser[6] in the first half-cube[6]. This was employed to create arbitrary angled inputs for the interrogation of the sample. All measurements were performed at 99.9GHz. Sample 12 was investigated which was an SrM anisotropic, unmagnetised Plastoferrite (which consisted of pulverised powdered SrM in a low loss polymer matrix) of thickness 3.73mm. The results of which are shown in Figure 2 below.

The (Phi) value, in Figure 2, is the measured angle of the manual rotary polariser wires from the vertical position. The results clearly show that the principle axis for Sample 12 is located in the horizontal and vertical axes of the ferrite. Furthermore, the horizontal and vertical axes of the ferrite are also square to the horizontal and vertical sides of the sheet of material that the ferrite was cut from. Hence, the principle axes are roughly parallel to the sides of the manufactured sheets of material. The measurement at PHI = 48° is very close to the angle that bisects the principle axis (namely 45°). The ratio of the maximum and minimum powers detected at this angle reveal the ratio of the refractive indices of the principle axes which is ~1:5. A point to note from the graph is that the major Faraday angle calculated should be the same as the input angle (PHI) of the radiation. However, the slight rotation detected suggests that there is some intrinsic remnant field in the unmagnetised sample. This remnant field can usually be attributed to the type of manufacturing process, [5]. The collated results from the above Figure 2 are shown in Figure 3.

Thus, for sample 12, it would be advisable to arrange for one of the principle axis to be oriented such that a vertically input polarised (E) vector would pass through it as it rotates through a full 45° upon propagation through the sample. As described in [2] this would suggest machining the ferrite such that the principle axis was inclined at 22.50 to the vertical. In order to demonstrate the hypothesis, a 100mm^2 Freespace Faraday Rotator[2] was manufactured and cut at 22.5^0 as the results suggested. As predicted the isolation is maximised in one direction and reduced in the other direction.

By examining the spatial variation of the isolation as the isolator was angled to the vertical one could locate the principal axes. The isolation was measured at a spot frequency of 99.9GHz and results shown in Figure 4.

As one can see the isolation is maximised when the isolator, and therefore one its principle axes, was inclined at 25° to the vertical. The experiment was performed manually so there could be a few degrees error on the results. However, this also gives weight to the results previous and shows that 22.5° would be a good angle at which to machine the ferrite to attain a maximum isolation in one direction.

Conclusion

A 'Rotary Polariser Quasi-Optical System' was used to locate the principal axes of a birifringent material by examining the ellipticity of beam that exited the sample. The ratio of the refractive indices of the principle axes were determined to be 1:5. The system also determined that 22.5^0 would be the best angle to machine the ferrite to produce maximum isolation. A Faraday rotator was then constructed to this specification. By examining the spatial variation of the isolation of the rotator it was shown that maximum isolation was indeed observed at this angle. Thus, such a method could be employed to determine the principle axes of a magnetic sample and prove useful in the optimizing the performance of a Faraday Rotator.

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References

[1] E. Hecht: ‘Optics’, (2nd Edition, Addison-Wesley Publishing), pp. 282-292.

[2] Unsworth C.P, Smith G.M, Kang S, Puplett E, Franklin D, Lesurf J.C.G, Microwave, Millimeter Wave & Submillimeter Wave Free-Space Faraday Rotators, IEEE MTT-S 1995 International Microwave Symposium, Orlando, USA, 1995.

[3] J.J.Went..: ‘Ferroxdure - A Clan Of New Permanent Magnet Materials’, Philips Tech.Rev., 13[7], 1952, pp.194-208,

[4] A.L. Stuijts, G.W.Rathenau, G.H.Weber.: ‘Ferroxdure II & III - Anisotropic Permanent Magnet Materials’, Philips Tech.Rev., 1954, 16 [5-6], pg.141.

[5] C. P. Unsworth.: ‘A Fully Automated Millimetric Rotary Polariser Quasi-Optical System’, PhD Thesis, 1997.

[6] Lesurf, J.C.G.: ‘Millimetre-wave Optics, Devices & Systems’, (Adam Hilger-IOP Publishing, 1990).

