

A Solid State W-band Radar Profiler for Cloud Observation

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Abstract—Millimetre wave radar has been successfully applied in cloud research for a number of decades. The Rutherford Appleton Laboratory (RAL) has developed a 94 GHz radar based on solid state components and operated in Frequency Modulated Continuous Wave (FMCW) mode. The approach for improving the RF design – including the implementation of Doppler capability – and the results of this activity will be presented.

I. INTRODUCTION

MILLIMETRE wave radar has been successfully applied in atmospheric research of cloud microphysics and processes for a number of decades. The first systems at K_a-band operated by NOAA ETL [1], [2] and at W-band used by Miami University [3] were based on vacuum tube technology and used the pulsed Doppler operation mode. For the majority of systems operated today for this purposes this is still the case. Due to the high manufacturing and operation costs, these systems were exclusively used for atmospheric research, typically in time-restricted research campaigns. To date there was no reasonable path foreseen to routine operational application, e.g. in networks of national weather services.

In the mid-1990s the first millimetre-wave radar profiler for atmospheric research based on solid-state devices [4] was developed. This system operated at W-band and used the Frequency Modulated Continuous Wave (FMCW) Doppler operation mode, which is much better suited for power generation by solid-state components than the pulsed operation mode. Around the same time the Rutherford Appleton Laboratory (RAL) developed a millimetre-wave radar profiler based on semiconductor devices that operated in non-Doppler FMCW mode [5], [6]. This system originally operated at V-band but later was converted to operation in W-band [7]. These systems provided the first indication of operational capabilities that might make millimetre wave radars suitable for the operational networks of national weather services.

In total three systems of the RAL radar cloud profiler were built and successfully deployed for atmospheric research. However, more recent results from atmospheric research – including observations from these systems themselves – leading to increased demands on the capability of radars for cloud research urge an improvement of the radar design.

II. APPROACH

An upgraded design was developed based on the technology and the components applied in the original design displayed in Fig. 1. The goal was to provide

- Introduction of Doppler capability
- Simplification of design where appropriate
- Maximum utilisation of in-house capabilities

The latter was achieved by including a W-band Schottky diode frequency tripler and a W-band third harmonic down-converter, both developed in-house, and W-band amplifier designs bonded and packaged in house, into the RF design. The amplifier designs include one utilising quadrature hybrid technology for power combining the output from two MMICs.

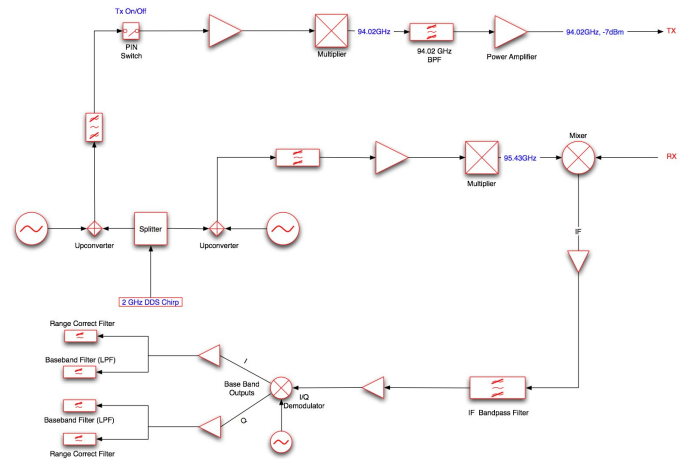


Fig. 1: RF design of the existing RAL radar cloud profiler.

The option to achieve the first goal was secured by exclusively applying components that fulfil the hardware requirements for FMCW Doppler operation. Doppler capability itself will then be achieved by implementing the proper methods in the data acquisition (DA) and digital signal processing (DSP) system.

A simple demonstrator RF design is displayed in Fig. 2. This design omits the intermediate IF step in the receiving branch present in the original design as detailed in Fig. 1. In this RF design components depicted in yellow colour are either developed in-house, or manufactured based on in-house capabilities.

