A 24 GHZ SCANNING RECEIVER ARRAY

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***Abstract* — A 24 GHz scanning receiver array is presented based on a frequency scan of the LO signal fed to the array mixers. To allow a wide scan with a reasonably low LO frequency variation, sufficiently long delay lines are employed between the coupling points for the separate mixers. Losses are kept low due to a standard metal waveguide network which later on may be replaced by waveguides fabricated by plastic injection molding. Scan range is nearly 50° with a LO frequency variation from 19.35 GHz to 19.8 GHz.**

INTRODUCTION

Antennas with electronic scanning facilities are becoming increasingly important. 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]. A frequency sweep, on the other hand, poses other problems, e.g. it reduces range resolution for a FM/CW radar sensor. In [2,3] 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 to be selected, leading to increased losses, especially for increasing frequencies. Therefore, in this contribution, a 24 GHz receiver array is investigated using a low-loss metal waveguide feed network, requiring a bandwidth of 0.45 GHz only for a 50° scan in the 19 – 20 GHz range. In this work, the network is machined from metal, but in a later stage, it easily may be fabricated using plastic injection molding and electroplating as demonstrated in [4], or other lower loss transmission line types like nonradiative dielectric (NRD) waveguide may be employed [5].

The need for a mixer for each antenna element, on the other hand, leads to an increased effort, but such circuits, including diode mixers and IF amplifiers, may be realized with approved and low cost silicon MMICs [6].

SETUP OF THE RECEIVER ARRAY

A basic block diagram of the scanning array is given in Fig. 1. Each of eight antenna elements is connected to a mixer. The LO signal is distributed via an E-plane standard waveguide network including broad wall couplers. In order to avoid any contact problem, the LO circuit is realized using two identical metal blocks cut in the E-plane (Fig. 2). The coupling values of the couplers are adjusted for an equal power distribution, although some deviations occur over the operation bandwidth. The lengths of the delay lines between the couplers are adjusted to obtain in-phase signals at the output ports for center LO frequency. As wavelength gets shorter for higher frequency, phase shift between adjacent output ports can be set by changing LO frequency.

Due to mechanical considerations, waveguide height and wall thickness were chosen to 2.5 mm and 0.5 mm, respectively. According to the network architecture (Fig. 2), this results in an element spacing of 9 mm (or 0.72 wavelength) and a limitation in scan range due to grating lobes. Replacing the network by a structure fabricated by plastic injection molding and electroplating, smaller dimensions and a closer element spacing are possible.

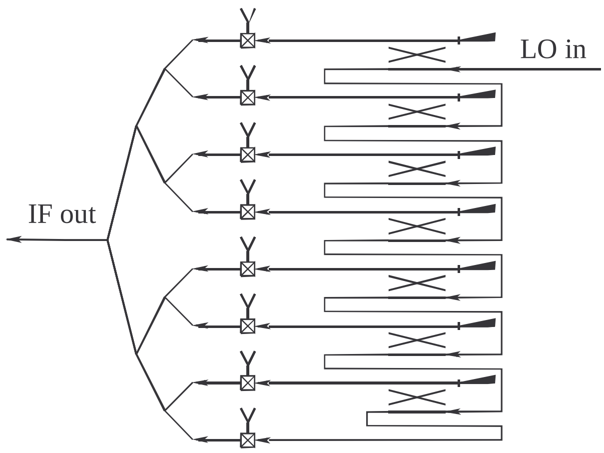

Fig. 1: Basic block diagram of the scanning array.

The mixers are realized as crossbar mixers [7], using low barrier silicon Schottky diodes for low LO power consumption. The basic principle of these mixers is shown in Fig. 3. An integrated balun [8] serves as transition from finline to coplanar line. Equally, however, other types of planar integrated mixers can be used for the mixer circuits.

The IF signals finally are combined in-phase by an eight-to-one combiner network.

