Fast Frequency Measurement Applied to a Microwave Distance Sensor

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Design and characteristics of a fast frequency counter at 35 GHz for a distance sensor are presented. The signal received from the target is measured using six-port technology, and therefore accurate frequency measurement is essential. The frequency counter is capable of measuring the frequency in 120 microseconds with a 20-bit resolution.

1. Introduction

The presented frequency counter is part of a precision microwave distance sensor for short range applications [1]. A varactor tuned Gunn-oscillator serves as a signal source. The microwave signal is transmitted and received via a single corrugated horn-lens combination. Magnitude and phase of the reflected wave are measured using a six-port device [2]. Due to the frequency dependence of the calibration parameters highly accurate measurements are possible only at the calibration points. The accuracy of the distance measurement directly depends on the accuracy of the frequency measurement. The frequency counter is used both for linearizing the Gunn-diode characteristic for fast frequency sweeps and for controlling the actual frequency in interferometer mode of operation [3].

2. Experimental

2.1 Frequency Counter

Figure 1 shows the block diagram of the module consisting of dynamic and static dividers, a gating circuit realized in GaAs-MESFET technology, and a standard counter module. The frequency counter provides a very high measuring rate and a resolution of 20 bit. These requirements can only be met by directly counting the RF signal instead of using the conventional approach of down-conversion. The 35 GHz signal is fed to a dynamic frequency divider reducing the frequency to 8.75 GHz. The dynamic divider was provided by the Fraunhofer Institute for Applied Solid-State Physics (IAF), Freiburg/Breisgau, Germany [4]. This signal is counted directly by using a 8.75 GHz gating circuit followed by cascaded static dividers. By inserting the gate at this high frequency it is possible to achieve the needed 20-bit resolution with a gating time of only 120 µs. A taper matches the coaxial Wiltron-"K" connector input of the module to the coplanar input of the chip [5]. The modules are connected together with bonding wires.

The gating module controls the operation of the following static divider chain. The measurement accuracy depends on the timing accuracy of the gate. The time base is built with a temperature stabilized quartz-oscillator. The gating module is controlled by signals generated from a programmable logic device (PLD) to switch the RF on and off.

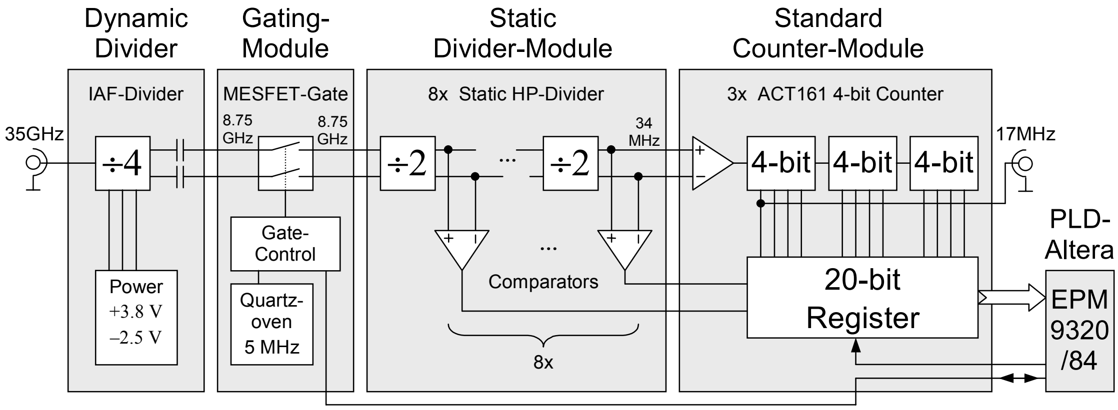

Fig. 1: Block diagram of the 35 GHz frequency counter.

