Compact 340 GHz homodyne transceiver modules for FMWC imaging radar arrays.

Citation for the original published paper (version of record):
Dahlbäck, R., Bryllert, T., Granström, G. et al (2016). Compact 340 GHz homodyne transceiver modules for FMWC imaging radar arrays.. IEEE MTT-S International Microwave Symposium Digest, 2016-August. http://dx.doi.org/10.1109/MWSYM.2016.7540113

(article starts on next page)

Compact 340 GHz homodyne transceiver modules for FMWC imaging radar arrays.

Robin Dahlbäck
and Tomas Bryllert
Wasa Millimeter Wave AB
Göteborg, Sweden
Email: dahlback@chalmers.se

Göran Granström
and Mattias Ferndahl
Gotmic AB
Göteborg, Sweden

Vladimir Drakinskiy
and Jan Stake
Terahertz and Millimeter Wave Laboratory
Department of Microtechnology and Nanoscience
Chalmers University of Technology
Göteborg, Sweden

***Abstract*— We present a solution where one single LO chain is used to feed a homodyne FMCW radar transceiver. An InGaAs pHEMT active frequency multiplier MMIC (x8) and a Schottky diode frequency doubler make up the LO chain. The novel Schottky diode based transceiver operates both as a frequency multiplier (x2) and as a sub-harmonic mixer.**

The modules operate at a center frequency of 340 GHz with a 30 GHz modulation bandwidth. An output power of 0 dBm, an IF noise level of -168 dBm/Hz and a receiver conversion loss of 18 dB is achieved in the band. The form factor of the modules is adapted to build one- or two-dimensional FMCW radar arrays. State of the art system performance is achieved while system complexity, size and cost is significantly reduced.

***Index Terms*— FMCW, Millimeter wave integrated circuits, radar, Schottky diodes, Submillimeter wave circuits, THz imaging, THz radar, transceiver**

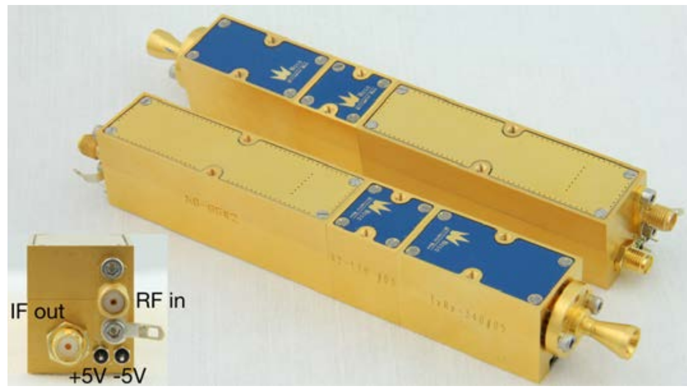

Fig. 1. Photograph of two complete transceiver chains. Insert shows the RF, IF and bias connections at the end of a module.

I. Introduction

Frequency Modulated Continuous Wave radar systems have in recent years seen great progress in the THz band. THz FMCW radars can be realised in a number of ways [1]. The most common is that the transmit and receive chains are quasi-optically combined into one beam path [2]. Other designs use waveguide couplers or orthomode transducers to combine the send and receive chain in one antenna feed [3]-[4]. A distinction can be made between systems using a separate antenna feed for the transmit and receive channels or systems combining both into the same feed. A single feed simplifies system quasi-optical design while separate feeds can achieve better isolation between the transmitter and receiver.

To enable video-rate imaging radars a current trend is to move towards more radar channels in the same system [5]. This can be compared to adding more pixels to a visible light camera sensor. However this is not unproblematic since the complexity of the system and system cost increase with the number of radar chains. Therefore multi-pixel FMCW radars benefits from the reduced complexity of an integrated transceiver chain with a single antenna feed.

