Analysis and Applications of Microwave Electronics

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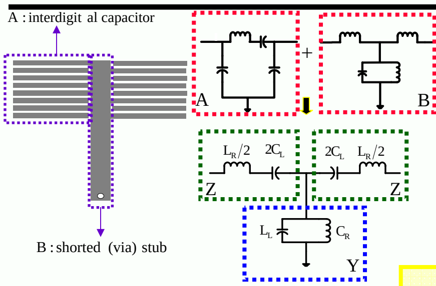
Outline

- ***Metamaterials Applications***
  - *Electronically-Scannable Leaky Wave Antenna*
  - *2D Conical Beam Antenna*
- ***Retrodirective Array Systems***
  - *60 GHz 4th Subharmonic Phase Conjugate System*
  - *Full Duplex System with Exclusive Uplink/Downlink Modulation*
- ***Novel Antenna Design and Applications***
  - *Broadband Quasi-Yagi Antenna*
  - *Single RF Channel SMART Antenna*
  - *Self-Biased Receiver System using Sector Antenna*

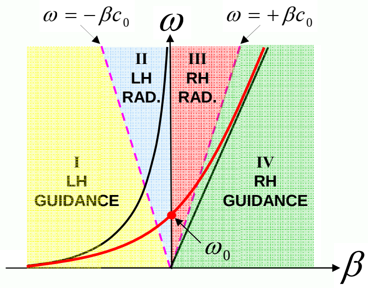
Electronically-Scannable Leaky Wave Antenna



$$\beta = \cos^{-1}(1 + Z'(\omega)Y'(\omega))/d$$

$$Z'(\omega) = \frac{1}{2}\left(j\omega L_R + \frac{1}{j\omega C_L}\right)$$

$$Y'(\omega) = j\omega C_R + \frac{1}{j\omega L_L}$$



- ❑ Dominant mode operation ($n = 0$)

$$\theta = \sin^{-1}\left(\frac{\beta_0 + 2n\pi/d}{k_0}\right) = \sin^{-1}\left(\frac{\beta_0}{k_0}\right)$$

- ❑ Efficient broadside radiation @ ω_0
- ❑ Backward (II. LH) and forward (III. RH) radiation

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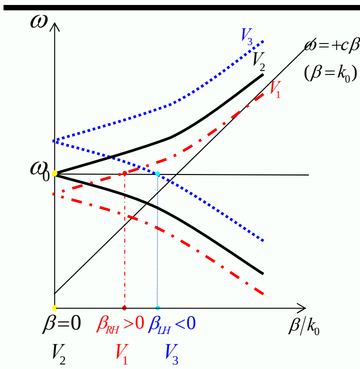
Electronically-Scannable Leaky Wave Antenna



$$\theta(V) = \sin^{-1}\left[\frac{\beta}{k_0}\right]$$

$$\theta(V) = \sin^{-1}\left[\frac{\beta(V)}{k_0}\right]$$

- ❑ Scanning angle is dependent on inductances and capacitances
  - ➔ Introducing varactor diodes
- ❑ Capacitive parameters are controlled by voltages
  - ➔ Dispersion curves are shifted vertically as bias voltages are varied
  - ➔ Radiating angle becomes a function of the varactor diode's voltages

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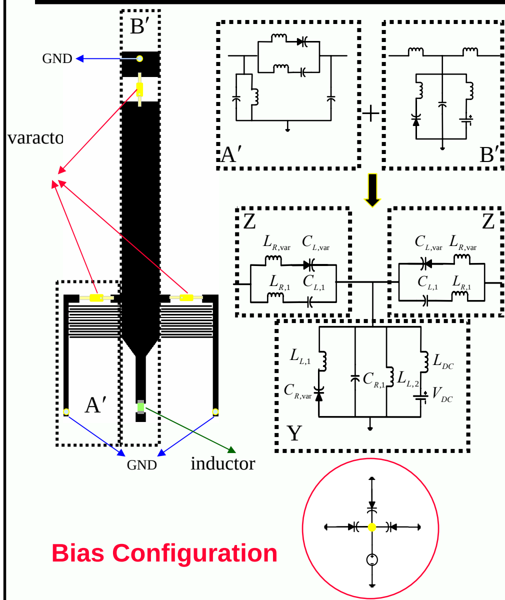
Electronically-Scannable Leaky Wave Antenna



