Low cost high gain antenna arrays for 60 GHz millimetre wave identification (MMID)

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***Abstract*- Low cost millimetre wave modules are needed for emerging 60 GHz applications such as high speed wireless communications and millimetre wave identification (MMID). All applications require high performance antenna arrays to overcome the high propagation losses. Two alternative antenna array designs on a low cost substrate (Taconic Taclamplus) are presented and analysed in this paper. The arrays are manufactured using standard printed circuit board (PCB) technology and have measured gains of 18 dBi and 23 dBi. The operational bandwidths are about 2 GHz around the center frequency. Transmitter and receiver modules based on the developed antenna arrays are also presented.**

I. INTRODUCTION

Various technologies exist for making millimetre wave modules and antennas such as LTCC [1,2], liquid crystal polymers (LCP) [3], PTFE, alumina etc. LTCC has the advantage that it can be used to make a complete hermetic module package including antennas. However, the cost of the package can be too high for high volume applications like MMID tags [4]. In the research work presented in this paper, the applicability of PTFE-based Taclamplus material by Taconic [5] is studied for 60 GHz antenna array application. Two microstrip line antenna arrays are analysed and characterised by measurements.

The used Taclamplus substrate has a 100μm thick dielectric with $\varepsilon_r = 2.1$ and tan $\delta = 0.0008$ at 60 GHz. The dielectric is laminated between a 1mm thick copper plate and a 17μm rolled-annealed copper foil. A special property of the material is that it can be laser ablated without residues. This facilitates easy engraving of MMIC cavities and via formation in multilayer structures. The low dielectric loss of Taclamplus facilitates cost effective manufacturing of high gain planar antenna arrays for millimetre waves.

II. OVERVIEW OF MMID SYSTEMS

Millimetre wave identification is an extension of the RFID concept to millimeter waves [4]. The use of a higher carrier frequency enables the use of highly directive antenna arrays in a small volume. The ISM band around 60 GHz is good for MMID since no licenses are required. 60 GHz MMID systems can provide high data transfer rates from e.g. sensors and also tag localization due to the use of directive antennas like shown in Figure 1. The MMID tags can be either active or passive. Active tags are usually preferred because of their longer operating range and higher versatility.

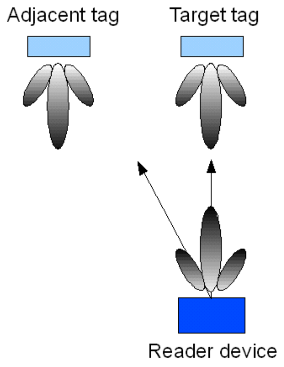

Figure 1. MMID application using directive tags and reader.

III. TACLAMPLUS MATERIAL

The use of PTFE as a dielectric substrate represents a mature technology in the field of RF and microwave circuit design. Taclamplus is a thin-core, ceramic-loaded, non-reinforced PTFE-based printed-circuit-board (PCB) substrate. Generally speaking non-reinforced thin-core PTFE materials (say 0.10mm thick) are difficult to process using conventional PCB manufacturing techniques. Dimensional stability is compromised and handling equipment must be capable of supporting what can be flimsy circuits without damaging features and structures. Whilst reinforcing agents such as woven glass can improve handling and general material stability; their loss characteristics preclude their use in very high-frequency applications. In addition laser ablation of such materials is hampered due the preferential energy absorption over plastics. As a result electroplated vias can appear rough and with unpredictable surface area contributing to increased conductor losses. To overcome the handling problems, Taclamplus is supplied as a laminate with at least one conductor capable of offering subsequent mechanical support. Usually this is a copper plate of thickness 0.5mm or greater but recently electrodeposited copper foils of ≥70μm have been used in multilayer structures. This supportive conductor doubles as ground-plane and heat-sink.