The module based tranceiver presented here uses a single antenna feed, thereby simplifying design of multi pixel radars. Furthermore, only one LO chain is needed for every radar channel which effectively cuts component cost and size in half. The output power and receiver noise together results in a signal to noise ratio suitable for most practical FMCW applications. Altogether this is an attractive solution for multi-pixel FMCW radar imagers. A photograph of two complete transceiver chains is shown in Figure 1.

II. Design

A complete transceiver chain is built using three sub-modules, with a total multiplication factor of 32 from the SMA RF input to the WR-03 waveguide output. A block diagram of the complete chain is shown in Figure 2. The first module houses an active times eight frequency multiplier. A 170 GHz Schottky diode based frequency doubler is mounted in the second waveguide block. These two modules are the LO-chain for the transceiver in the third and final waveguide block. More details on the respective modules and the complete chain is given below.

A. x8 active multiplier

The MMIC developed for the chain is a multiply-by-8 frequency multiplier with an output frequency centered at 85 GHz. Efficiently achieving flat high output power

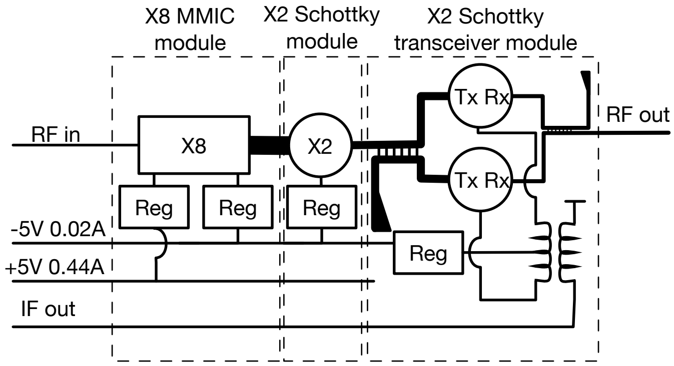

Fig. 2. Block diagram detailing the subcircuits in the three modules used in a complete chain. To the left is the x8 module with bias, input RF and output IF connections. In the middle the x2 frequency multiplier. To the right is the transceiver module with the combined x2 frequency multiplier and subharmonic mixer. The antenna feed WR-03 UG-385 flange connects to the far right side.

is challenging across the entire bandwidth in addition to high harmonic rejection. Therefore a cascade of three multiply-by-2 balanced frequency multipliers have been integrated together with inter-stage buffers and a high power output buffer. Integrating all circuits in one chip simplifies mounting and reduces the number of bond wires required between stages which contribute to more predictable and reproducible performance. Furthermore, the use of balanced multipliers ensures a broadband response with exceptional harmonic suppression. Another challenge is to keep the SWR low at the output which would otherwise cause an uncertainty in the power entering the subsequent multiplier module. The x8 chip measured output power is 18.5 ± 1 dBm across the 80 to 90 GHz bands with better than 55 dBc harmonic rejection of 7th and 9th tone at an input power level of 10 dBm with 1.5 W power consumption.

The technology used is an InGaAs 0.1μm pHEMT technology with typical electrical parameters are 135/200 GHz transition frequency (fT) and maximum oscillation frequency (fmax) for a 2x75 μm wide transistor. The current saturation (IDmax) is 760 mA/mm and saturated power of 850 mW/mm. Further, this III-V process includes front and backside metallisation, vias between the front and backside, 50 Ohm/sq Thin Film Resistors and 400 pF/mm^2 Metal Insulator Metal capacitors. The scalable transistor model being used in the design was developed in house.

B. 170 GHz frequency doubler

The 170 GHz frequency doubler is manufactured using a monolithically integrated Schottky diode membrane process where the RF circuit is fabricated on a 3 μm thin membrane. The circuit architecture is the well-known waveguide-coupled balanced doubler, originally presented by Erickson et al. [6]. The output power is 11$\pm$1 dBm over the frequency band 160-180 GHz corresponding to a typical conversion loss of 8 dB. An important design parameter was to keep the return loss (S11) of the module lower than -10 dB over the frequency band 160 - 180 GHz, at input power levels ranging from 17 - 20 dBm. This is important to reduce standing waves in the transmitter chain and to avoid excessive amplitude modulation of the transmitted radar waveform.