Bias Configuration

- ❑ Reverse biasing to Varactors
  - ➔ Anodes of varactors : GND
  - ➔ Cathodes of varactors: Biasing
- ❑ The cathodes of three varactors in the same direction
  - ➔ Only one bias circuitry in unit cell
- ❑ Series and Shunt Varactors
  - ➔ Fairly constant characteristic impedance
  - ➔ Additional degree of freedom for wider scanning range
- ❑ Back to back configuration of two series varactors
  - ➔ Fundamental signals : in phase and add up
  - ➔ Harmonic signals: out of phase and cancel

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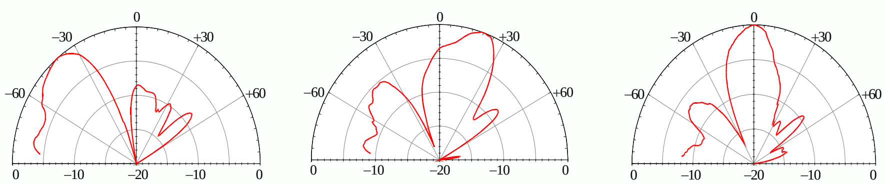
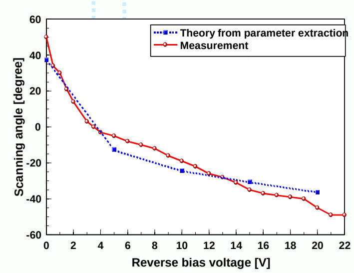
Electronically-Scannable Leaky Wave Antenna



V = 18 V, LH (β < 0)　　*V = 1.5 V, RH (β > 0)*　　*V = 3.5 V, Broadside (β = 0)*

- ❑ Scanning Range ***Δθ* = 99º** (-49º to +50º)
  - ➔ Backward, forward, and broadside
- ❑ Biasing Range ***ΔV* = 21 V** (0 to 21 V)
- ❑ **Fixed** operating frequency : **3.33 GHz**
- ❑ Maximum Gain: **18 dBi** at broadside
- ❑ Antenna dimension

$38.34\ cm\ (5.87\lambda_{eff}^{\mu strip})$



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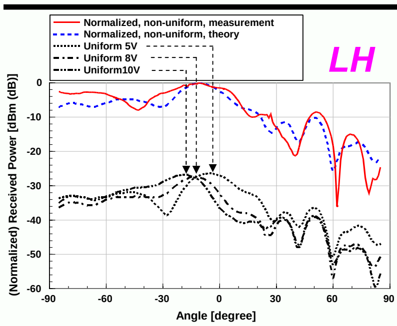
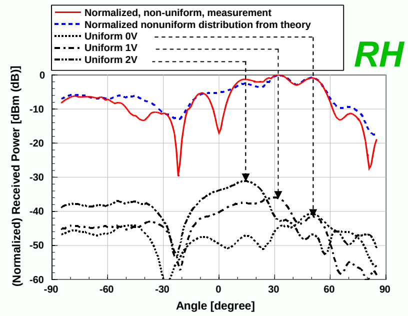
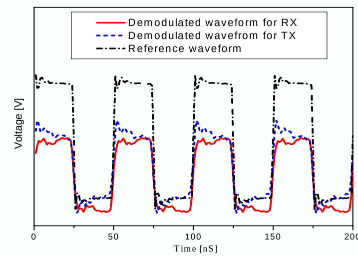
Electronically-Scannable Leaky Wave Antenna





Beamwidth Tuning Capability with Non-Uniform Biasing

BPSK Data Transmission Test



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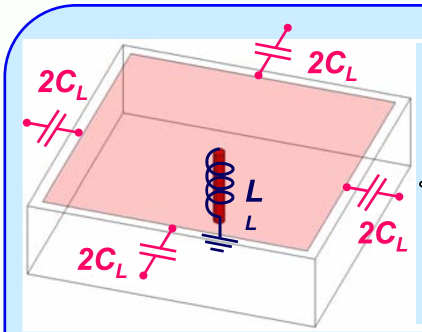
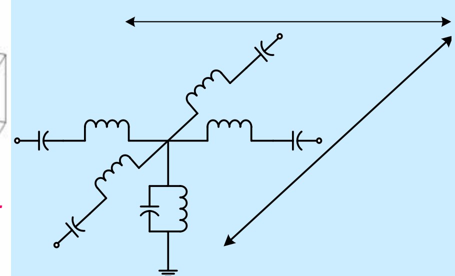
2D Conical Beam Antenna



Mushroom Unit Cell



2-D Model

- C_R, L_R → Conventional (RH) Transmission Line
- C_L, L_L → *LH Transmission Line,*
  series capacitance, shunt inductance

