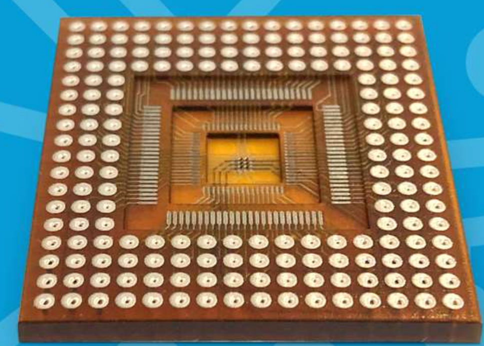
NANO DIMENSION

Electrifying Additive Manufacturing®

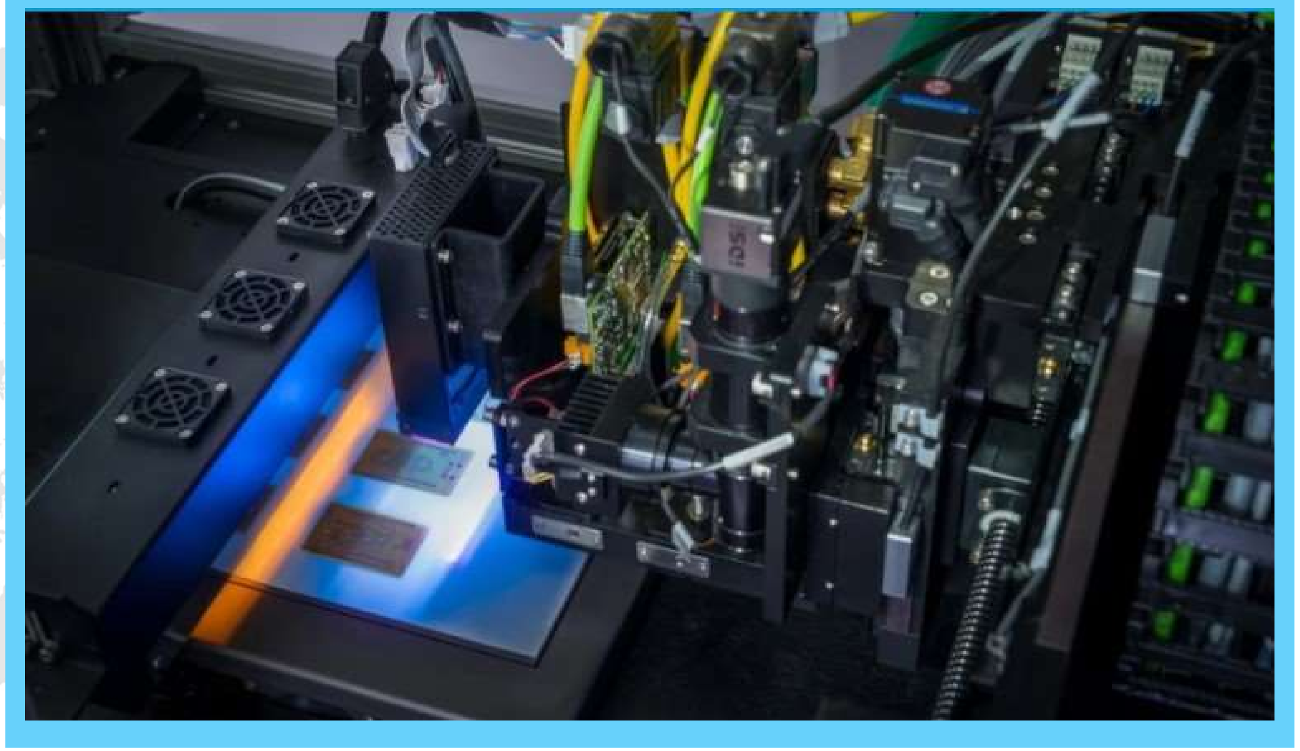
ADDITIVELY MANUFACTURED ELECTRONICS (AME)

Nov 2020 I Next Generation Manufacturing I NASDAQ: NNDM



NANO DIMENSION

- **Industry Leader:**
  Additive Manufactured Electronics (AME)
- **More than a dozen patents granted, and more than three dozen patent applications**
- **First-to-Market** Advantage
- The **ONLY** technology that converts CAD files into functional devices in a single operation
- **Approximately 60 Systems** Worldwide



OUR MISSION

Our **DragonFly™** **AME Machines** (controlled by AI algorithms) produce electronic devices through simultaneous precision jetting of dielectric and conductive materials to fabricate, within hours:

3D High Performance Electronic Devices: Hi-PEDs™

Sensors, Antennas, Capacitators, Convertors for unique geometries and complex devices

We develop and produce proprietary complimentary inks as consumables in our AME machines.

All are **mission critical** and **economical** for our customers.

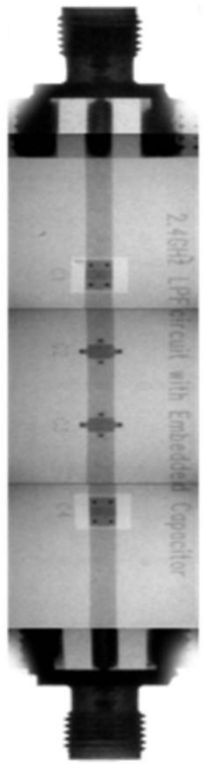
DRAGONFLY IV: A DIGITAL FACTORY IN A BOX

ALL OF THIS …

…REPLACED BY THIS!

EXAMPLE OF Hi-PEDs™: LOW PASS FILTER (LPF)

Printed LP

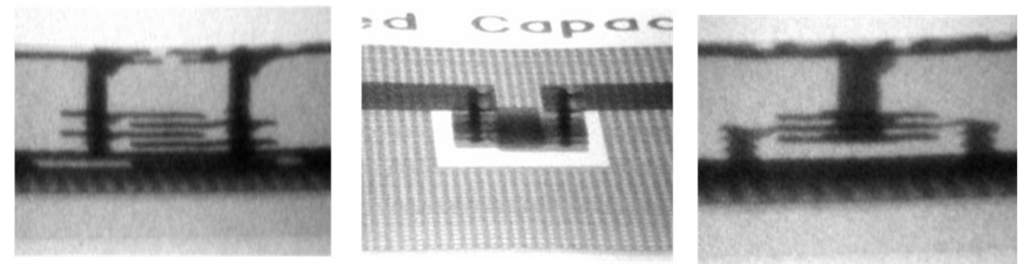


X-ray of Printed LP

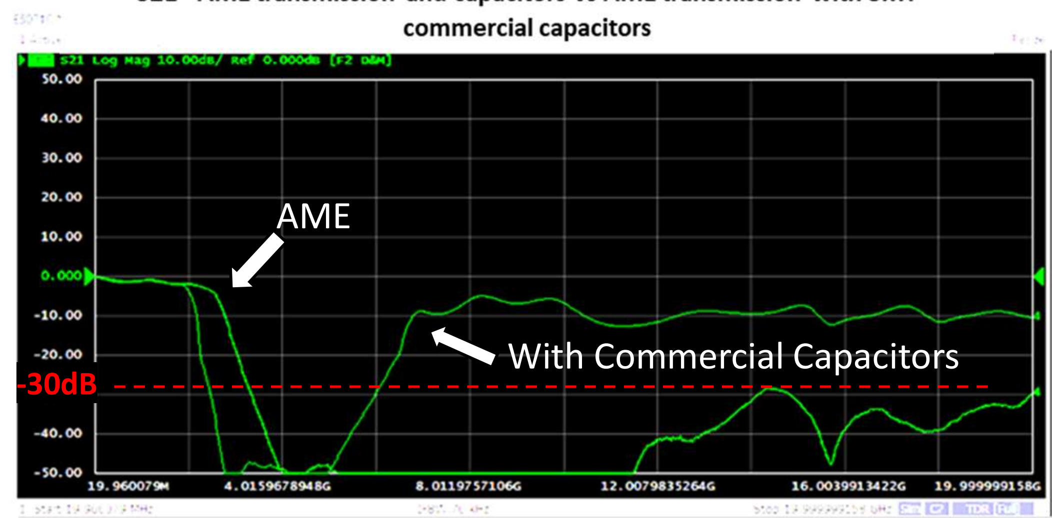
LPF uses AME capacitors fabricated simultaneously inside the AME board together with strip lines.

The AME capacitor and the strip line can be placed on any layer or on different layers in the AME board

X-ray of LPF capacitors and transmission strip lines



S21 - AME transmission and capacitors vs AME transmission with SMT commercial capacitors

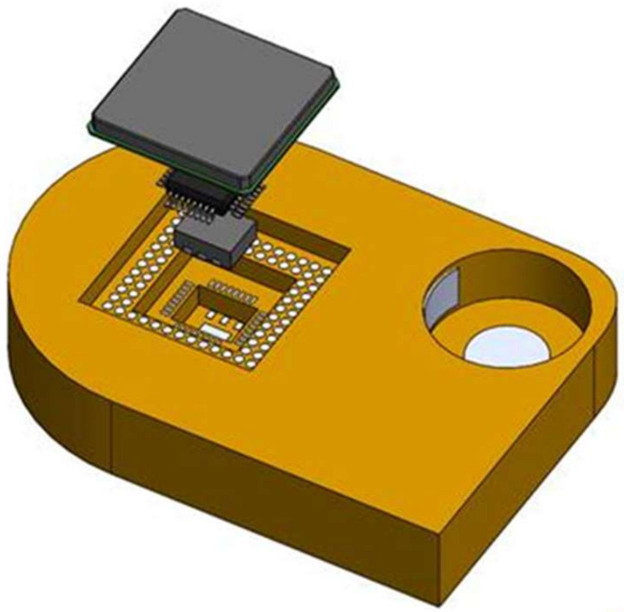


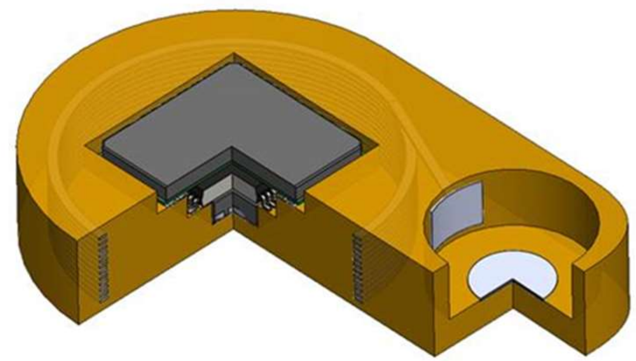
LPF with AME Capacitors filters the signal at least up to 20GHz. (less than -30db)

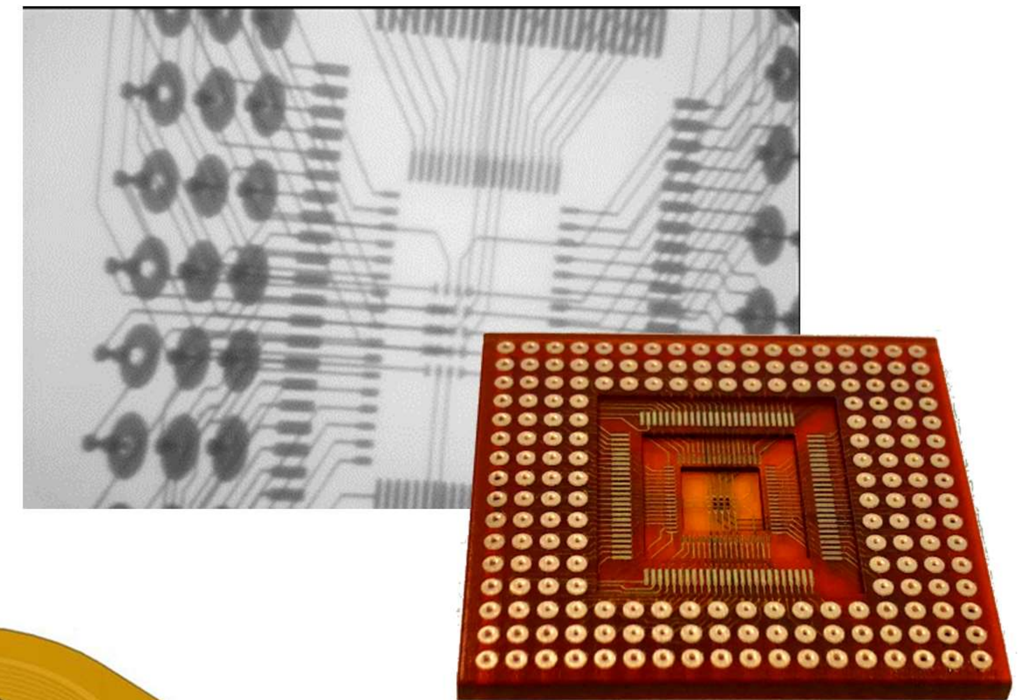
LPF with Commercial Capacitors stops filtering at 6GHz

EXAMPLE OF Hi-PEDs™: VERTICALLY STACKED INTEGRATED CIRCUITS (ICS)

Stacked ICs have a higher circuitry density than traditional PCBs by allowing ICs to be mounted and interconnected on top of each other.



