METAMAGNETICS

Small, Low-mass Radar Components for Wideband Passive Radar Reflectivity Measurements

NASA ACT Program Managers

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Grant # NNX15AB39G, 80NSSC18K0118

June, 2018

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ESTF2018
Earth Science Technology Forum 2018

Circulator Agenda

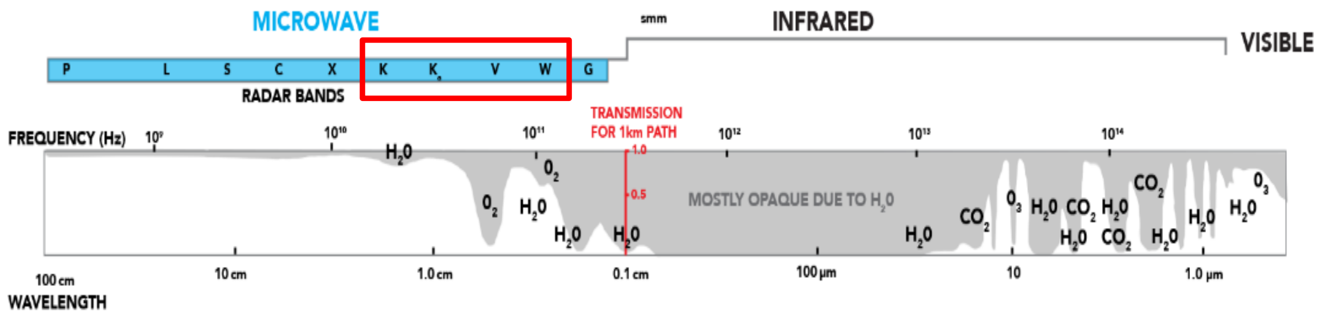
- Earth Science Context
- Circulator Applications
- Circulator Improvements
- Ongoing Circulator Development

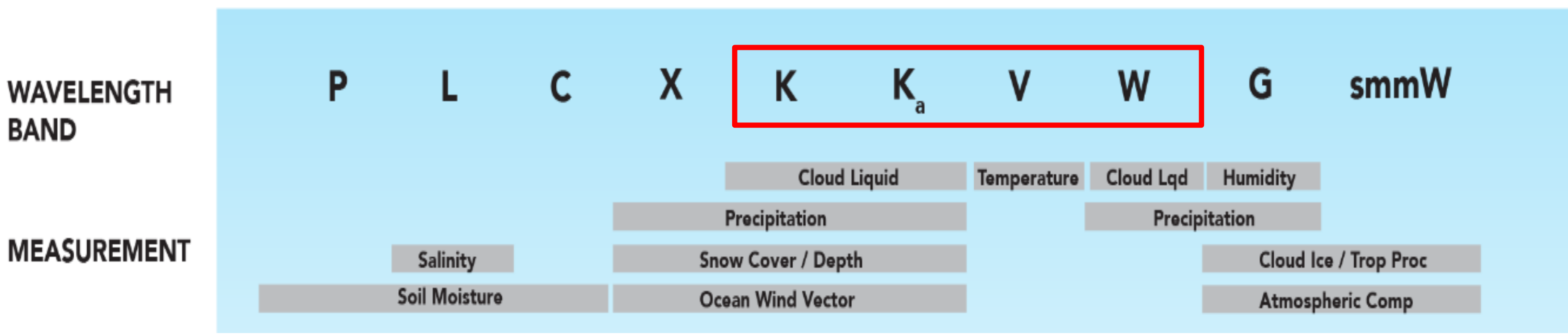
2017-2027 Decadal Survey for Earth science and Applications from Space (ESAS 2017)

Clouds, Convection, and Precipitation:

- Radars with multi-frequency passive microwave Radiometers
- *Designated* priority observing system for coupled cloud-precipitation state and dynamics for monitoring global hydrological cycle and understanding contributing processes including cloud feedback
- Radar reflectivity measurements at multiple frequencies provide a means to derive mean particle diameter, along with estimates of terminal fall speed and density

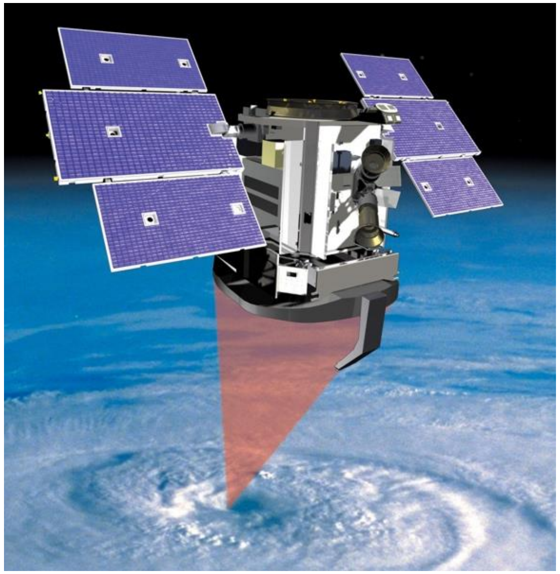
Radar Frequency Response & Earth Science Goals





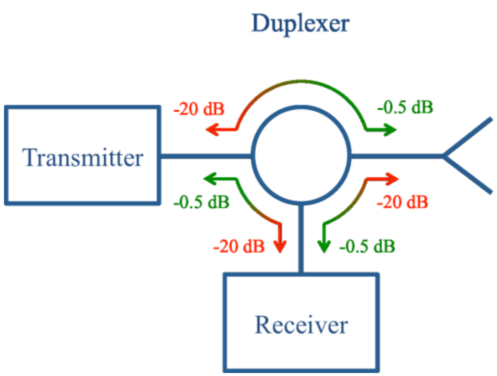
RADAR Observations of Clouds, Convection, and Precipitation

- Observation of ice masses
- Particle fall velocities
- Vertical air motions
- Surface precipitation rates
- Precipitation efficiency
- Convective mass fluxes
- Sedimentation rates
- Assess low and high cloud feedback
- Assist with seasonal/interannual climate variability and its prediction
- Observe processes at core of severe/extreme weather

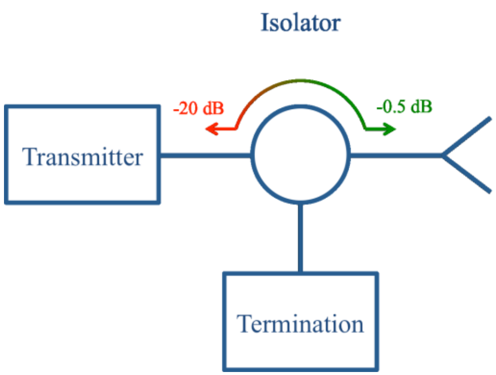


CloudSat uses W-band radar to investigate cloud cover

Circulators in Radars & Communications Systems



Circulator configured as duplexer to allow Tx and Rx through a shared aperture, enabling Simultaneous Transmission and Reception (STAR)



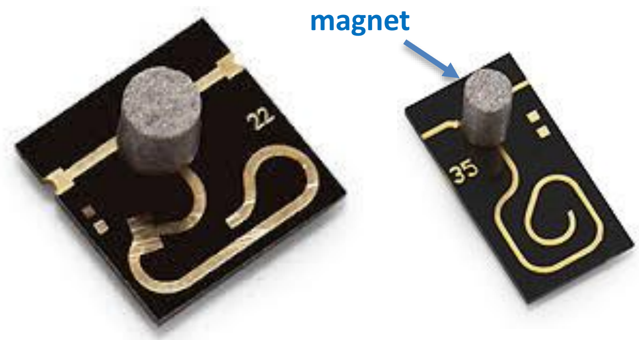
Circulator configured as isolator to isolate Tx from load impedance variation