C. Balanced 340 GHz multiplier/mixer

The transceiver operates both as a transmitter frequency multiplier (x2) and as a sub-harmonic mixer. A lower frequency version of the concept used has been presented in [7]. To cancel the AM-noise carried by the drive signal two chips are used in a balanced configuration, using a 45 degree waveguide hybrid at the input and a 90 degree hybrid at the output. The semiconductor technology is the same as for the 170 GHz doubler circuit - monolithically integrated Schottky diode membranes. The IF signal containing the radar information appears as a differential signal and is extracted through a 300 MHz bandwidth transformer that rejects the common mode noise and also converts the signal to a single-ended signal. A single feedhorn, used for both transmitting the output signal and receiving the radar reflection is attached to the UG-385 compatible WR-03 waveguide flange.

D. Mechanical packaging

The components are integrated in a compact, modular and easily assembled waveguide module system. RF, IF and DC connectors are all accessible from the short end of the first module and the antenna waveguide interface is located on the opposite short side. DC bias is internally routed on a bus running through all modules. Bias regulation and filtering are done at the respective loads in the modules, shown in Figure 2.

The current modules have a 21 mm by 25 mm front face enabling the construction of compact 1- or 2-dimensional radar arrays. The overal length of a complete tranceiver chain is 136 mm.

III. Measured performance

Measured output power and conversion loss of one of the complete chains is presented in Figure 3. Output power levels from the x8 and x2 sub-modules are given in Figure 4. The conversion loss is measured at a 50 MHz offset with the signal from another chain attenuated to approximately -20 dBm as RF source. Figure 5 shows a radar test done using only the WR3 horn antenna without focusing optics. The target was a 18 cm x 18 cm metal sheet at 4 m distance. The radar measurement was recorded using a chirp bandwidth of 9.6 GHz and a chirp time of only 5 us. An FFT was performed on the recorded 5 us time-trace but no other data compensation or signal

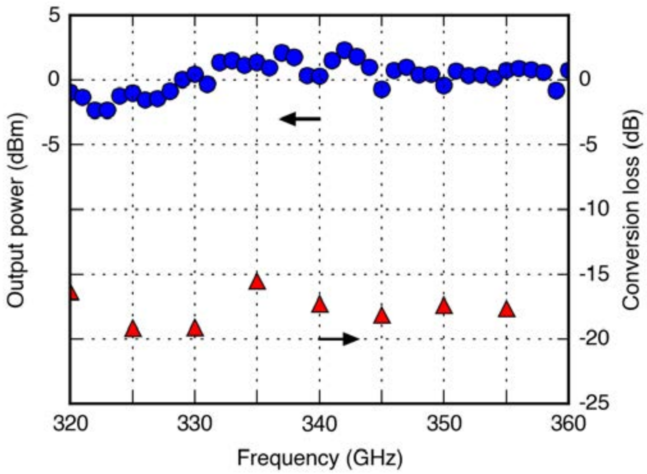

Fig. 3. Measured output power and conversion loss from one of the complete transceiver chains. The operational band used is between 325 - 355 GHz.

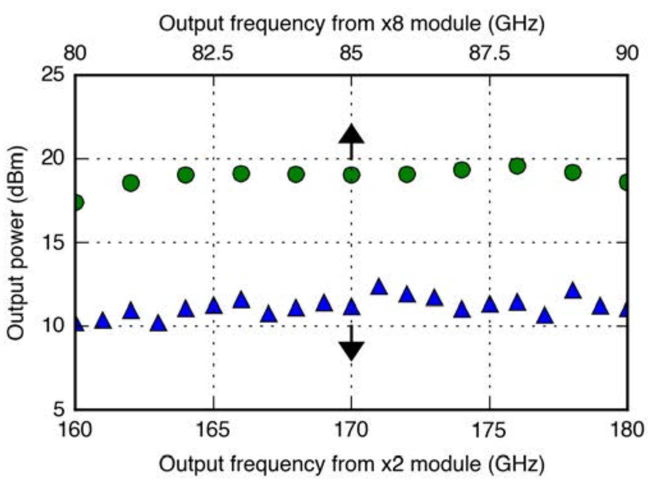

Fig. 4. Measured output power from the x8 and x2 modules. The top curve shows the output power from a x8 active frequency multiplier module. The bottom curve is the measured output power from a x2 frequency multiplier module attached to the first x8 module.

