1 Introduction

For advanced communication and sensor applications, antennas with low profile, low loss, and low production cost are required. While planar antennas are very well-suited with respect to antenna depth and cost, they suffer from high losses due to the feeding network, especially for narrow beamwidths [1, 2]. In the case of a microstrip array with corporate microstrip feeding network, the losses increase strongly with the overall size of the antenna array, Fig. 1.1 and [3]. If an element spacing of half a free space wavelength and a microstrip transmission line loss of 0.15 dB per guide wavelength are assumed, maximum gain is in the range of 30 dBi to 35 dBi. With increasing antenna size beamwidth still decreases, but gain decreases, too. With a series feeding the feed network loss can be reduced, but only at the cost of bandwidth. Another issue with series feeding is the specific beam tilt over frequency, which is problematic especially

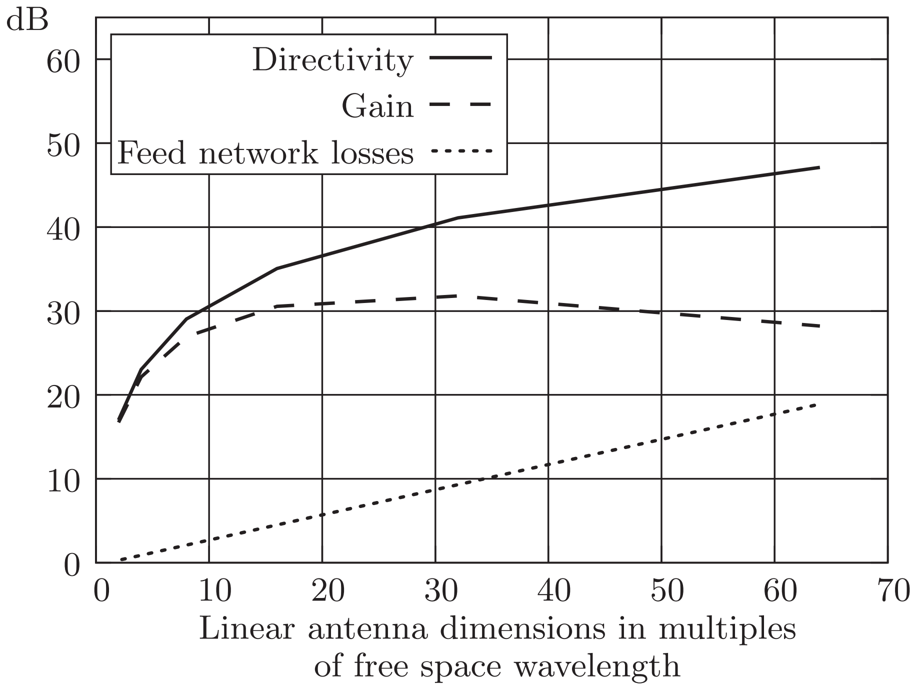

Fig. 1.1: Feed network losses, directivity and gain of a microstrip array with corporate microstrip feed network.

for high gain pencil beam antennas with extremely narrow beamwidths. Arrays of horn antennas with a waveguide feed network [4] or waveguide slotted arrays [5–7] which are typically based on a series feeding, are lower in loss, but partly narrow band and usually complicated in design, and they do not readily lend themselves to low cost fabrication. In a former project some work was reported on the fabrication of waveguide networks and antennas [8] as well as waveguide filters and diplexers [9] using plastic injection molding and electroplating, but the authors reported significant reduction of gain compared to the results achieved with a prototype machined from solid aluminum [4]. Printed reflectarrays are known to be an alternative solution leading to high gain and low loss antennas [10], but for some communication applications, the antenna depth even with a folding approach [11] is still too big. Another approach combines microstrip antenna arrays with a waveguide feed network [12–15] for the reduction of feed network losses. Again, the waveguide network may be fabricated using plastic injection molding and electroplating to reduce fabrication cost. Nevertheless, waveguide is still quite bulky and provides some difficulties in designing and assembling the feed network for a restricted space behind the antenna.

In this work an alternative waveguide, the nonradiative dielectric (NRD) waveguide, has been investigated for feeding planar mm-wave antennas. This approach combines the low loss behavior of the NRD-guide feeding network with low profile and low production cost of planar antennas (e.g. microstrip arrays).

