resonant input impedance of about 150Ω. This is an increase of more than a factor of three, which is more than the factor of two increase in polarisability of the dogbone relative to the rectangular slot. We then use an $L = 9$ mm, $W = 1$ mm dogbone, which gave a resonant resistance of about 56Ω. This implies that a dogbone aperture can be made about 30% shorter than a rectangular slot, for the same level of input impedance. Of course, the ends of the dogbone slot take up more space than a rectangular slot of the same length. The resonant frequency in each of the above cases was about 3·5 GHz, with slight variations due to the different slot sizes.

Conclusion: The dogbone-shaped slot can give an increase of more than three in the input impedance of an aperture coupled microstrip antenna, as compared with a rectangular slot of the same length. This allows the use of smaller coupling apertures for this antenna, which will reduce the back radiation as well as ease positioning constraints for antennas with multiple aperture feeds. Probably the only disadvantage with this technique is that the dogbone shape complicates the theoretical analysis of the antenna.

Other variations of end-loaded slots, such as dumbell slots, or slots with rectangular loading slots, are expected to give similar improvements in coupling. It is interesting to speculate on the optimum aperture shape that would give maximum linear dimension.

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COMPENSATION FOR TEMPERATURE DEPENDENCE OF FARADAY EFFECT IN DIAMAGNETIC MATERIALS: APPLICATION TO OPTICAL FIBRE SENSORS

Indexing terms: Faraday effect, Optical fibres, Magnetism

The temperature dependence of the Faraday effect in a diamagnetic material can be compensated for by varying the polarisation state of the light entering the material as a function of temperature. We demonstrate that this can be done automatically by exploiting the temperature dependence of a linear retarder (waveplate).

The Faraday effect is a magnetic field-induced circular birefringence, more commonly described as a rotation of the plane of polarisation of linearly polarised light. It is described by

$$\theta = V \int_0^L \boldsymbol{B} \, . \, \boldsymbol{dh} \tag{1}$$

where θ is the induced rotation, $\boldsymbol{B}$ is the magnetic field vector, $\boldsymbol{dh}$ is a vector along the direction of propagation of the light, L is the length of the interaction, and V is a material parameter known as the Verdet constant, assumed here to be uniform throughout the material.

In a magnetic field sensor based on the Faraday effect, the temperature dependence of the Verdet constant and the thermal expansion of the material set a fundamental limit to the precision of the measurement. Diamagnetic materials are usually chosen as the sensing elements in high precision applications because they are less dependent on temperature than paramagnetic or ferromagnetic materials.[1] Measurements of $[d(VL)/dT]/(VL)$, the normalised temperature dependences of the Faraday effect, on various diamagnetic crystals show values that range between -10^{-3} and $+10^{-3}$/K.[2] Measurements on diagmagnetic glasses show values of the order of $+10^{-4}$/K[3]. If greater stability is to be achieved, some form of temperature compensation must be used.

The sensitivity of a Faraday effect sensor is reduced by increasing the ellipticity of the input polarisation state. The temperature dependence of a linear retarder (waveplate) can be used to attain a temperature dependent ellipticity. We show here that by using a waveplate with the correct parameters, the change in sensitivity owing to the temperature-induced change in polarisation state can be made to cancel the $[d(VL)/dT]/(VL)$ temperature dependence.

Fig. 1 shows a typical polarimetric sensor configuration in which a waveplate, with a retardance δ, has been inserted into the sensor immediately before the sensing element. The axes of the waveplate are oriented at 45° to the input polariser. The Wollaston prism at the output splits the light into two orthogonal polarisations (oriented at $\pm 45°$ to the input polariser). Both output components are detected and their difference Δ and sum Σ obtained. If there is no linear birefringence in the sensing element, the ratio of the difference to the sum is

$$\frac{\Delta}{\Sigma} = \sin(2\theta)\cos(\delta) \tag{2}$$

If the Faraday rotation is small ($\sin\theta \simeq \theta$), and the magnetic field is uniform throughout the sample, the normalised temperature derivative of eqn. 2 is