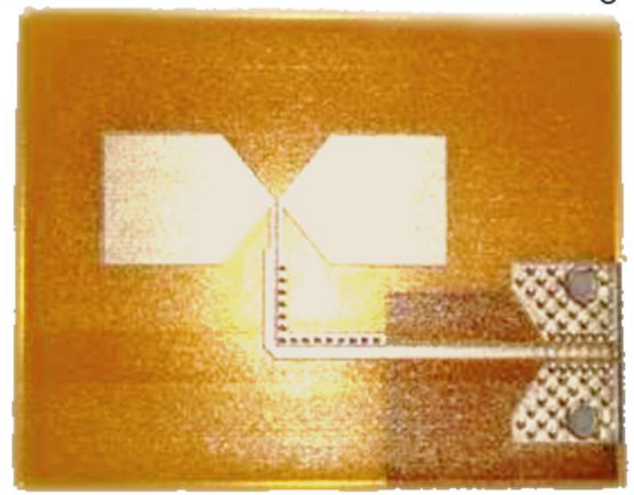


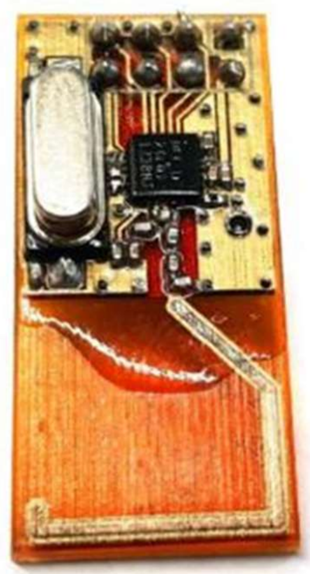


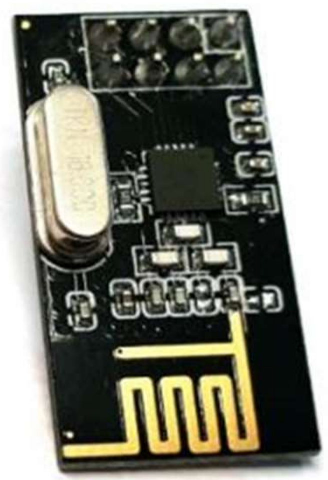
EXAMPLE OF Hi-PEDs™: RF ANTENNAS & AMPLIFIERS UP TO 6GHZ

NANO DIMENSION CAN DO IT

Our capability to print UHF & SHF RF signal transmission line and antennas.
RF antennas & amplifier applications with up to 6GHz frequency.



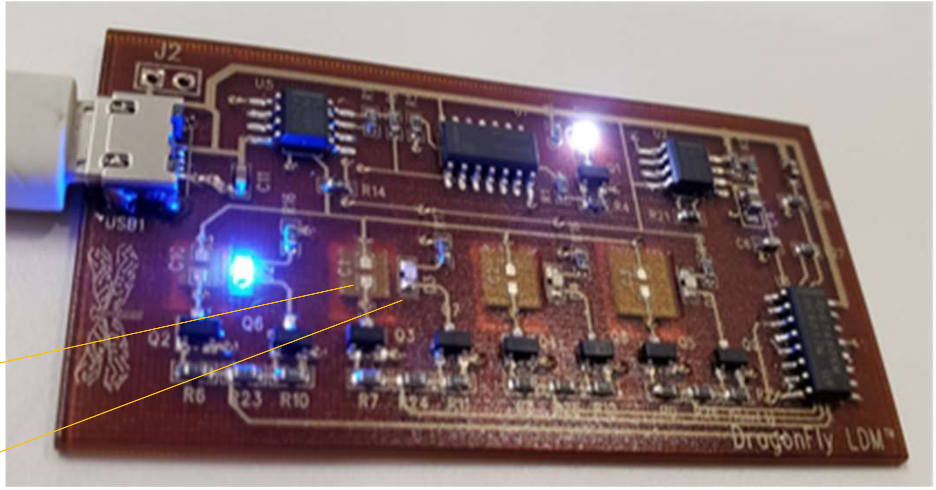


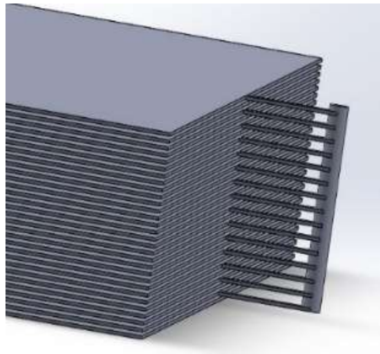


Transmitter to receiver (173000 samplings)	Regular to Regular	Regular to printed	Printed to Regular	Printed to printed
1m	88.9%	99.3%	90.2%	99.49%
10m	88%	99%	90.8%	99.41%
20m	90%	93.68%	89%	99.01%

EXAMPLE OF Hi-PEDs™: FUNCTIONAL CAPACITORS BY ADDITIVE MANUFACTURING

- Produced simultaneously during the additive manufacturing of PCBs
- Reduce the total size of the PCB
- Freeing surface area for mounting other PCB components



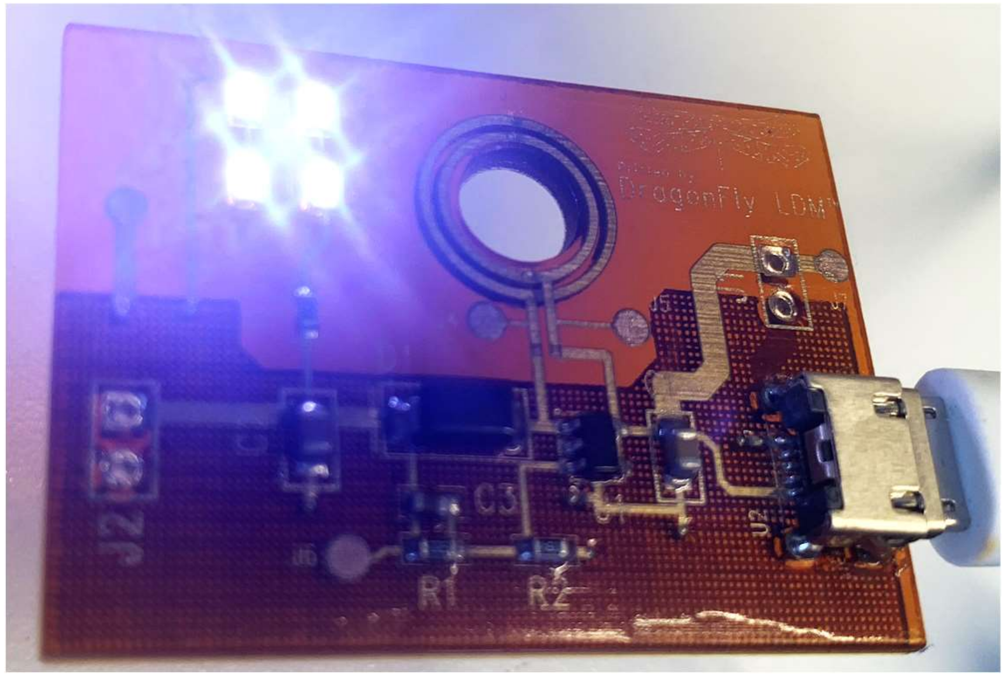


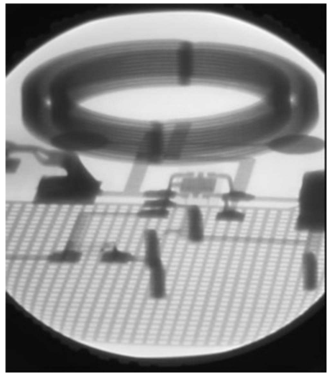
Design

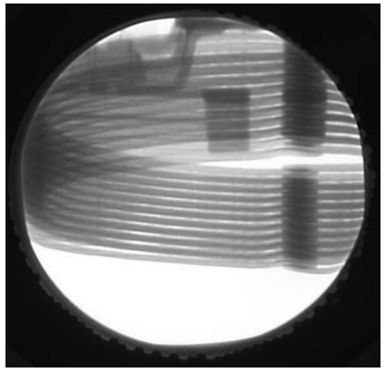
Actual

EXAMPLE OF Hi-PEDs™: IN PCB PLANAR DC-DC UP CONVERTER

- The most common DC-DC Up Converters are units mounted on a PCB
- By producing the device as an integrated part of the PCB, surface area usage, assembly time, and other overhead costs are reduced.