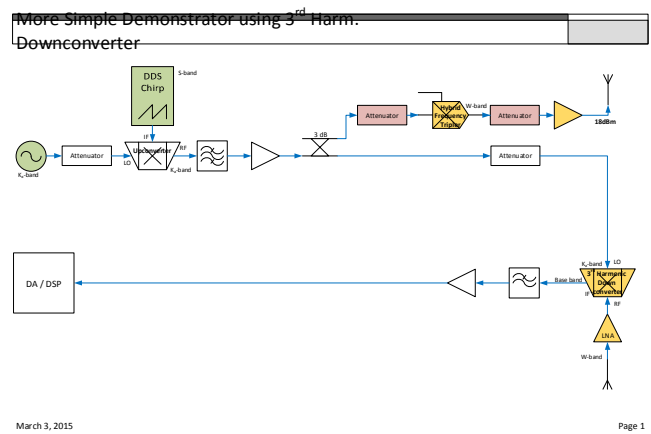


Fig. 2: RF design for a FM-CW Doppler cloud radar demonstrator.

The intermediate IF step in the receiving branch present in the original system will be re-introduced in the final RF design of the updated cloud radar profiler. Though avoiding this intermediate IF step would lead to a more simple RF design, it is anticipated that keeping the intermediate IF step will significantly reduce the noise level of the radar. This directly translates into higher detection sensitivity.

III. RESULTS

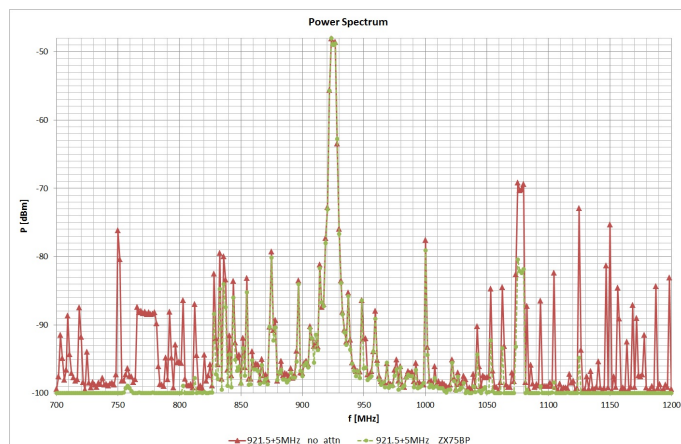


Fig. 3: Primary FM-CW signal with 5 MHz bandwidth centred around 924 MHz generated by the DDS that will be utilised for the demonstrator. For the measurement displayed by the green dashed line a band pass filter was applied.

The generation of the primary FMCW signal by means of a Direct Digital Synthesiser (DDS) has been tested successfully. An example for a chirp of 5 MHz bandwidth centred around 924 MHz is displayed in Fig. 3. The solid red line shows that the DDS produces a significant number of spurious lines. This is not uncommon for digital synthesisers. The dashed green line shows the effect of applying a band pass filter to the primary FMCW signal generated by the DDS. However, a significantly more narrow band pass filter will have to be applied for setting up a simple demonstrator.

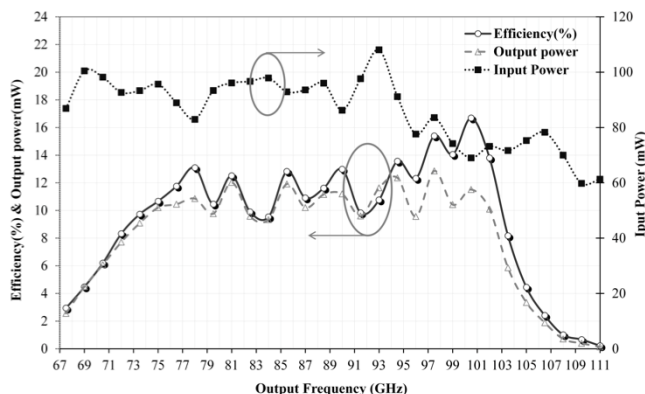


Fig. 4: Results from assessing the W-band frequency tripler.