Taclamplus dielectric is a PTFE/ceramic composite; the dielectric constant measures 2.08 ± 0.02 at mm-wave frequencies. The inclusion of ceramic facilitates laser ablation to create cavities (for MMIC die) which is best achieved using IR laser machining. Laser ablation of MMIC cavities is shown to offer best accuracy and cavity geometry (as opposed to mechanical milling). Figure 2 shows some images of laser-ablated cavities on Taclamplus.

Copper-foil adhesion on Taclamplus is comparatively high; this is a pre-requisite for fine-feature resolution. Good foil adhesion is achieved without the need for high RMS copper-foils. Low RMS foils make for lower conductor losses which is especially true at high frequencies. Copper-peel strength is typically 10lb/in [1.8N/mm] for 17µm ED copper.

Waveguide launch techniques are easily accommodated and Taclamplus is compatible with a wide range of assembly techniques, including lead-free assembly and gold-wire bonding. In addition it satisfies the UL-94 V0 requirement without the need of any flame-retardants.

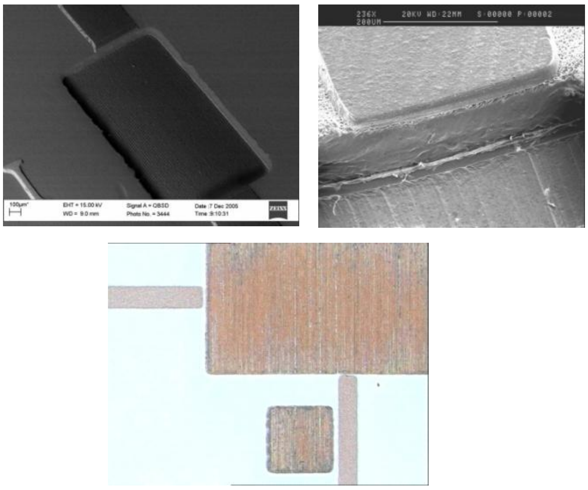

Figure 2. SEM and optical images of laser-ablated cavities in Taclamplus. Courtesy of Varioprint AG.

IV. ANTENNA DESIGN AND MANUFACTURING

Two different antenna arrays for 60 GHz center frequency have been designed and manufactured on a 100µm thick Taclamplus substrate. The base copper thickness is 1.0mm and the patterned copper film is 17µm. The antenna structure is shown in Figure 3. The antennas are manufactured using a standard PCB process with 200µm minimum line and gap widths. The antennas have been designed with Zeland IE3D v14 software using the Method-of-Moments (MoM) technique.

The first antenna array shown in Figure 4 is a traveling wave type antenna consisting of eight parallel microstrip line chains. The radiation mechanism of chain antennas is originally analysed in [6]. The chain antenna presented in this paper is designed so that most energy is radiated before the end of the line and no termination load is required. Thus the radiation efficiency is very high. The vertical strips marked with red in Figure 3 radiate in the vertical direction and sum up in the far field while the horizontal strips marked with blue effectively cancel each others radiation.

Like with all traveling wave antennas the main beam direction in the E-plane is changed when frequency is offset from the center frequency. Beam scanning inside the operating frequency range is about 5 degrees.

Simulated input matching of the chain antenna is shown in Figure 5. The frequency range of the antenna according to simulations is 58.0–60.5 GHz. Measured frequency range is shifted a bit upwards and is 59.0–61.0 GHz. Simulated radiation patterns are shown with the test results in the next section. Simulated maximum gain is 21 dBi at 60 GHz. Size of the manufactured antenna including the reactive power dividers is 35x35 mm^2.

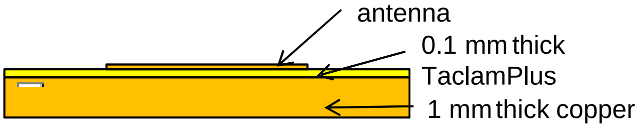

Figure 3. Antenna structure on Taclamplus.

