METAMAGNETICS

Miniaturized, Low-cost, Self-biased Circulators for Space and Airborne Applications

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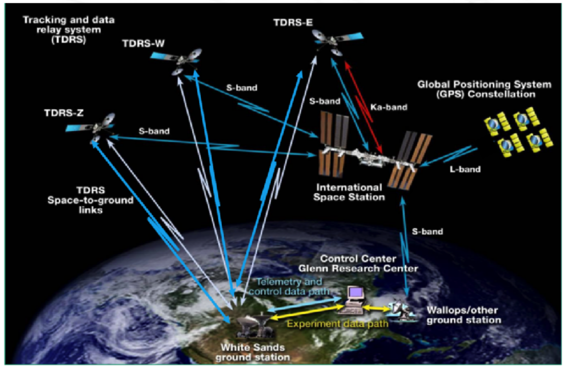
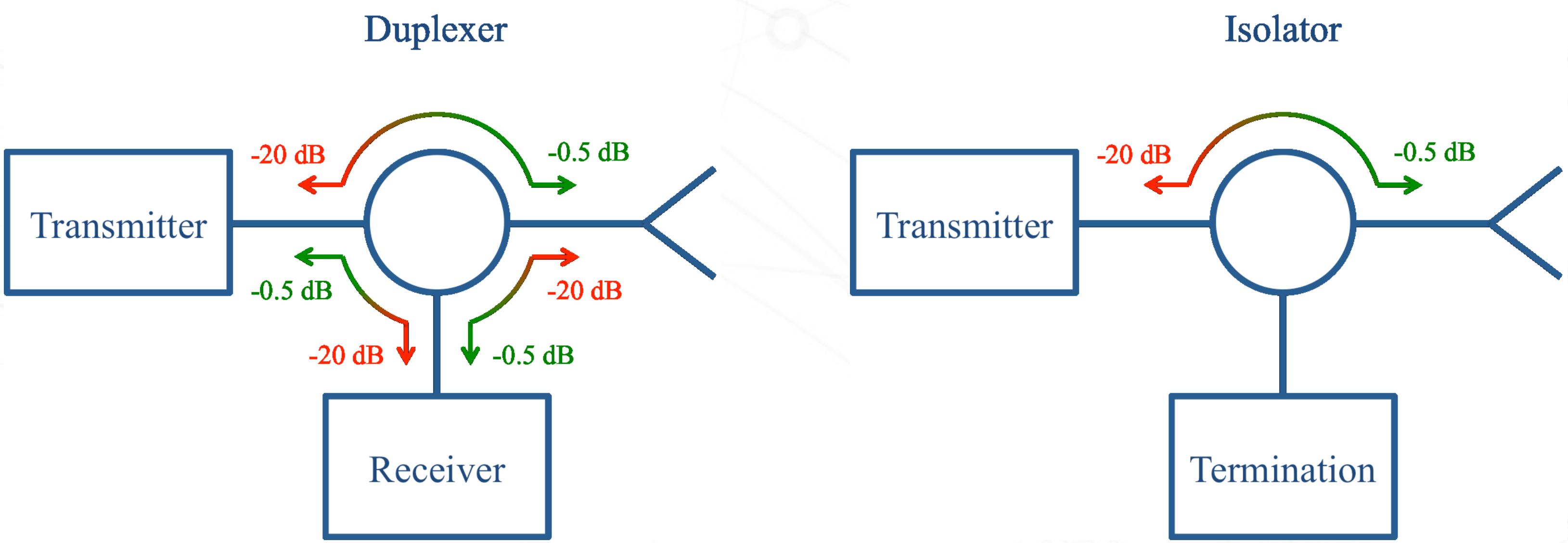
Self-Biased Circulator R&D Funded by NASA

- NASA SBIR Phase I, II, and III
  - Self-Biased Radiation Hardened Ka-Band Circulators for Size, Weight and Power Restricted Long Range Space Applications