Radar System Challenges

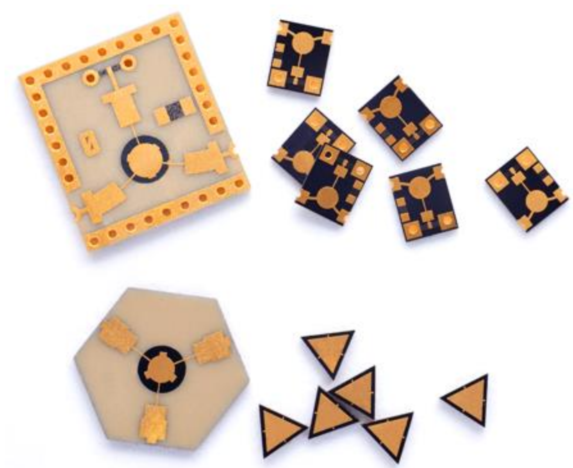
Available Circulators for Radar are Large/Massive due to External Magnets

- Circulators are passive control components that are made using ferrite materials
- Traditional circulators are biased with large magnets
- For phased array antennas operating at high frequencies, small circulators are needed, but historically have not been available

Ferrite circulator under bias magnet

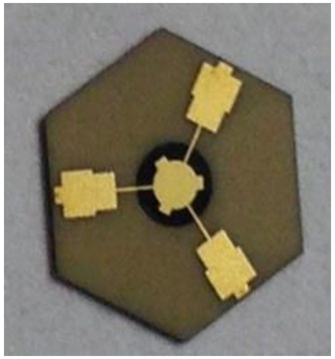


COTS microstrip isolators at K_U-and K_A-bands



K_A-band Self-Biased Isolators & Circulators

Metamagnetics Small, Low-Mass, Self-Biased Circulators for Multiple Radar Frequencies



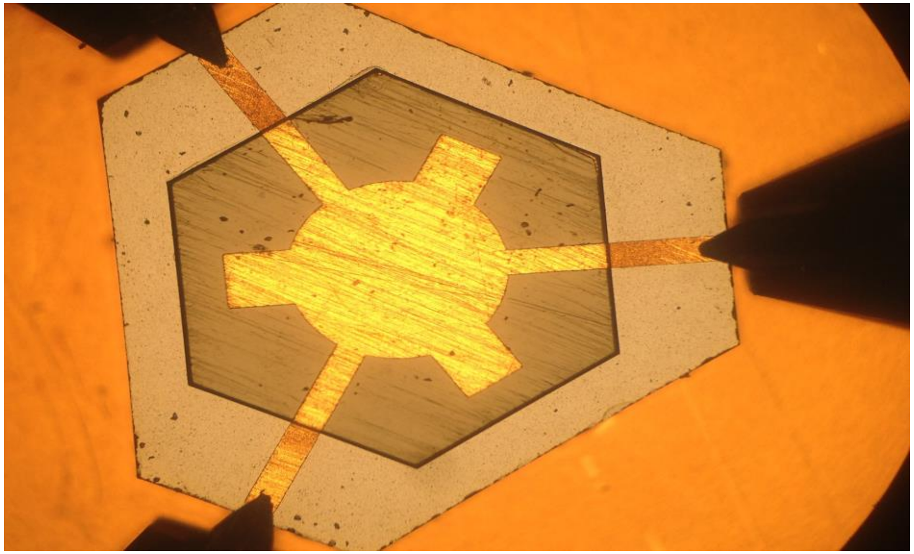
Typical circulator (**L**) has large permanent magnet, self-biasing circulator has no external magnet (**R**)

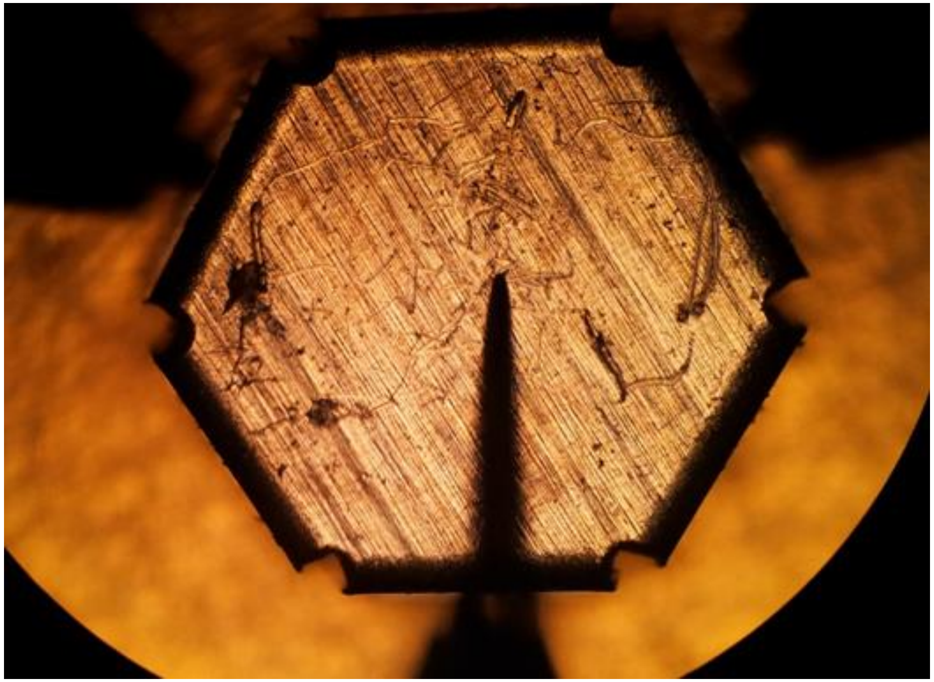
Typical Circulator

Self biased Circulator

Size comparison between typical W-band waveguide circulator (left) and a self-biased circulator (right, inside of red circle)