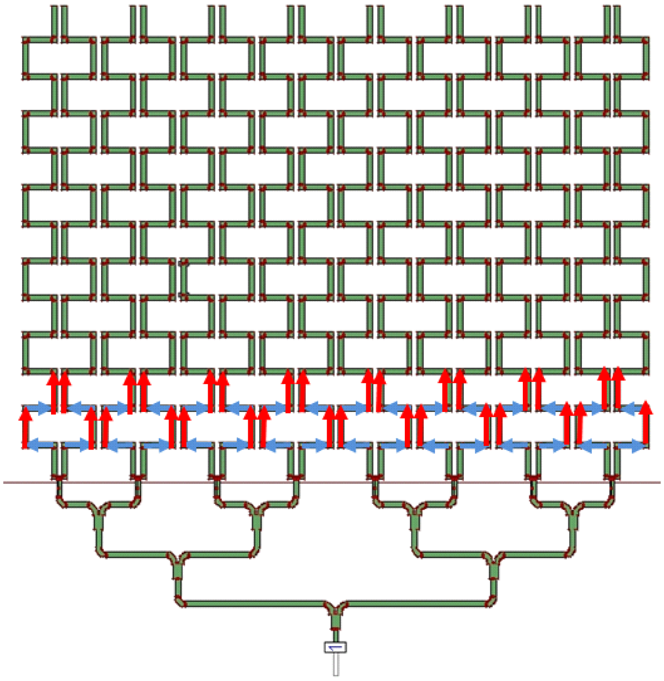

Figure 4. Chain antenna array for 60 GHz.

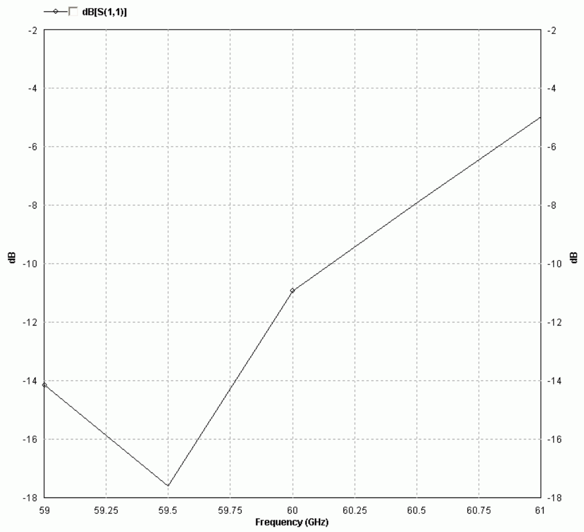

Figure 5. Simulated matching of the chain antenna array.

The second antenna array shown in Figure 6 is based on series-fed microstrip patch antennas which are separated by one guided wavelength at the center frequency. The developed array consists of eight columns with four patches each and has a size of 31x21 mm^2 including a reactive power divider feed network. Simulated input matching is shown in Figure 7 and the estimated operating frequency range is 56.0–59.0 GHz. Again the measured operating band is shifter upwards and is 58.0–60.5 GHz. Maximum simulated gain is 17.5 dB. Radiation patterns are compared in the next section. Beam scanning with frequency offset is also observed with this antenna. Change in the main beam direction is about 5 degrees inside the range of 3 GHz.

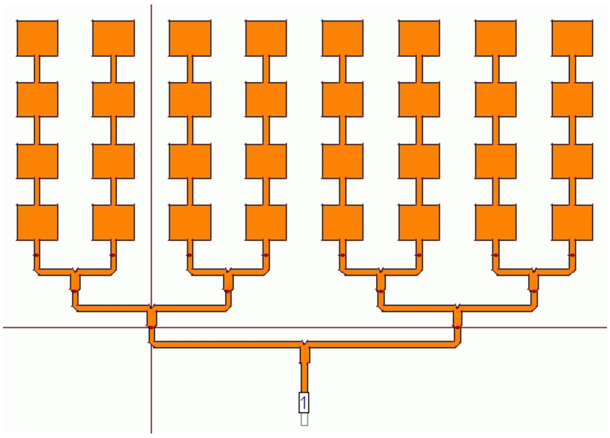

Figure 6. Series-fed patch antenna array for 60 GHz.