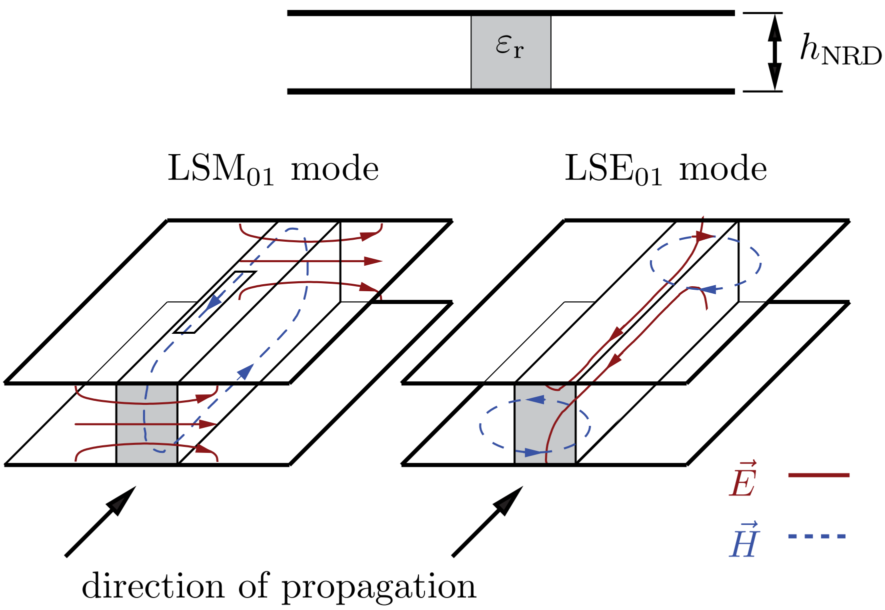

Fig. 1.2: Fundamental modes on the NRD-guide.

The NRD-guide, according to Fig. 1.2, consists of a dielectric strip sandwiched between two metal plates with a spacing h_{NRD} smaller than a half of free space wavelength. Assuming the same potential for both metal plates, i.e. a symmetry of the electromagnetic fields with a magnetic wall in the plane at half the NRD-guide height, assures that all modes are guided by the dielectric strip. As a result, radiation can only be caused by asymmetries along the NRD-guide height generating the parallel plate mode which is not guided by the dielectric strip. Thus it is feasible to design a group of non-radiative building blocks including bends, curves, and T-junctions, required for complex parallel or series feeding networks. The wave is guided by the dielectric strip in the form of longitudinal section electric (LSE) and longitudinal section magnetic (LSM) waves.

In practical applications, especially in the microwave and mm-wave range, more complicated feeding structures based on the ideal NRD-guide are difficult to implement due to alignment problems. In order to circumvent these problems, different forms of implementations indicated in Fig. 1.3 have been presented in the past.

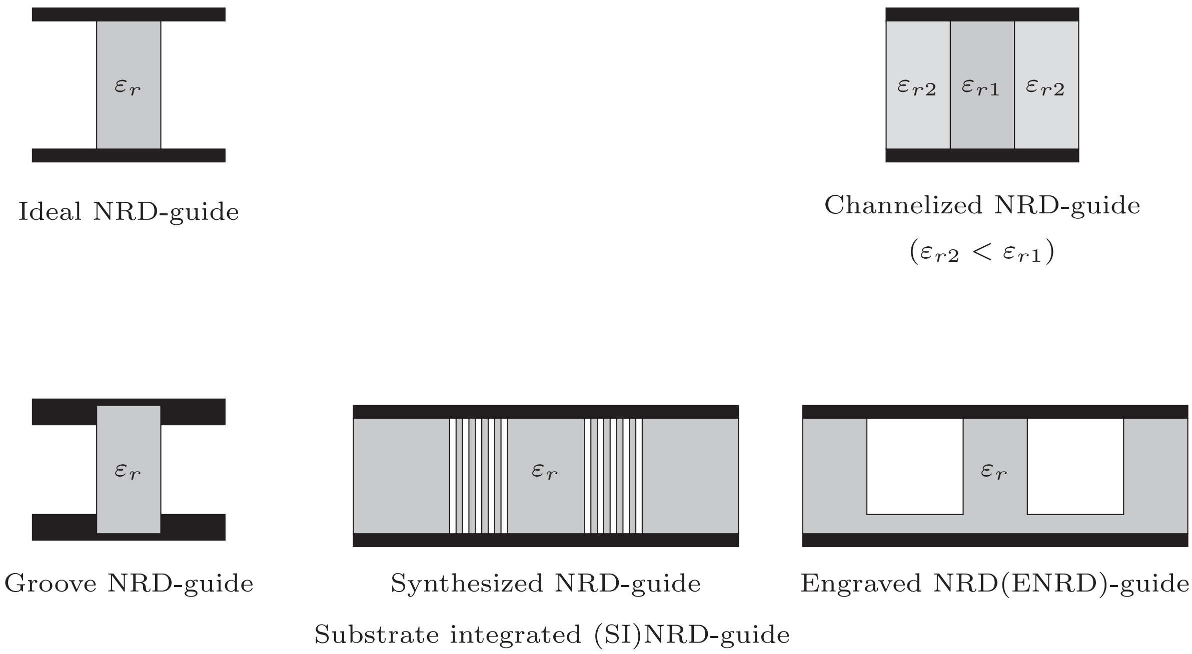

Fig. 1.3: Nonradiative dielectric waveguide (NRD-guide) and several alternative setups.