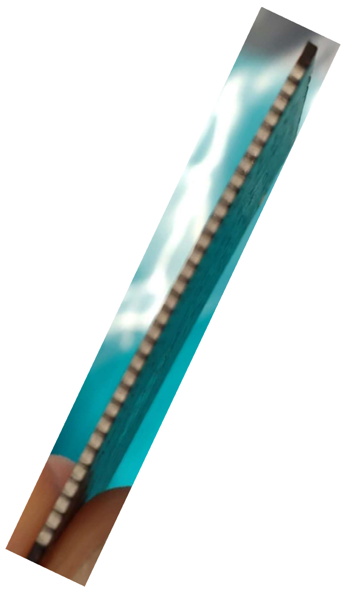


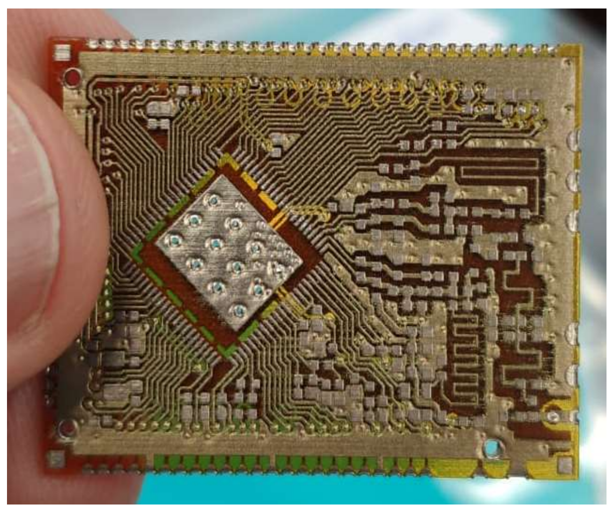


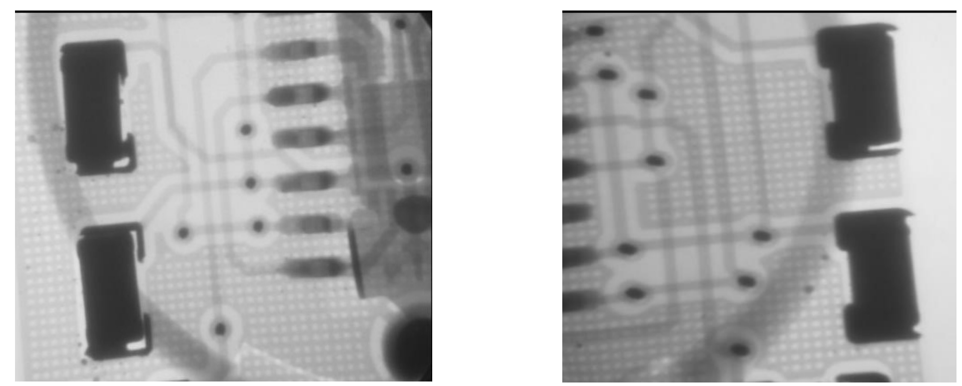


EXAMPLE OF Hi-PEDs™: SIDE MOUNT/CONTACT AND INSERTED COMPONENTS

- Enables the use of an area not common for PCB components
- Enables the creation of customized small PCBs that can be inserted into a socket







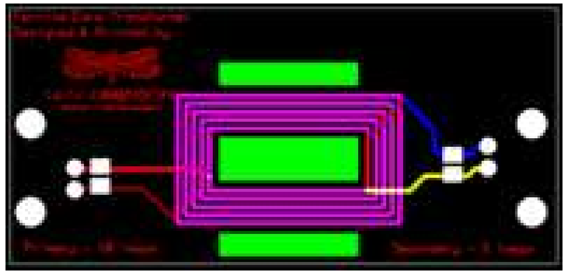
a) b)

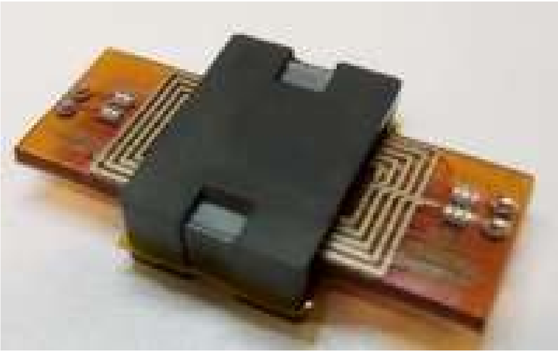
Figure 1 X-ray view of a) inserted, and b) side mounted components soldered to vertical contacts manufactured as part of the PCB additive manufacturing technology in the DragonFly LDM™

EXAMPLE OF Hi-PEDs™: BUILT IN POWER TRANSFORMERS

Custom Coil Designs

For Unique Applications

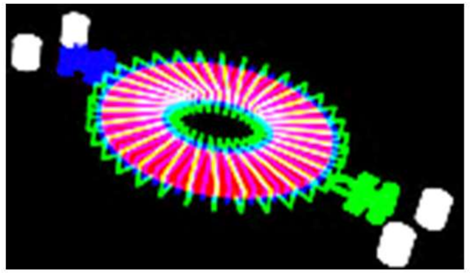


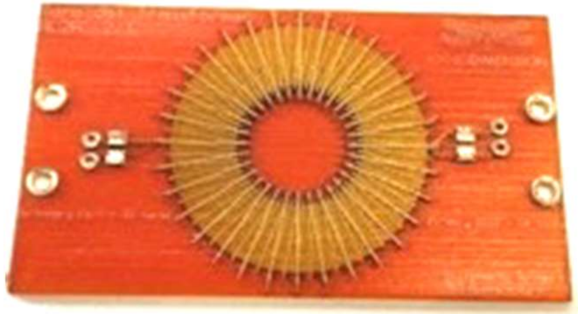


AC-AC

Transformer with

ferrite core





AC-AC Up

Converter (x10)

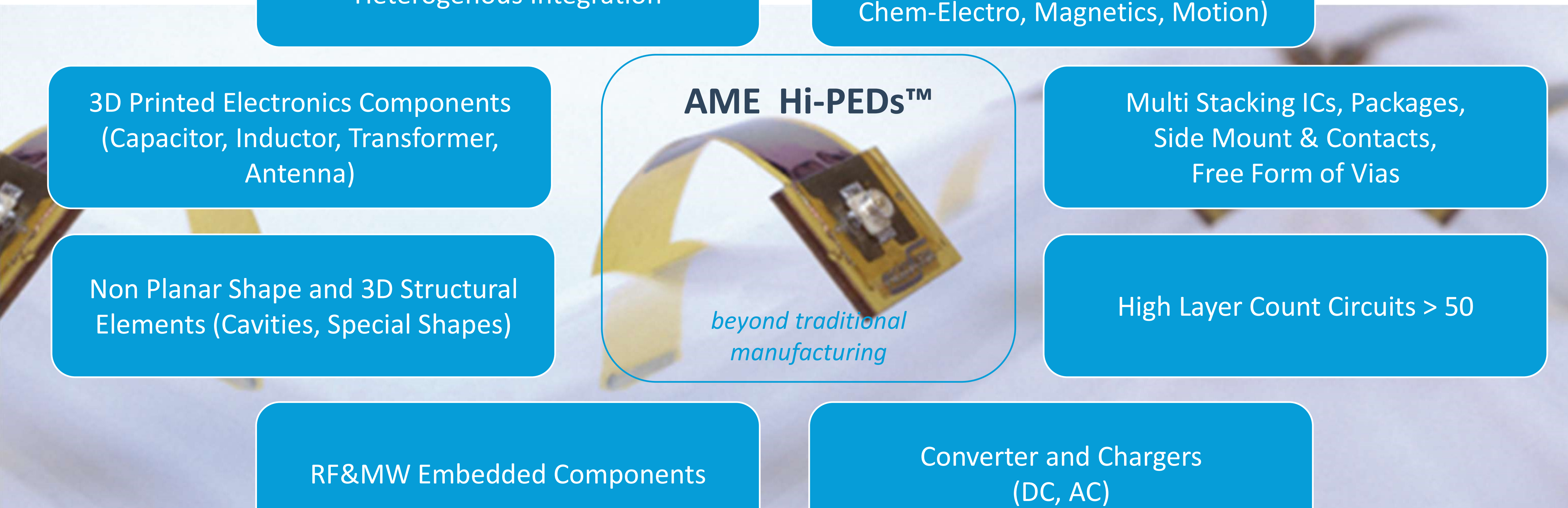
ADDITIVE MANUFACTURING OF 3D ELECTRONICS

Real 3D Embedded Electronics for Heterogenous Integration

Electronics integration (MEMS, Sensors, Transistors, ICs, Opto, Piezo, Chem-Electro, Magnetics, Motion)

3D Printed Electronics Components (Capacitor, Inductor, Transformer, Antenna)

AME Hi-PEDs™



beyond traditional manufacturing

Multi Stacking ICs, Packages, Side Mount & Contacts, Free Form of Vias

Non Planar Shape and 3D Structural Elements (Cavities, Special Shapes)

High Layer Count Circuits > 50

RF&MW Embedded Components

Converter and Chargers (DC, AC)

PRODUCE COMPLEX PCB AND Hi-PEDS™

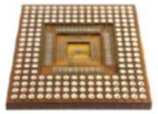
Hi-PEDs™

HIGH PERFORMANCE ELECTRONIC DEVICES

AME Circuit with Capacitors

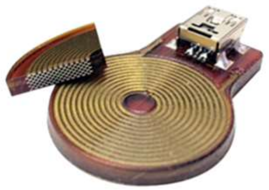
IOT Access Point

AME with Side Mounted Components



Vertically Stacked Integrated Circuits

Low Pass Filter



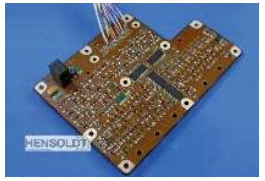
Coils & Inductors

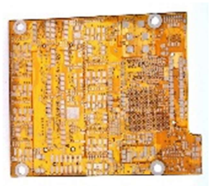
3D MID

RF Antenna

- Fast prototyping, hours vs weeks
- Tens of layers in a 3mm board
- Printed embedded components
- Expand 3D scales

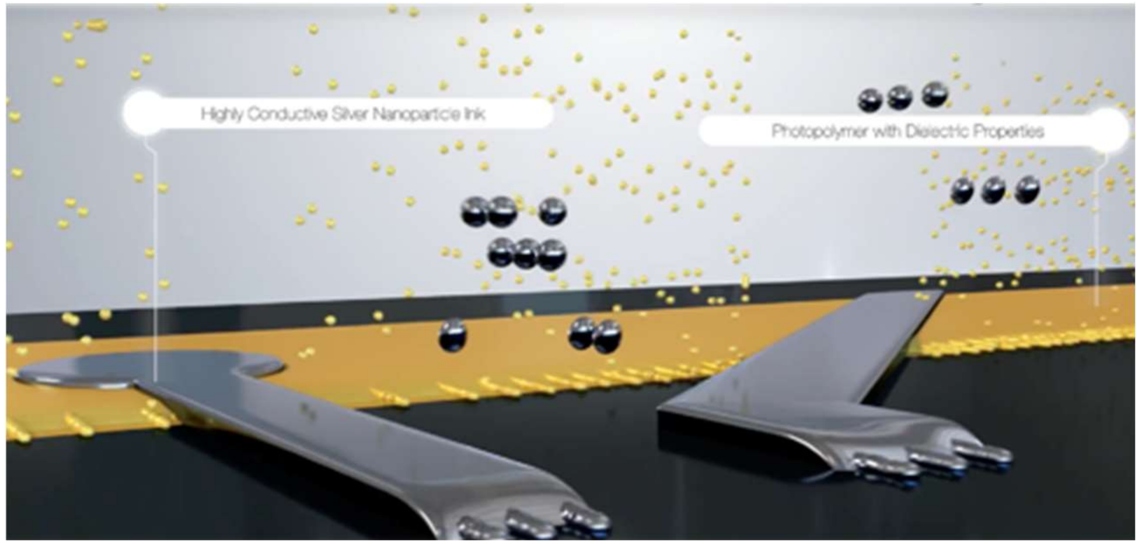
COMPLEX MULTILAYER PCB (50 LAYERS)





- Filled Vias: No need for drilling

HOW DOES IT WORK ?



Just one manufacturing step:
No need for etching,
pressing, electroplating!

TWO PRINTHEADS INKJET BOTH MATERIALS SIMULTANEOUSLY:

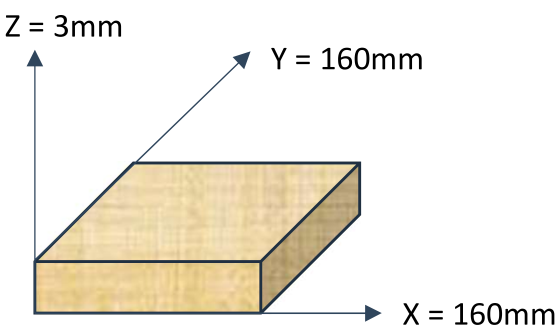
- Both conductor & insulator substrate are printed
- Both materials are activated in real – time on-the-fly
- 100% fully additive process!