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Figure Captions

Figure 1 : Quasi-Optical Experimental Setup

Figure 2 : Ellipticity measurements for different input polarisations

Figure 3 : Location of Principal Axes

Figure 4 : Variation of Isolation with spatial orientation

Figure 1

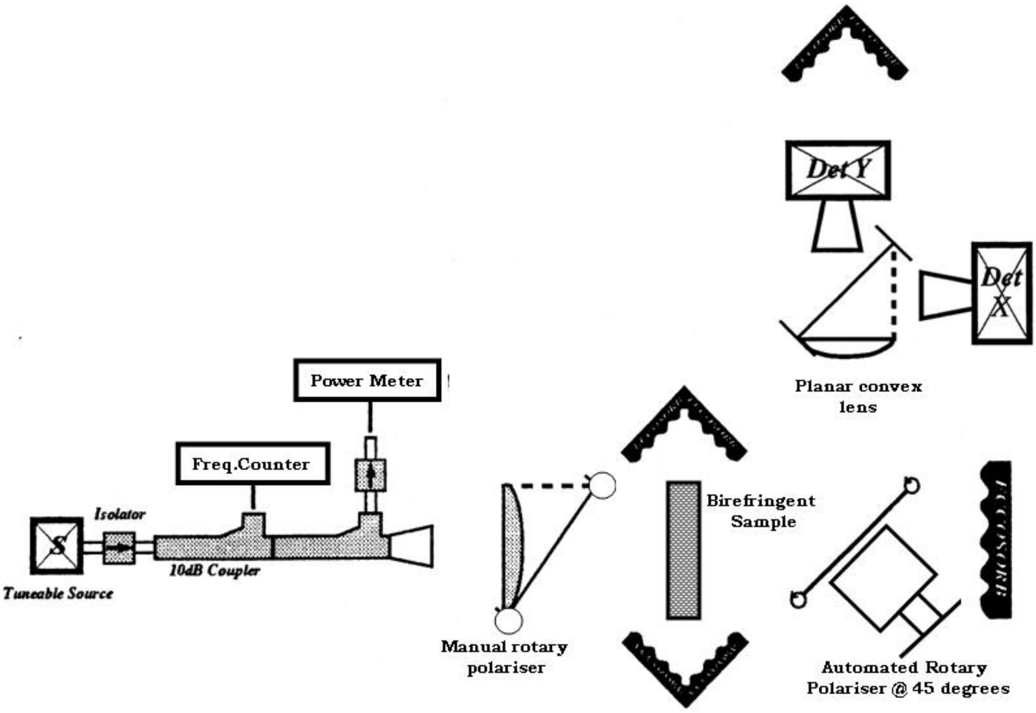
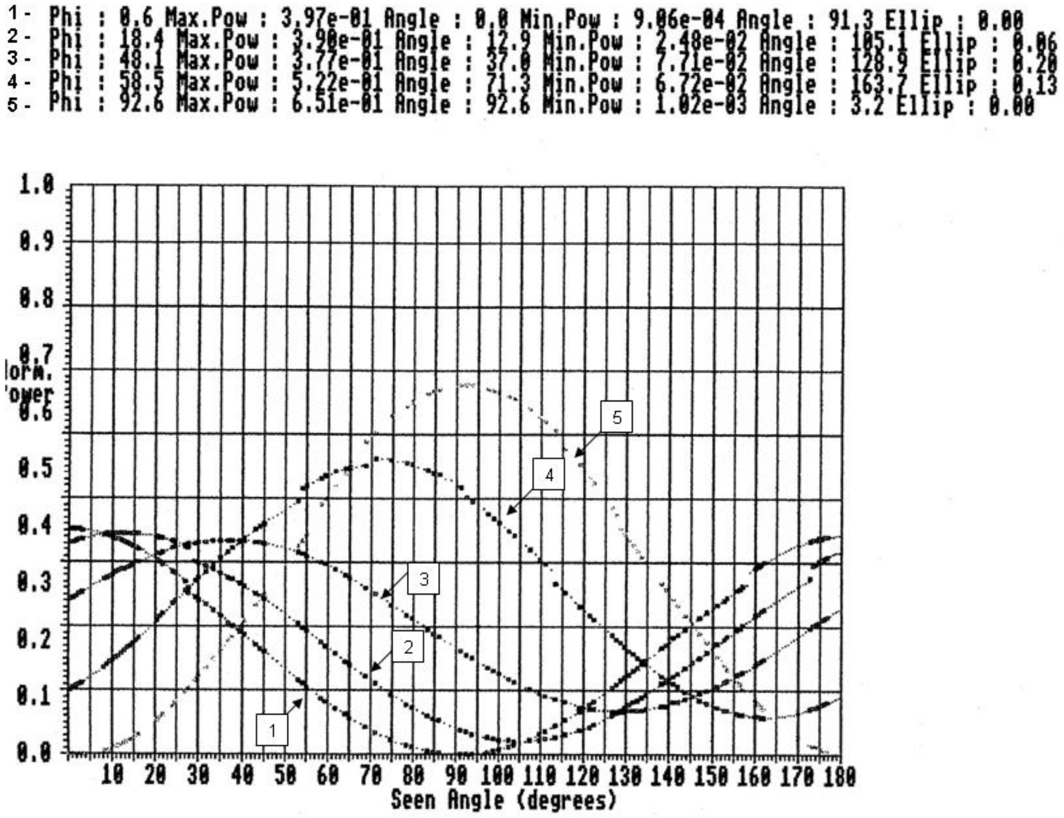

Det Y
Det X
Planar convex lens
Power Meter
Freq.Counter
Isolator
S
10dB Coupler
Tuneable Source
Birefringent Sample
Manual rotary polariser
Automated Rotary Polariser @ 45 degrees
ECCOSORB

