A Low Cost Low Profile 19 GHz Scanning Receiver Array with a Nonradiative Dielectric Waveguide Feeding Network

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***Abstract*— A 19 GHz scanning receiver array is presented based on a frequency scan of the LO signal fed to an array of mixers. To allow a low loss, low profile setup, the LO feed is implemented in non-radiative dielectric (NRD) waveguide technique. Scan range is nearly 30° with an LO frequency variation from 22.8 GHz to 24.8 GHz. In addition a modification of the LO feed is proposed for a wider scan with a reasonably low LO frequency variation.**

I. Introduction

Antennas with electronic scanning facilities are becoming increasingly important not only in the car industry. In the higher frequency range, this typically is associated with increasing loss and cost using conventional phased array techniques. A possible solution is the use of frequency scanned arrays, as it is demonstrated for automotive radar applications, e.g. in [1]. In [2] a wide scanning range was was achieved with a frequency scanned antenna array using a suspended stripline negative index transmission line. A frequency sweep, on the other hand, poses other problems, e.g. it reduces range resolution for a FM/CW radar sensor. In [3], [4] alternative approaches have been presented using heterodyne principles with a frequency sweep in the LO path. Thus, RF frequency can be kept constant, and available bandwidth can be fully exploited for other purposes. In order to keep the LO and, consequently, the IF frequency variation small, long delay lines between the tapping points of the LO feed line have been selected [5], leading to a rather bulky and costly setup as rectangular waveguide was chosen for low loss behaviour. The non-radiative dielectric (NRD) waveguide on the other hand is known to be a low loss waveguide especially for increased frequencies, while allowing for low profile and low cost applications [6]. Therefore, in this contribution, a 19 GHz receiver array using an NRD-guide LO feed line is investigated. The RF signal is received by an array of 4 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 to the IF band including the phase shift. The Wilkinson power combiner adds the IF signals in-phase.

An LO variation of 2.0 GHz in the 22.8 GHz to 24.8 GHz range allows for a 28° scan. In order to have a wide scanning range while maintaining the circuit rather small, the LO signal is chosen to be higher than the RF signal (high-frequency injection). The receiver array consists of two layers. Antenna elements, mixers, filters and the IF power combination are implemented as planar structures on Ultralam 2000 ($\varepsilon_r = 2.48$, thickness = 0.26mm). The LO feeding network is made of an NRD-guide with Rogers TMM 6 ($\varepsilon_r = 6$, $W_{NRD} = 6$ mm, $H_{NRD} = 3.18$ mm). The total height of the antenna is 3.5 mm only, plus the backsided aluminium plate.

II. Setup of the Receiver Array

A basic block diagram of the investigated scanning array is given in figure 1. Each of four antenna elements is connected to a mixer. The LO signal is distributed via a serial NRD-guide feeding. An NRD-guide section with one of the

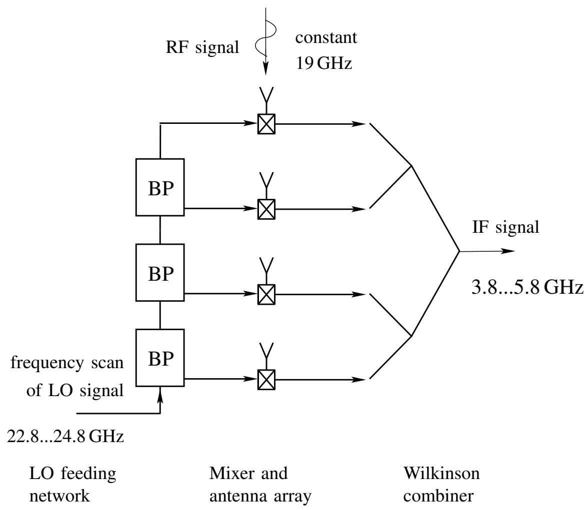

Fig. 1. Basic block diagram of the scanning array.

couplers is depicted in figure 2. First, a 3 resonator NRD-guide bandpass is designed, where the 4 impedance inverters are implemented by drill holes in the dielectric material. Then one of the smaller holes is replaced by the coupler NRD-guide to microstrip line including the coupling slot in the common ground metallization between the planar structure and the backsided LO feeding network. The coupling values of the couplers are adjusted for an equal power distribution,