Both developed antenna arrays have minimum linewidths of about 200 microns and can thus be manufactured with a regular low cost printed circuit board (PCB) process.

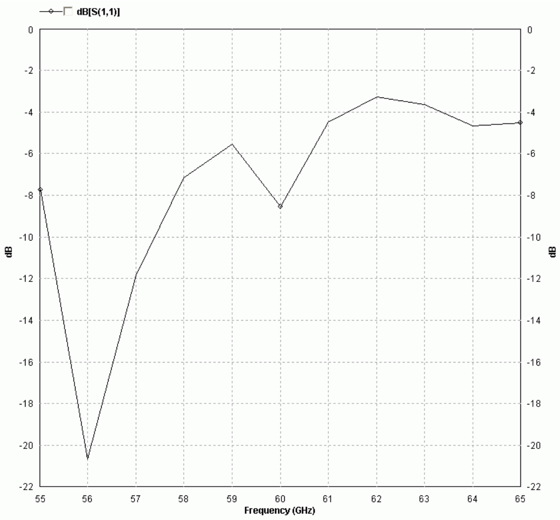

Figure 7. Simulated input matching of the series-fed patch array.

V. TEST RESULTS

The antenna arrays were mounted on a Anritsu-Wiltron 3680V test jig. Input matching was measured with a vector network analyser by using time gating to remove the effect of the measurement jig. The radiation patterns of the antenna arrays have been measured in an anechoic chamber at VTT. The antenna-under-test (AUT) is attached to the measurement jig like shown in Figure 8 for the chain antenna. The 1.85mm coaxial cable connects the jig to an Agilent V-band downconverter mixer. The jig and downconverter are fixed to a Rohacell pylon on top of a small rotation table. The antenna rotation is controlled by a LabView program which also records the received power from an Agilent spectrum analyser.

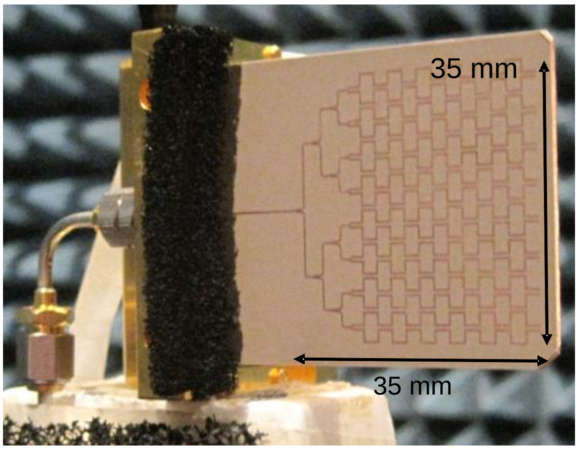

Figure 8. Chain antenna on the measurement jig.

Input matching of the chain antenna was measured on the jig. The measurement was calibrated to the end of the coaxial 1.85mm cable as no Taclamplus calibration kit was available.

Therefore the effect of the jig including a V-connector and the mounting clamp was eliminated by time gating. A Taclamplus calibration kit for the jig will be manufactured when new antenna structures are processed in the near future. Using this to calibrate the measurement to the jig clamp interface will greatly improve the measurement accuracy. The non-gated and gated responses from the chain antenna over 55 – 65 GHz are shown in Figure 9. Best matching is obtained at 59.5 GHz although there are multiple reflections which cause problems in measurement accuracy. Based on subsequent radiation pattern and gain measurements the operating range of the chain antenna is 59–61 GHz.