THE OBJECT IS BUILT UP, LAYER BY LAYER, THROUGH FULL STACK THICKNESS:

- Conductive layers & Dielectric layers
- Drills and vias bottom up printed
- Soldermask & Annotation

AME Design Rules – May 2020

Dimensions



Layer Count

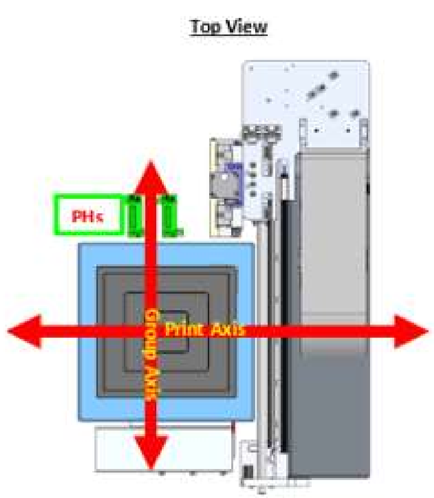
Stackup options related to 3mm total thickness:		
Signal layer thickness	17 um	57 layers
Signal layer thickness	35 um	42 layers
Signal layer thickness	70 um	21 layers

Overall AME thickness	0.7 – 3.0 mm, tolerance of less than ± 5%
Signal / plane layer thickness*	Min: 17 um, 6 um steps up to 101 um.
Prepreg between signal layers / signal to plane layer	Min: 25um ± 5% , 6um steps. Max: full job 3mm

Dielectric Properties

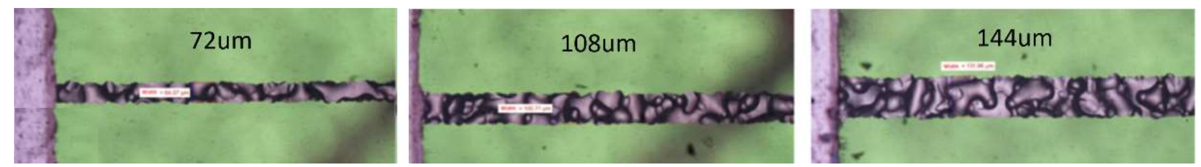
Through Hole (TH) diameter	Min 400 um ± 36 um
Plated TH diameter	Min 400 um ± 36 um Pad surrounding TH ≥ (TH diameter + 200 um)
VIA (filled) diameter	Min 200 micron ± 36 um Pad surrounding via ≥ (via diameter + 200 um) `
Minimum plating ring width	144 um

Dimensions



Trace and Space

Minimum recommended Trace width	110 (um)
Minimum recommended electrical clearance / space between traces/planes Electrical clearance)	110 (um)



	Trace width (um)	Direction	Trace Thickness (um)	% chance failure
Trace	72	Group	17,35,70	0.00%*
		Print	17,35,70	0.00%*
		Diagonal	35,70	0.00%*
			17	30.00%
	108	Group	17,35,70	0.00%
		Print	17,35,70	0.00%
		Diagonal	17,35,70	0.00%
	144	Group	17,35,70	0.00%
		Print	17,35,70	0.00%
		Diagonal	17,35,70	0.00%

*When rendering OK

72 um line width is equivalent to 2 pixels

Focus on Rendering Algorithm for Consistency and repeatability

NANO DIMENSION OFFERING

DRAGONFLY IV SYSTEM

- System
- Training and Support
- *Leasing Options*

NANOS – 3D FABRICATION SERVICE

- Co-creation / Design
- Prototyping and Low Volume Production

THANK YOU

For more information visit:
www.nano-di.com

UTS:ENGINEERING AND INFORMATION TECHNOLOGY

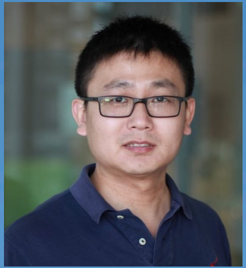
NANODIMENSION 3D PRINTED ELECTRONICS

UTS UNIVERSITY OF TECHNOLOGY, SYDNEY

3D PRINTED 5G ANTENNAS AND ADVANCED MICROWAVE DEVICES WITH AME TECHNOLOGY

– Development of Advanced AME Devices using the DragonFly LDM

Speaker: Dr. Yang Yang



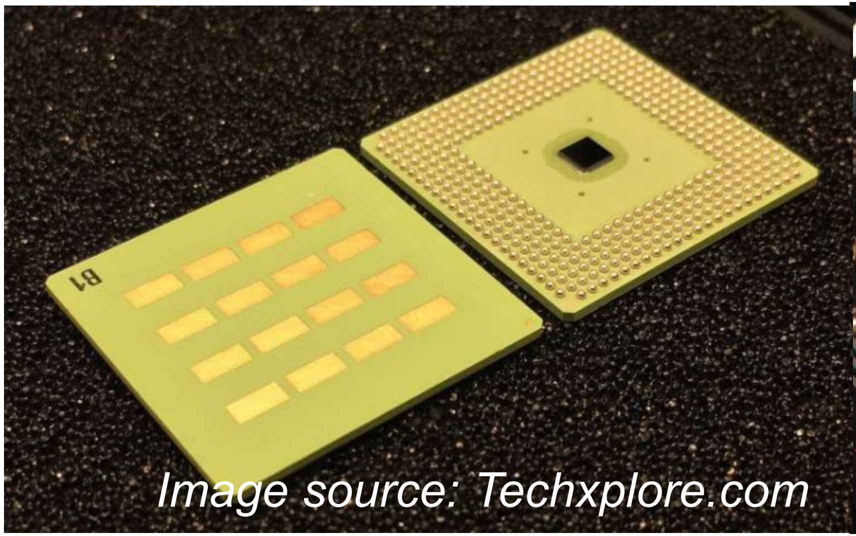
Team Leader of Millimetre-Wave Circuits and Antennas
School of Electrical and Data Engineering | Tech Lab
Faculty of Engineering and Information Technology | University of Technology Sydney

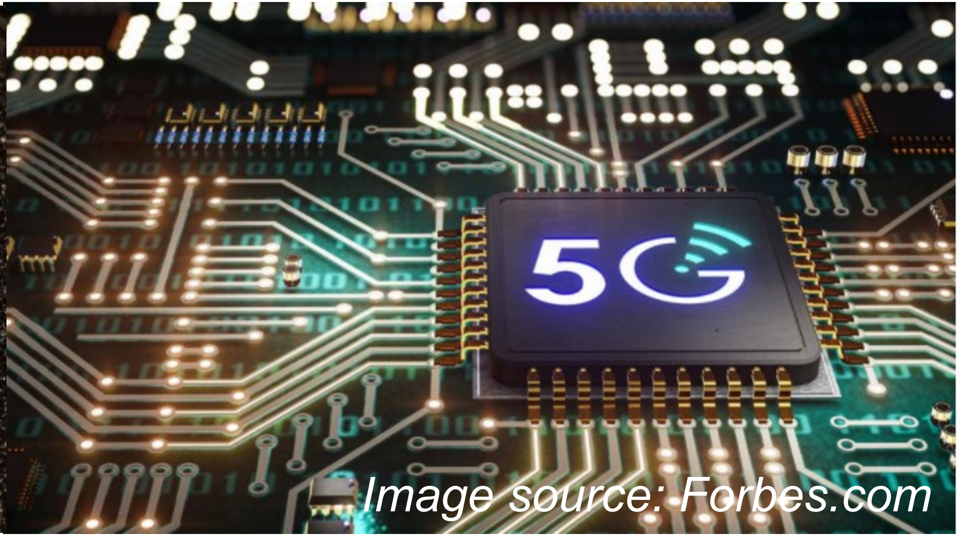
Innovation in practice
eng.uts.edu.au • it.uts.edu.au

CONTENTS

Vision and Mission

Vision and Mission -Future of High Speed RF Electronic Devices





High performance

Low cost

Multifunctional

Compact

Low power

Application driven

Vision and Mission - Key Technologies in 5G and Beyond

Multidisciplinary Research

1) **Materials/Process**

a. Rogers b. Silicon c. III/V d. PLA/ABS/PDMS … and AMEs Fabricated with the DragonFly LDM

2) **Fabrication**

a. PCB b. Semiconductor c. Packaging d. Additive Manufacturing…

3) **Radio Frequency Technologies**

a. Microwave/mm-wave b. Wireless propagation c. Photonics d. Integrated circuits e. Signal processing…

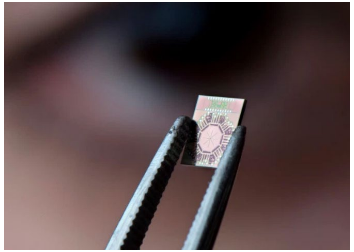
4) **Electronic components**

a. Antennas b. Packaged RF electronics c. Amplifiers d. Filters e. VCO f. Mixers g. Switches …

Vision and Mission - Opportunities in RF Electronics

Microwave and millimeter-wave (mm-wave) applications

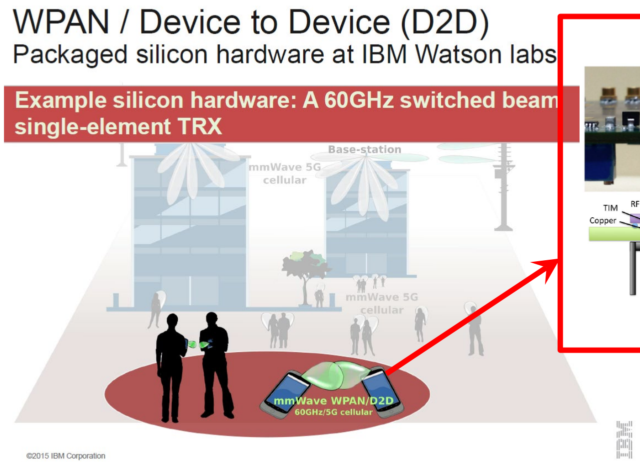
1) 5G system Frontend – microwave/mm-wave
2) Anti-collision Devices/Sensors – mm-wave
3) Security – mm-wave scanner
4) Space Remote Sensing - mm-wave/THz
5) Terrestrial and Satellite Communications – microwave/mm-wave

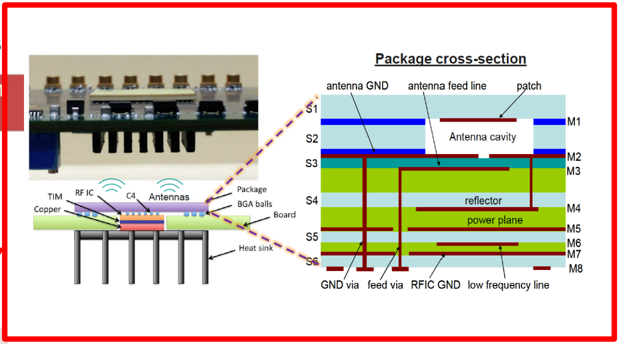


State-of-The-Art Antenna-In-Package

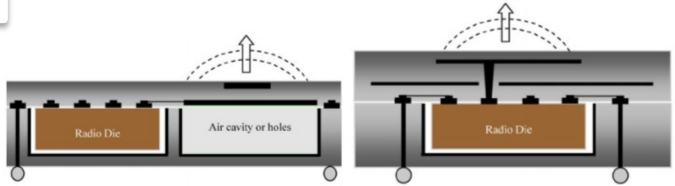
State-of-The-Art Antenna-in-Package

5G and beyond [1]

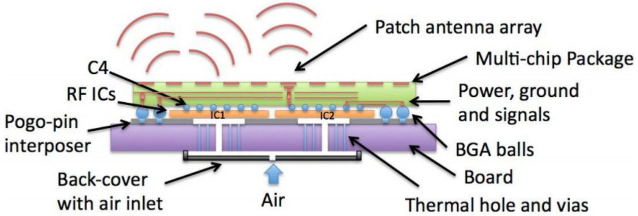




Mm-wave LTCC AiP 2009 [2]



Mm-wave phased array 2015 [3]



AiP – LTCC, glass, organic polymer, BGA

[1] B. Sadhu, "Enabling 5G: mmWave silicon integration and packaging," IBM Research, T. J. Watson Research Center, 5G Summit, 2015.