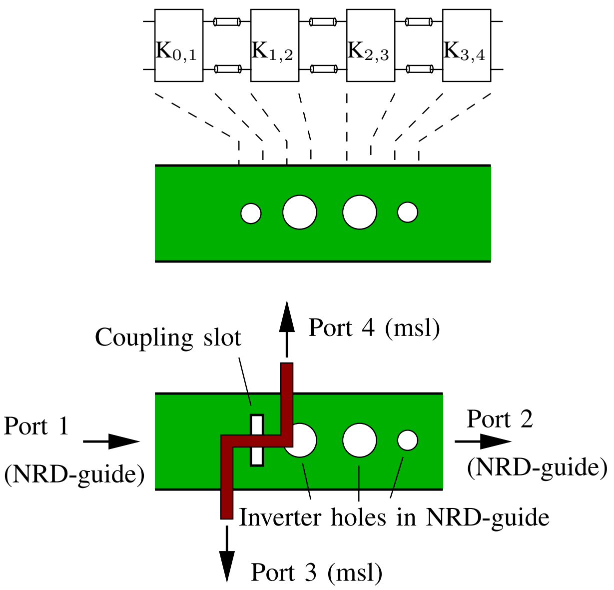

Fig. 2. Design steps of the couplers NRD-guide to microstrip line.

although some deviations occur over the operation bandwidth. Figure 3 shows the simulated S parameters of one exemplary coupler with a coupling coefficient of -10 dB. In the range from 22 GHz to 24.5 GHz a constant coupling factor of -10 dB is observed. Above 24.5 GHz the coupling factor is slowly increasing.

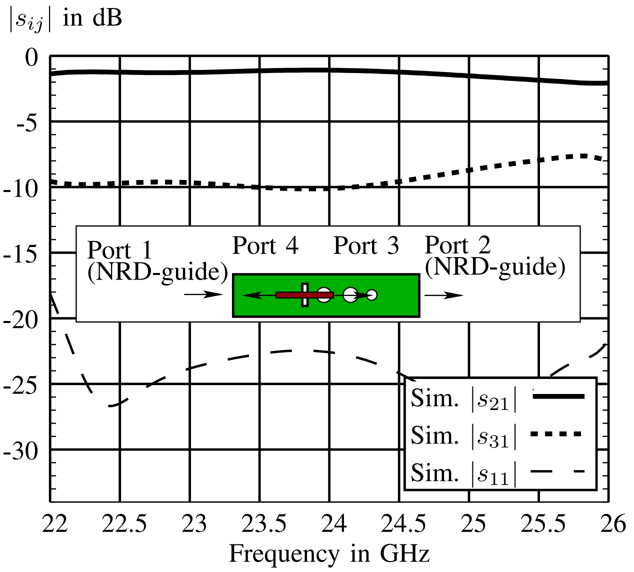

Fig. 3. Simulated S parameters of the second coupler.

The NRD-guide feeding network is operated in the longitudinal section electric (LSE) mode. This makes the delay lines shorter, as the wavelength is shorter compared to the longitudinal section magnetic (LSM) mode. The mixers are implemented as single balanced mixers, using low barrier silicon Schottky diode pairs DMF 2828(504-012) for low LO power consumption. The basic principle of the mixers

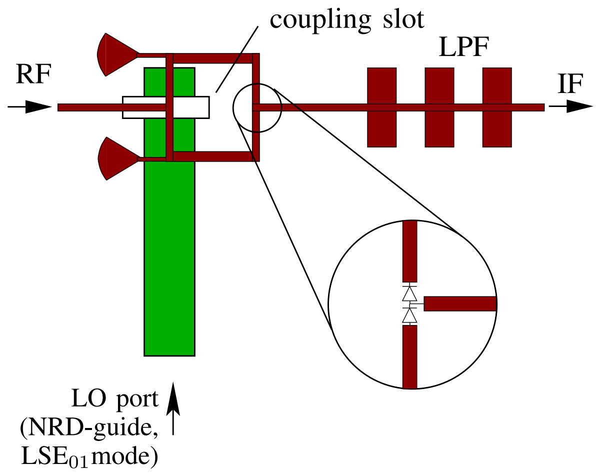

Fig. 4. Setup of the balanced mixer.