$$\frac{1}{(\Delta/\Sigma)}\frac{d(\Delta/\Sigma)}{dT} = \frac{1}{(VL)}\frac{d(VL)}{dT} - \gamma\delta\tan(\delta) \tag{3}$$

where $\gamma = (d\delta/dT)/\delta$ is the normalised temperature dependence of the waveplate retardance. Eqn. 3 is the effective temperature dependence of the sensor. For a given Faraday material, it can, in principle, be made arbitrarily small by the choice of a retarder with an appropriate δ and γ. Specifically, the waveplate should be chosen so that

$$\gamma\delta\tan(\delta) = \frac{1}{(VL)}\frac{d(VL)}{dT} \tag{4}$$

We tested eqn. 3 using SF-57 glass as the sensor material and a quartz waveplate. SF-57 is commonly used in Faraday effect sensors because it has a larger Verdet constant than most glasses and its stress optic coefficient is unusually small.[4] The temperature dependence of the Verdet constant of SF-57 is $[d(VL)/dT]/(VL) = +(1{\cdot}35 \pm 0{\cdot}08) \times 10^{-4}$/K.[3] For quartz,

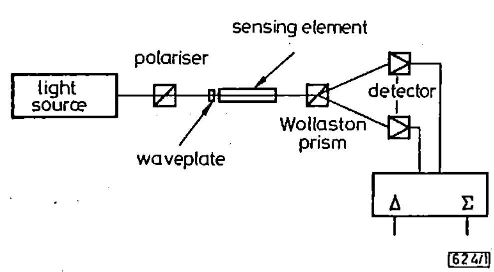

Fig. 1 *Typical polarimetric sensor configuration with waveplate added for temperature compensation*

the most widely used material for waveplates, $\gamma = -(1{\cdot}14 \pm 0{\cdot}05) \times 10^{-4}$/K. Using these values, which were measured at 20°C and at a wavelength of 633 nm, eqn. 3 is plotted in Fig. 2 for $0 < \delta < 180°$. Within this range, zero temperature dependence is obtained when $\delta \simeq 156°$. At this retardance, the sensitivity is diminished by only ~9% (eqn. 2), yielding a practical operating point. Higher order waveplates could also be used, but the slope of the $[d(\Delta/\Sigma)/dT]/(\Delta/\Sigma)$ curve near those zero crossings is greater, requiring a greater accuracy of the waveplate retardance.

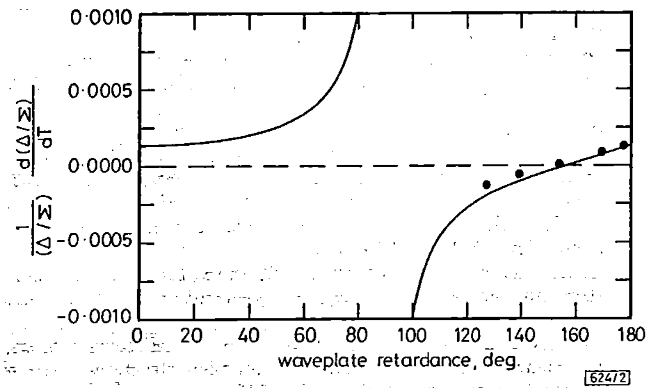

Fig. 2 *Temperature dependence of normalised response of sensor* $\{[d(\Delta/\Sigma)/dT]/(\Delta/\Sigma)\}$ *as function of retardance of waveplate*

——— theoretical prediction of eqn. 3

● experimental values at 128°, 139°, 154°, 169°, and 177°

Our apparatus was similar to that reported previously,[3] except that a tungsten–halogen lamp with a monochromator was substituted for the laser source. By varying the wavelength, we were able to change the retardance of the waveplate without disturbing the configuration. This, of course, assumes negligible dispersion in γ and $[d(VL)/dT]/(VL)$, which appears to be the case over the range used. The data were taken as previously described.[3]

