There are several other dielectrically anisotropic substrate materials, notably AR-1000®1, single crystal quartz and some semiconductor substrates˚ in particular developed in the same manner to provide a design basis.

Mariki and Yeh [102] have reported a three-dimensional TLM analysis of microstrip on an anisotropic substrate. Their results are entirely concerned with dispersion for this case, and are considered in rather more detail in Chapter 5.

4.9 MICROSTRIP ON A FERRITE SUBSTRATE

A number of circuits have been designed and built on various ferriet substrates and is appears that the earliest significant papers appeared as long ago as 1957˚ 58 [103, 104]. However, the realization of production circuits using ferrite substrates is expensive, on account of the relatively high cost of the ferrite and its finishing. Further, many circuit functions certainly do not require ferrite for their operation indeed, greater quality is generally achievable on purely dielectric substrates such as sapphire, alumina, quartz, etc. Where non-reciprocal properties are demanded, ferrite devices may be inserted into the substrate. Therefore only a brief treatment of the design problem is presented here.

For magnetically saturated ferrite, magnetized in the z direction and with an RF field propagating in this direction, the Polder tensor is

$$\bar{\mu} = \mu_0 \begin{bmatrix} \mu & -jk & 0 \\ jk & \mu & 0 \\ 0 & 0 & \mu_z \end{bmatrix} \tag{4.66}$$

where μ_z = 1 and the permeability elements μ and k are exactly related to precession frequency, microwave frequency, saturation magnetization. DC magnetic field, macroscopic relaxation time, and resonance line width. In the limit of high applied field or high frequency, the ferrite behaves as a dielectric medium with a moderately low loss ($\tan \delta \cong 0.001$ typically) and permittivity range

$$9 \leq \varepsilon_r \leq 16. \tag{4.67}$$

In the partially magnetized state (common in practice) μ is somewhat less than unity, and

$$K = \frac{\gamma(4\pi M)}{\omega} \tag{4.68}$$

Where γ and $4\pi M$ are respectively the gyromagnetic ratio and the average magnetizations for the ferrite.

Effective permeability μ_{eff} is an important quantity which is analous to a bulk substrate relative permeability, and is thus very useful in design. The defining formula is

$$\mu_{eff} = (\mu^{2-} k^{2}) / \mu \tag{4.69}$$

At sufficiently high frequency $\omega >> \gamma (4\pi M)$ and $k \rightarrow 0$ so that $\mu_{eff} \rightarrow \mu$. Under these conditions, μ_{eff} is not much less than unity :

$$0.7 \leq \mu_{eff} \leq 1.0 \text{ (as } \omega \rightarrow \infty) \tag{4.70}$$

The quantity k/μ is usually termed the (ferrite) anisotropy. In the case of microstip an empirical correction has been given for μ_{eff} [105]. However, the above comments remain approximately true.

It is useful to define an effective microstrip permability μ_{eff} as being analogous to the effective microstrip permittivity defined earlier in this chapter by (4.17) and repeated here,

$$\varepsilon_{eff} = 1 + q(\varepsilon_r - 1) \tag{4.71}$$

where the filling factor q, and hence ε_{eff} are functions of w/h and ε_r,

Provided some basic and reasonable assumptions are made regarding a microstrip line (perfect conductors ; isotropic, homogeneous, non-gyromagnetic substrate) [105], then its dielectric properties will not affect the magnetic field distribution and its magnetic properties will not affect its electric field distribution. We can then write down a magnetic electric duality statement :

$$\mu_e\{(w/h), \mu_{eff}\} = (\varepsilon_{eff}\{(w/h), \varepsilon_{eff}\})^{-1} \tag{4.72}$$

By analogy with (4.71), we can also write

$$\mu_e = \left(1 + q_m\left\{\frac{1}{\mu_{eff}} - 1\right\}\right) \quad (4.73)$$

where q_m is the magnetic filling factor. This completely defines μ_e. however, although not explicitly indicated here, it must be appreciated that both q_m and μ_{eff} are functions of w/h for the microstrip. For CAD purposes, Pucel and Masse [105] give analytical expressions for e and μ_{eff}. These expressions will not be repeated here, but a graph is given (Figure 4.12) as a design aid.

We also require expressions for the characteristic impedance and the guide wavelength. Using (4.1), $Z_0 = (L/C)^{\frac{1}{2}}$, we obtain

$$Z_0 = \left(\frac{\mu_e L_1}{\varepsilon_{eff} C_1}\right)^{\frac{1}{2}} \quad (4.74)$$

Where L_1 and C_1 are for the air-spaced case. Hence

$$Z_0 = Z_{01}\sqrt{\mu_e / \varepsilon_{eff}}\ \mu \quad (4.75)$$

Also, using

$$\upsilon_p = C/\sqrt{\mu_e / \varepsilon_{eff}} \quad (4.76)$$

we obtain

$$\lambda_g = \frac{\lambda_0}{\sqrt{\mu_e \varepsilon_{eff}}} \quad (4.77)$$

or

$$\lambda_g = \frac{300}{\sqrt{\mu_e \varepsilon_{eff}}}\ \text{mm} \quad (4.78)$$

(which can be compared to Equation (4.21)).

For synthesis, where ω and λ_g are desired, it is recommended that the design is first carried out assuming a non-ferrite substrate (but, of course, with the appropriate