is shown in figure 4. The LO signal must be divided in two equal amplitude anti-phase signals to pump each diode. The coupling mechanism of the transition from NRD-guide to microstrip line via the slot in the common ground plane provides this 180° phase difference between the two microstrip line branches. In this way for the LO signal the connecting point between the two diodes is set virtually to ground. Radial stubs are used for a broadband IF blocking. The IF signals finally are combined in-phase by a four-to-one Wilkinson combiner network (see figure 5). A stronger weighting of the inner two channels is used for reduction of the side lobe level and in order to compensate for the deviation of the power distribution of the LO feeding network mentioned above.

III. Results

The receiver array mounted for antenna measurements is shown in figure 5. Its lateral dimensions are 120 mm x 95 mm. This might be reduced by a smaller design of the planar parts. The thickness is 3.5 mm, plus the backsided aluminium plate.

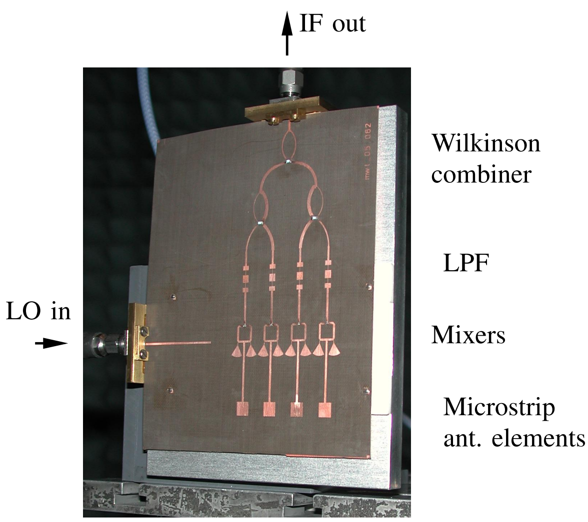

Fig. 5. Photo of the complete antenna.

A block diagram of the basic measurement setup for the radiation diagrams of the antenna is given in figure 6. Part of the transmit signal is fed to another mixer providing a reference signal. Both reference (IF) signal and receiver array output are fed to the downconverter of a network analyzer operated in a dual frequency mode. In this way, a coherent and sensitive measurement setup could be achieved [7].

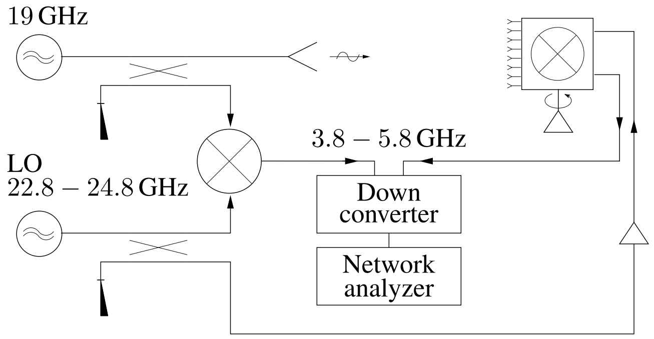

Fig. 6. Basic block diagram of the antenna measurement setup.

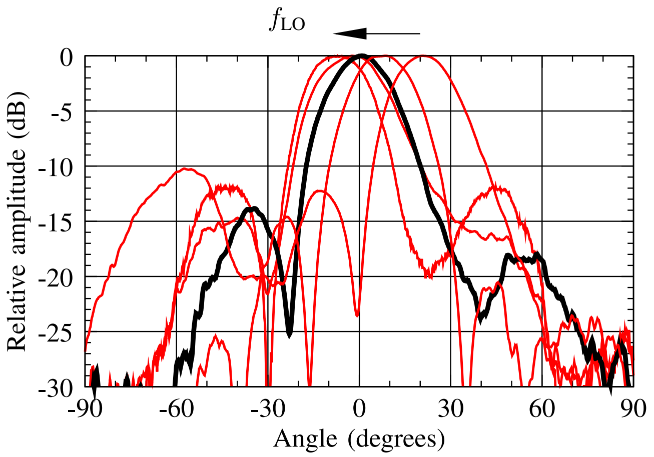

Fig. 7. H-plane radiation diagrams of the antenna array operated in the receive mode at 19 GHz (LO frequency 22.8 GHz to 24.8 GHz, IF frequency 3.8 GHz to 5.8 GHz, all diagrams normalized to 0 dB).

