A 24 GHZ DOPPLER/FMCW-RADAR USING A NOVEL COUPLER/BALANCED MIXER CONFIGURATION

Wolfgang Menzel, Microwave Techniques, University of Ulm, Germany

ABSTRACT

A CW/FMCW radar sensor incorporating a novel coupler/balanced mixer configuration to reduce the AM noise of the transmitter/LO is presented. The novel coupler, at the same time, separates transmitter and receiver and provides the necessary circuitry for the mixer. It is based on the well-known hybrid ring coupler, abandoning, however, the double symmetry, but maintaining the quadrature phase behavior which is used - together with an additional quarter wave transmission line - to feed the mixer diodes with the proper phase relations. In this way, a very compact and low cost Doppler/FMCW module can be realized. The design of the coupler/mixer combination and the other components of the sensor together with first results will be reported in this contribution.

INTRODUCTION

Doppler sensors in the micro- and mm-wave range are gaining increasing interest for a number of applications like measurement of speed over ground, traffic monitoring, or intruder alarm. FMCW sensors, on the other hand, provide cost effective solutions for distance measurements in traffic or industrial environments like filling height of big vessels /1/, /2/. MIC or MMIC circuits for Doppler or FMCW radar sensors often include FET oscillators which show an increased noise level close to the carrier. With respect to the AM portion of this noise, a balanced mixer configuration would be favorable which, however, mostly would lead to an increase in circuit complexity and costs when using standard components like two 3dB couplers for LO coupling and the mixer plus a circulator or a coupler as T/R diplexer. The arrangement presented here combines all these functions into a single coupler with specific performance. Design aspects and results of the novel coupler and the mixer will be given in detail. This coupler/mixer configuration then is used as part of a complete radar front-end which can equally be used for CW as well as FMCW applications.

DESIGN OF COUPLER/MIXER ARRANGEMENT

The coupler as indicated above has to provide both T/R diplexing as well as the function of a 90° hybrid for the mixer. Its general structure as well as the basic scattering matrix is given in Fig. 1. As can be seen immediately, there is no longer a symmetry between ports (1, 2) and (3, 4). The oscillator is connected to port 1, the antenna to port 2, and the mixer diodes - via a suitable amplitude and phase matching network - to ports 3 and 4. Accordingly, there has to be a nonzero transmission coefficient between ports 1 and 2, and, in accordance with a standard hybrid coupler, a 90° phase shift between ports 3 and 4 was assumed. In a first step, a simple transmission line calculation showed that a coupler with the required performance can be realized, resulting, however, in a modified transmission line impedance and nonzero reflection coefficients at ports 3 and 4. The last item, however, is not critical as long as the diode impedance can be matched sufficiently to the line impedance. Some possible combinations of impedances and coupling coefficients are given in Table I. All line lengths are a quarter of a wavelength at the center frequency. For close range applications, the required transmitter power typically is low, so a major part of the oscillator power may be used for driving the mixer diodes (small t, larger k, see Fig. 1).

Based on the last set of data from Table I, a microstrip design of the coupler was optimized employing a commercial CAD program. Due to geometrical problems, the line lengths between ports 1 and 4 and 2 and 3, respectively, were modified to 0.75 wavelengths. As substrate material, TMM3 with a dielectric constant of 3.25 and a thickness of 0.38 mm was used. The resulting coupler layout and its measured S-parameters are shown in Fig. 2. A bandwidth of about 1.5 to 2

GHz is available. Based on this coupler, a balanced mixer was designed including the necessary phase delay for one of the diode ports, RF and IF ground as well as the IF lowpass filter; its final layout is plotted in Fig. 3 together with its experimental conversion loss as a function of LO power and IF impedance. The conversion loss includes the RF losses due to the leakage into the LO port ($|s_{21}| > 0$). To get a first impression of the AM noise suppression of the LO, a AM modulated signal with a 10 % modulation index was fed to the LO port, and the spectrum of the signal leaking to the IF port was observed. The sideband suppression is plotted in Fig. 4 as a function of LO power. For the designed input power of 7 ... 8 dB, more than 25 dB can be stated.