[2] Y. Zhang and D. Liu, "Antenna-on-Chip and Antenna-in-Package Solutions to Highly Integrated Millimeter-Wave Devices for Wireless Communications", IEEE Transactions on Antennas and Propagation 57(10) DOI: 10.1109/TAP.2009.2029295.

[3] X. Gu, et al., "W-band Scalable Phased Arrays for Imaging and Communications", IEEE Communication Magazine, April 2015

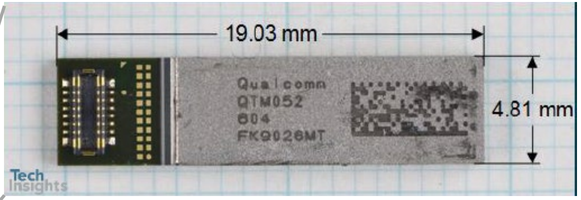
State-of-The-Art Antenna-in-Package

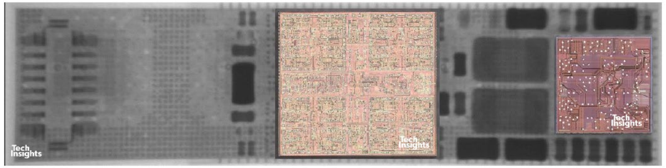
Qualcomm QTM052 RF mm-wave antenna Module

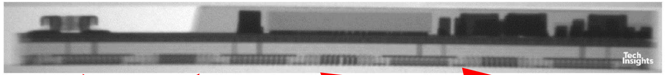
- World's first-announced fully-integrated mm-wave RF solution

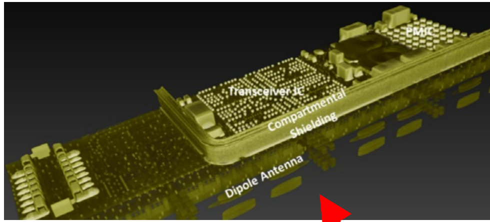
QTM052 – on MD1005G PCB
(Motorola Moto 5G)

Source: TechInsights.com









Source: google image

Antenna array

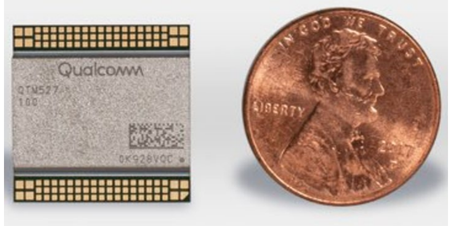
Antenna array integrated into the PCB (Bottom layer)

State-of-The-Art Antenna-in-Package

Other Qualcomm Antenna Modules

QTM525 Ant Module

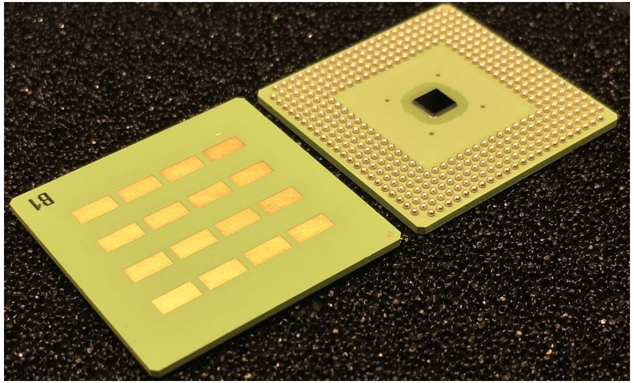
QTM527 Ant Module

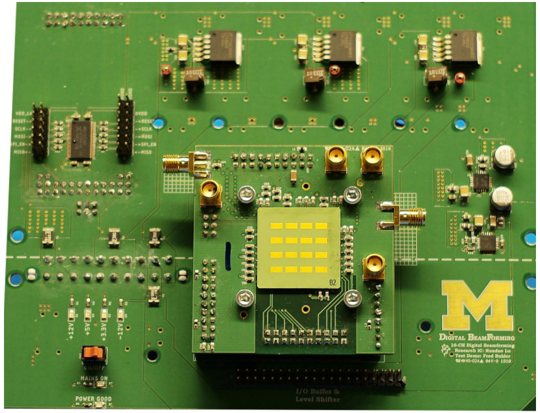


Source: google image

28GHz – 39 GHz bands

First digital single-chip millimeter-wave beamformer





16-antenna beamformer array in package

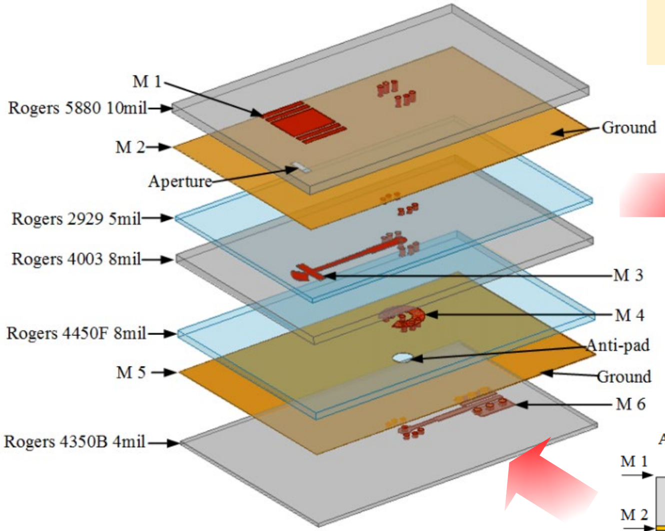
By University of Michigan

Source: News- University of Michigan
Released on **13 Nov. 2020**

Why AME ?

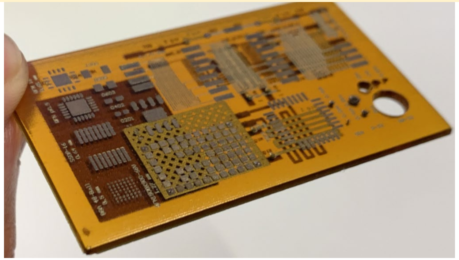
Advantages:

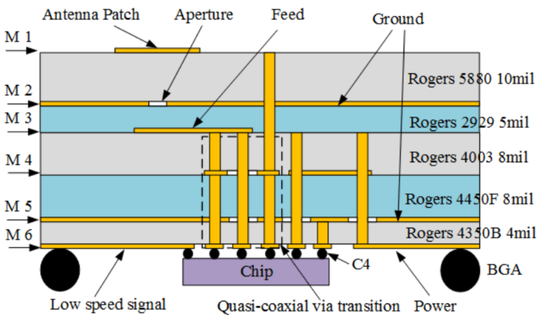
- Fast prototyping (in-house)
- 24/7 production
- Short run manufacturing
- Low entry cost (Excellent for prototyping)
- Customized designs / design flexibility
- Advanced design freedom - Conformal shapes and flexible layout
- Single substrate with multiple metal layers
- Risk-free confidentiality / Protected IPs
- Ideal for packaging by seamlessly combing PCB and chips



Traditional multi-layer antenna by stacking up PCBs

Additively manufactured multi-layer antennas in single substrate with design flexibility





T. Zhang, et.al, "Low-cost aperture-coupled 60-GHz-phased array antenna package with compact matching network," IEEE Transactions on Antennas and Propagation, vol. 65, no. 12, Dec. 2017.

Material RF Performance

Materials - Electrical Characteristics from 200 MHz - 20 GHz

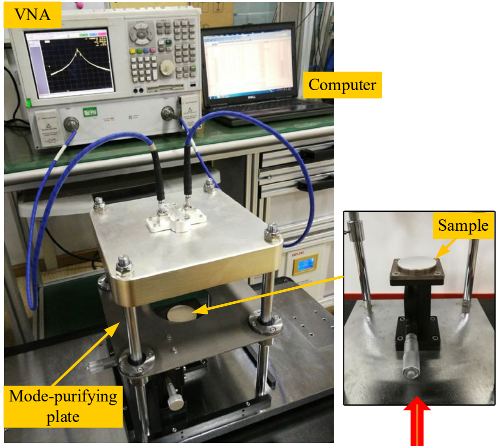
Conductivity (silver nano particles)*	$3.15 \times 10^6 - 2.52 \times 10^7$ [σ (S/m) at 20 °C] Printing and sintering conditions dependent***							
Dielectric Constant (Dk) (1092 ink)* Acrylate based polymer	200MHz	500MHz	1GHz	2GHz	5GHz	10GHz	15GHz	20GHz
	2.80	2.81	2.81	2.80	2.78	2.76	2.75	2.78
Tangential loss (Df) (1092 ink)* Acrylate based polymer	200MHz	500MHz	1GHz	2GHz	5GHz	10GHz	15GHz	20GHz
	0.000	0.004	0.006	0.011	0.012	0.013	0.013	0.012
Dielectric breakdown voltage (thickness 0.6 mm)	40.3KV, tested based on IPC-TM-650 2.5.6							

* Due to the nature of the additive manufacturing process, variation on the conductivity is a result of the position of the ground vs signal planes and proximity to the printing chuck. By Q3 2020, the company will release a software feature that minimizes this variation.

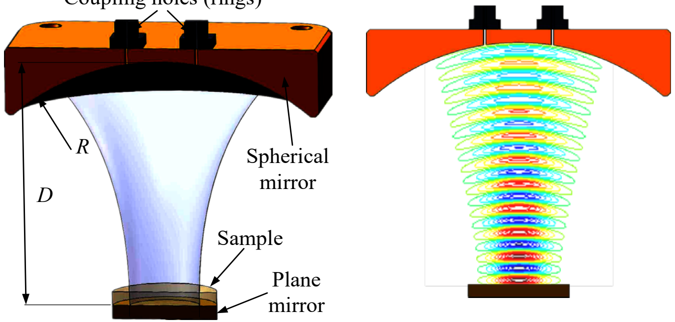
** These numbers are measurement technique dependent. They are provided as a reference to start the AME design. For an optimum number it is recommended that customers requiring precise Dk and Df numbers, perform measurements with the equipment they use inhouse.