The digital counter consists of eight static dividers and three integrated 4-bit counters. The counter value is transferred to a data latch while the counter chain is stopped. Therefore static dividers operating down to DC are used. The counter values are sampled using comparators that are attached to the high frequency line via resistive TEE structures. A fast comparator converts the differential signal to a logic signal compatible with 5 V logic. The logic outputs of each divider stage are combined at this module, stored in a register, and transferred to the PLD.

2.2 Gating Circuit

The circuit combines two functions. Primarily, the gating of the RF-signal is accomplished by switching transistors on and off. The second function is a logic operation, which is required for generating the gating signal. To guarantee a high accuracy of the counter, attention is paid to supply a gating signal with very precise rising and falling edges. This is done by combining the timing signal of a reference counter (realized in a PLD) and the edges of the clock signal provided by a temperature controlled crystal oscillator (TCXO). Instead of using high speed logic gates, the logic operation is carried out by the RF transistors.

Figure 2 shows the schematic of the gating circuit. The gates of the transistors T_2 are excited by the clock signal of the TCXO. The transistors T_1 and T_3 are used to switch on or to switch off the gate regardless of the clock signal. The transistors used for this gating chip are 0.5 µm GaAs-MESFETs. A scanning electron microscope picture of the chip is shown in Fig. 3. The transistors T_1 and T_2 are half as wide as the transistors T_3.

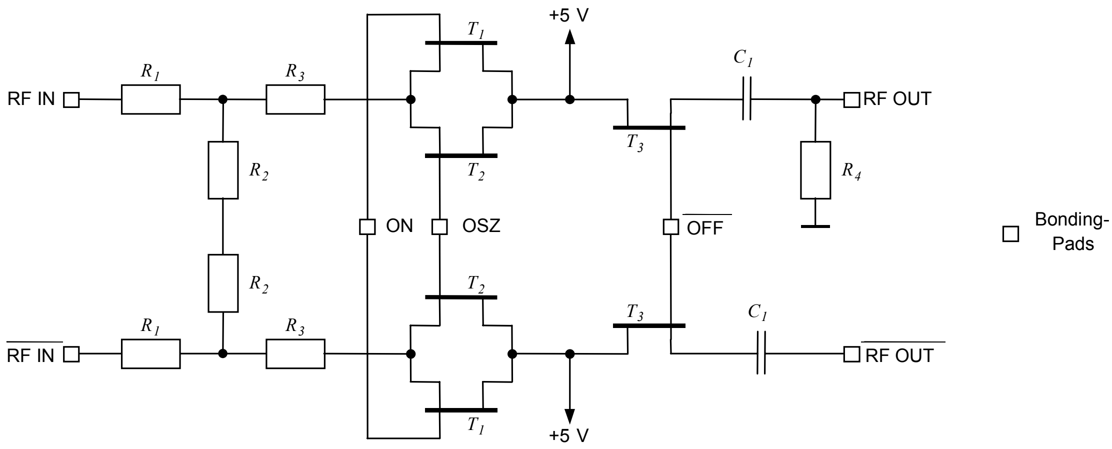

Fig. 2: Schematic of the 8.75 GHz gating-circuit realizing the logic operation $\overline{\text{OFF}} \wedge (\text{ON} \vee \text{OSC})$.

