3 Planar Directional Couplers and Filters

Planar directional couplers allow for separation of forward and backward travelling waves within scattering parameter testsets of vector network analyzers (VNA). In combination with power detectors (chapter 5), couplers are used for overload protection and automatic level control of signal generators (chapter 6).

Section 3.1 introduces the modal and nodal scattering and impedance network parameters of coupled transmission lines according to the general waveguide circuit theory (GWCT) [1]. This analysis is based on the results of 2D EM Eigenmode analysis.

Backward wave directional couplers achieve directivity at frequencies as low as 10 MHz and 70 kHz, what is difficult to realize together with high maximum operating frequencies like 50 GHz and 70 GHz. Directivity is directly related to equalized phase velocities of the propagating modes. A synthesis procedure for nonuniform transmission line couplers is included. Theoretical and experimental investigations on backward wave couplers with dielectric overlay technique (stripline) and wiggly-line technique to equalize the even and odd mode phase velocities are presented.

If directional coupler operation at low frequencies is not required, codirectional couplers are the method of choice. Section 3.3 includes a synthesis procedure and simulated and measured results of various codirectional couplers on thin-film processed alumina, including the couplers used within the modules of chapter 6.

Although commercially available directional couplers with coaxial or hollow waveguide interface make use of external terminations, couplers for planar integration require internal nonreflective impedance
terminations. In section 3.4, several 50 Ω terminations based on nickel chrome (NiCr) sheet resistors are presented. It further includes simulation and measurement results of the author’s DC to 110 GHz attenuator series.

Beside directional coupler designs, equalized phase velocities are also beneficial for edge and broadside coupled line bandpass filters (BPF) to suppress the parasitic second passband. This is demonstrated in section 3.5 by applying wiggly-line technique to the first and last filter element of an edge coupled line BPF on 10 mil alumina.

### 3.1 Theoretical Foundations of Cascaded Coupled Waveguides

With the results from 2D EM Eigenmode analysis as a starting point, the modal impedance $Z_{mt} = Z_m$ and scattering $S_{mt} = S_m$ matrices of uniformly\(^1\) coupled asymmetric lines are derived [1, 2]. The nonuniform case is covered by cascading a sufficiently high number of short uniform lines. Beside the modal description, power normalized conductor impedance $Z_{ct} = Z_n$ and scattering $S_{ct} = S_n$ matrices are introduced. Such nodal matrices are required to connect transmission lines with arbitrary lumped elements or discrete components like diodes (compare chapter 2). Nodal scattering matrices are accessible to conventional measurement. Modal scattering parameter measurements require sophisticated calibration algorithms, like TRL. Following this approach, leads to the results from Tripathi [3–5], the conductor impedance matrix of asymmetric coupled lines, but maintains a clear connection to the results from 2D EM Eigenmode analysis.

#### 2D EM Eigenmode Analysis

Fig. 3.1 shows a cross-sectional view of coupled asymmetric lines, consisting of thin conductors, substrate material and metallic enclosure. All material properties are assumed

\(^{1}\)The term uniform means cross section does not change in the direction of wave propagation (z-axis).