OTHER COMPONENTS

As transmitter, a dielectric resonator stabilized oscillator (DRO) with a GaAs MESFET was employed /4/, /5/. The basic layout is depicted in Fig. 5. The substrate material was 0.254 mm thick Duroid with $\varepsilon_r = 2.2$. A symmetric configuration was chosen to reduce internal coupling and tolerance sensitivity. Both feedback circuits in the source path include resistors for self bias of the gate. The output power of the oscillator was 8.5 dBm, sufficient for this application. Due to some load dependence of the oscillator, a redesign and the design of a buffer amplifier presently is going on.

For a first possible application as a CW radar measuring speed over ground, a transposed comb line array /3/ was used as antenna, realized on a 0.5 mm thick Duroid substrate ($\varepsilon_r = 2.2$) as shown in Fig. 6. Four chains of elements were connected in parallel, and a radiation beam angle of about 45° from broadside was chosen for this application. The H-plane (longitudinal) radiation diagram and the E-plane diagram measured in the maximum of the H-plane diagram are plotted in Figs. 7 and 8, showing beamwidths of 9° and 12°, respectively. A steep decay of the H-plane characteristic towards broadside can be seen, important for low reflections from critical steep reflections from the ground.

CONCLUSION

Components for a 24 GHz Doppler or FMCW radar have been presented. Key component is a novel coupler/balanced mixer configuration which combines the functions of transmit/receive diplexer and 90° hybrid coupler for a balanced mixer. In this way, a AM suppression of around 25 dB is possible, resulting in improved radar performance, e. g. for higher sensitivity of a Doppler radar over water or ice. An improved DRO presently in under development, and tests of the complete sensor are planned in the near future.

REFERENCES

/1/ Meinel, H. H.: Applications of Microwaves and Millimeterwaves for Vehicle Communication and Control in Europe. IEEE Intern. Microw. Symp. MTT-S, 1992, Albuquerque, 609 - 612.

/2/ Zimmermann, B., Wiesbeck, W.: 24 GHz Microwave Close-range Sensors for Industrial Measurement Applications. Microw. Journ., May 1996, 228 - 238.

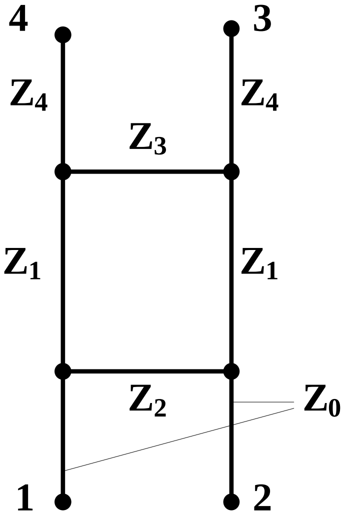
/3/ James, J. R., Hall, P. S.: Handbook of Microstrip Antennas, Vol. 2, Peter Peregrinus Ltd., London, 1989.

/4/ Güttich, U.: Active Elements Used in Microstrip Dielectric Resonator Oscillators. Microw. Journ., April 1996, 92 - 96.

/5/ Müller, A.: Design and Fabrication of a 24 GHz Doppler Radar (in German), diploma thesis, Univ. of Ulm, March 1995.

Z_1/Z_0	Z_2/Z_0	Z_3/Z_0	Z_4/Z_0	$\|t\|=\|r\|$	$\|k\|$
1	**1**	**2**	**1**	**0.33**	**0.67**
1.2	**1**	**3**	**1**	**0.5**	**0.61**
1.2	**1**	**2.9**	**0.5**	**0.7**	**0.5**
1	**1**	**2.1**	**0.7**	**0.5**	**0.61**

Table I: Possible combinations of line impedances and coupling coefficients.



$$\overleftrightarrow{S} = \begin{pmatrix} 0 & t & -jk & k \\ t & 0 & k & -jk \\ -jk & k & r & 0 \\ k & -jk & 0 & r \end{pmatrix}$$

Fig. 1: Transmission line equivalent circuit of coupler and basic S-matrix.