- NASA ACT grant
  - Compact magnet-less circulators for ACE and other missions
  - Infusion into NASA Aerosols, Clouds and Ecosystems (ACE) IIP
  - Grant # NNX15AB39G
  - NASA Program Manager: Joseph Famiglietti
  - Objectives:
    - Develop “magnet-less” ferrite circulators for use in space-based phased array sensors by applying recent materials science breakthrough funded in part by NASA’s SBIR program
    - Demonstrate magnet-less components > 90% smaller and lighter than traditional circulators largely due to lack of permanent biasing magnets
    - Develop customized packaging for system integration
    - Demonstrate increased ruggedness (by monolithic construction) in high shock and vibration environments

Circulators and Isolators



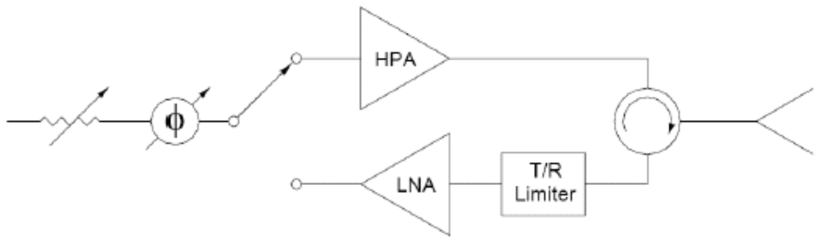
- Passive, non-reciprocal microwave devices
- Energy can be made to circulate in either clockwise or counterclockwise direction
- Usually composed of anisotropic materials, such as ferrites
- Ferrite needs to be biased with a static magnetic field

Circulators and Isolators in T/R Modules

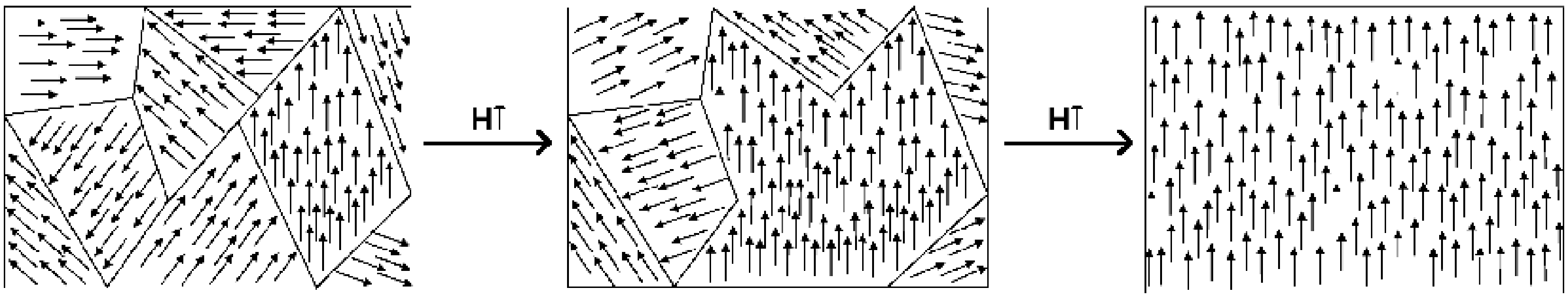
- Fundamental building blocks of Transmit/Receive modules (TRMs) utilized in high data rate active space transceivers and transponders for long range (LR) and low earth orbit (LEO) systems

- During the transmit cycle, circulators protect high power amplifiers (HPA) from destabilizing, and potentially harmful, power reflections from the antenna element

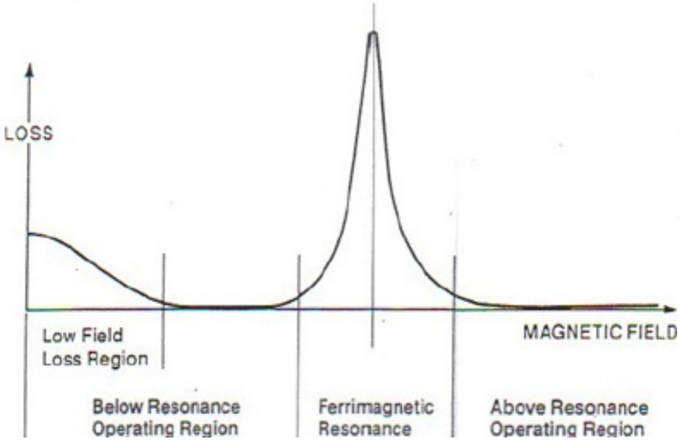
- During the receive cycle, circulators direct lower power received signals with minimal attenuation to the low noise amplifiers (LNA)



Why is bias needed?