*** Bulk silver conductivity = 6.30×107 σ (S/m) at 20 °C.

Materials - Testing System from 20 MHz - 40 GHz

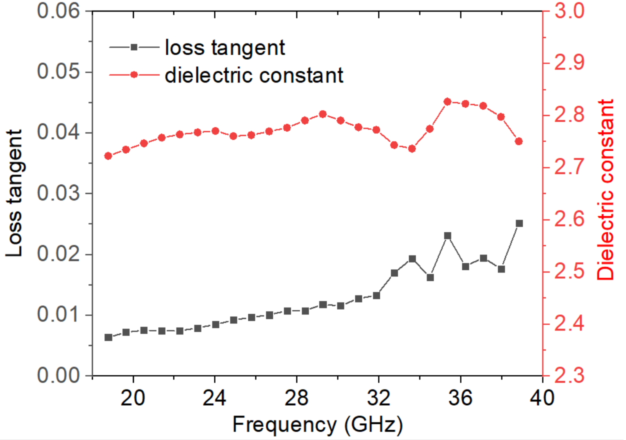


quasi-optical cavity test system.



(a) (b)

The applied semi-symmetric quasi-optical cavity measurement setup: (a) Schematic diagram, and (b) Fundamental mode field distribution.

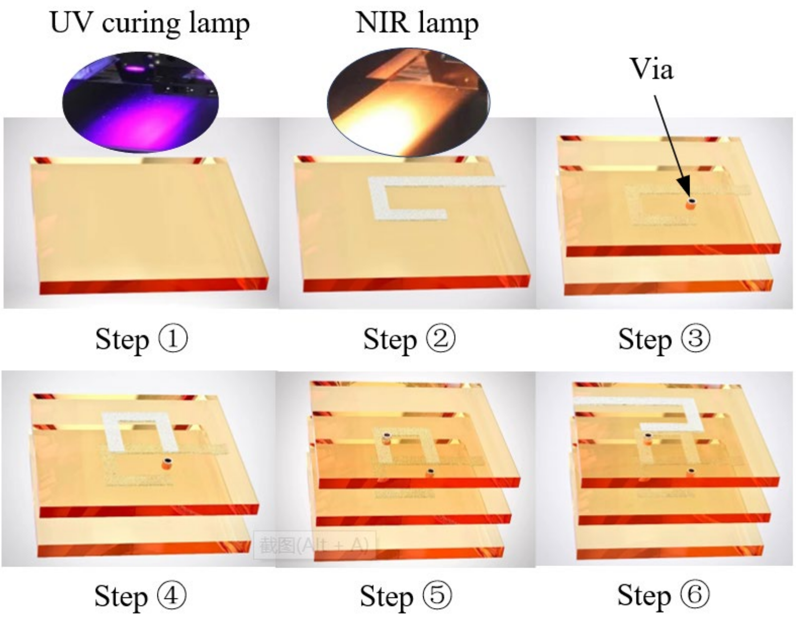


Acrylates dielectric constant and loss tangent response.

Dielectric materials can be characterized by DAK-TL3.5-P from 200 MHz to 20 GHz (with a sample size of 30 mm). To characterize the material performance above 20 GHz, quasi-optical cavity approach is adopted. samples of acrylates are characterized by cavity resonant method with the highest possible accuracy.

M. Li, Y. Yang, F. Iacopi, S. Ram, J. Nulman, “A Fully Integrated Conductive and Dielectric Additive Manufacturing Technology for Microwave Circuits and Antennas”, 5th European Microwave Conference, Jaarbeurs Utrecht, Jan. 2021.

Process and Manufacturing Technology – Taking a inductor for example

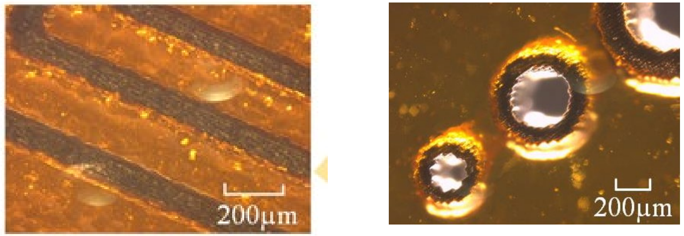


The proposed low-temperature additively manufacturing electronics (AME) process

In Step 1, an ultraviolet (UV) lamp curing the acrylate inks after they are printed out from the nozzles.

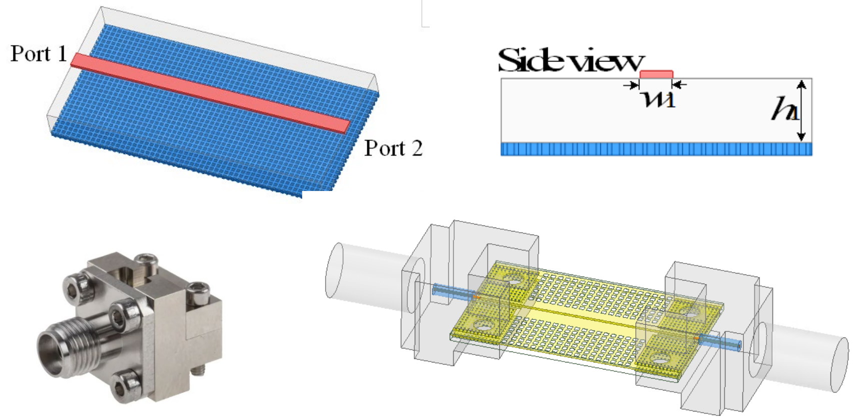
In Step 2, a metal strip line is printed on the acrylate layer. A near infrared radiation (NIR) lamp is used to sinter the conductive inks.

In Steps 3 – 6, acrylate and conductive inks are printed layer by layer to construct the 3D spiral inductor. Vias can be printed simultaneously in the acrylate layer to connect metal strip lines in different layers, as depicted in Step 3.



Photograph of printed traces and through holes

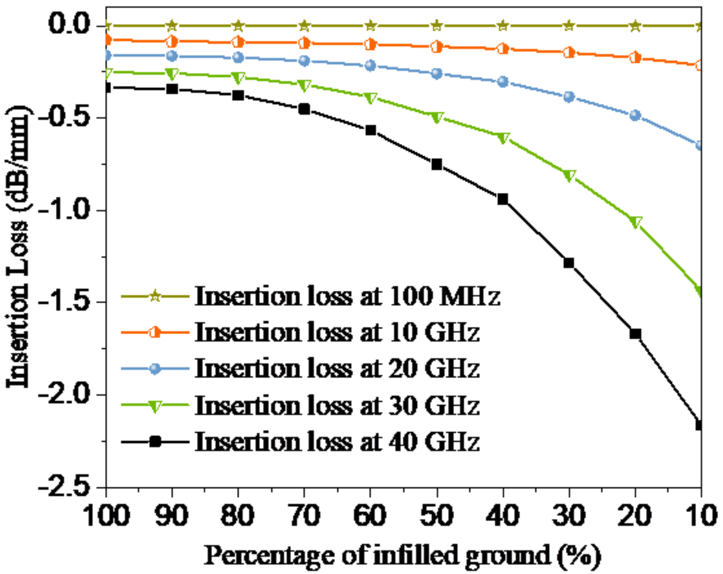
Applications in Microwave – Transmission Line



SMK connectors

New model under optimization with SMK connectors (better for measurement)

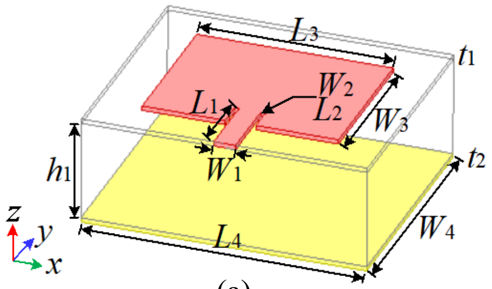
(a)



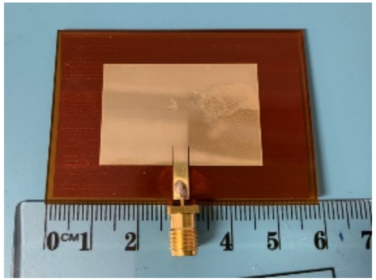
(b)

(a) Construction of infilled-ground transmission line. (b) Simulated insertion loss varied percentage of infilled-ground at different frequency.

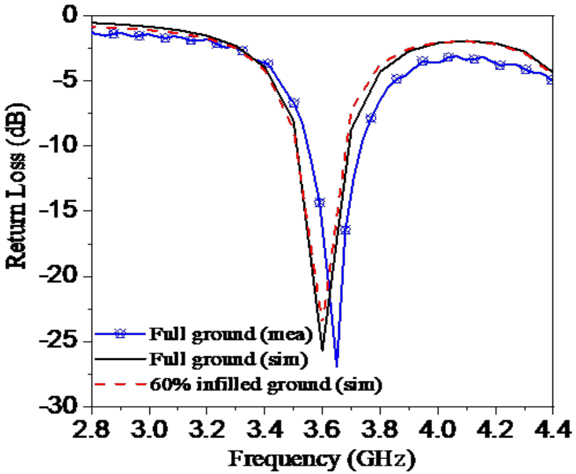
Applications in Microwave – Patch Antenna



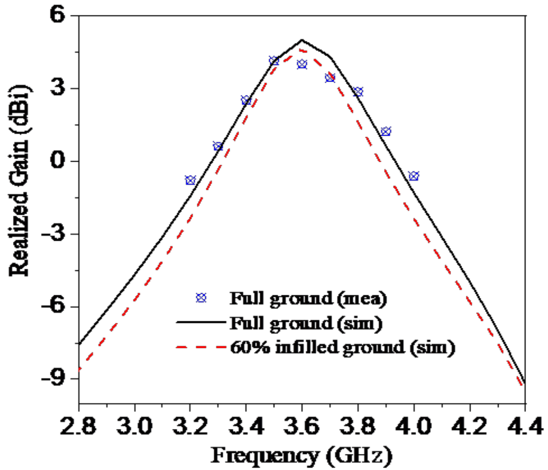
(a)



(b)



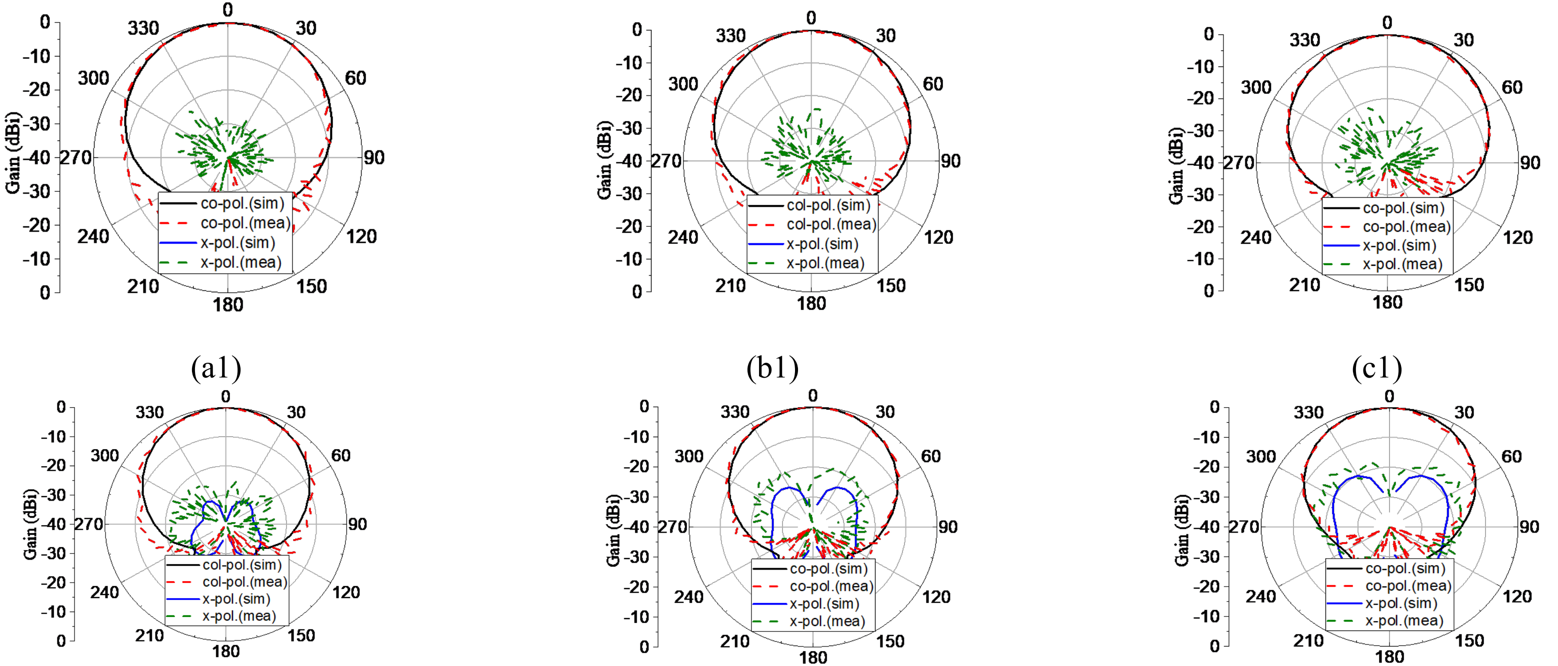
(c)