K_A-band Circulator Development at Metamagnetics

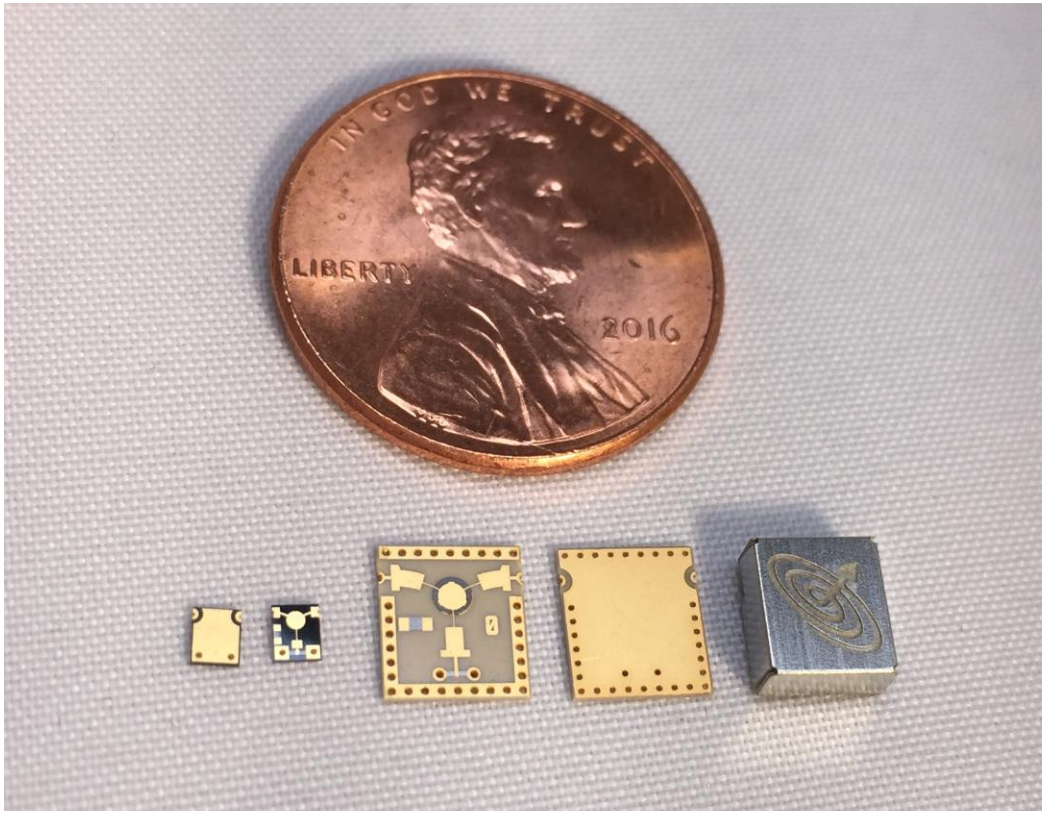




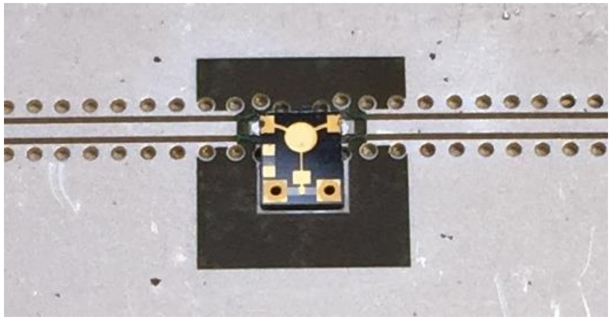
Progression of K_A-band Circulator Development

Circulator Performance Metrics Summary					
Parameter	Program Goals	Iteration I	Iteration II	Iteration III	Iteration IV
Insertion Loss	0.3 – 0.5 dB	≤ 1.2 dB	≤ 1.3 dB	≤ 0.8 dB	< 0.5 dB
Return Loss	> 20 dB	> 18 dB	> 14.5 dB	> 20 dB	> 20 dB
Isolation	> 20 dB	> 14 dB	> 19.5 dB	> 21 dB	> 21 dB
Operating Temperature	-25 – +70°C	-25 – +75°C	-25 – +75°C	-25 – +75°C	-25 – +75°C
Storage Temperature	-40°C – +70°C	-40°C – +75°C	-40°C – +70°C	-40°C – +70°C	-40°C – +70°C
Size	Not specified	2.0 x 2.0 x 0.3 mm	2.0 x 2.0 x 0.3 mm	ø2.4 x 0.7 mm	ø2.4 x 0.7 mm
Power (Peak and/or Average)	7-10 watts (1.56% duty cycle)	8 watts (1.56 % duty cycle)	8 watts (1.56 % duty cycle)	8 watts (1.56 % duty cycle)	8 watts (1.56 % duty cycle)
Bandwidth	0.28 % ± 50 MHz	0.28 % ± 50 MHz	0.28 % ± 50 MHz	0.28 % ± 50 MHz	0.28 % ± 50 MHz
Center Frequency	35.55 GHz	34 GHz	35.55 GHz	35.55 GHz	35.55 GHz

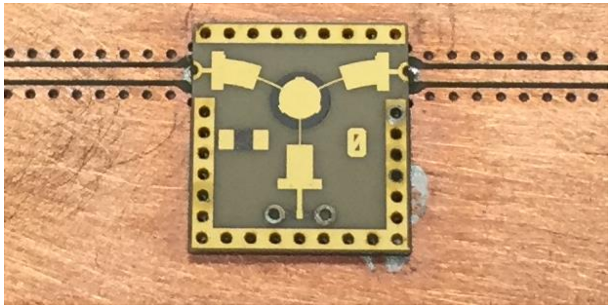
Surface Mountable Commercial Isolator Product Line



Designed for PCB mounting using industry-standard solder reflow processes. EM shielding optional.