Demagnetized state | Partially magnetized state | Fully magnetized state



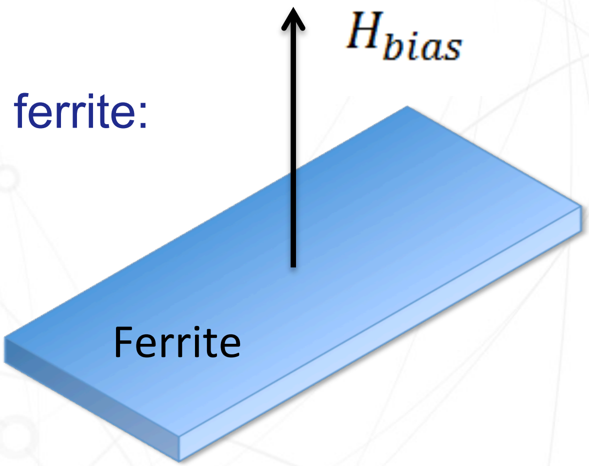
Images adapted from Google Images

- For the realization of many microwave devices the ferrite material needs to respond uniformly, as a single magnetic domain
- Externally applied magnetic field must be strong enough to overcome demagnetizing field and sweep out magnetic domain walls

The Polder Tensor

- The tensor permeability of an out-of-plane biased ferrite:

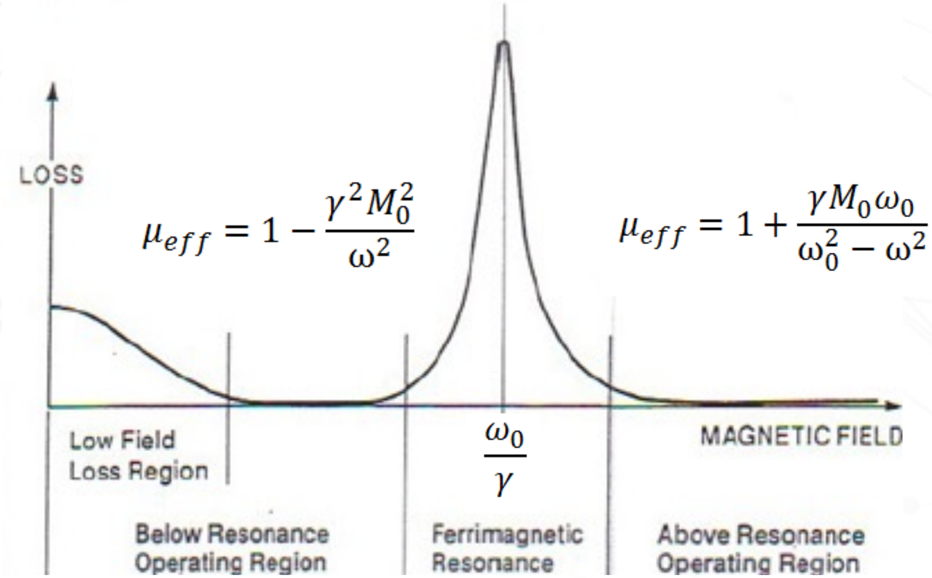
$$\vec{\mu} = \begin{pmatrix} \mu & j\kappa & 0 \\ -j\kappa & \mu & 0 \\ 0 & 0 & 1 \end{pmatrix}$$