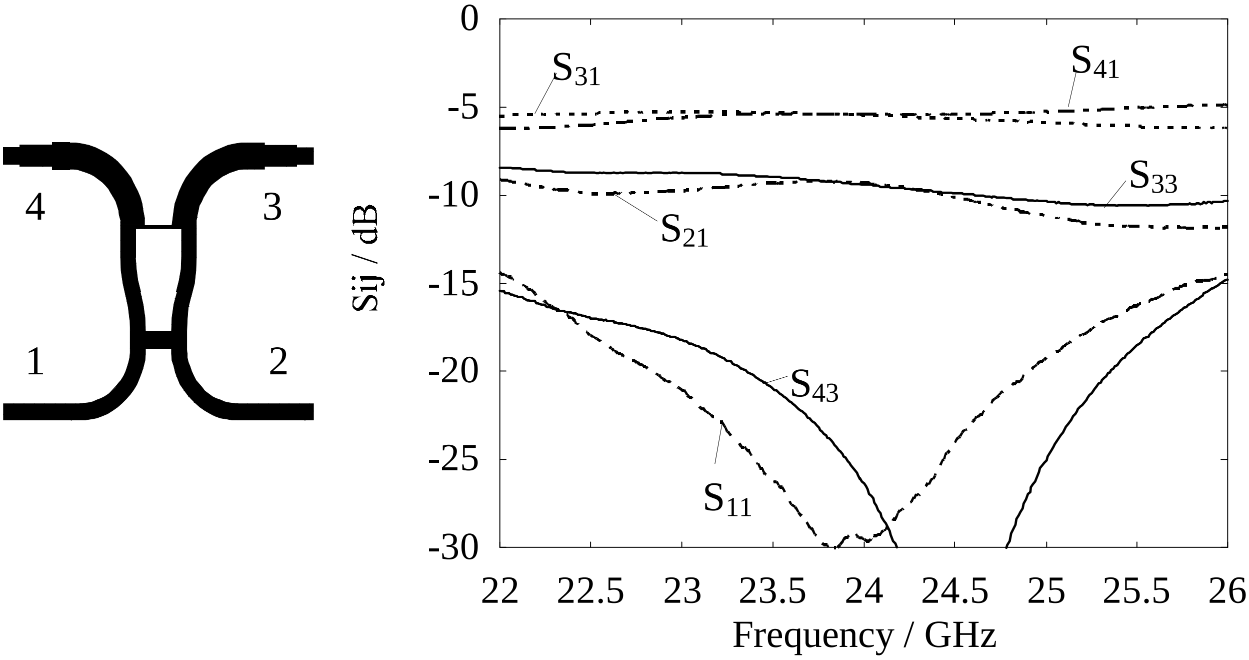


Fig. 2: Layout and measured S-parameter of novel coupler.