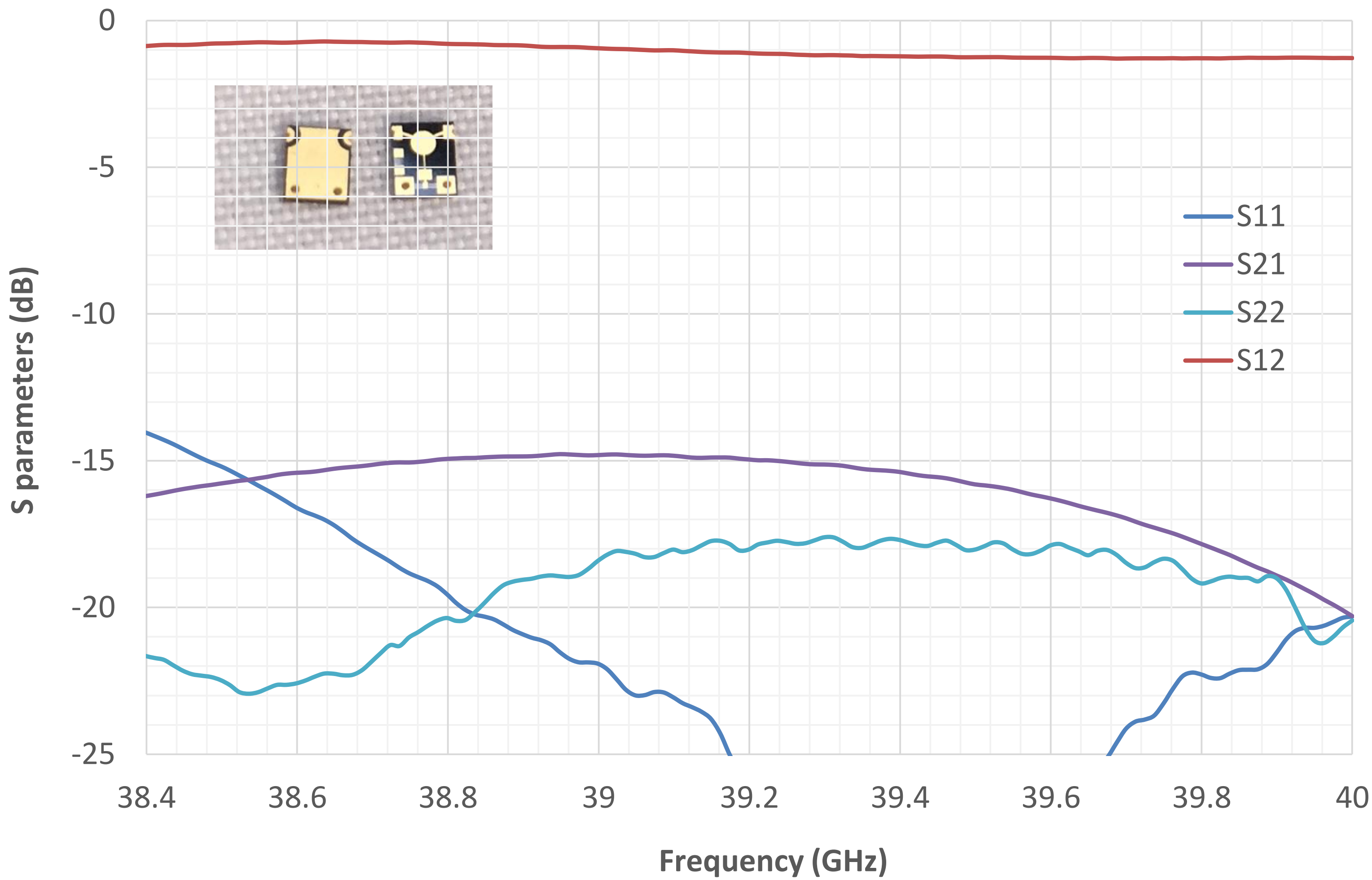


Isolator 38.4 to 40 GHz

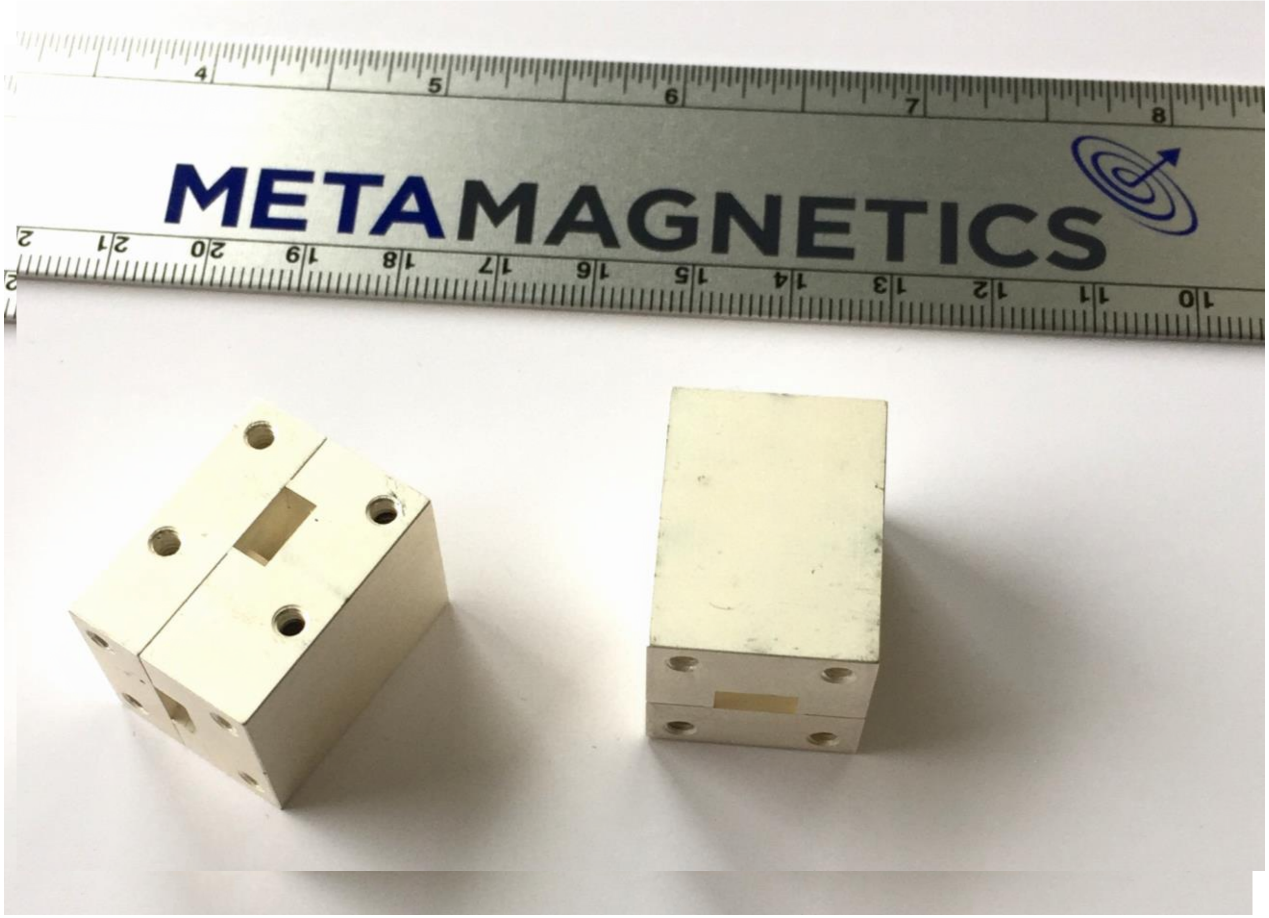


Isolator 26.6 to 29.2 GHz

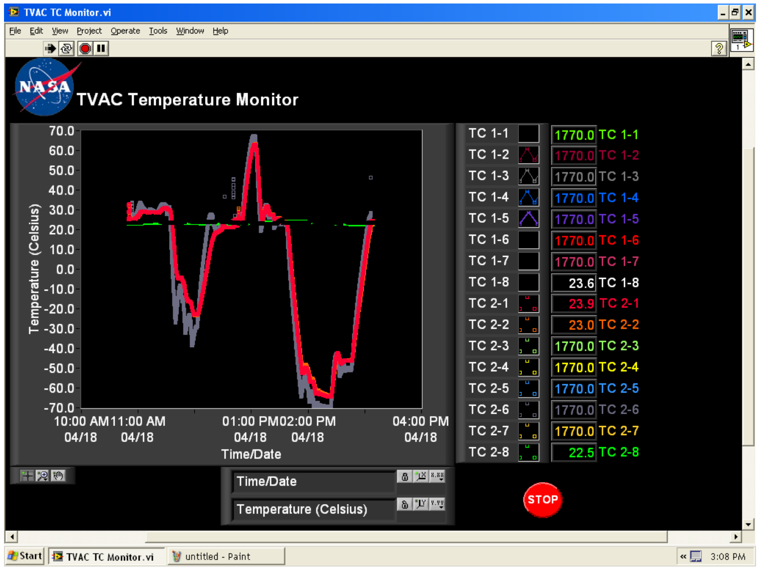
Circulator Performance at 38.4 – 40 GHz

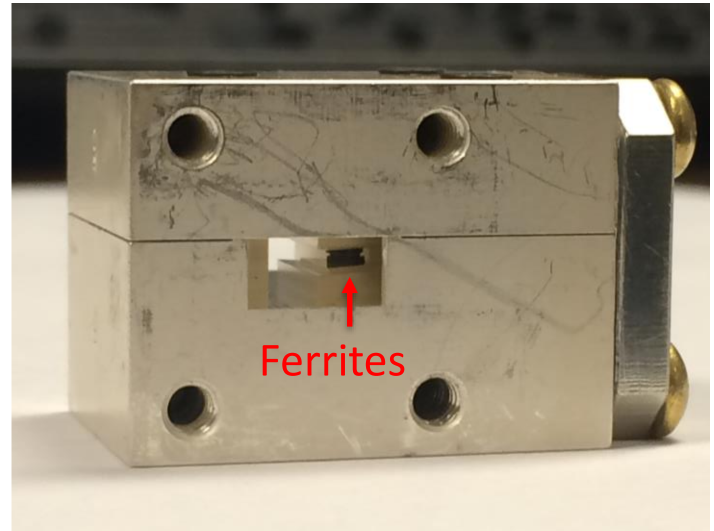


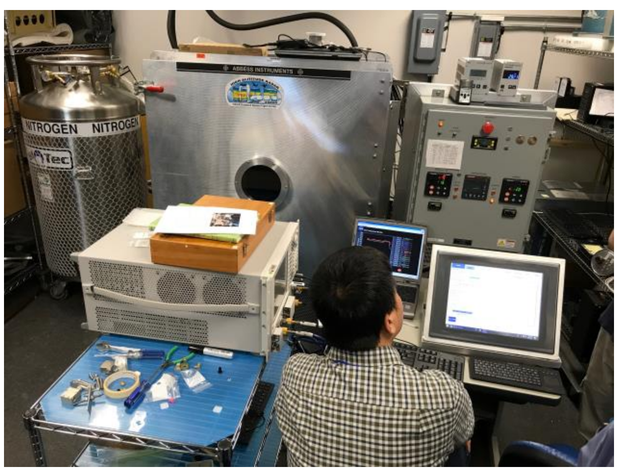
Assembled V4 Waveguide Circulators Environmental Testing at GSFC