- For a plane wave propagating transverse to the bias:

$$\mu_{eff} = \frac{\mu^2 - \kappa^2}{\mu}$$

Circulator Operating Regions

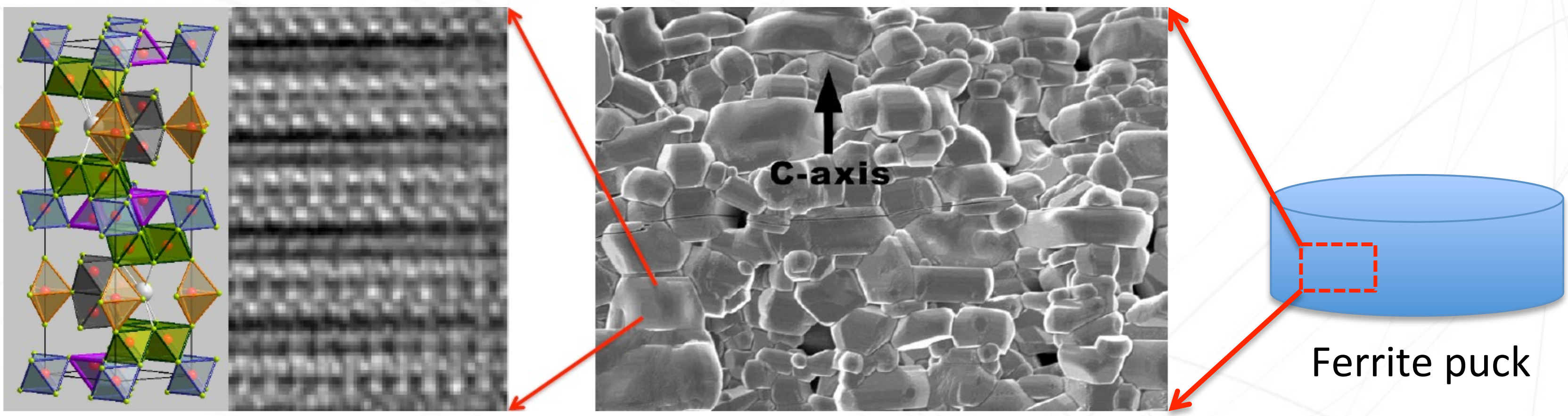


$$\omega_0 = \gamma H_0$$

$$H_0 = \sqrt{(H_{bias} + (N_x - N_z)M_0)(H_{bias} + (N_y - N_z)M_0)}$$

- For a self-biased circulator: $H_{bias} = H_{anisotropy}$
- Design equation for a disk-shaped circulator: $R = \frac{1.84\lambda}{2\pi\sqrt{\mu_{eff}\varepsilon}}$

Self-Bias in Hexagonal Ferrites



- Below a certain size, each microscopic grain forms a single magnetic domain
- Grains are oriented, pressed, and sintered to form an oriented compact
- The resulting compact remains magnetized in the absence of external field

Image adapted from Z. Chen, et al., “Structure, magnetic, and microwave properties of thick Ba-hexaferrite films epitaxially grown on GaN/Al2O3 substrates,” Appl. Phys. Lett. 88, 062516 (2006).

Image adapted from Y. Chen, et al., “Oriented barium hexaferrite thick films with narrow ferromagnetic resonance linewidth,” Appl. Phys. Lett. 88, 062516 (2006).

Metamagnetics Material Breakthroughs

- High remnant magnetization
- Excellent machinability and chemical stability
- Low magnetic losses
  - small resonance linewidth (< 100 Oe)
- Low dielectric losses
  - loss tangent of ~0.02 or less
- Allows for smaller circulators with substantially lower losses
  - Insertion losses of less than 1 dB can be achieved

Key Characteristics of Metamagnetics' Circulators

- Composed of advanced self-biased materials fabricated without rare-earth elements
- Maximum isolation without compromise to micro- and millimeter-wave frequencies (Ku band and beyond)
- Ideal for weight-, size- and cost constrained systems
- Alleviate problems in high shock or vibration environments

Traditional Ferrite Circulators and Isolators

- Size of the magnet increases with operating frequency

  $$f_0 = \gamma^*(H-4\pi Mr)$$

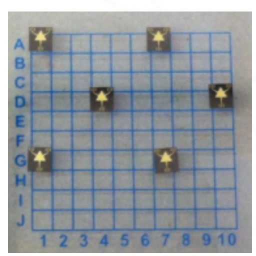
- Magnet adds weight, profile height, and cost
- At frequencies above ~20 GHz biasing magnets become so large they are difficult to fit within phased array lattice spacing
- Bonded permanent magnets do not survive high shock or vibration