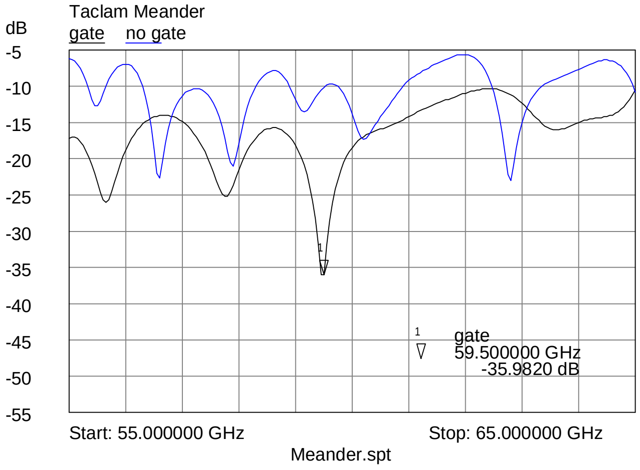

Figure 9. Measured input matching of the chain antenna with and without time gating.

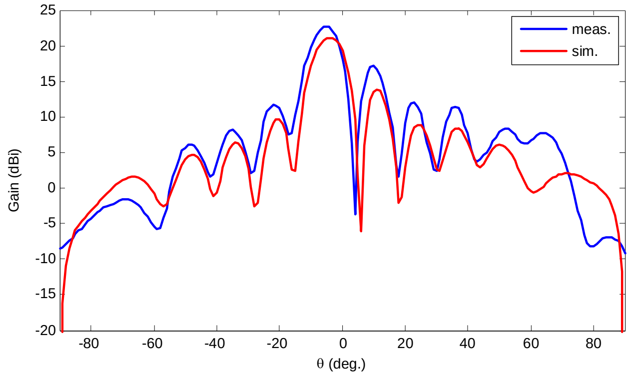

Figure 10. E-plane radiation patterns of the chain antenna at 60 GHz.

The simulated and measured radiation patterns of the chain antenna are shown in Figure 10–11 for E-plane and H-plane, respectively. The maximum measured gain is 23 dBi at 60 GHz. Half-power beamwidth in the E-plane is 9 degs and 7 degs in the H-plane. The beam offset in E-plane from boresight is –5 degrees at 60 GHz. The first sidelobe is quite high and only about 6 dB below the main lobe. The high sidelobe level can cause some problems in separating adjacent MMID tags. The simulated and measured patterns compare very well. Asymmetry in the E-plane patterns is a characteristic of traveling wave antennas and is also partly due to feed network radiation.

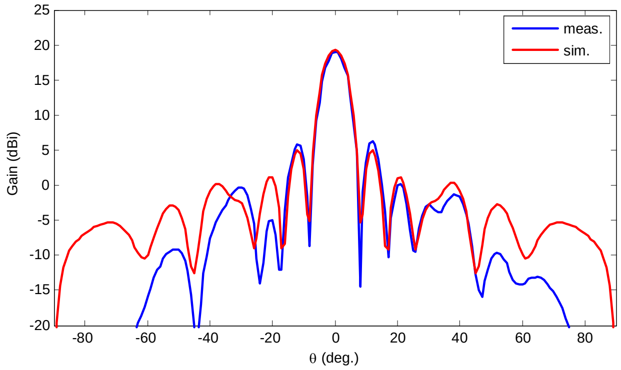

Figure 11. H-plane radiation patterns of the chain antenna at 60 GHz.

The manufactured series-fed patch array mounted on the test jig is shown in Figure 12. Again the input matching was measured by using time gating and is shown in Figure 13. Best matching is obtained at 59.5 GHz and the operating range based also on radiation pattern and gain measurements is 58–60.5 GHz.

The simulated and measured radiation patterns are compared in Figures 14–15 for E-plane and H-plane, respectively. The maximum measured gain is 18 dBi at 60 GHz. Half-power beamwidth in the E-plane is 23 degs and 7 degs in the H-plane. Again, asymmetry in the E-plane patterns is partly caused by feed network radiation.