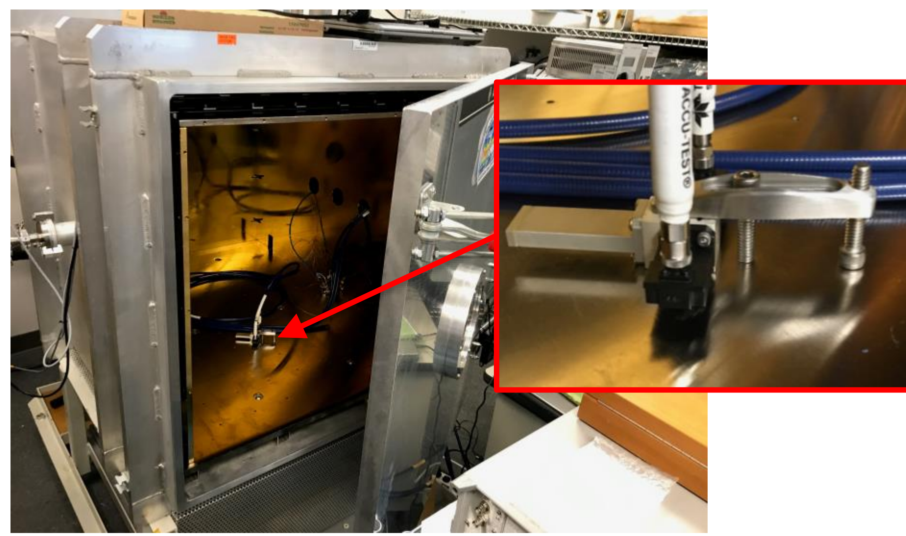


Thermal & Vacuum Testing – NASA Goddard Space Flight Center









Environmental Testing of K_A-band Circulator at GSFC

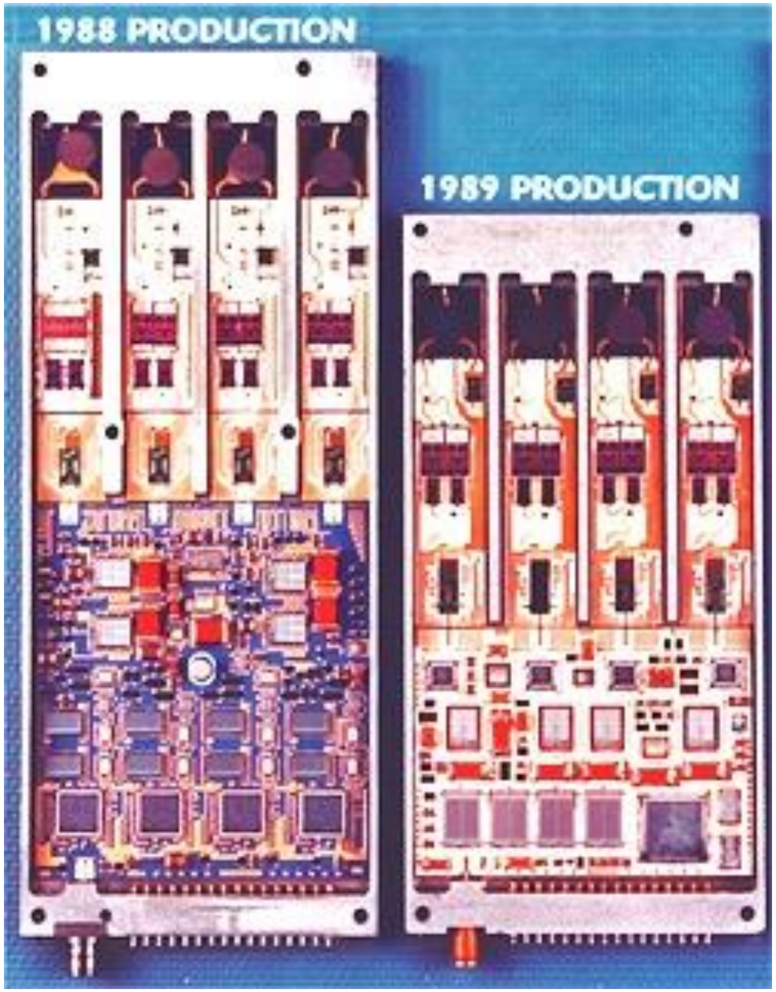
Test/Conditions	Temperature, °C	Insertion Loss, dB	Isolation, dB	Comments	Image File
Test at Metamagnetics before trip to GSFC	+25	0.46	≈ 22		N/A
NASA GSFC test before temperature run	+25	≈ 0.6	≈ 23		20180418-KaCir-2-3-in-chamber-room-condition.png
In chamber, at -20 °C and < 1 Torr pressure	-20	0.95	≈ 21		20180418-KaCir-2-in-chamber-n20degree.png
After -20 °C exposure and after re-calibration	+25	0.56	23	Possible loss calibration error before re-calibration: 0.62 dB	20180418-KaCir-2-3-in-chamber-room-condition-aft-recal.png
Hot excursion	+60	1.06	18		20180418-KaCir-2-3-in-chamber-60degree.png
After +60 °C exposure	+24	0.61	22		20180418-KaCir-2-3-in-chamber-24degree-after60.png
Extreme cold excursion	-60	0.55	17		20180418-KaCir-2-3-in-chamber-n60degree.png
After -60 °C exposure and after re-calibration	+25	0.48	23	Possible loss calibration error before re-calibration: 1.01 dB	20180418-KaCir-2-roomcondition-aft-n60-aftrecal.png

Performance characteristics of Metamagnetics V4 circulator S/N 2 operating at 35.5 GHz

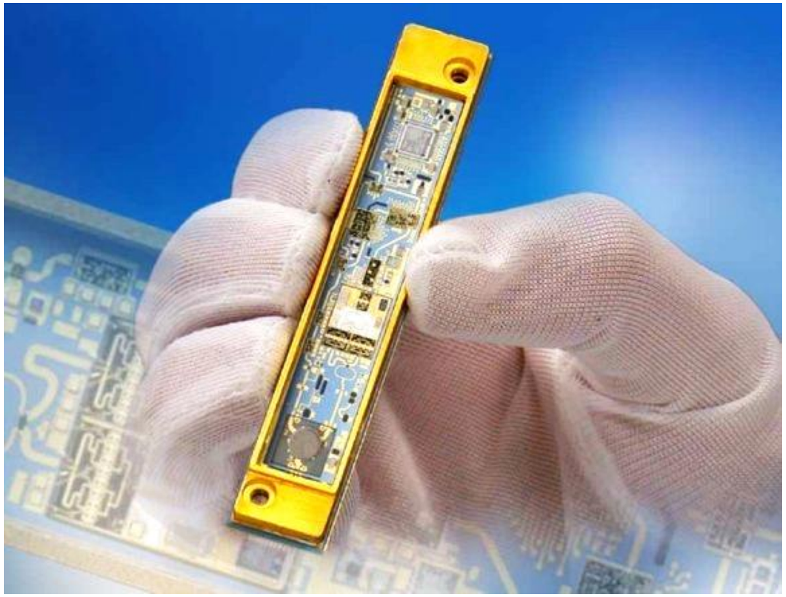
Circulator Development and Availability

Metamagnetics Circulator and Integration Activities		
Component	**Frequency Range (GHz)**	**Development Status**
K_U-band	12 – 18	Developed
K-band	18 – 27	Developed
K_A-band	27 – 40	Developed, Sales exceed 4,000 units
V-band	40 – 75	Under Development
W-band	75 – 110	Planned Development
MMIC integration	18 - 40	Under Development

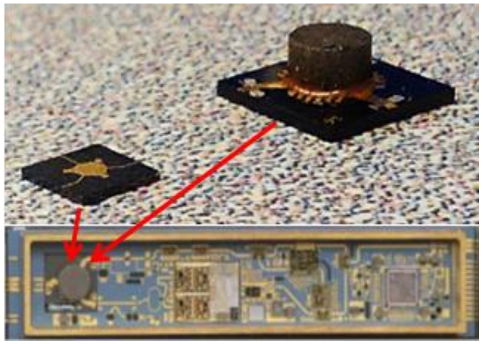
Phased Array Electronics – SoA and Potential Advancements