Photographs adapted from dorado-intl.com

Conventional vs MTMGX Self-Biased Circulators

Conventional circulator:

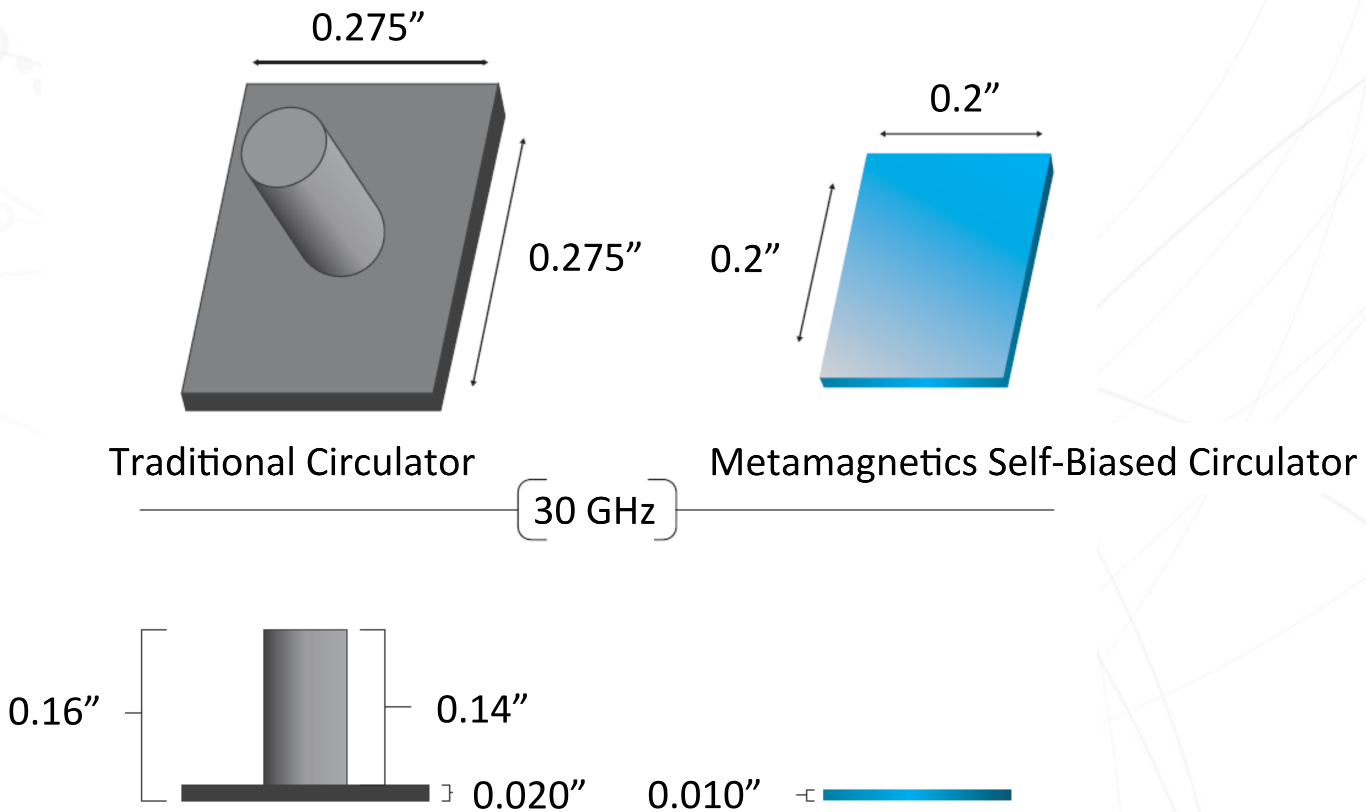
- Utilizes a permanent magnet
- Often produced using rare-earth metals: e.g. NdFeB or SmCo