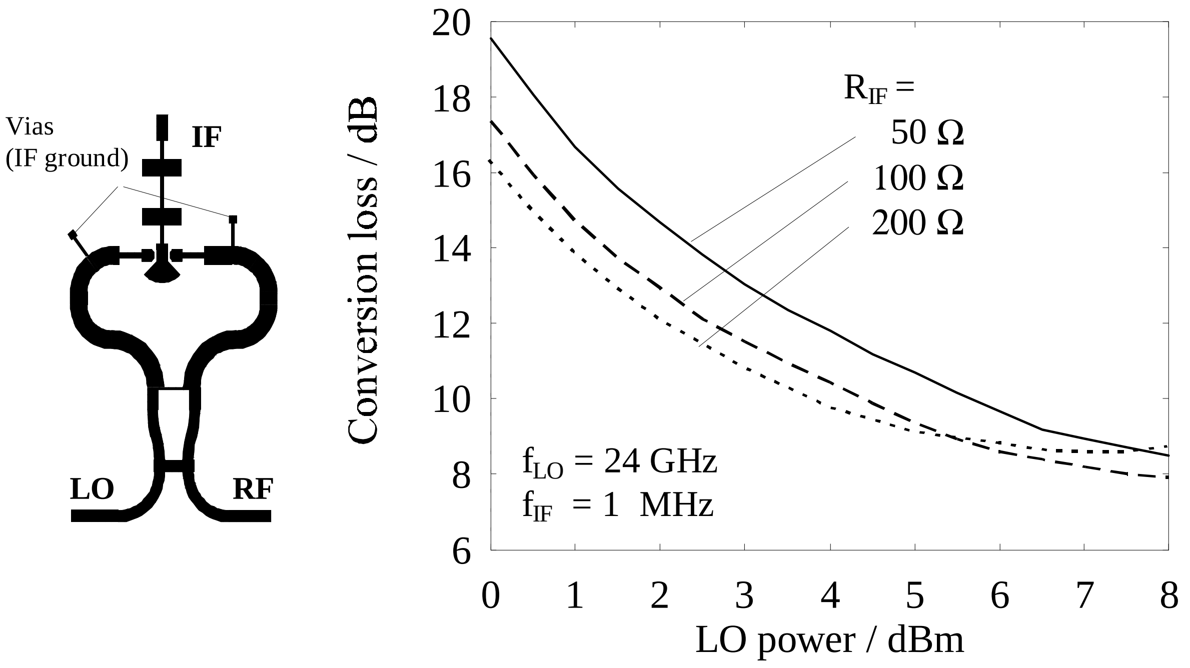


Fig. 3: Layout and measured conversion loss of Doppler mixer as a function of LO power and IF impedance.

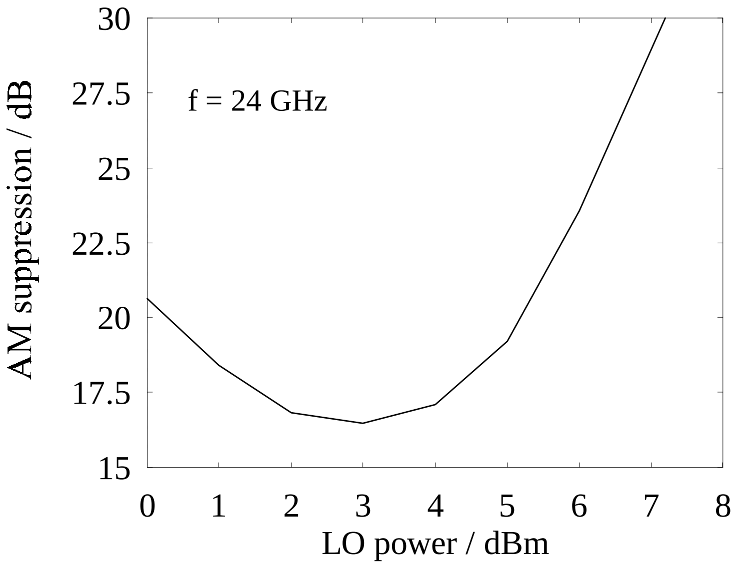


Fig. 4: AM suppression of balanced mixer as a function of LO power.