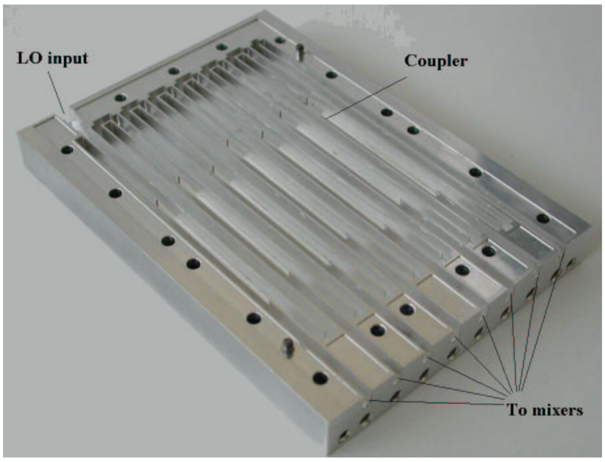

Fig. 2: Photograph of one half of the LO block (the other part is symmetric to this one).

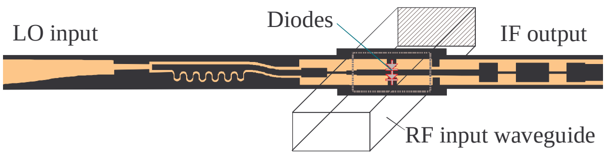

Fig. 3: Layout and principle of the crossbar mixer.

RESULTS

In a first step, LO network and mixers were designed, fabricated, and tested separately. In Fig. 4, a near-field scan along the open output waveguides of the LO network is shown. Amplitude distribution is not completely flat but sufficient for this application, and – except for some ripple due to the type of measurement – a reasonably linear phase performance with different slopes at different frequencies can be stated. Although the open waveguide ends are not very efficient radiators, the LO network can be used as a frequency scanned antenna by itself. Fig. 5 shows the E-plane radiation diagrams for frequencies from 19.35 GHz to 19.8 GHz. Except for some slight unsymmetries of the three diagrams on the right side, a sidelobe level of around -13 dB can be seen, as it is expected for a reasonably constant amplitude distribution. Within the LO frequency range, a scanning range of nearly 60° is possible until grating lobes exceed a –10dB level.

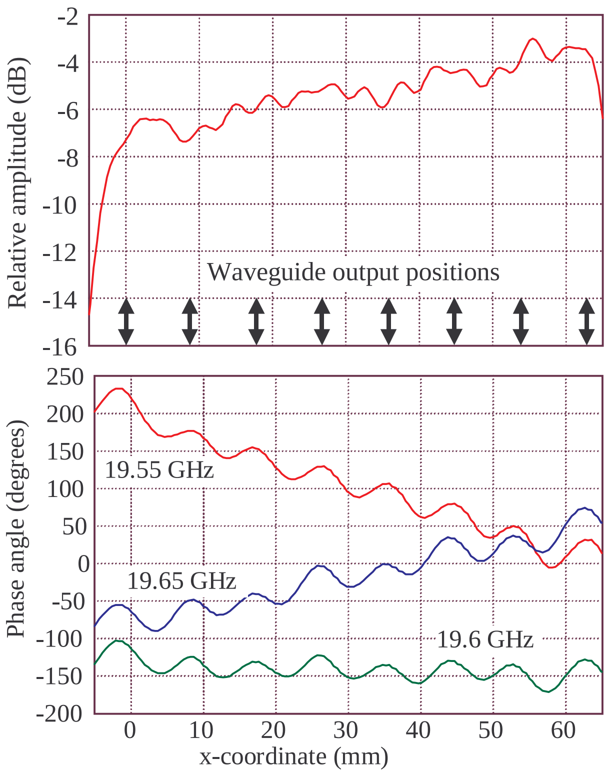

Fig. 4: Near-field scan of amplitude and phase of the waveguide openings of the LO feed network.