(d)

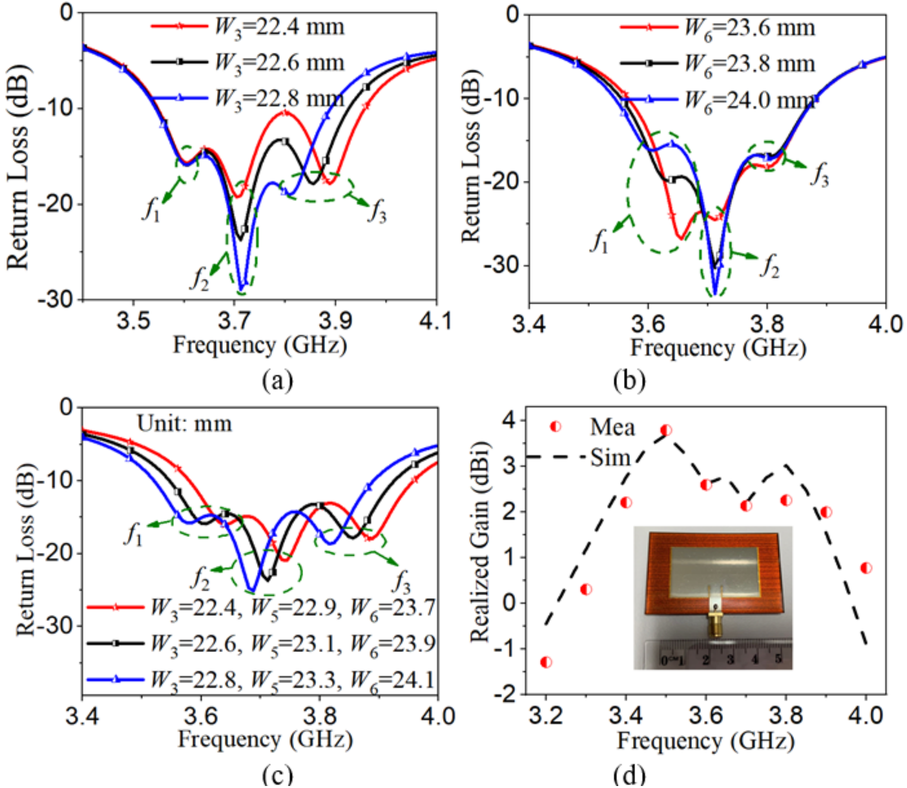
Antenna prototype: (a) Design model in HFSS, (b) Photograph of full ground patch antenna, (c) Simulated and measured return loss, and (d) Simulated and measured realized gain (including a simulated 60% infilled ground patch antenna). Dimensions: t_1=t_2=0.02, h_1=1.46, L_1=11, L_2=4, L_3=37, L_4=57, W_1=3.3, W_2=0.3, W_3=22.9, W_4=36.9, (unit: mm).

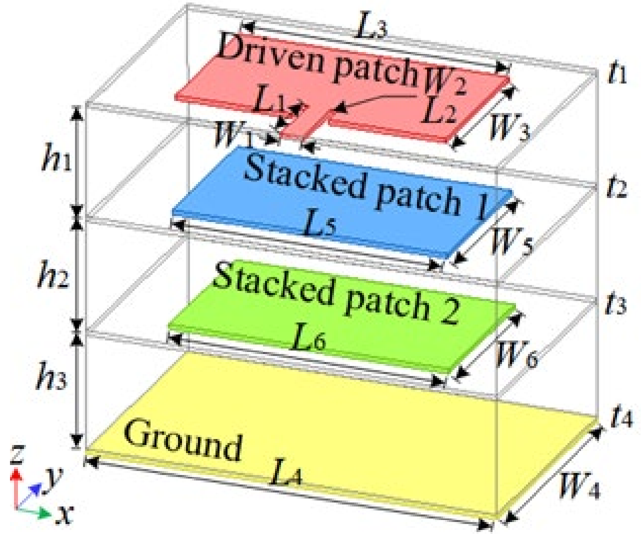
Applications in Microwave – Patch Antenna



Radiation patterns of the prototyped full-gound patch antenna. (a1) *YOZ*-plane at 3.5GHz, (a2) *XOZ*-plane at 3.5GHz, (b1) *YOZ*-plane at 3.6GHz, (b2) *XOZ*-plane at 3.6GHz, (c1) *YOZ*-plane at 3.7GHz, (c2) *XOZ*-plane at 3.7GHz

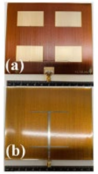
SUMMARY OF KEY RESULTS - DESIGN EXAMPLE 2

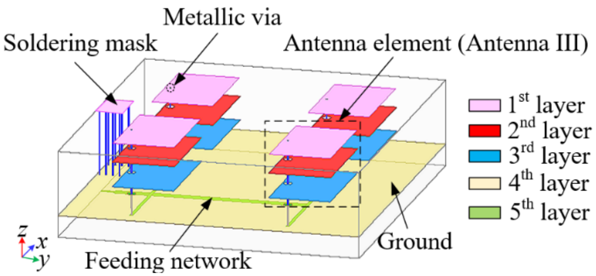


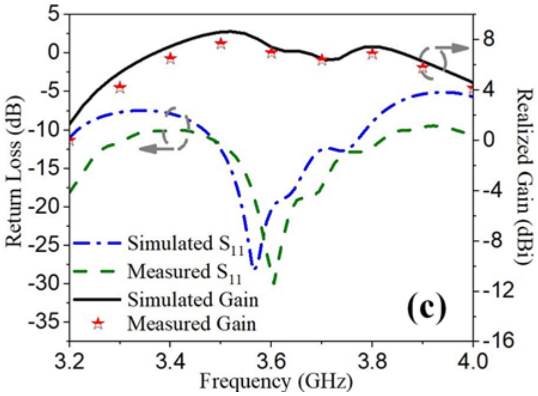


Adjustable modes can be introduced by adding staked patches of multi-metal layer antennas to obtain wider operational band with compact size.

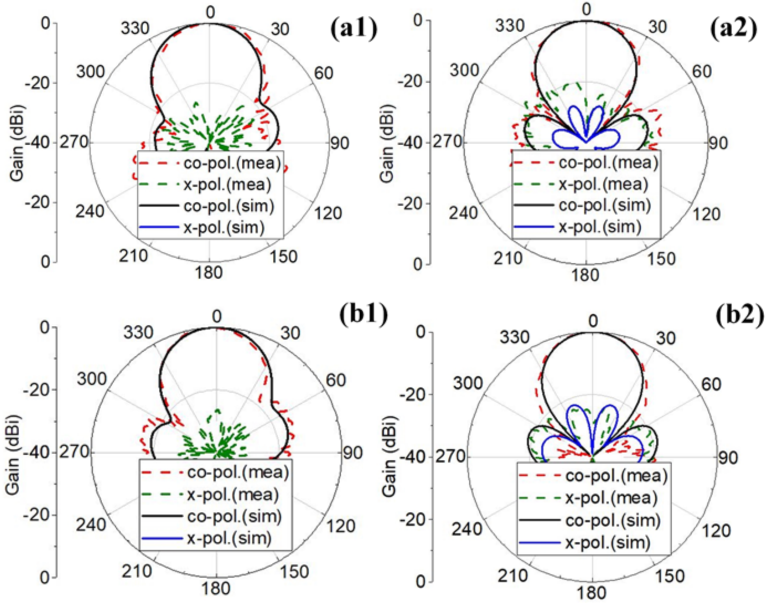
Applications in Microwave – Patch Antenna Array (Linearly Polarized)





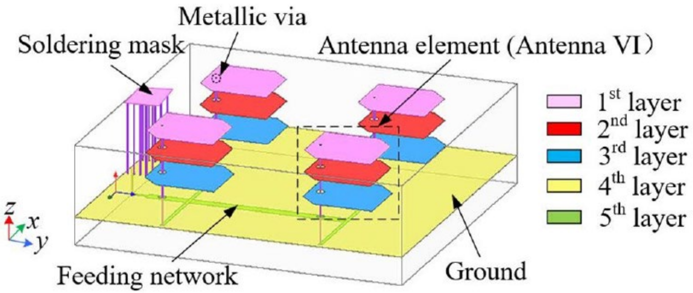


- Centre Frequency – 3.6 GHz
- Measured peak gain – 7.7 dBi
- Three-mode

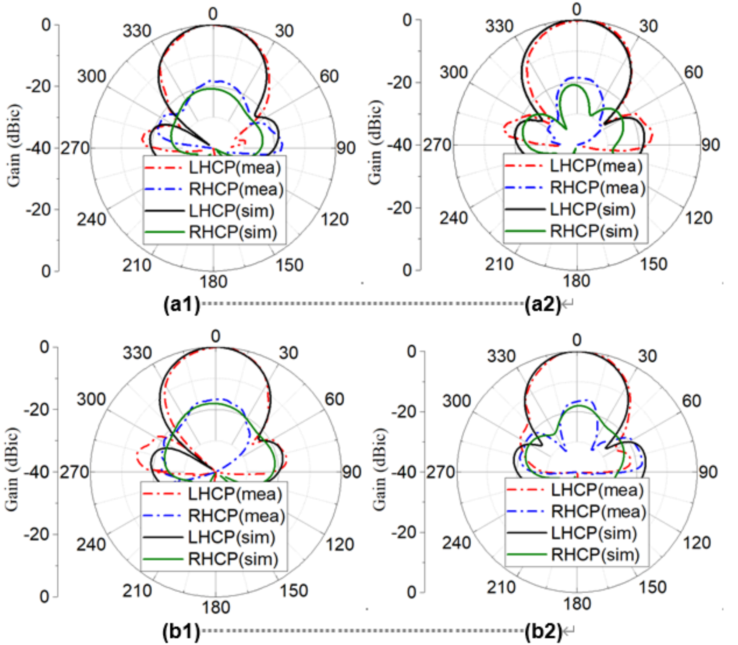


Radiation patterns of LP multilayer antenna array. (a1) *YOZ*-plane at 3.5 GHz, (a2) *XOZ*-plane at 3.5 GHz, (b1) *YOZ*-plane at 3.6 GHz, (b2) *XOZ* -plane at 3.6 GHz.