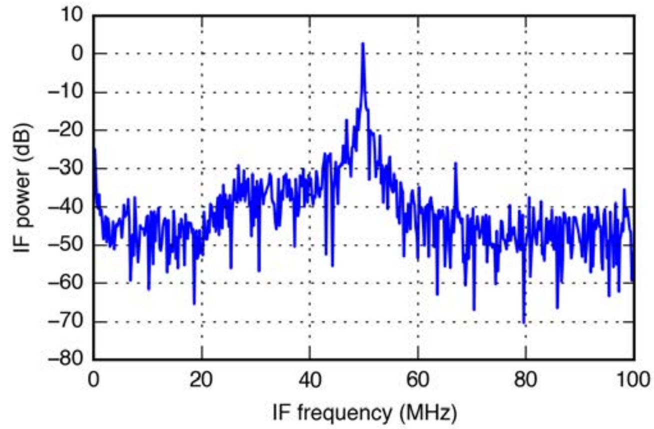

Fig. 5. FMCW radar responce using a chirp bandwidth of 9.6 GHz and a chirp time of only 5 μs. Target distance is 4 m.

processing was done. The signal-to-noise on this raw signal is better than 30 dB.

Figure 6 presents the IF noise level of the transceiver. The bottom trace is measure with the LO power switched off. A 50 dB gain low noise amplifier is used to raise the noise power above the noise floor of the spectrum analyser used in the measurement. With the noise power corrected for the 50 dB gain and the 100 kHz resolution bandwidth the spectral density is close to the thermal noise floor of 174 dBm/Hz. Switching on the LO at different frequencies across the radar band cause a slight increase of the noise level, on the order of 3-5 dB in the IF band used for radar measurements (30 - 150 MHz).

IV. Discussion

All three sub-modules in the tranceiver chain show state of the art performance. With a transmit power of 0 dBm, an IF noiselevel of -168 dBm/Hz and a receiver conversion loss of approximately 18 dB over the 30 GHz radar bandwidth the achievable dynamic range for short range imaging radar is huge - even at short transmit chirps (e.g. 100 us). A modular approach allows for adaptation to other frequency bands or simple replacement of system subcomponents.

The x8 multiplier module currently contains fully adjustable bias circuits used to optimize the performance. With a fixed bias for the x8 MMIC the module could be significantly shortened resulting in an overall length of less than 100 mm for the complete tranceiver chain.

A total of 16 complete chains are in production and will be incorporated in an FMCW imaging radar for stand off security scanning.

V. Conclusion

The compact homodyne tranceiver modules presented enable easy implementation of arrays of radar channels operating at 340 GHz. Multipixel systems can thus easily be assembled and all connections except the antenna interface are easily accessible form one side of the module. The transceiver nature of the module greatly simplifies the optical design of the imaging radar by reducing the need to align the receive and transmit channel through beamsplitters or similar solutions. Meanwhile the performance of the module are state of the art.