Figure 2



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1 -  Phi : 0.6 Max.Pow : 3.97e-01 Angle : 0.0 Min.Pow : 9.06e-04 Angle : 91.3 Ellip : 0.00
2 -  Phi : 18.4 Max.Pow : 3.90e-01 Angle : 12.9 Min.Pow : 2.48e-02 Angle : 105.1 Ellip : 0.06
3 -  Phi : 48.1 Max.Pow : 3.77e-01 Angle : 37.0 Min.Pow : 7.71e-02 Angle : 128.9 Ellip : 0.20
4 -  Phi : 58.5 Max.Pow : 5.22e-01 Angle : 71.3 Min.Pow : 6.72e-02 Angle : 163.7 Ellip : 0.13
5 -  Phi : 92.6 Max.Pow : 6.51e-01 Angle : 92.6 Min.Pow : 1.02e-03 Angle : 3.2 Ellip : 0.00
```

Figure 3

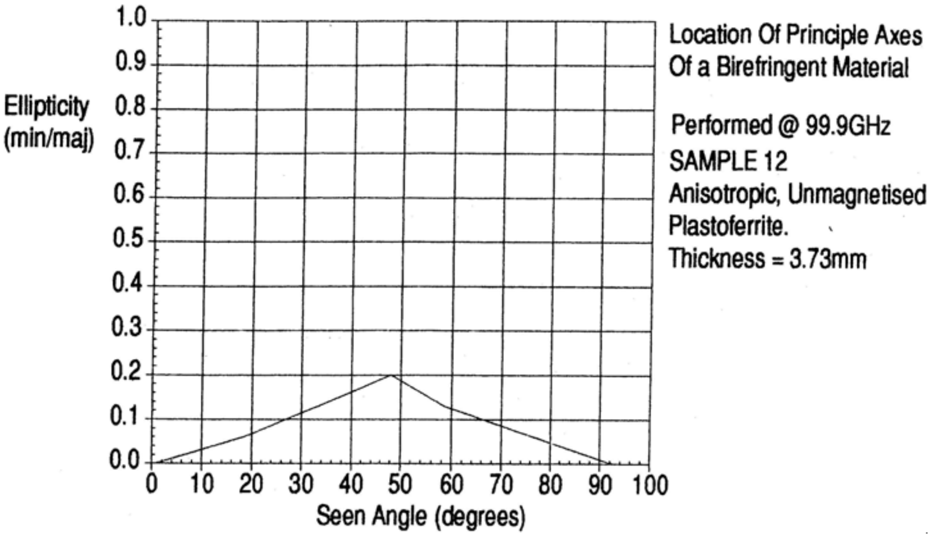
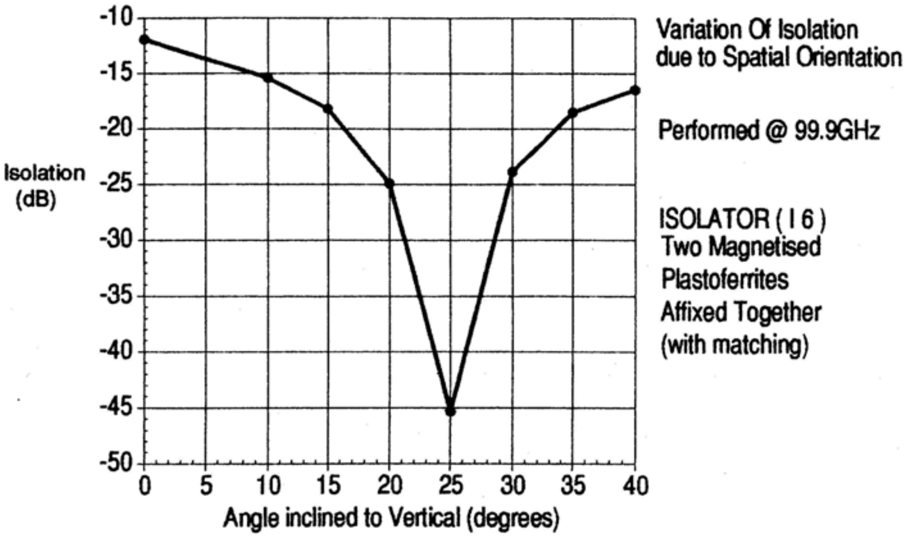

Ellipticity
(min/maj)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
70
80
90
100
Seen Angle (degrees)
Location Of Principle Axes
Of a Birefringent Material
Performed @ 99.9GHz
SAMPLE 12
Anisotropic, Unmagnetised
Plastoferrite.
Thickness = 3.73mm

Figure 4



-10
-15
-20
-25
-30
-35
-40
-45
-50
Isolation (dB)
0
5
10
15
20
25
30
35
40
Angle inclined to Vertical (degrees)
Variation Of Isolation due to Spatial Orientation
Performed @ 99.9GHz
ISOLATOR (I 6)
Two Magnetised Plastoferrites Affixed Together (with matching)