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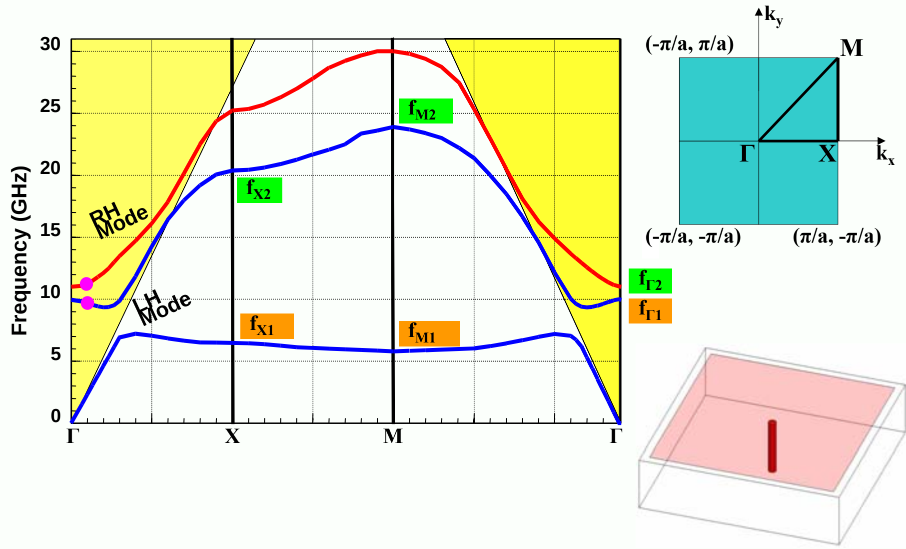
2D Conical Beam Antenna



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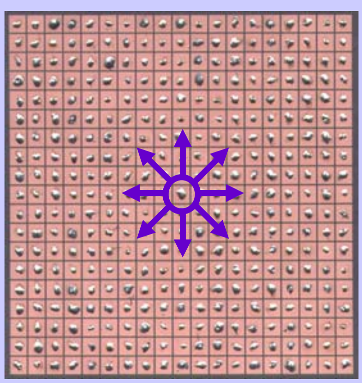
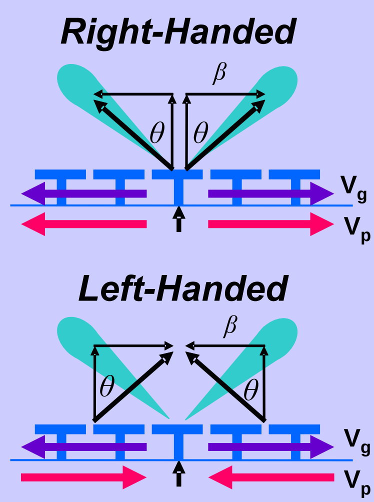
2D Conical Beam Antenna



$\theta = sin^{-1} (\beta/k_0)$



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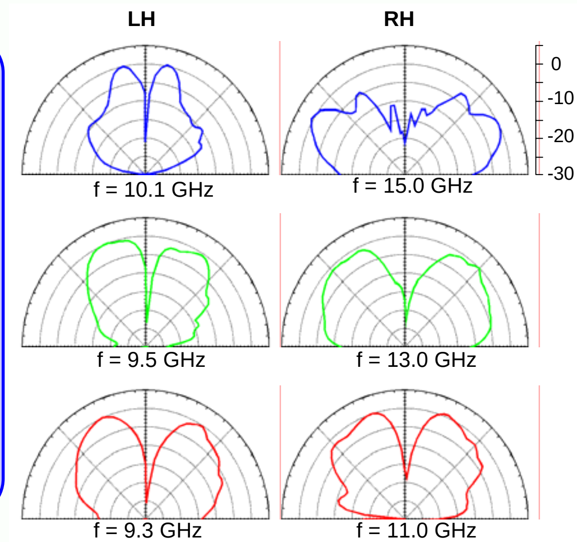
2D Conical Beam Antenna

- ***LH Region***
  Cone closes as f ↑
- ***RH Region***
  Cone opens as f ↑
- ***Minimum gain: 12.4 dB***



