RF Radar Systems

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After a treatment of standard radar techniques the development of a radar sensor capable of measuring distance with 0.1 mm accuracy is presented. The operating frequency of the front-end is 34 – 36 GHz. The proposed prototype sensor makes use of some new techniques such as direct homodyne receiving and direct frequency measurement.

1. Introduction

The driving force in the field of radar technology has always been the development of military equipment. Especially during the Second World War the existence of operational radar sensors was crucial and fostered research. But the same is true for today's military R&D. Nevertheless, the end of the Cold War had a strong impact on the financial situation of the microwave industry forcing the opening of commercial markets.

Another reason for the rapid growth of the commercial radar market is the availability of microelectronic devices. A radar front-end is no longer a clumsy waveguide device but can be realized in a rather compact way. In addition, new manufacturing processes reduced the cost of such sensors significantly.

1.1 Frequency Allocation

One fundamental problem of every industrial radar application is the limited bandwidth. The resolution of a radar sensor is inversely proportional to the bandwidth. The frequencies that can be used by industrial sensors are restricted to the so called ISM-bands (industrial, scientific, medical). Table 1 shows the allocation of these frequencies.

1.2 Resolution and Accuracy

In contrast to the commonly used nomenclature the word resolution has a different meaning when used in connection with radar techniques. Converting a voltage to a number using an A/D-converter quantizes the information with the least significant digit being the resolution.

The resolution of a radar sensor is defined similar to the resolution of an optical microscope. It quantifies the minimum distance between two resolvable targets. For this reason, the accuracy of a radar measurement of a single target is usually much better than the resolution.

ISM-Band	Frequency range	Bandwidth	Resolution
1	26,957 – 27,283 MHz	326 kHz	460 m
2	40,660 – 40,700 MHz	40 kHz	3750 m
3	433,050 – 434,790 MHz	1,74 MHz	86 m
4	868,000 – 870,000 MHz	2 MHz	75 m
5	2,400 – 2,483 GHz	83 MHz	1,8 m
6	5,725 – 5,875 GHz	150 MHz	1 m
7	24,000 – 24,250 GHz	250 MHz	600 mm
8	61,000 – 61,500 GHz	500 MHz	300 mm
9	122,000 – 123,000 GHz	1 GHz	150 mm
10	244,000 – 246,000 GHz	2 GHz	75 mm

Table 1: ISM-Bands [1] and corresponding radar resolution.

2. Radar Principles

The two physical effects mainly used for measurements are (1) the Doppler effect, which allows the determination of the speed of a target, and (2) the propagation time of a wave for determining the distance to a target. Additional information can be obtained by evaluating other physical effects as attenuation, phase change, or rotation of the polarization plane.

Two different sensors were built at the Microelectronics Institute. A low cost speed sensor [2] using a microwave oscillator [3] and an InGaAs/GaAs detector diode [4] both developed in-house and a high end distance radar capable of measuring distance with an accuracy of 0.1 mm.

3. High Accuracy Distance Radar

On the initiative of the VOEST Alpine Stahl AG a highly accurate level sensor was developed. Due to the rather harsh environment in a steel plant laser sensors do not work satisfactorily, so applying microwaves was the technology of choice. This distance radar should be part of a closed loop control guaranteeing a constant level of liquid steel in a crucible.

3.1 Specifications

Not only the high temperature and the existence of fumes make the design of such a sensor challenging but also the demand for fast measurement cycles. The distance range is 0.5 to 1 m, the accuracy specification 0.1 mm. The sensor will be placed inside a metallic enclosure which allows sweeping the frequency over a larger bandwidth than specified in the ISM-bands.

3.2 Sensor Prototype

As a trade-off between accuracy and costs the frequency of operation was chosen to be 34 to 36 GHz. In this range most devices are commercially available with the exception of direct frequency counters.

To achieve the high accuracy the combination of two modes of operation is necessary: (1) a phase evaluation of the reflected wave at a constant frequency and (2) an analysis of a linear sweep (FM-CW … frequency modulated continuous wave). The phase measurement, which is unambiguous within a quarter of a wavelength, supplies the high accuracy while the coarse FM-CW measurement gives an absolute distance reading.

There are two possibilities of realizing a radar front-end: The conventional way is the application of a highly stable and, hence, expensive signal source. It is not only the stability of the frequency which is an issue but also the possibility of producing a very linear frequency sweep. This is essential for obtaining an accurate distance value using the FM-CW mode. By contrast, the signal source of the presented prototype sensor is a cost-effective varactor tuned Gunn oscillator (VCO … voltage controlled oscillator). The controlling bias of the varactor is provided via a digital/analog converter by a digital signal processor (DSP). After characterizing the control characteristic of the VCO by means of sweeping through the full bandwidth and recording the actual frequency, the generation of a precisely linear sweep is possible. Details of the direct frequency counter were published in [5]. A photograph of the whole radar set-up is shown in Fig. 1.