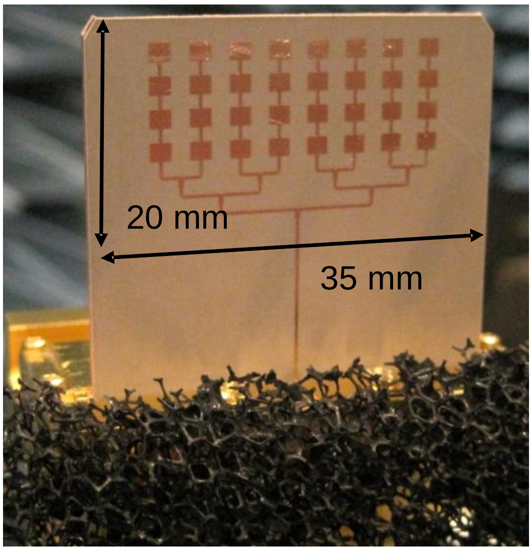

Figure 12. Series-fed antenna array on measurement jig.

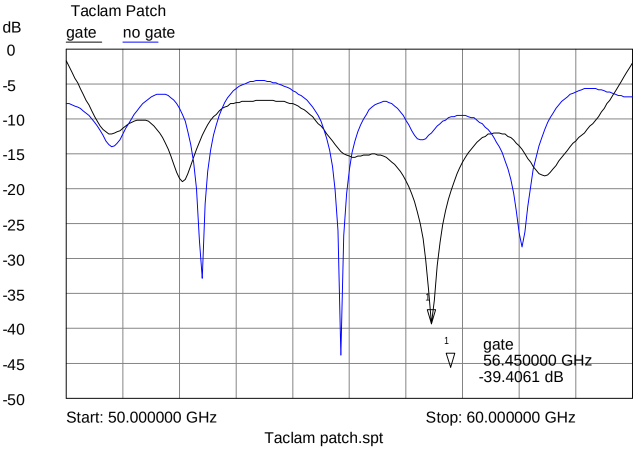

Figure 13. Measured input matching of the series-fed array with and without time gating.

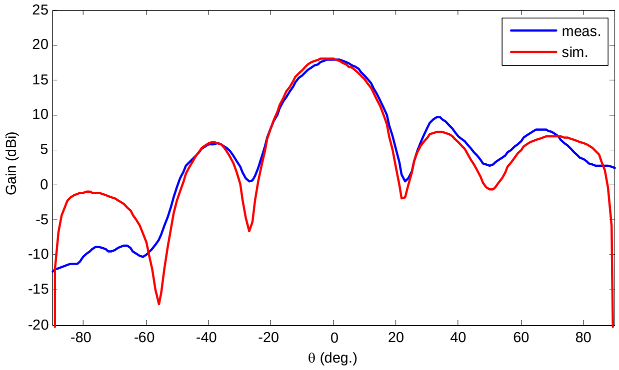

Figure 14. E-plane radiation patterns of the series-fed array at 60 GHz.

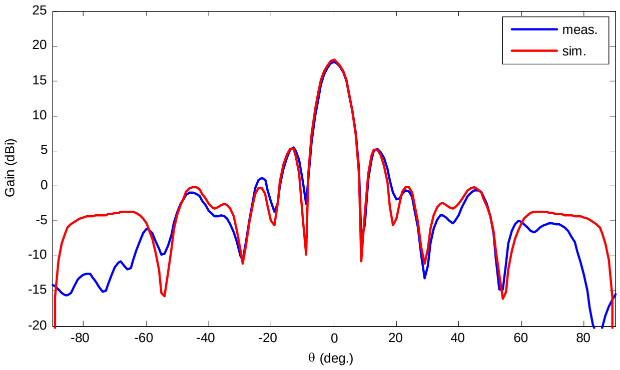

Figure 15. H-plane radiation patterns of the series-fed array at 60 GHz.

VI. RF-MODULES FOR MMID

Transmitter and receiver modules using the presented antenna arrays have been designed and manufactured for 60 GHz. The modules are based on a commercially available GaAs chipset from Gotmic AB. The transmitter chip is TXQ060A01[7] and the receiver is RXQ060A01[8]. The chips are mounted on cavities on the Taclamplus substrate and wire-bonded. A close-up photograph of a mounted chip is shown in Figure 16 and the manufactured receiver module without chip in Figure 17. The MMIC cavities were accomplished with mechanical milling because the used PCB manufacturer didn’t have laser ablation capability. The chips have quadrature inputs/outputs (I & Q) and internal local oscillator (LO) quadruplers. LO frequency from in-house developed PLL synthesizers to the modules is around 15 GHz.