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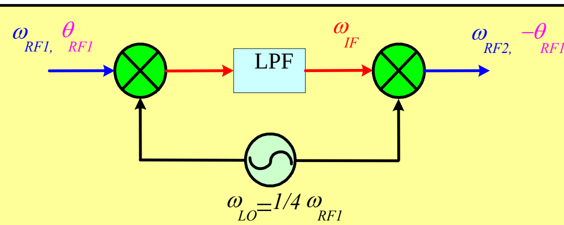
4th Subharmonic Phase-Conjugated Retrodirective Array



$$V_{IF} = V_{RF1}\cos(\omega_{RF1}t + \theta_{RF1}) \times V_{LO}\cos(\omega_{LO}t)$$

$$= \frac{1}{2}V_{RF1}V_{LO}\left[\cos((\omega_{LO} - \omega_{RF1})t - \theta_{RF1}) + \cos((\omega_{LO} + \omega_{RF1})t + \theta_{RF1})\right]$$

$$V_{RF2} = \frac{1}{2}V_{RF1}V_{LO}(\cos((\omega_{LO} - \omega_{RF1})t - \theta_{RF1})) \times V_{LO}\cos(\omega_{LO}t)$$

$$= \frac{1}{4}V_{RF1}V_{LO}^{2}\left[\cos((\omega_{LO} + \omega_{IF})t - \theta_{RF1}) + \cos((\omega_{RF1})t - \theta_{RF1})\right]$$

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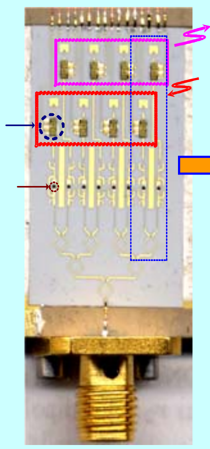
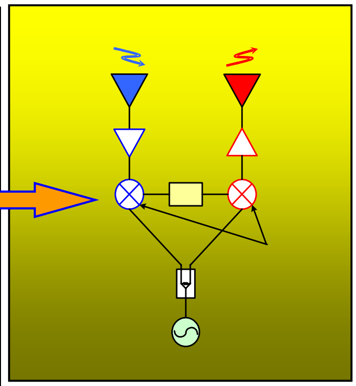
4th Subharmonic Phase-Conjugated Retrodirective Array





- **Four-element antenna array w/ 0.6 λ**
- **Subharmonic mixer w/ APDP**
- **Substrate : ε_r = 0.8, h = 5 mils**

• Circuit size : 15 × 25 *mm*²

Tx Array

Rx Array

MMIC LNA Chip

Bypass Capacitors

F_{RF2} = 61.53

F_{RF1} = 61.33 G

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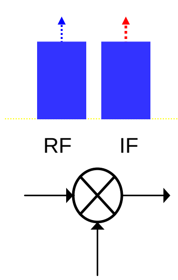
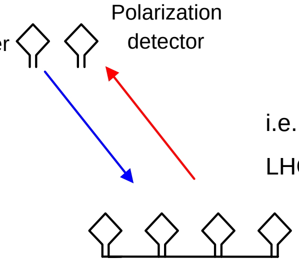
Exclusive Uplink/Downlink Modulation Retrodirective Array

- Received information contained in time domain (AM, BPSK, etc.)
- Retrodirected information contained in polarization
- Limited for line of sight use due to scattering effect on polarization





F_{LO} = 15.3575 GH

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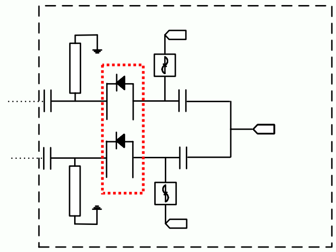
Exclusive Uplink/Downlink Modulation Retrodirective Array

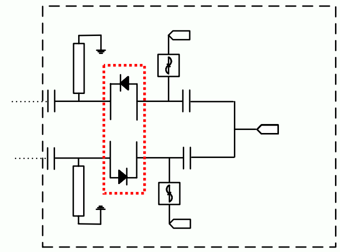
Case 1: V1=V2

(Co-directional Diode Current)



Case 2: V1=-V2

(Anti-directional Diode Current)



H_{in}	V_{in}	Pol-$Sense_{in}$	V(data)	H_{out}	V_{out}	Pol-$Sense_{out}$
0°	-90°	LHCP (-z prop)	V1=V2	0°	-(90)=+90°	LHCP (+z prop)
0°	-90°	LHCP (-z prop)	V1=-V2	0°	-(-90)-180=-90°	RHCP (+z prop)

V1(Data)