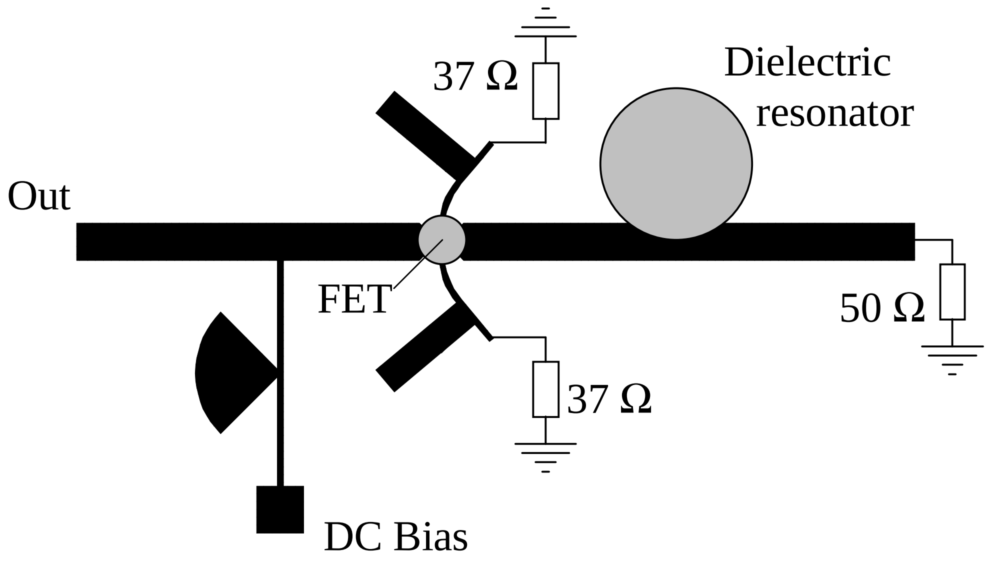


Fig. 5: Basic layout of dielectric resonator oscillator.

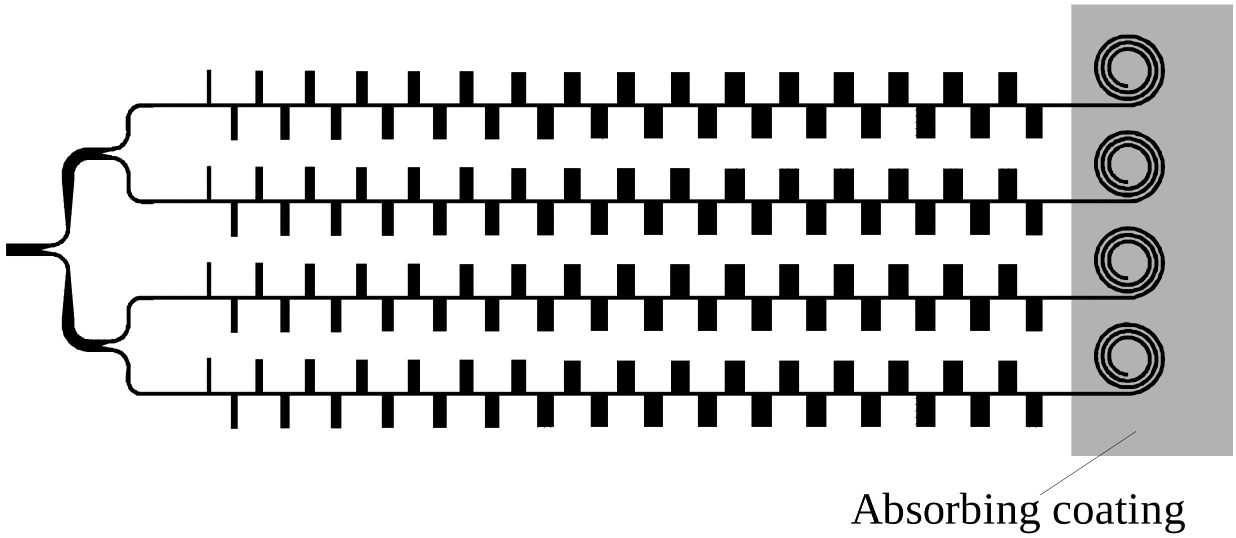


Fig. 6: Basic layout of sensor antenna.