The channelized NRD-guide [16] consists of two materials with different values of ε_{r}, where the material with the lower relative dielectric constant $\varepsilon_{\mathrm{r2}}$ serves for alignment and might be a type of foam with electrical properties similar to air.

The groove NRD-guide [17–19] features a groove milled into the metal ground planes which makes alignment of the guiding strip easier and more precise. In the synthesized NRD-guide, or substrate integrated NRD (SINRD) waveguide [20–22], the transmission line is defined by a set of holes along the wave guiding area, implementing the low dielectric region as compared to the channelized NRD-guide. The engraved NRD(ENRD)-guide [23] is milled out of a solid block of dielectric material which again avoids tolerance problems.

This work includes three different types of antennas which all consist of a planar antenna part and a feeding network made of one of the above described implementations of the NRD-guide.

The antennas investigated in this thesis are implemented in the K-band (18 GHz–26.5 GHz) as for this frequency range measurement facilities and power amplifiers were readily available, but actually they lend themselves for applications in the millimeter-wave range where the low loss characteristic of the NRD-guide is even more pronounced, e.g. for point-to-point or point-to-multipoint communication links, radiometry, and for radar sensors.

Chapter 2 of this thesis deals first with the derivation of the eigenvalue equations for the propagation constants of all solutions in the NRD-guide structure assuming the loss-free case. Solving these eigenvalue equations leads to characteristic values including propagation constants, cutoff-frequencies, and single mode propagation bandwidth. In a second step the equations for the attenuation constants according to different loss mechanisms are derived under the assumption of low loss nature with the electromagnetic fields similar to the loss-free case, and by applying a perturbational method. Those equations are then used to choose the proper dimensions of the NRD-guide structure for specific applications described in the following chapters.

The first type of antenna introduced in **Chapter 3** is an antenna for point-to-point or point-to-multipoint applications with low loss, low profile and low production cost. A corporate network of NRD-guides made of low loss high density polyethylene (HDPE) dielectric material serves as feed for planar microstrip patch antenna sub arrays. Smaller sub arrays of microstrip patches are used where losses still are low. The sub arrays are coupled to the back side NRD-guide network via coupling slots in the ground plane of the planar structure. The total height of this antenna is 6.3 mm only. Such a low profile can otherwise only be achieved with purely planar techniques like microstrip antennas fed by a microstrip line feeding network, but then at the cost of increased loss and reduced efficiency.

In the second type of antenna introduced in **Chapter 4** the multimode characteristic of the NRD-guide is used to implement a feeding network of a dual polarization antenna. The NRD-guide is used for the first time as a dual mode waveguide. The longitudinal section electric (LSE) and the longitudinal section magnetic (LSM) mode are excited independently by separate transitions from microstrip line to NRD-guide. Each of the modes causes the planar patch arrays to radiate in one linear polarization. Based on these investigations a dual polarization antenna was implemented using a 2×2 array of microstrip patch antenna elements with a small microstrip feeding network, and a substrate integrated NRD-guide feed to avoid alignment problems. In an alternative implementation the ideal NRD-guide is used as a feeding network, and independent matching of LSM and LSE modes is conducted by a step in the NRD-guide width, acting as a highly reflective stub for the LSM mode only. This matching technique is the subject of a patent application.[†] Based on this technique a dual polarization antenna array consisting of two 2×2 sub arrays has been implemented.

The third type of antenna described in **Chapter 5** is a low cost low profile scanning receiver array with an NRD-guide feeding network. A possible solution for low loss and low cost antennas with electronic scanning facilities is the use of frequency scanned arrays. In this work mixers are used with a frequency sweep in the local oscillator (LO) path. The radio frequency (RF) can be kept constant, and bandwidth can be fully exploited for other purposes like communication or full range resolution in a frequency modulated continuous wave (FM/CW) radar sensor. The RF signal is received by four microstrip antenna elements. Each antenna element is connected to a mixer. The LO signal is distributed via a serial NRD-guide feeding providing the frequency dependent phase shift for beam scanning. In the mixers the RF signals are down-converted in the intermediate frequency (IF) band including the phase shift. A Wilkinson power combiner adds the IF signals in phase. In this scanning receiver array an LO frequency sweep from 22.8 GHz to 24.8 GHz was necessary for a scan range of 35°.

[†] The transitions and T-junctions described in Section 4.2 are the subject of a patent application at the German Patent and Trade Mark Office entitled “Anordnung für einen nichtstrahlenden dielektrischen Rechteckwellenleiter zur unabhängigen Nutzung zweier oder mehrerer Moden zur Signal-Übertragung” with application number AZ 10 2011 107 128.1 and date of filing July 12, 2011.