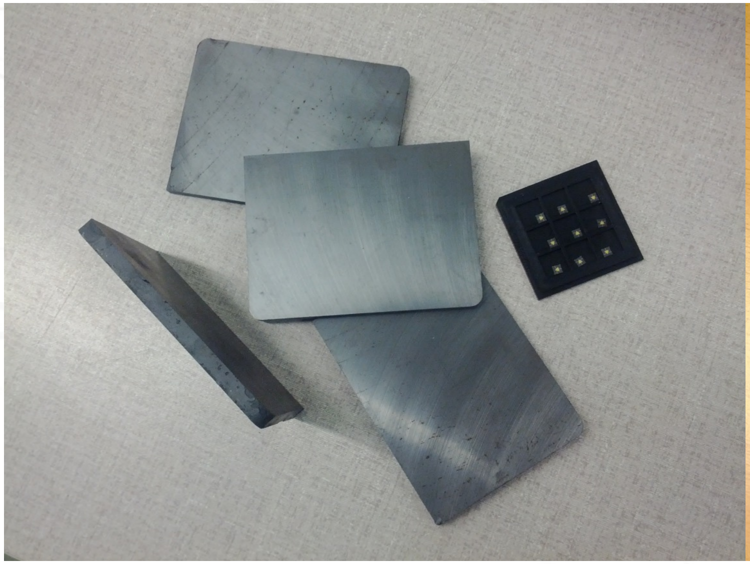
MTMGX Self-biased circulator:

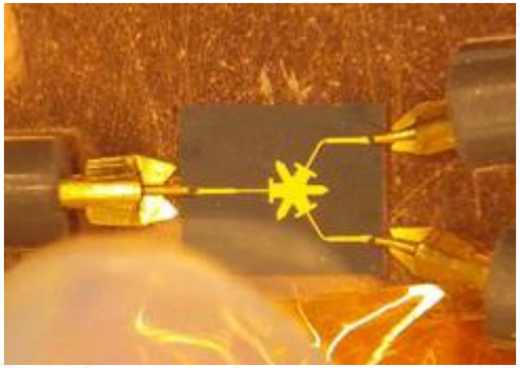
- No permanent magnet
- 95% lighter and 90% smaller
- Exceptional shock and vibration tolerance
- no magnet “pop-off” at launch
- High ionizing radiation tolerance
- 100% domestically produced
- Best suited for AESA, comms, sensors, satellite, airborne, and UAV platforms