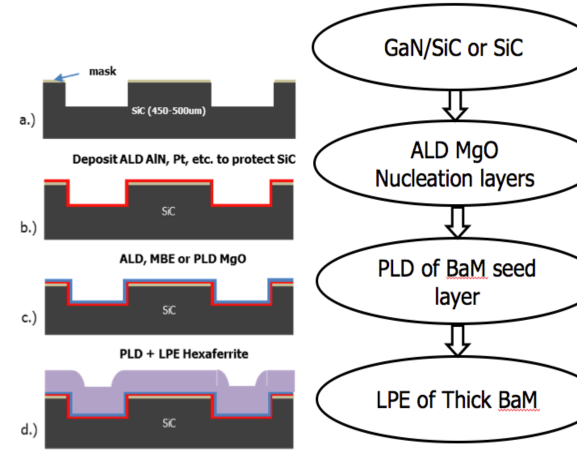
- Radar & Communications systems continue to push size, cost, bandwidth, and power efficiency limits
  - Spectrum efficiency
  - Power efficiency
  - SWaP-C
- Circulator/isolator is a key component that hasn't advanced in 50 years
  - Designed out of systems because of size and cost
  - Performance sacrificed to replace circulator with switch (TDD) or wider bandwidth (FDD)



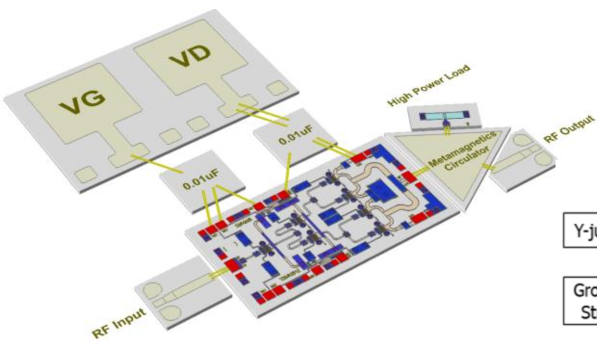
Potential Further Size and Mass Reduction through Circulator Integration with MMICs



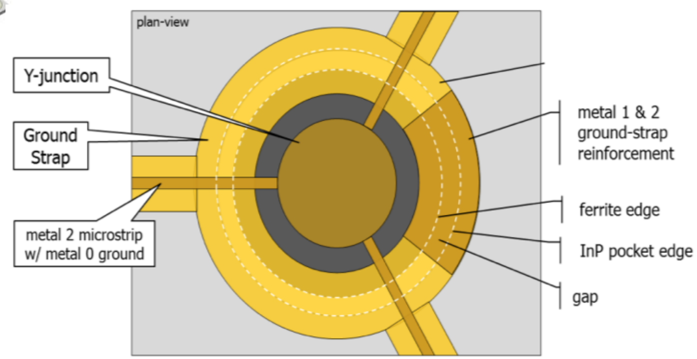
Heterogeneous integration with III-V semiconductor fabrication process, a hexaferrite puck is embedded in an InP wafer



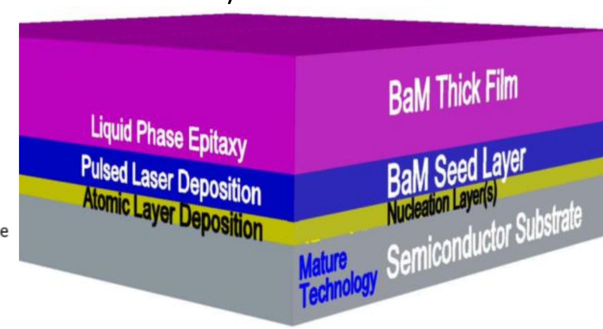
Highest level of integration involves circulator ferrite growth directly on the SiC or GaN/SiC MMIC substrate



MCM integration reduces parasitics by placing miniaturized circulator in intimate proximity to MMIC on a carrier wafer or PCB.

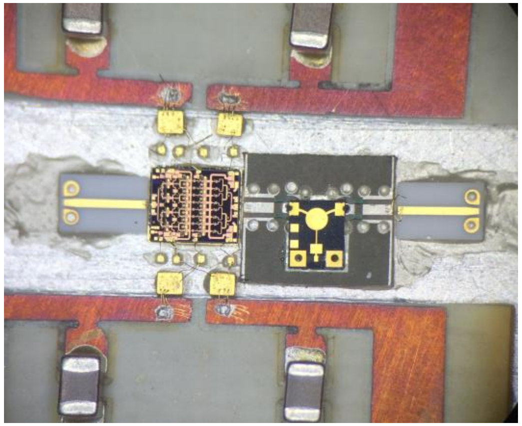


Self-biased circulator with InP and HBT integration concept

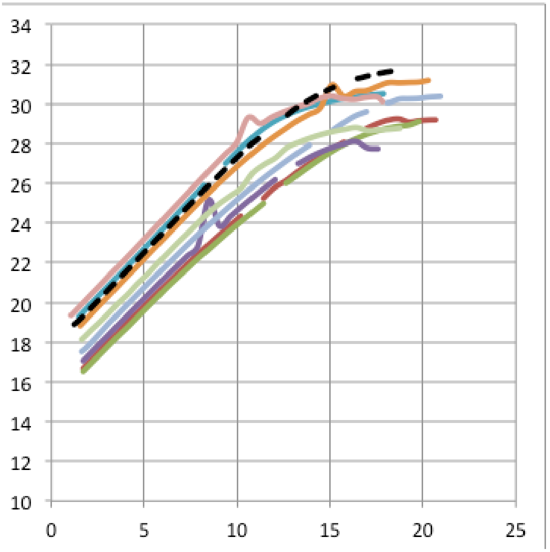


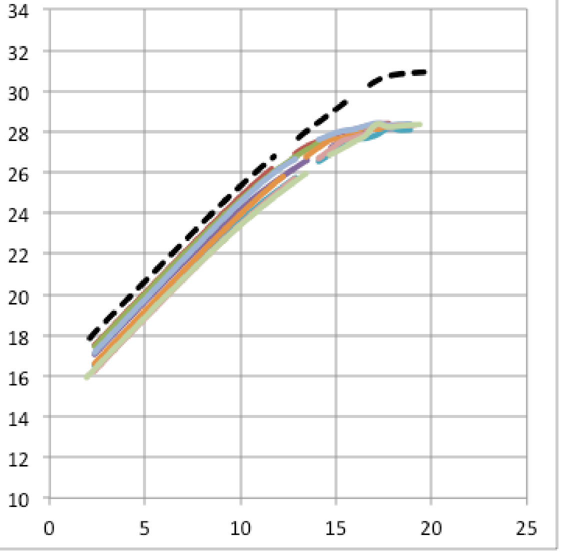
BaM and related hexaferrites can be epitaxially grown directly on a MMIC substrate