Phase conjugator/ polarization modulator

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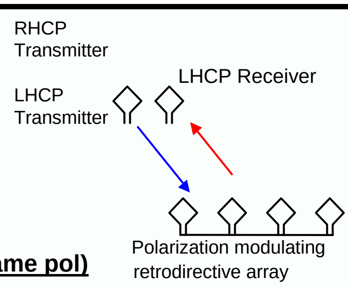
V-pol

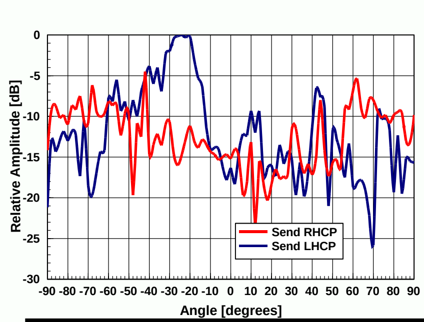
LO

RF)

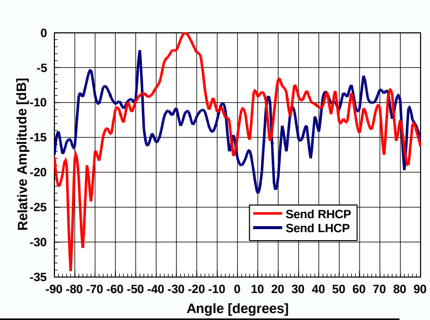
Exclusive Uplink/Downlink Modulation Retrodirective Array



V1=V2 (resend same pol)



V1=-V2 (resend opp. pol)



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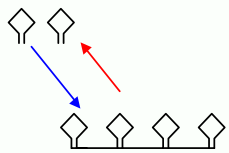
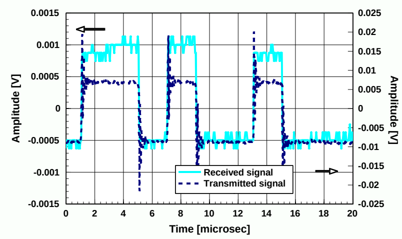
Exclusive Uplink/Downlink Modulation Retrodirective Array

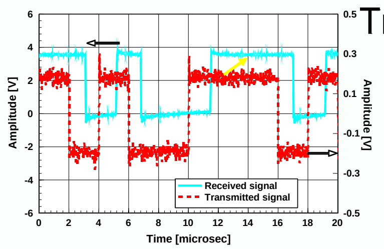


Received signal at receiver array (transmitted by transmitter-time domain)

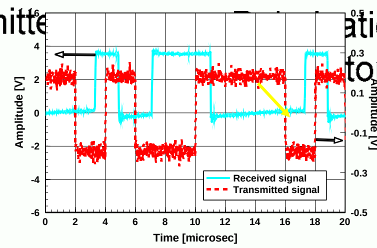


Recovered polarization modulation data

RHCP Transmitter



LHCP Transmitter



Transmitte ation tor

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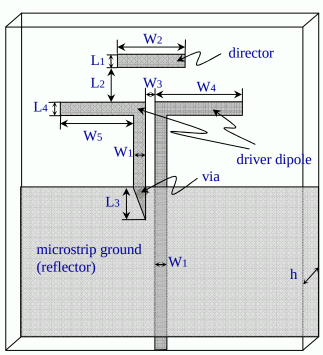
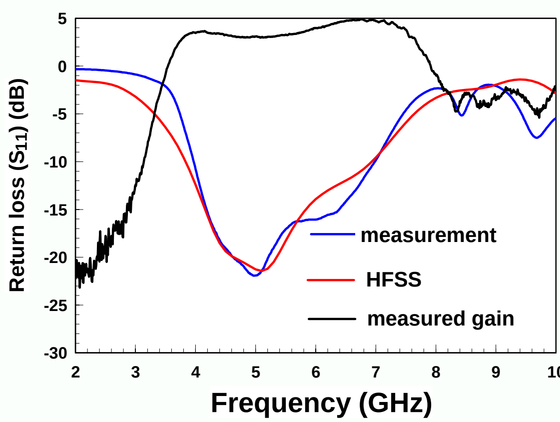
Receiver array   Polarization modulating retrodirective array

Broadband Quasi-Yagi Antenna





-Impedance Bandwidth:

S11 < -10 dB

55 % form 3.9 GHz to 7.0 GHz

-Constant Gain Bandwidth:

antenna gain of 3~5 dB

70 % form 3.8 GHz to 7.6 GHz

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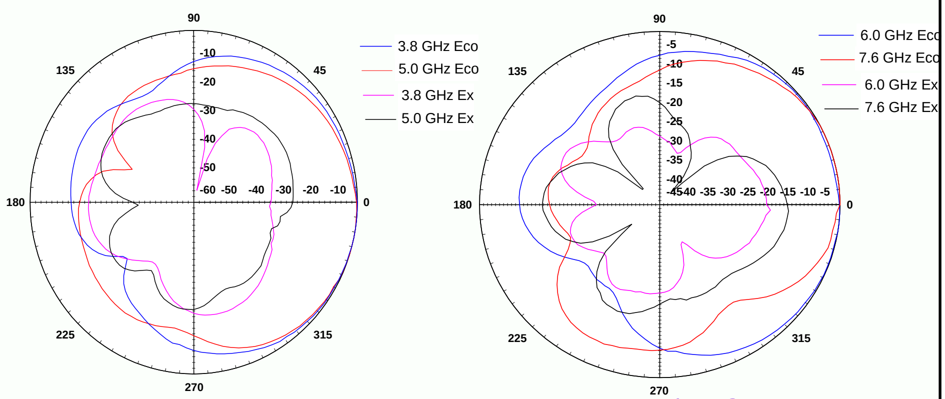
Broadband Quasi-Yagi Antenna



FTBR = 14 dB @ 3.8 GHz

X-pol. < -20 dB @ 3.8 GHz

FTBR = 12 dB @ 5.0 GHz

X-pol. < -21 dB @ 5.0 GHz

FTBR = 10 dB @ 6.0 GHz

X-pol. < -18 dB @ 6.0 GHz

FTBR = 11 dB @ 7.6 GHz

X-pol. < -13 dB @ 7.6 GHz

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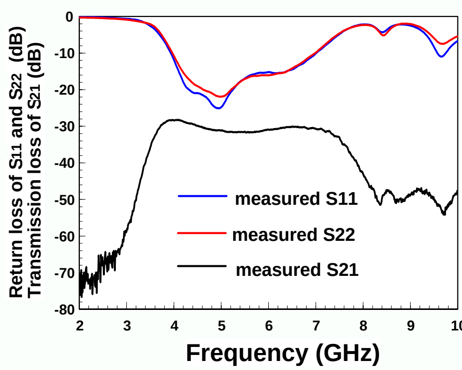
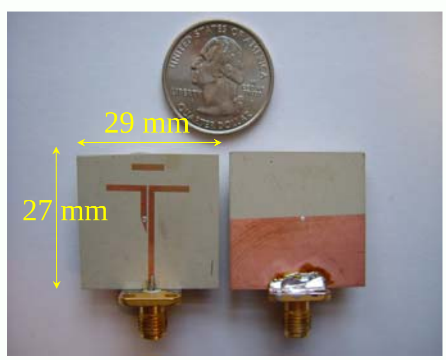
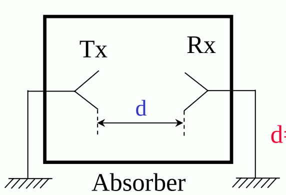
Broadband Quasi-Yagi Antenna







d=300 mm

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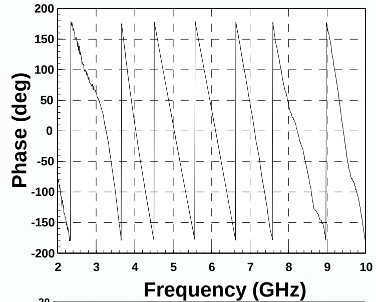
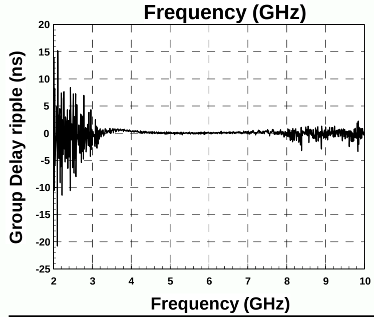
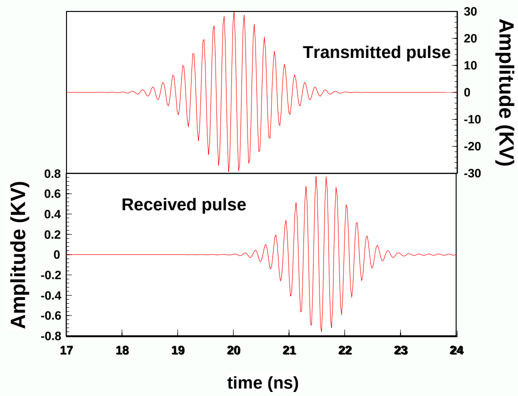
Broadband Quasi-Yagi Antenna