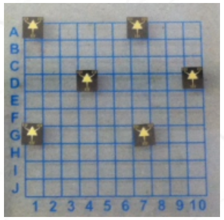
Size Comparison



Metamagnetics Circulators Fabricated in Bulk

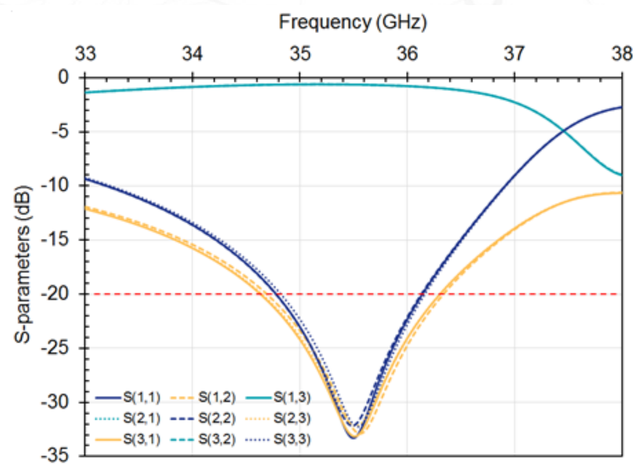


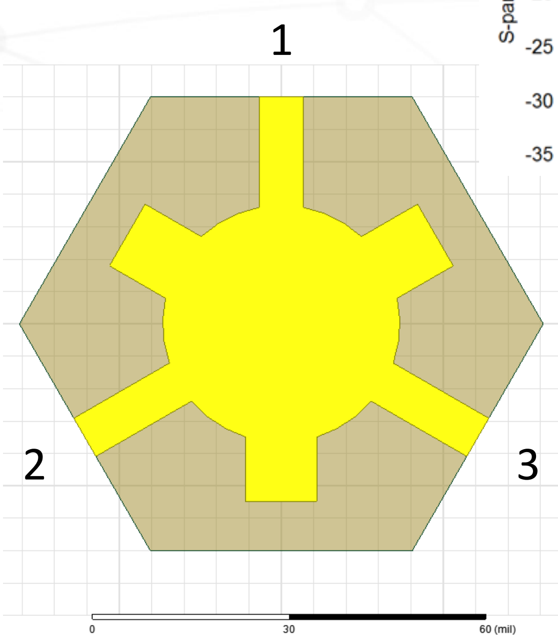


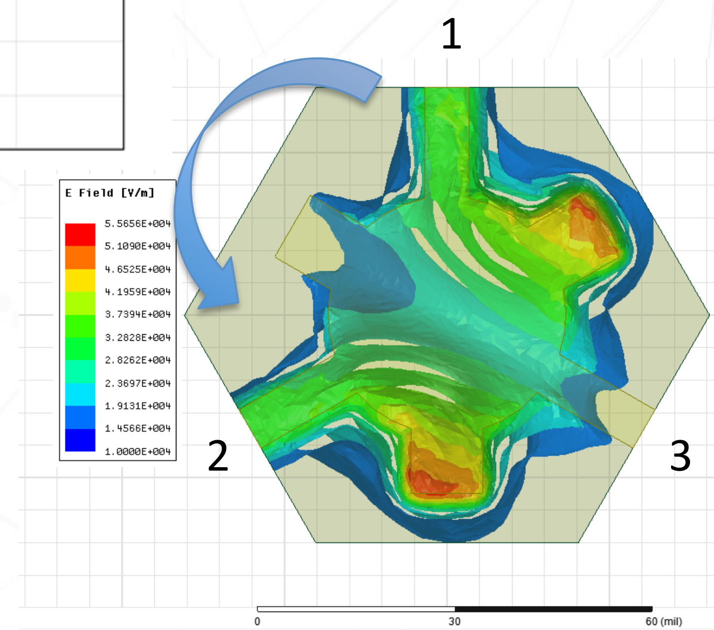


- Ferrite materials are produced as large tiles
- The fabrication process involves dicing and lapping, metallization and patterning
- At Ka-band, devices are 5x5x0.25 mm^3 or smaller.