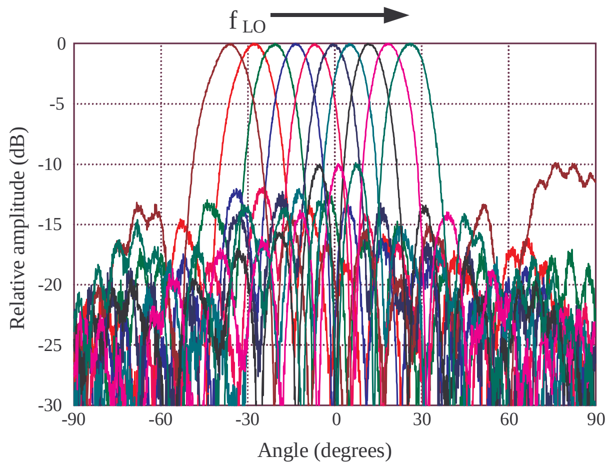

Fig. 5: E-plane radiation diagrams of the waveguide apertures of the LO feed network for frequencies from 19.35 GHz to 19.8 GHz (all curves normalized to 0 dB).

A single mixer was tested first, showing a flat conversion loss of 10...12 dB at 0 dBm and 8 dB at 4.4 dBm LO power over the 19 GHz to 20 GHz LO frequency range (or 4 GHz to 5 GHz IF frequency range). Using an amplifier with up to 20 dBm output power at the input of the complete LO network, and taking into account about 2.5 dB loss of a 3 m long cable (the amplifier was not mounted on the antenna turntable during measurement), sufficient LO power for each mixer finally was available. In that way, the variation in the power distribution of the network (Fig. 4 top) does no longer play a major role.

As antenna elements for the complete receiver, an open K-band waveguide array was connected to the mixer array. The receiver array mounted for antenna measurements is shown in Fig. 6, a block diagram of the basic measurement setup for the radiation diagrams of the antenna is given in Fig. 7. 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 [9].

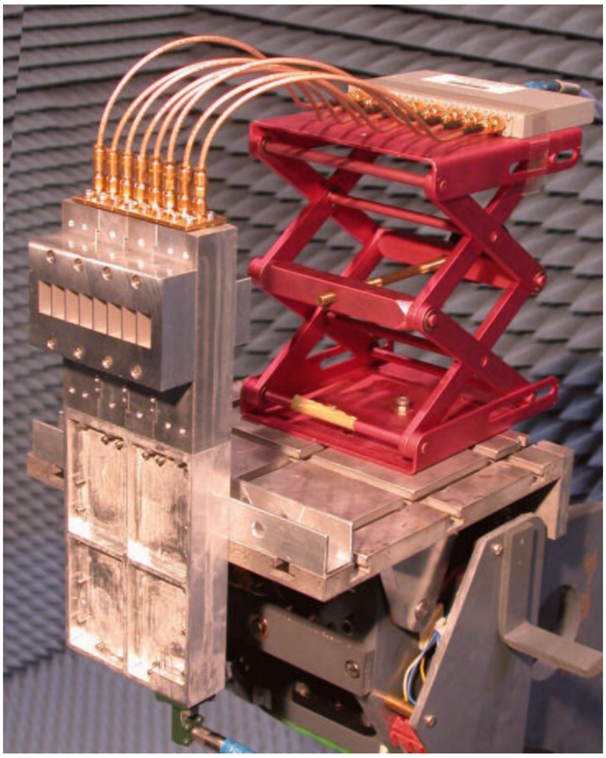

Fig. 6: Photograph of the complete receiver array mounted on the turntable for antenna measurements.

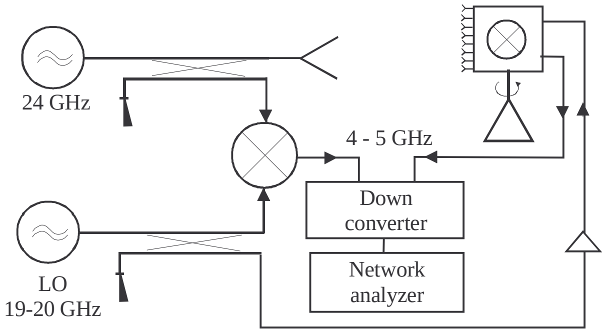

Fig. 7: Basic block diagram of the antenna measurement setup.

Fig. 8 shows the E-plane radiation diagrams of the receiver arrangement at 24 GHz for LO frequencies from 19.35 GHz to 19.8 GHz, resulting in a scan range from –28° to +21°. A limit was set again for a grating lobe level of –10 dB. Except for two beams, sidelobe level is between -11 dB and -14 dB. A separate test showed that there was a phase error of the different IF signals in the range of ±30°, probably due to phase errors and reflections in the LO network and some variations of cable lengths in the IF range. In addition to improving this, a combination of the IF signals with a non-constant weighting will give an improved sidelobe behavior.