The components based on RAL in-house capabilities as detailed above have been assessed. The results of this were found to be reasonably close to the theoretically expected performance. One example – the W-band frequency tripler – is shown in Fig. 4. Its peak power conversion efficiency is 16.7%. The full band efficiency is above 5% over the range

69.5-105 GHz, and better than 10% over the range 73-103 GHz. There is good agreement between the predicted and measured maximum efficiencies, although the optimum performance is shifted upwards from 93 to 101 GHz.

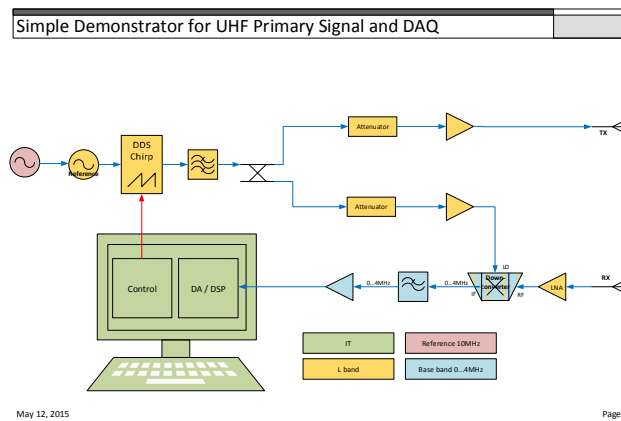


Fig. 5: Simple demonstrator for primary signal generation at UHF or L-band and for testing the data acquisition system. Components applied are colour coded: red for the 10 MHz reference oscillator, gold for L-band components and blue for base band components.

IV. OUTLOOK

The next step will be setting up an UHF / L-band demonstrator for fully integrated primary signal manipulation and data acquisition / digital signal processing. The principle, as displayed in Fig. 5, is based on the DDS assessed in Fig. 3. Following this, the simple demonstrator at W-band shown in Fig. 2 will be set up and tested. Then the complete RF frontend design will be implemented and assessed. Finally the RF frontend will be incorporated in weather proof housing and applied for atmospheric research.

Further results that already exist as well as progress until then will be presented at the conference.

REFERENCES

- [1]. A Millimeter-Wavelength Dual-Polarization Doppler Radar for Cloud and Precipitation Studies. Pasqualucci, F., et al., et al. 5, s.l.: American Meteorological Society, 1983, Journal of Applied Meteorology and Climatology, Vol. 22. ISSN: 0733-3021.
- [2]. The upgraded WPL dual-polarization 8-mm wavelength Doppler radar for microphysical and climate research. Kropfli, R. A., Bartram, B. W. and Matrosov, S. Y. San Francisco: American Meteorological Society, 1990. Proceeding Conference on Cloud Physics.
- [3]. Small Cumuli Observed with a 3-mm Wavelength Doppler Radar. Lhermitte, R. E. 7, s.l.: American Geophysical Union, 1987, Geophysical Research Letters, Vol. 14. ISSN: 0094-8276.
- [4]. D. Klugmann and R. Judaschke, "A 94 GHz FM-CW Doppler Radar Profiler Using a Solid State Transmitter," *Beitr. Phys. Atmosph.*, vol. 69, pp. 239-246, February 1996, ISSN: 0005-8173/96/01.
- [5]. B. N. Ellison, M. Oldfield, and W. J. Bradford, "Millimetre wave cloud radar," *9th International Workshop on the technical and scientific aspects of MST radar – MST9*, Toulouse, France, 2000.
- [6]. D. Lyth, J. Nash, and M. Oldfield, "Observing fog and low cloud with a combination of 78 GHz cloud radar and laser ceilometer," *WMO CIMO TECO-2005*, p. P2(11), Bucharest, Romania, 2005.
- [7]. P. G. Huggard, et al., "94 GHz FMCW Cloud Radar," *SPIE Symposium 7117-3 on Millimetre Wave and Terahertz Sensors and Technology*, Cardiff UK, 2008.