The results are shown in Fig. 3, where the response of the sensor (Δ/Σ) is divided by its extrapolated 20°C value $((\Delta/\Sigma)_0)$ and plotted as a function of temperature. Curve (i) is previously reported data on uncompensated (no waveplate) SF-37 using a 633 nm laser as the source.[3] Curves (ii), (iii) and (iv) are data taken using the method described above, for wavelengths such that $\delta = 139°$ (undercompensated), 154° (well compensated), and 169° (overcompensated), respectively. For $\delta = 154°$, the slope is 0 within experimental uncertainty. The results for five values of retardance are plotted as points in Fig. 2. The experimental uncertainty in the data is less than the size of the points. The uncertainty in the theoretical curve is about three times the width of the curve; this comes from the estimated experimental uncertainties in $[d(VL)/dT]/(VL)$ for SF-57 and γ for quartz.

This compensation method appears to be a practical and general method of compensating for the temperature dependence of the Faraday effect in diamagnetic materials.

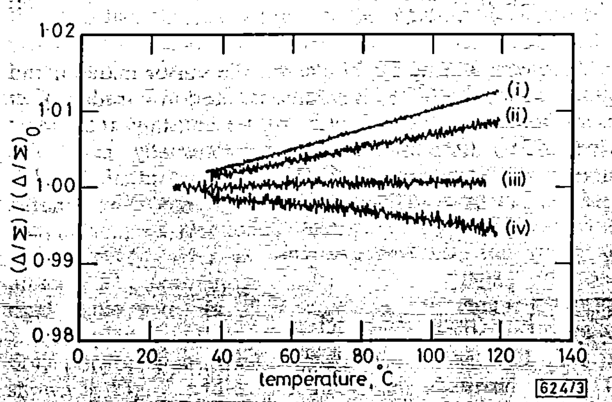

Fig. 3 *Typical data showing normalised response* $[(\Delta/\Sigma)/(\Delta/\Sigma)_0]$ *as function of temperature for SF-57*

(i) uncompensated sample
(ii) Wavelength retardance = 139°
(iii) Wavelength retardance = 154°
(iv) Wavelength retardance = 169°

However, it depends on an accurate knowledge of the temperature dependences of the materials involved, and may therefore require some empirical adjustments. It should also be applicable to paramagnetic and ferromagnetic or ferrimagnetic materials in those cases or temperature ranges where their temperature dependence is approximately linear. It is not restricted to cases where the temperature dependence of the Faraday effect is positive; eqn. 3 has solutions for either sign of $[d(VL)/dT]/(VL)$.

The method is adaptable to a Faraday effect current sensor, in which the sensing material (optical fibre for example) makes a closed path around the conductor. By the Ampere law, the line integral of the magnetic field along a closed optical path is equal to the current through the path, independent of the path length and the spatial distribution of the current. For the current sensor, it is therefore $(dV/dT)/V$ rather than $[d(VL)/dT]/(VL)$ which must be compensated for, and the requirement of a spatially uniform magnetic field is no longer a necessary assumption.

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EFFICIENT VLSI DIGITAL LOGARITHMIC CODECS

Indexing terms: Large-scale integration, Coding

N bit digital words can be logarithmically encoded and compressed to a word length of $(\log_2 n + m - 1)$ bit maintaining a relative accuracy of m bit over $(n - m)$ octaves of signal level. A bit-serial VLSI coder is reported, which requires little more than a $\log_2 n$ counter and an output register and it has a latency of one wordlength. The bit-parallel coder can be built with less than n^2 transistors and has less than $n/4$ gate delays. The decoder has similar properties and it expands the logarithm to an antilogarithm with n bit of dynamic range. Using these codecs, digital multiplication, division, powers and roots are reduced to additions, subtractions and shifts, respectively.

Introduction: VLSI digital processing of signals from or for natural systems always needs sufficient dynamic range, say n bit, but it can often tolerate a more limited relative accuracy or signal-to-noise ratio of m bit $(m < n)$. Compressive logarithmic coding of signals into $(\log_2 n + m - 1)$ bit yields m bit accuracy over $(n - m)$ octaves of signal level. Although this bit-rate compression in itself is of interest, the real significance of logarithmic coding lies in the fact that multiplications and divisions are reduced to additions and subtractions, respectively, and powers and roots of digital data become simple