A MMID test system has been constructed using the developed modules. The MMID transmitter tags are operated at an IF frequency of 2.4 GHz with custom RFID transmitters. The tags are now transmitting only their identity code but could also include some sensory data in a real application. The receiver downconverts the 60 GHz signal to an IF frequency of 2.4 GHz for a custom RFID receiver. Tag reading has been verified for more than 10 m reliable reading distance. Direct coupling from transmitter to receiver at the IF frequency causes some problems in the system, and this has been mitigated by the choice of different 2.4 GHz transmit and receive channels. This is accomplished by using slightly different local oscillator frequencies for the transmitter and receiver mixers.

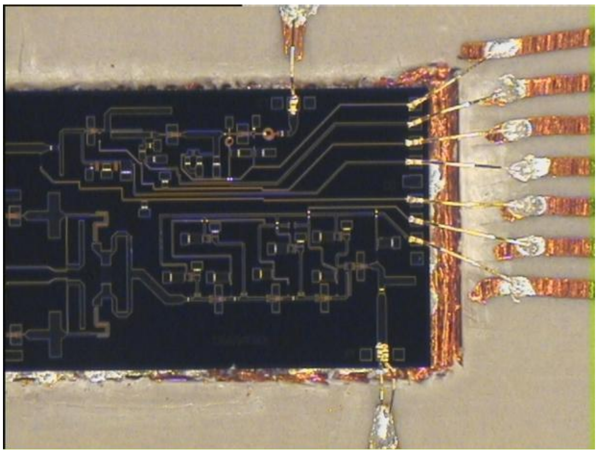

Figure 16. MMIC mounted in a cavity and wire-bonded.

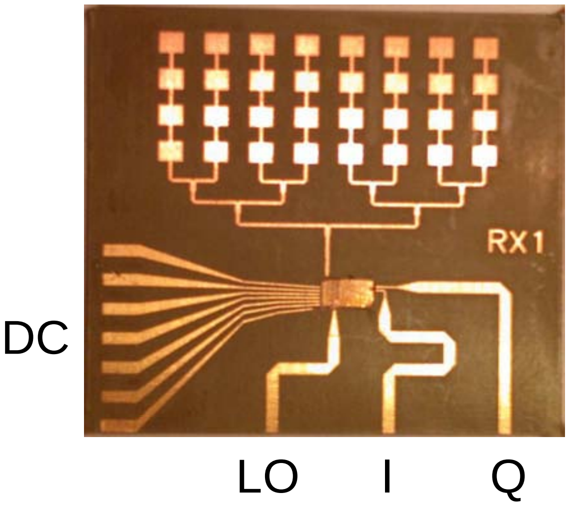

Figure 17. 60 GHz receiver module using the series-fed antenna array.

VII. CONCLUSIONS

Two low cost and high gain antenna arrays for MMID application around 60 GHz are presented. Simulations and measurements compare very well. Sidelobes of the chain antenna are quite high for MMID application, and need to be addressed in future designs. The original design was aimed at maximum possible gain. The used material thickness and single-layer process restrict the available feed mechanisms. The radiation patterns of the chain antenna can be made more symmetrical and less dependent on frequency with a more complicated feed system which is under study.

Transmitter and receiver modules using the developed antenna arrays have been demonstrated. These have been used in a MMID test system and resulted in a more than 10 m reading distance.

Taclamplus represents a cost-effective microwave substrate that can be used to create very low-loss structures both with single dielectric layers and multiple layers. Exceptional copper-foil adhesion allows small-feature resolution and the unique composition of the dielectric facilitates clean laser ablation for micro-via and component-cavity formation. The use of metal-plate such as 1 mm copper helps to maintain dimensional stability and provides a sound ground plane and ideal heat-sinking properties.

ACKNOWLEDGEMENTS

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