Gaussian Pulse Pulse width : 4ns

Group delay ripple less than 0.06 ns

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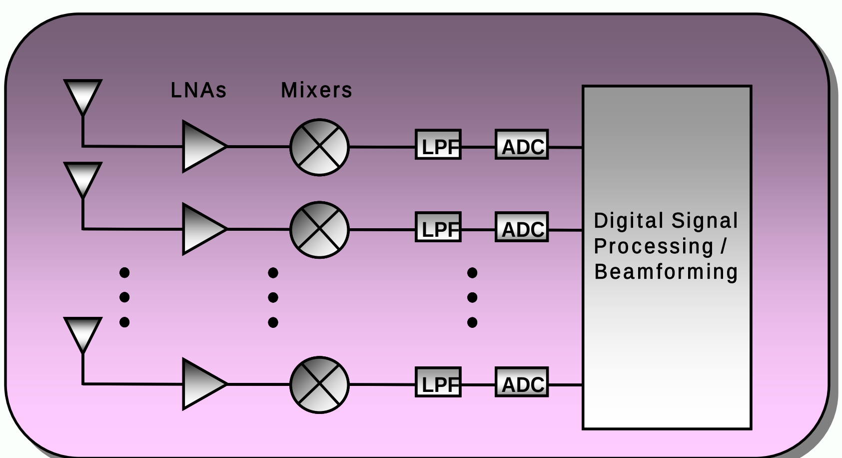
Single RF Channel SMART Antenna System



- N-channel array requires N individual receiver chains
- Each channel must be well matched and calibrated

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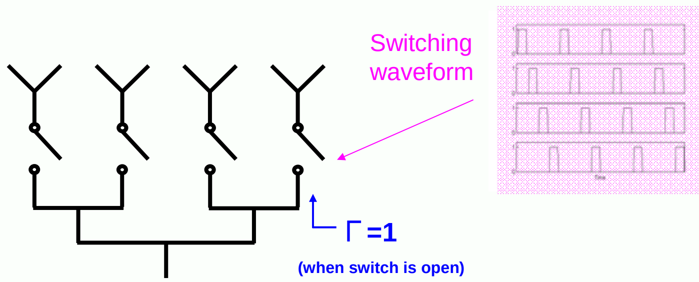
Single RF Channel SMART Antenna System



- SMILE (**S**patial **M**ult**I**plexing of **L**ocal **E**lements) scheme
  - ✓ Sequential switching samples signal at each element
  - ✓ Sampling rate greater than Nyquist rate
  - ✓ Parallel feed network retains all signal information
  - ✓ Sampling frequency limits signal modulation bandwidth

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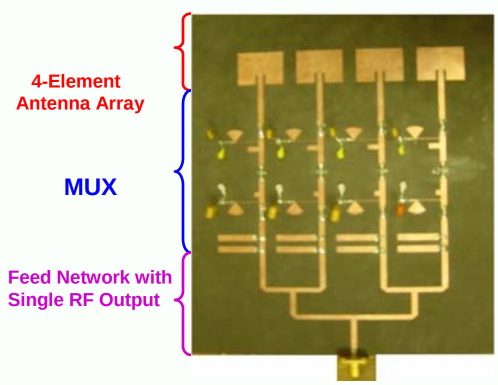
Single RF Channel SMART Antenna System



LNA MUX with patch antenna element at 5.8 GHz

- LNA MUX
  - ✓ NEC32485C Pseudomorphic HJ FET (LNAs) as switching element
  - ✓ Low-noise switching improves overall noise figure compared with passive switch
  - ✓ No current required to drive switching

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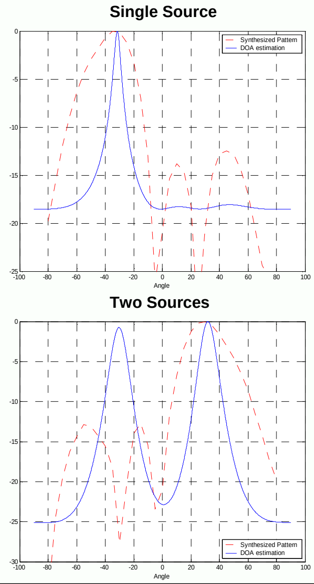
Single RF Channel SMART Antenna System