Figure 7 shows the H-plane radiation diagrams of the receiver arrangement at 19 GHz for LO frequencies from 22.8 GHz to 24.8 GHz, resulting in a scan range from -7° to +21°. Figure 8 shows that in the frequency range from 22.8 GHz to 24.8 GHz the side lobe level is below -10 dB. Measurement of the radiation diagrams for a wider range of LO frequencies showed that allowing a slightly higher side lobe level of -8 dB, the scan range is extended to -11.8° to +23.5°.

In [5] it was shown that by inserting a 3.8 GHz to 5.8 GHz signal at the IF port and a 22.8 GHz to 24.8 GHz signal at the LO input port (figure 5), the antenna can also be operated in transmit mode with a constant RF signal at 19 GHz.

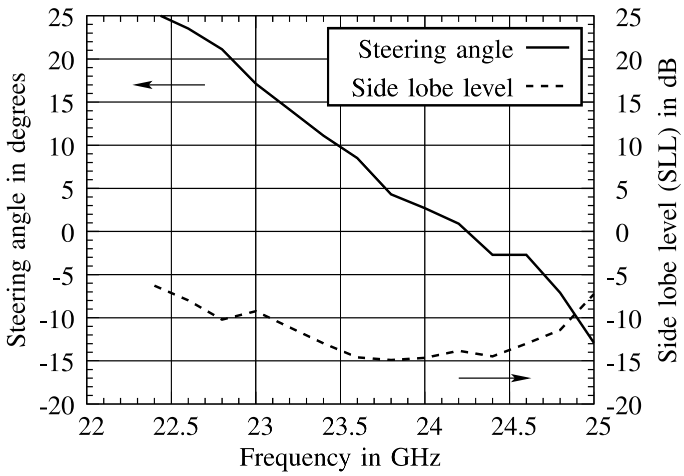

Fig. 8. Measured steering angle and side lobe level of the radiation diagram of the receiver array dependent on the LO frequency.

IV. Two-path Bandpass Filter for Steep Phase Increment

In [8] a class of two-path multimode bandpass filters using the NRD-guide (figure 9) was proposed, providing an additional pole of attenuation in the stop band close to the cut-off frequency thus offering higher rates of cut-off than one-path NRD-guide bandpass filters.

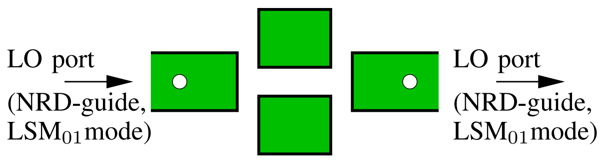

Fig. 9. Basic block diagram of the two-path NRD-guide bandpass filter.

In this contribution two-path bandpass filters are proposed to provide a steep phase increment over frequency to allow for a wide scanning range with a low LO frequency variation. The step from the one-path NRD-guide to the two-path NRD-guide excites both the LSE and the LSM mode in the two-path NRD-guide section. This increases the order of the bandpass filter by 1. The symmetry along the NRD-guide prevents the excitation of the LSE mode in the one-path NRD-guide section. So actually the two-path NRD-guide bandpass filter is a resonator of order 4 and has therefore a steeper phase increment compared to the one-path NRD-guide bandpass filter. In figure 10 only 3 zeros can be observed, this is because of improper filter design.