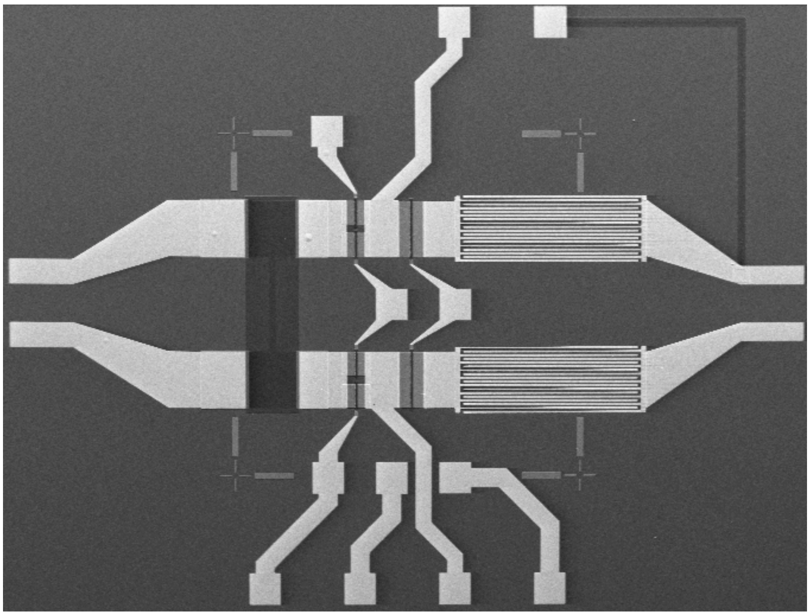

Fig. 3: Scanning electron microscope picture of the 8.75 GHz gating circuit.

The frequency counter-module described above is used in two modes of operation. One mode is to create the voltage/frequency characteristic of the voltage controlled oscillator. With this data in memory it is possible to select arbitrary frequencies of operation. For instance, a very fast linear frequency sweep can be generated.

The second mode of operation is used for selecting a frequency point with high accuracy. Because of the fast measuring cycle it is possible to implement a closed loop control for frequency adjustment. In contrast to the offset drift of the voltage/frequency characteristic, the derivative of this characteristic remains stable. Hence, the selected frequency point can be reached in two steps using a gradient technique, resulting in an overall settling time of 240 µs.

3. Conclusion

The presented frequency counter and six-port are used to determine the phase of the reflected signal in a high precision distance sensor. The frequency counter allows in-system linearization of the oscillator characteristics for fast and linear frequency sweeps. Furthermore, a frequency control loop provides a precise Gunn frequency for the high accuracy interferometer mode. A frequency accuracy of ±0.3 kHz @ 35 GHz was achieved. The measurement time was 120 µs for the frequency measurement and 6 µs for the six-port phase measurement.

Acknowledgements

The authors would like to thank M. Hinterreiter and J. Katzenmayer for fabricating and testing the devices. This work was supported by the Austrian Science Foundation (FWF) under Contract number P11424-ÖPY.

References

[1] A. Stelzer, C. G. Diskus, H. W. Thim, “A Microwave Position Sensor with Sub-Millimeter Accuracy”, *Digest to the IEEE MTT-S International Microwave Symposium*, June 13-19, 1999, Anaheim, California, vol. 4, pp. 1599-1602.

[2] G. F. Engen, “An Improved Circuit for Implementing the Six-Port Technique of Microwave Measurements”, *IEEE Transactions on Microwave Theory and Techniques*, Vol. MTT-25, No. 12, December 1977, pp. 1080-1083.

[3] G. S. Woods, D. L. Maskell, M. V. Mahoney, “A High Accuracy Microwave Ranging System for Industrial Applications”, *IEEE Transactions on Instrumentation and Measurement,* Vol. 42, No. 4, Aug. 93, pp. 812-816.

[4] Z. Lao, W. Bronner, A. Thiede, M. Schlechtweg, A. Hülsmann, M. Rieger-Motzer, G. Kaufel, B. Raynor, M. Sedler, “35-GHz Static and 48-GHz Dynamic Frequency Divider IC´s Using 0.2-µm AlGaAs/GaAs-HEMT´s”, *IEEE Journal of Solid-State Circuits*, Vol. 32, No. 10, Oct. 97, pp. 1556-1562.

[5] A. Stelzer, C. G. Diskus, A. Thiede, K. Lübke, A. L. Springer, “A 35 GHz Frequency Divider Module”, *IEEE Workshop on MMIC Design, Packaging, and System Applications*, Oct. 22-23, 1998, Freiburg/Brsg., pp. 111-112.