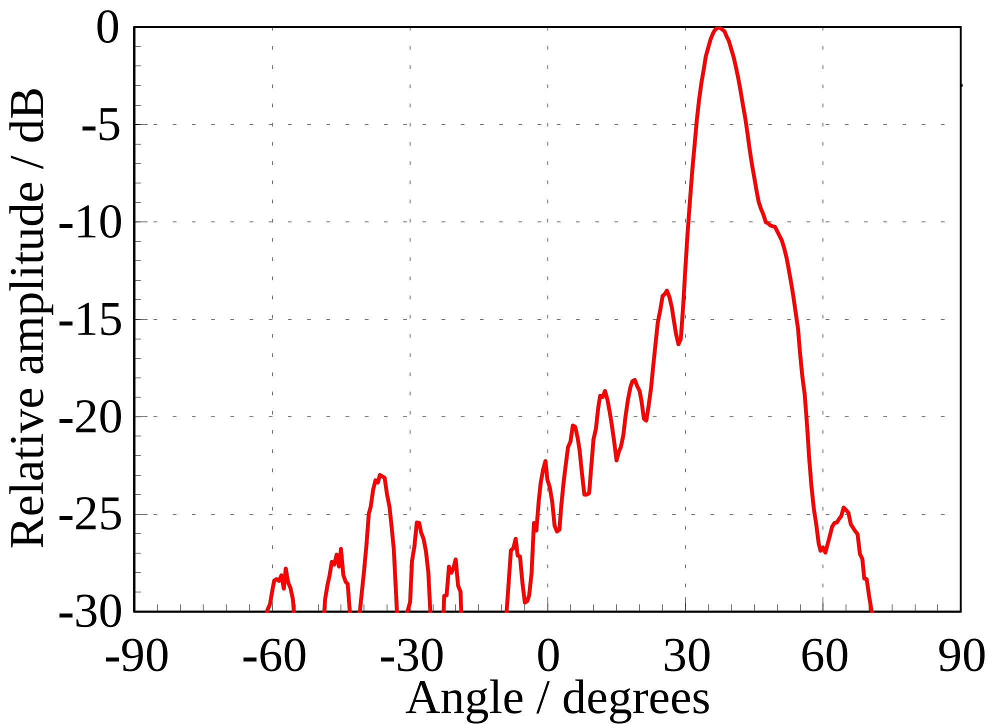


Fig. 7: H-plane radiation diagram of antenna.

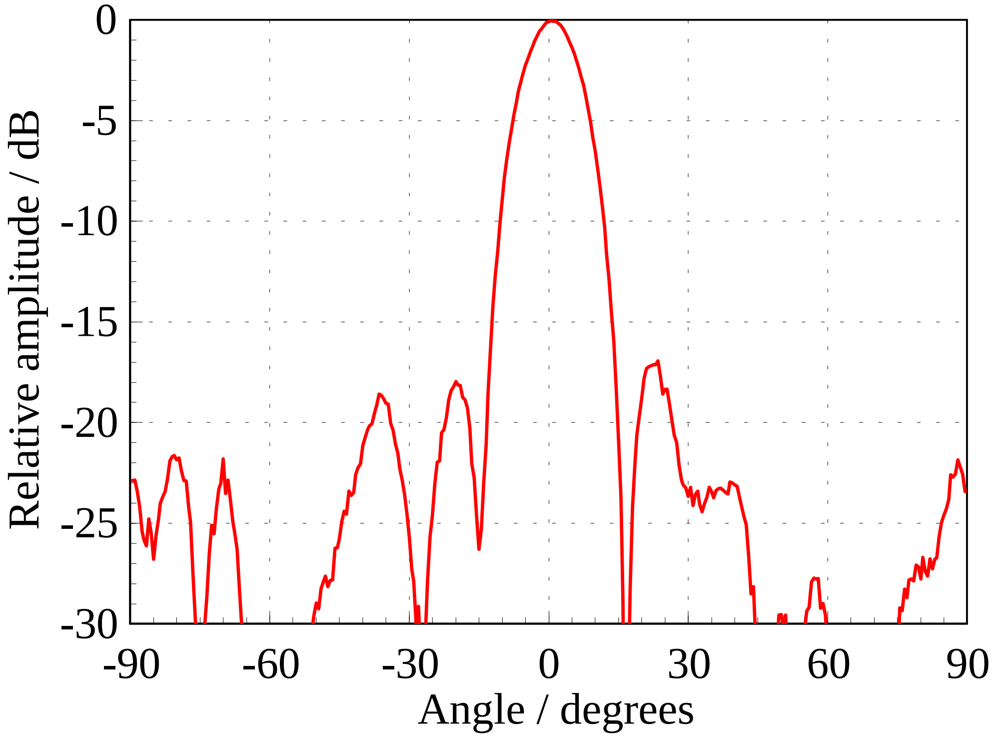


Fig. 8: E-plane radiation diagram of antenna.