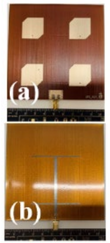
Applications in Microwave – Patch Antenna Array (Circularly Polarized)

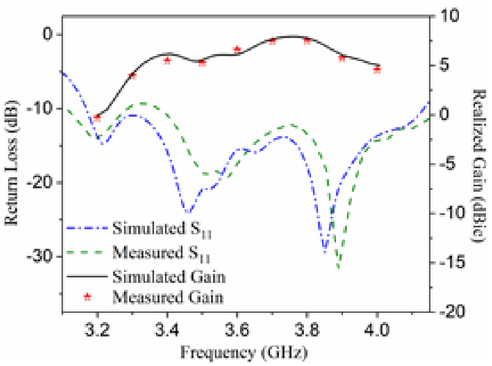


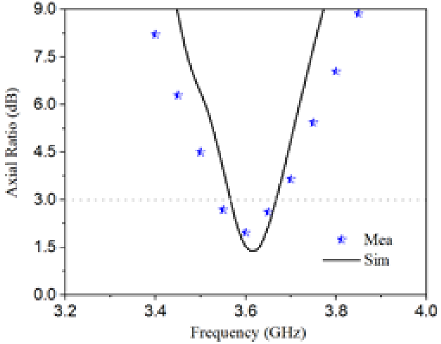
- Centre Frequency – 3.6 GHz
- Measured peak gain – 7.6 dBic
- AR Bandwidth – 3.54 to 3.68 GHz
- Multi-mode

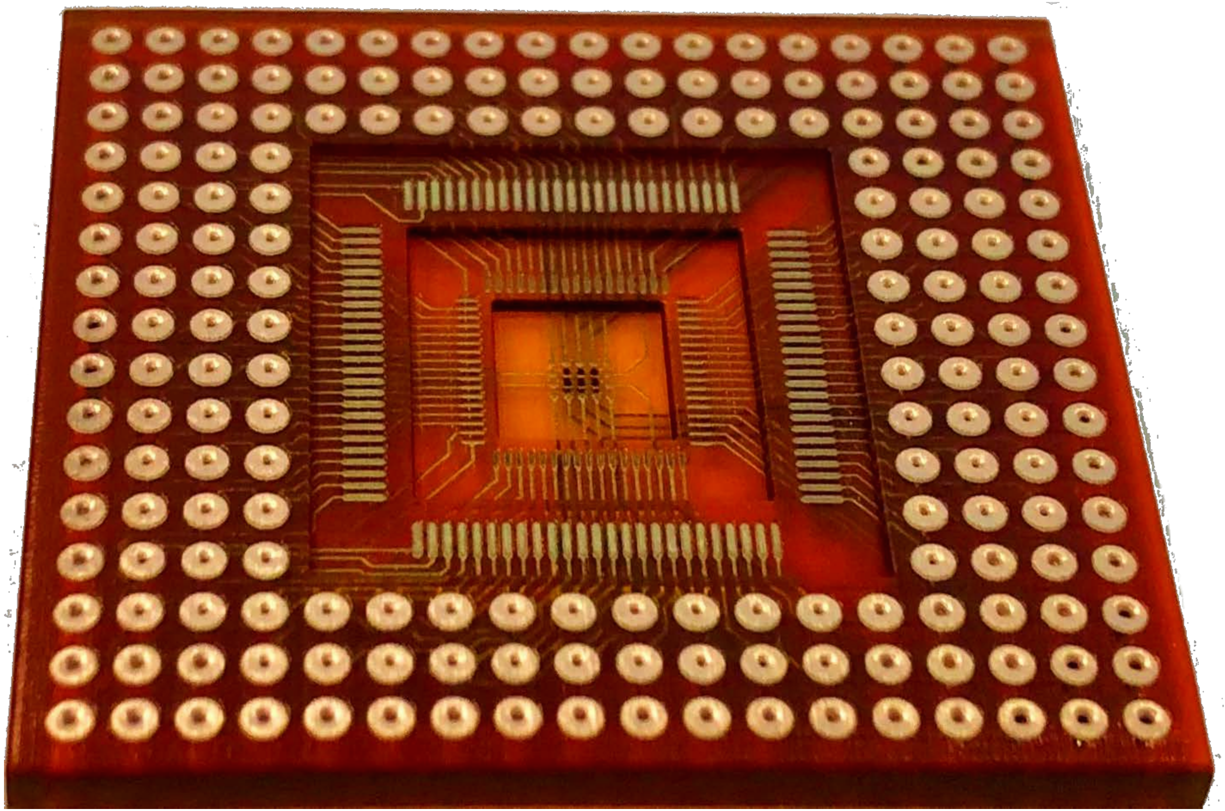


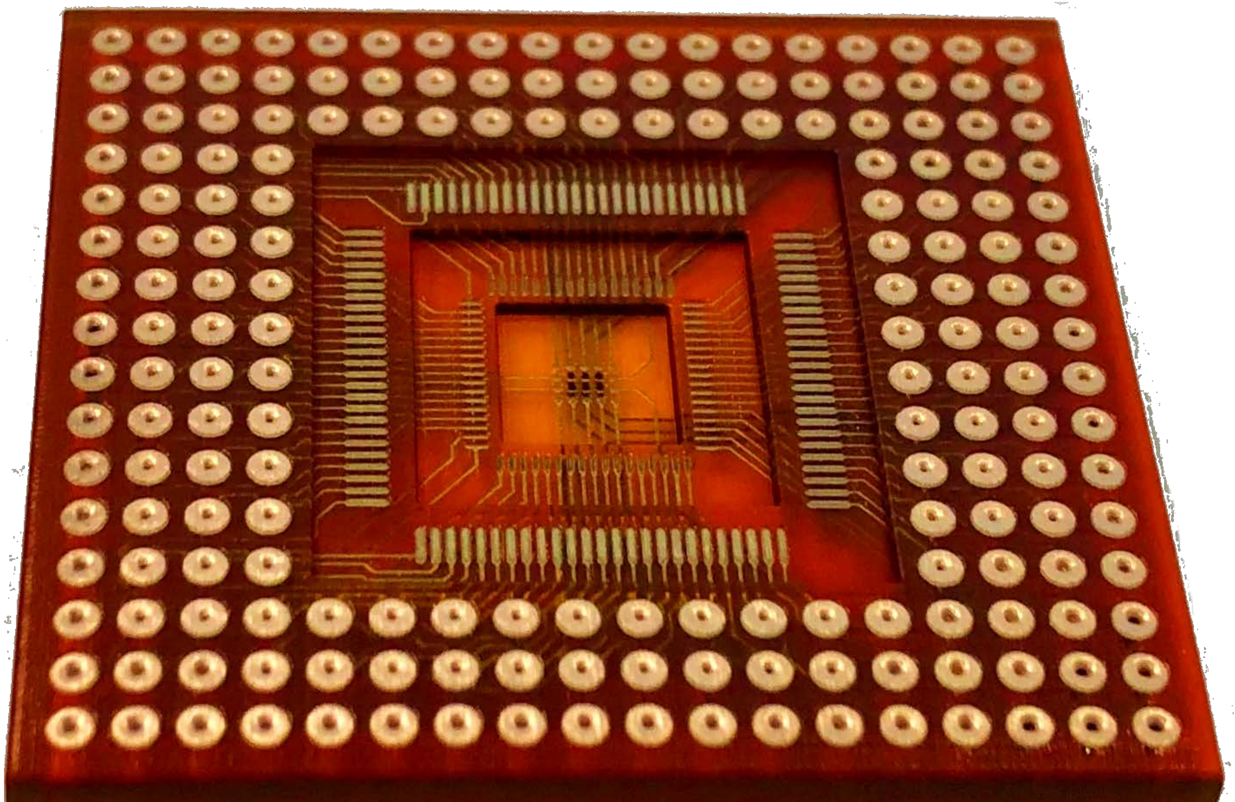
Radiation patterns of CP multilayer antenna array. (a1) *YOZ*-plane at 3.6 GHz, (a2) *XOZ*-plane at 3.6 GHz, (b1) *YOZ*-plane at 3.65 GHz, (b2) *XOZ* -plane at 3.65 GHz



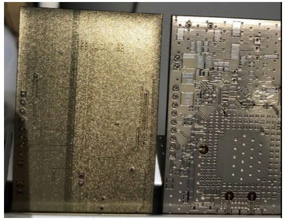


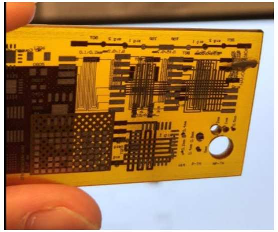






Fabrication site - Team at UTS



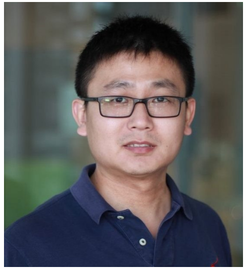


Conclusion

- A novel conductor and dielectric one-stop additively manufactured electronics (AME) solution is introduced
- An infilled-ground transmission line and patch antenna are designed and fabricated for proof-of-concept.
- Multilayer LP and CP antenna arrays for 5G sub-6GHz.
- Ultra-compact bandpass filter with good out-of-band suppression.
- Metasurface antennas at mm-wave bands for 5G and beyond.
- Above applications suggest the possibility of applying this low-cost and flexible-designing technology bridging the gap between PCB and semiconductor chips

Team Acknowledgement

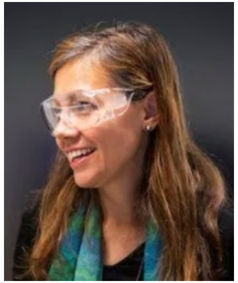
Dr. Yang



Miss Li

Dr. Nulman

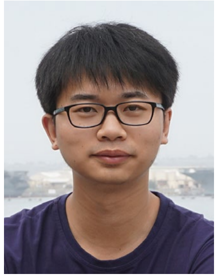
Dr Yang Yang – University of Technology Sydney（Australia）
Mengze Li – University of Technology Sydney（Australia）
Dr Jaim Nulman (CTO – Nano Dimension， US/Israel/HK)
Prof. Francesca Iacopi (UTS – Nanofabrication， Australia)
Mr Gilad Reshef (VP – Nano Dimension， HK)
Mr Harry Lam (Service Engineer – Nano Dimension， HK)
Mr Minoru Yamada (Application Engineer – Nano Dimension， HK)
Mr Daniel Sokol (Application Engineer – Nano Dimension， Israel)
Mr Nir Sade (VP of Product – Nano Dimension， Israel)
Mr Jon O’Neil (Ground Manager – UTS ProtoSpace， Australia)
Mr Daniel La Mela (Machine Operator – UTS ProtoSpace， Australia)
Dr Yunpeng Zhang – UESTC （China）
Tracy Tsang (Nano Dimension， HK)



Prof. Francesca

Mr Sade

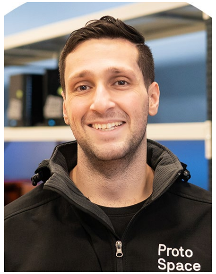
Mr Sokol



Dr Zhang

Mr Reshef

Mr O’Neil



Mr Mela


THANK YOU!