Testing Chip Level Integration of Self-Biased Circulators



Prototype integrated GaN K_A-band PA and self-biased isolator



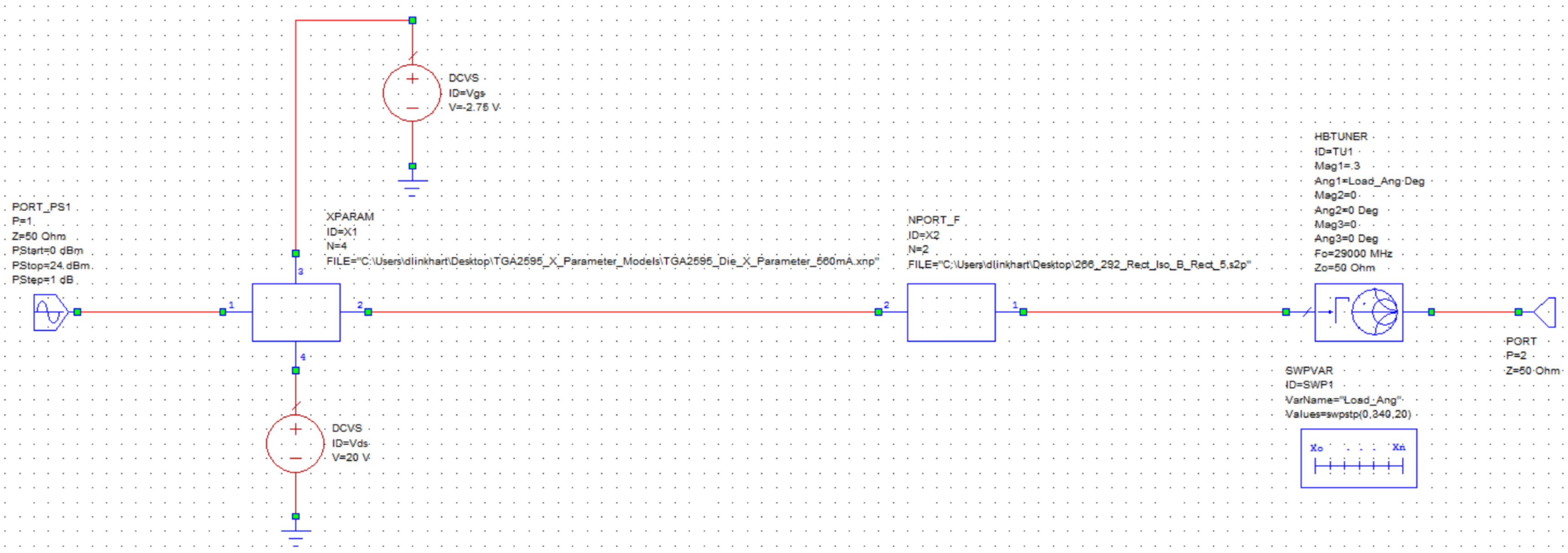


Significant reduction in load pull with self-biased isolator

- Load pull degrades output power and efficiency
- Integrated isolator improves stability of GaN PAs

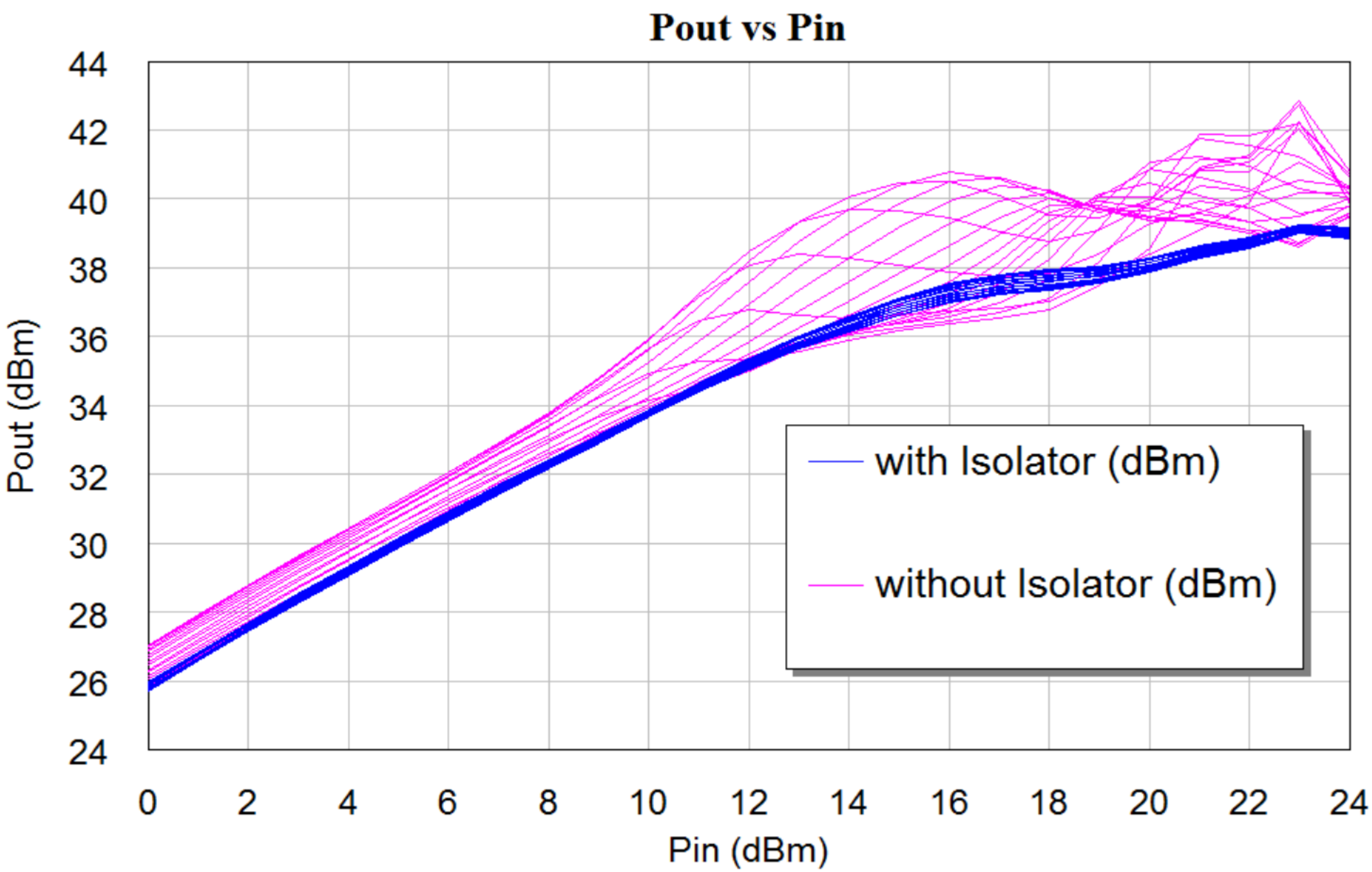
METAMAGNETICS

Testing Chip Level Integration of Self-Biased Circulators

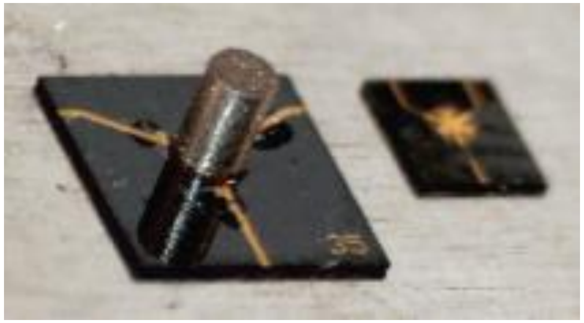


MTMGX.com

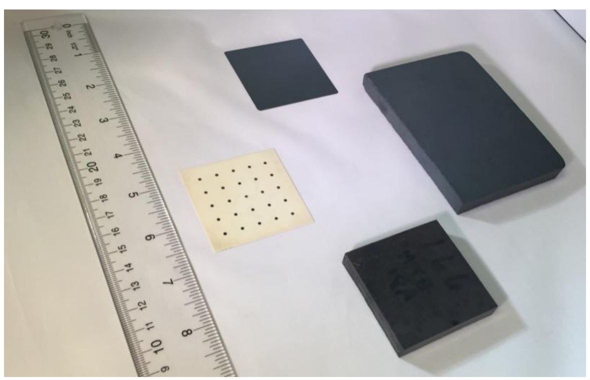
Testing Chip Level Integration of Self-Biased Circulators