Design of a Self-Biased Circulator in HFSS

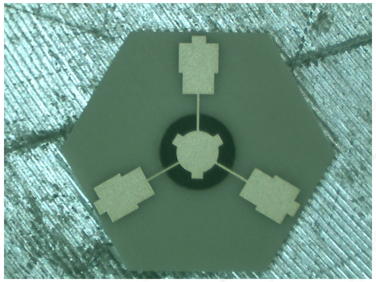


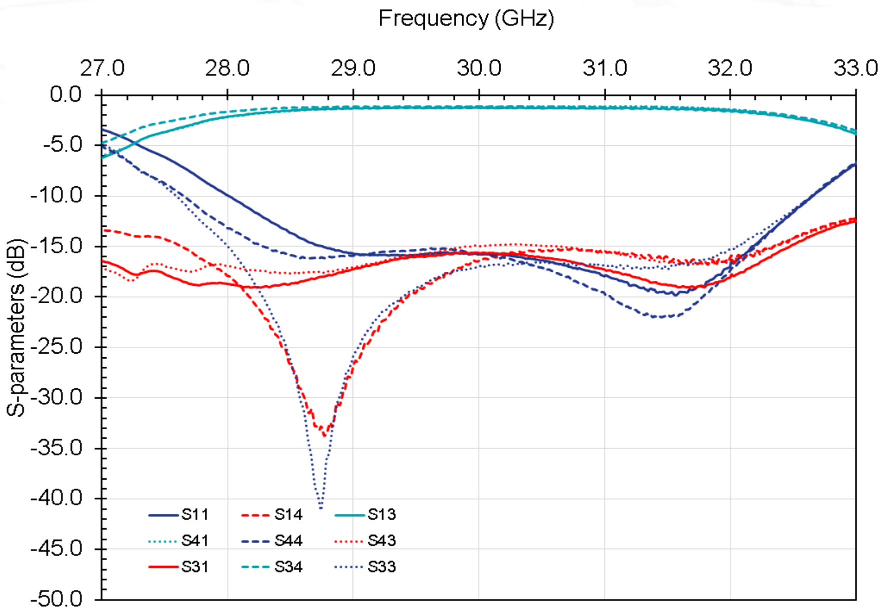


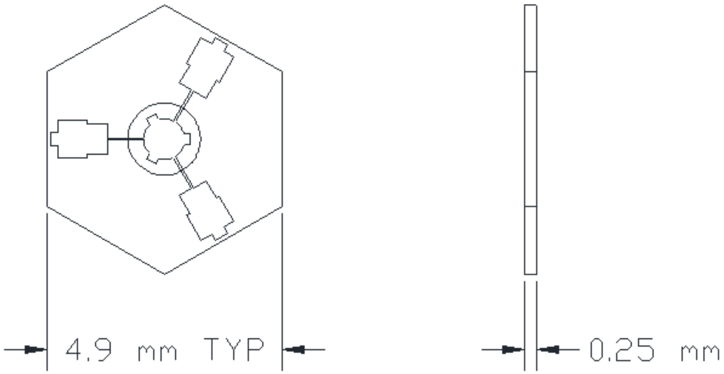


30 GHz Self-Biased Circulator

- Small size (< 0.2” lateral size, 0.01” thickness)
- Excellent isolation and return loss (> 15 dB)
- Low insertion loss (< 1.2 dB)
- Bandwidth of ~10 % in the Ka-band

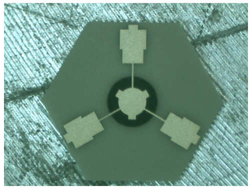


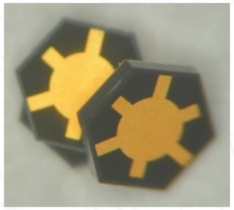




Ka-band Self-Biased Circulators and Isolators

Frequency GHz	Bandwidth GHz	Isolation dB (min)	Insertion Loss dB (max)	VSWR (max)	Power Handling W CW	Operating Temperature, °C
28 - 32	(full)	14	1.3	1.45:1	8	0 to +50
29 – 31	(full)	19	1.2	1.25:1	10	0 to +50
29.5 – 30.5	(full)	20	1.0	1.20:1	10	0 to +50
29.6 – 30.6	(full)	20	1.0	1.20:1	10	0 to +50
34.5 – 35.5	(full)	20	1.0	1.20:1	10	0 to +50
26 – 40	1	20	1.0	1.20:1	8	0 to +50
26 - 39	2	18	1.3	1.30:1	8	0 to +50
26 - 38	4	13	1.4	1.50:1	8	0 to +50





Form Factor Options

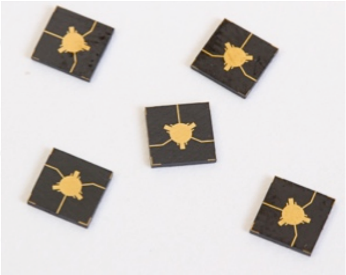
- Lower center frequencies with slightly reduced performance
- Rectangular footprints with Y or T port configurations
- Isolators: termination options include small integrated termination or high-power dc-isolated meander-line terminations
- Ground vias for coplanar waveguide launches
- Surface-mount versions

The Benefits of a Self-Biased Circulator

- Smaller
  - 90 % reduction in component size
  - Enable novel RF system layouts, such as stackable T/R modules
  - Can fit in phased array radar systems operating above 20 GHz
- Lighter
  - 95 % reduction in component weight
  - Ideal for weight-sensitive applications, such as UAVs, missiles, and space systems
- Resistant to Shock and Vibration
  - Eliminate the problem of component failure in missile and rocket systems during launch
- Economical
  - Metamagnetics has removed many of the costly steps in the manufacturing process

Company Focus

- Advanced materials development
  - Advanced ferrite materials for nonlinear transmission lines and high power microwave generation
  - Low-loss inductor and transformer cores
  - Self-biased ferrite materials



- Low profile and high power handling devices
  - Microstrip ferrite phase shifters for cost effective arrays
  - Tunable microstrip ferrite filters for densely populated EM environments

- Miniaturized RF components
  - Self-biased ferrite junction circulators and isolators
  - Metamaterial based antennas

Questions?

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