Reducing the element spacing by a modified setup, an even wider scanning range will be possible without grating lobe problems.

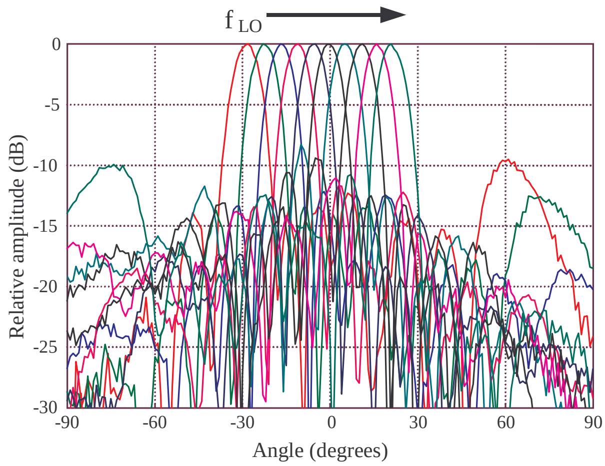

Fig. 8: E-plane radiation diagrams of the receiver array at 24 GHz (LO frequency 19.35 GHz ... 19.8 GHz, all diagrams normalized to 0 dB).

TRANSMIT MODE OPERATION OF THE ANTENNA

By inserting in-phase 4.2 GHz to 4.65 GHz IF signals at the IF input ports of the mixer array and a 19.8 GHz to 19.35 GHz LO signal at the input port of the LO waveguide network, the antenna can also be operated in transmit mode with a constant RF signal at 24 GHz. Fig. 9 shows the measured E-plane radiation diagrams of the antenna array in the transmit mode, where sidelobe level was improved by weighting the IF signals at the IF input ports of the mixer array as proposed above. The scan range from –28° to +21°is the same as in the receive mode (Fig. 8).

It should be noted that, according to the reversed signal flow at the IF input, the scanning angle of the main beam as a function of LO frequency is inverse compared to the receive mode (Fig. 8).

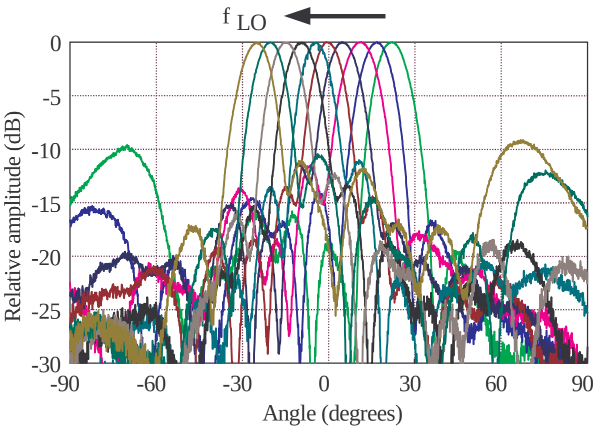

Fig. 9: E-plane radiation diagrams of the antenna array operated in transmit mode at 24 GHz (LO frequency 19.35 GHz ... 19.8 GHz, IF frequency 4.65 GHz ... 4.2 GHz, all diagrams normalized to 0 dB).

CONCLUSION

A 24 GHz scannable receiver array with eight antenna elements has been presented. The antenna beam scanning is achieved by a frequency scan of the LO signal. A reasonably small frequency variation is achieved using long delay lines for the LO distribution network; losses are kept small due to the use of metal waveguide. Although this included a high effort for this experimental array, plastic injection molding techniques and electro-plating finally may considerably reduce the fabrication effort. In this array, scan range was limited to –28° to 21° due to an element spacing of 0.72 wavelengths which will be reduced in a future array.

Furthermore the possibility to drive the antenna array in a transmit mode has been shown, where the scan range is identical to the scan range in receive mode (–28° to 21°) but inverse over LO frequency.

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