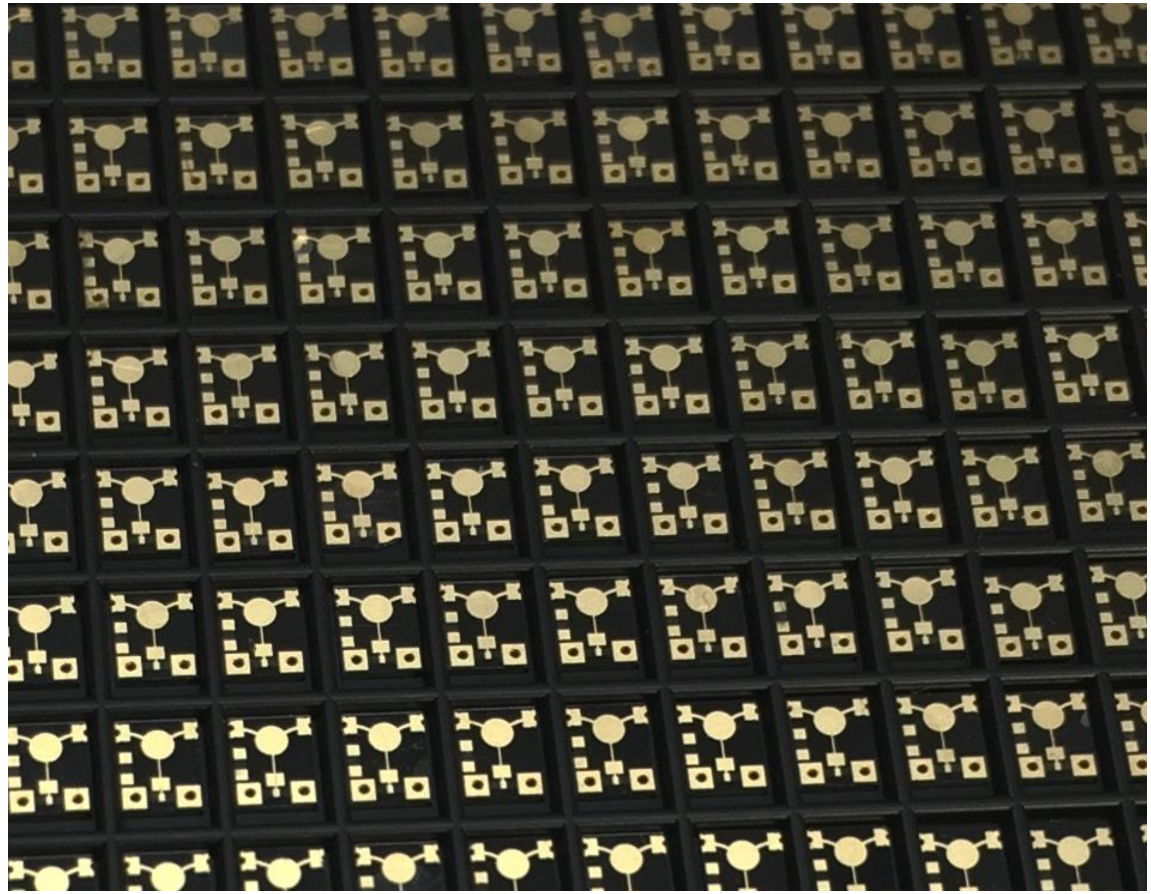
Production of Self-biased Circulators at Metamagnetics



Self-biased circulators are smaller than conventional circulators in all dimensions at a given frequency



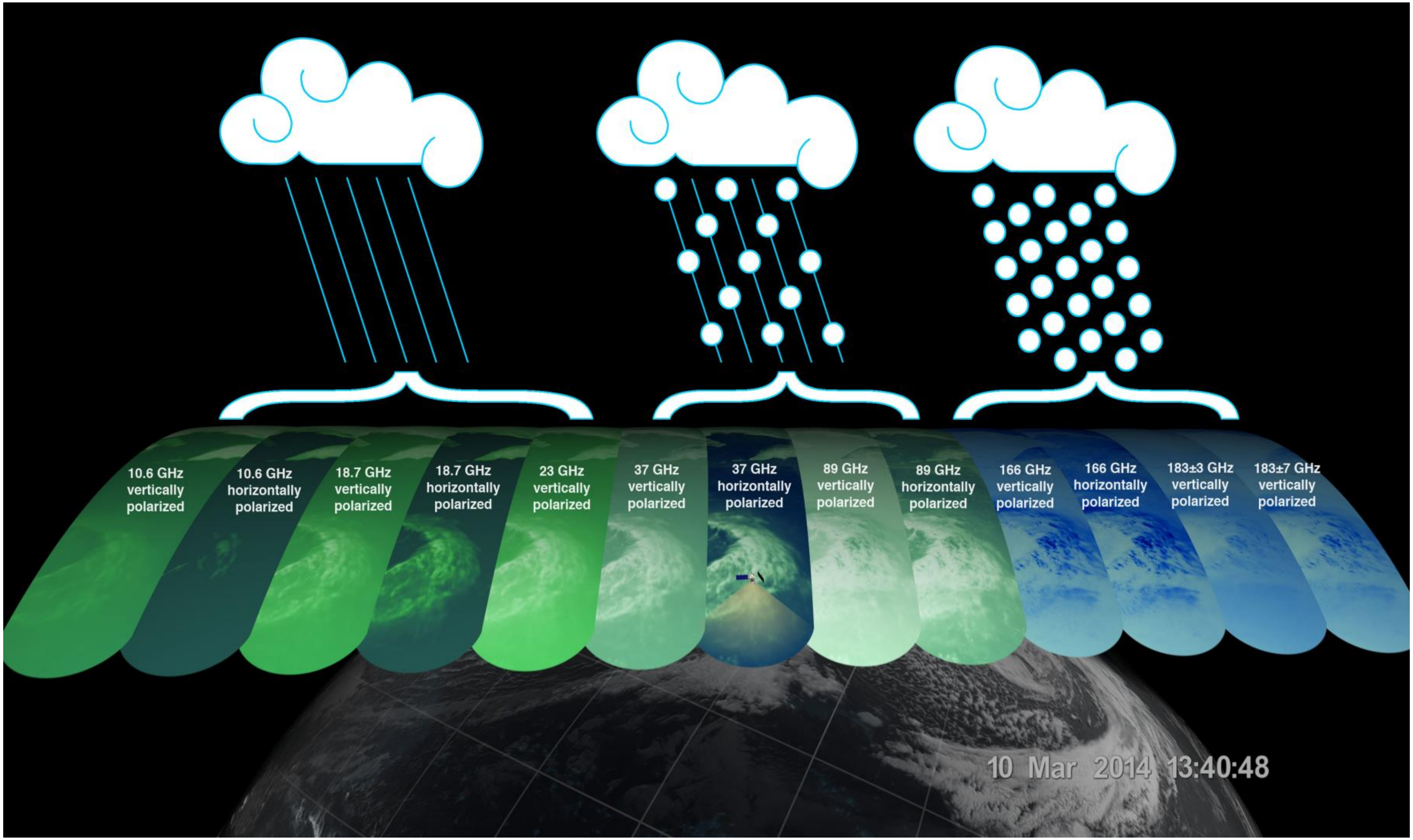
Self-biased ferrite material is produced in a high-throughput full scale manufacturing environment



Batch of 39-GHz isolators in a 2 inch waffle pack

Largest order to date: > 4500 units

Thank You!


10.6 GHz vertically polarized
10.6 GHz horizontally polarized
18.7 GHz vertically polarized
18.7 GHz horizontally polarized
23 GHz vertically polarized
37 GHz vertically polarized
37 GHz horizontally polarized
89 GHz vertically polarized
89 GHz horizontally polarized
166 GHz vertically polarized
166 GHz horizontally polarized
183±3 GHz vertically polarized
183±7 GHz vertically polarized
10 Mar 2014 13:40:48

Questions?

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