Acknowledgment

The authors would like to acknowledge the financial support received from the EU project "Concealed Ob-

978-1-5090-0698-4/16/$31.00 ©2016 IEEE

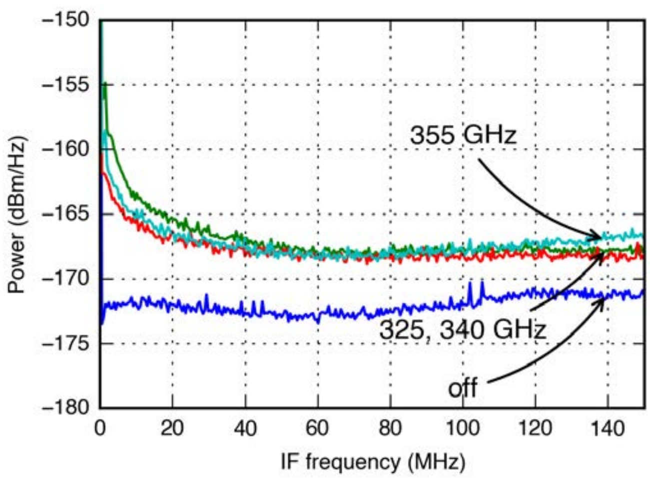

Fig. 6. Measured IF noise as a function of frequency. In the 30 - 150 MHz where this module usually operates the spectral density is 3-5 dB above the thermal noise floor. The different curves represent the thermal noise floor with the transceiver switched off, lower radar band edge at 325 GHz, band center at 340 Ghz and upper band edge at 355 GHz.

ject Stand-Off Real-Time Imaging for Security", grant agreement number: 312745. This work was supported in part by the GigaHertz Centre in a Joint Research Project Financed by the Swedish Governmental Agency of Innovation Systems, Chalmers University of Technology, Omnisys Instruments AB, Wasa Millimeter Wave, Low-Noise Factory, and SP Technical Research Institute of Sweden

REFERENCES

[1] K. B. Cooper and G. Chattopadhyay, "Submillimeter-Wave Radar: Solid-State System Design and Applications," *IEEE microwave magazine*, vol. 15, no. 7, pp. 51–67, 2014.

[2] K. B. Cooper, R. J. Dengler, N. Llombart, B. Thomas, G. Chattopadhyay, and P. H. Siegel, "THz Imaging Radar for Standoff Personnel Screening," *IEEE Trans. THz Sci. Technol.*, vol. 1, no. 1, pp. 169–182, Sep. 2011.

[3] C. A. Leal-Sevillano, K. B. Cooper, E. Decrossas, R. J. Dengler, J. A. Ruiz-Cruz, J. R. Montejo-Garai, G. Chattopadhyay, and J. M. Rebollar, "Compact Duplexing for a 680-GHz Radar Using a Waveguide Orthomode Transducer," *IEEE Trans. Microw. Theory Tech.*, vol. 62, no. 11, pp. 2833–2842, Oct. 2014.

[4] K. B. Cooper, T. A. Reck, C. Jung-Kubiak, C. Lee, J. V. Siles, R. H. Lin, A. Peralta, E. Decrossas, E. T. Schlecht, G. Chattopadhyay, and I. Mehdi, "Transceiver array development for submillimeter-wave imaging radars," in *SPIE Defense, Security, and Sensing*. SPIE, May 2013, pp. 87 150A–8.

[5] F. Friederich, W. von Spiegel, M. Bauer, F. Meng, M. D. Thomson, S. Boppel, A. Lisauskas, B. Hils, V. Krozer, A. Keil, T. Loffler, R. Henneberger, A. K. Huhn, G. Spickermann, P. H. Bolivar, and H. G. Roskos, "THz Active Imaging Systems With Real-Time Capabilities," *IEEE Trans. THz Sci. Technol.*, vol. 1, no. 1, pp. 183–200, Aug. 2011.

[6] D. W. Porterfield, T. W. Crowe, R. F. Bradley, and N. R. Erickson, "A high-power fixed-tuned millimeter-wave balanced frequency doubler," *IEEE Trans. Microw. Theory Tech.*, vol. 47, no. 4, pp. 419–425, Apr. 1999.

[7] T. Bryllert, V. Drakinskiy, K. B. Cooper, and J. Stake, "Integrated 200—240-GHz FMCW Radar Transceiver Module," *IEEE Trans. Microw. Theory Tech.*, vol. 61, no. 10, pp. 3808–3815, 2013.