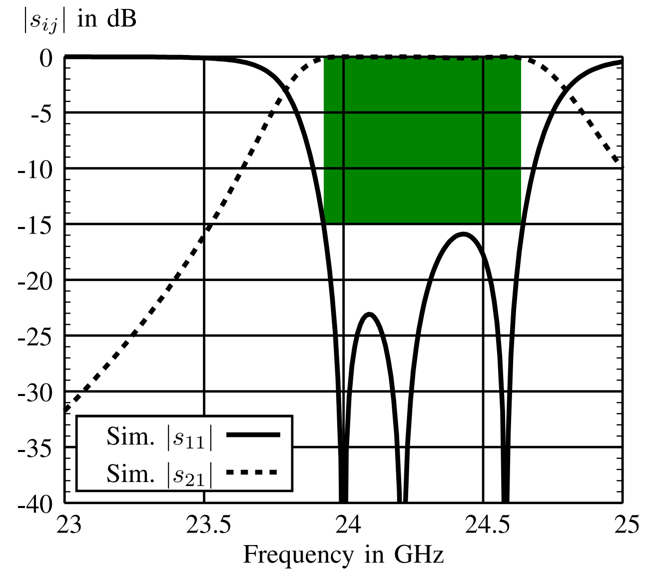

Fig. 10. Simulated S-parameters of the two-path NRDguide bandpass filter.

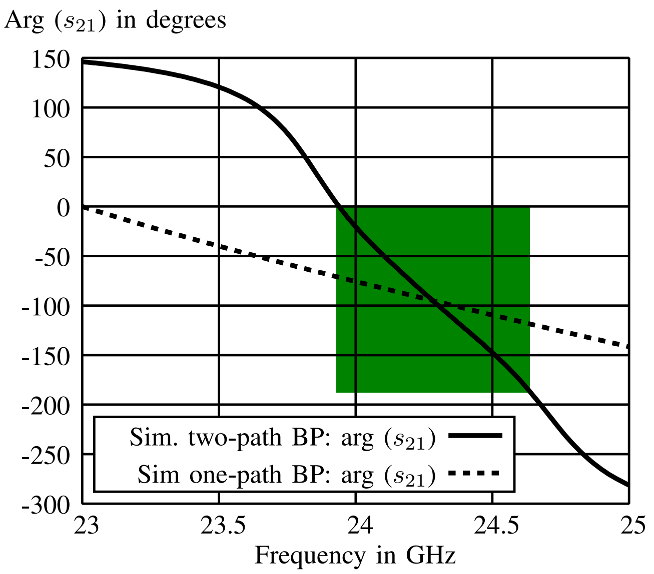

Fig. 11. Phase behavior of the two-path NRD-guide bandpass filter (figure 9) and of the one-path NRD-guide bandpass filter (figure 2, middle), showing the steeper characteristic of the first.

The comparison of the phase increments (figure 11) of a two-path NRD-guide bandpass filter and of a one-path NRD-guide bandpass filter shows the big advantage of the first. In the 0.72 GHz range from 23.92 GHz to 24.64 GHz where return loss is below -15 dB (figure 10), a variation of the phase increment by 188° is achievable, leading to a wider scaning range compared to the 2 GHz range from 23 GHz to 25 GHz where only a variation of the phase increment by 145° is achievable with the one-path NRD-guide bandpass filter.

V. Conclusion

A 19 GHz scannable receiver array with four antenna elements has been presented. The antenna beam scanning is achieved by a frequency scan of the LO signal. In this array, scan range was limited to -11.8° to +23.5° due to a phase offset of the couplers and a limited phase increment. Prelimary investigations have been presented for a scanning receiver array with reduced LO frequency variation and wider scanning range using two-path NRD-guide bandpass filters. Such an array is currently under investigation and is expected to make a scanning range of ± 50° feasible. For a smaller beamwidth in the H-plane, the array can be easily extended to 8 antenna elements. In the E-plane the beam might be narrowed by using a set of serial fed patches. The lateral dimensions of the antenna (120 mm x 95 mm) could be further reduced by the use of smaller designs of the planar parts including approved and low cost MMIC mixers. The possibility to drive this type of antenna arrays in a transmit mode was shown in a previous contribution [5], where the scan range is identical to the scan range in receive mode but inverse over LO frequency.

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