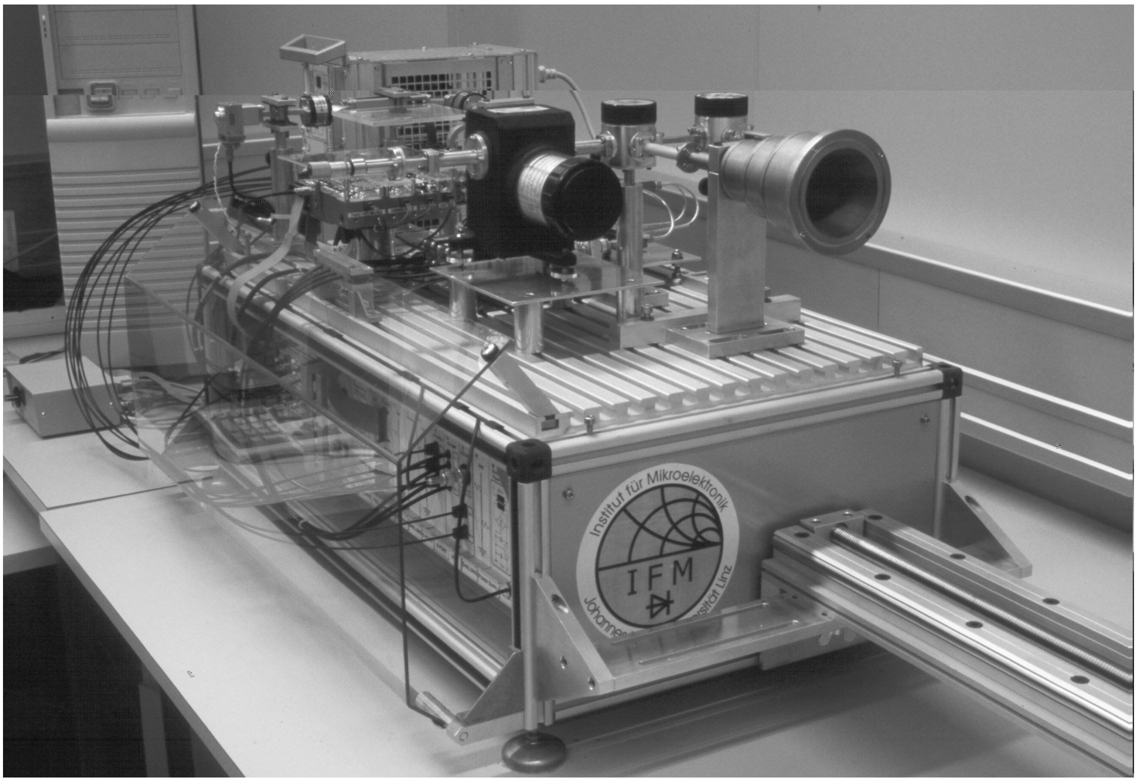

Fig. 1: Radar prototype consisting of waveguide and coaxial components.

The receiving part of the radar front-end is a so called six-port. This device has been used more and more since the early 1970's [6] in laboratories and research establishments and represents an attractive alternative to a conventional heterodyne receiver. The six-port technique is primarily used for measuring magnitude and phase of a received wave. In the proposed sensor the six-port allows measuring the phase of the reflected wave with respect to the incident wave with an accuracy of ±3 degrees which corresponds to about one hundredth of a wavelength.

3.3 Results

The distance measurement is accomplished in two steps. Firstly, a linear frequency sweep is applied yielding the absolute distance with an accuracy of ±1 mm. Note that the resolution of an FM-CW measurement with 2 GHz bandwidth is about 75 mm. Secondly, a constant 35.1 GHz signal is transmitted and the phase of the reflected wave is evaluated. This enhances the accuracy of the distance measurement to ±0.1 mm. The stability of the distance reading is one order of magnitude better [7].

Due to the application of a direct frequency counter the measurement cycle of a 20 bit frequency measurement is 120 µs. These time steps are only necessary for calibrating the VCO. The cycle time during the FM sweep (open loop control) is 6 µs.

4. Conclusion and Outlook

The proposed prototype sensor makes use of some new techniques such as direct homodyne receiving and direct frequency measurement. With these features the sensor operating in the 34 – 36 GHz range is capable of measuring distance with ±0.1 mm accuracy. Future work will concentrate on shrinking the sensor set-up by integrating the six-port and the detector diodes on GaAs.

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