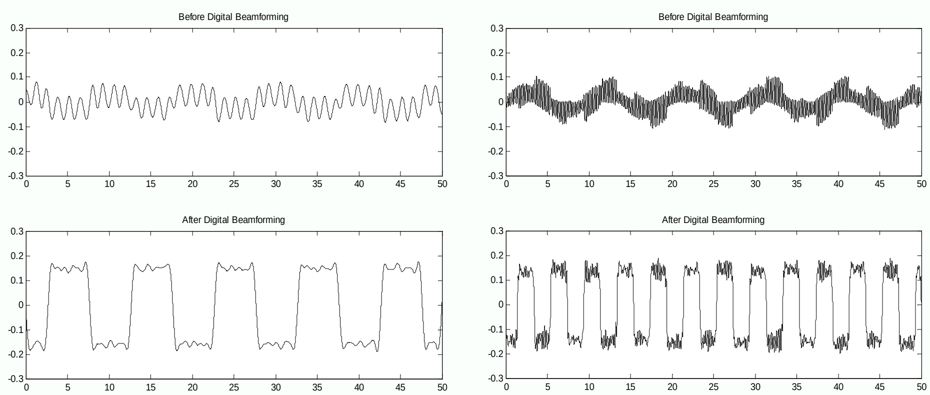
➢DOA Estimation

- ✓ Proper recovery of IF channel data allows advanced beamforming algorithms and DOA estimation
- ✓ MUSIC algorithm detects proper direction of signals

➢Synthesized Beamforming

- ✓ Beam formed indirection of source
- ✓ Null formed in direction of unwanted signal

Single RF Channel SMART Antenna System



➢Single Source Data Recovery

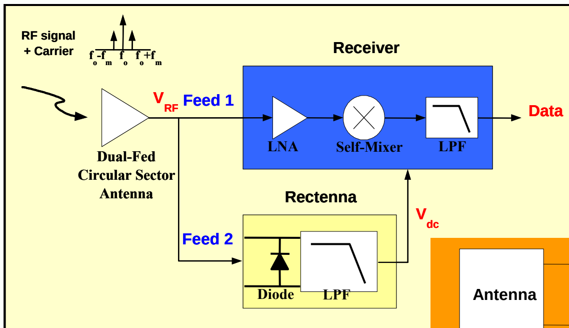
- ✓ **Coherent summation = clearer pattern**
- ✓ **More evident for angles off broadside**

➢Two Source Data Recovery

Incoherent demodulation does not resemble a digital pattern

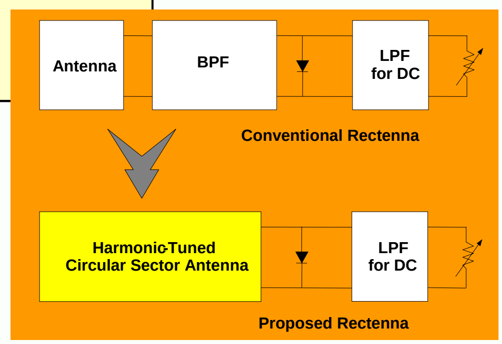
Interference 'nulling' shows spatial filtering

Self-Biased Receive System Using Sector Antenna



Important Roles of Filters

- **BPF** : Block the regenerated harmonic power from the diode
- **LPF** : Block all RF power



New Design

- Compact and Efficient Design
- Eliminate the BPF
- Higher-order harmonic rejection

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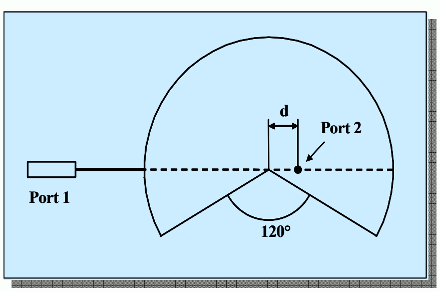
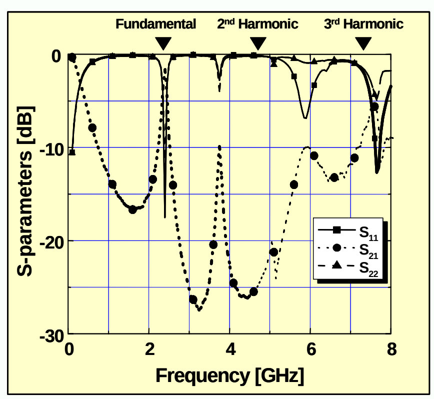
Self-Biased Receive System Using Sector Antenna

Layout



- Port 1 is for a receiver system
- Port 2 is for a rectenna

Measured S-parameters



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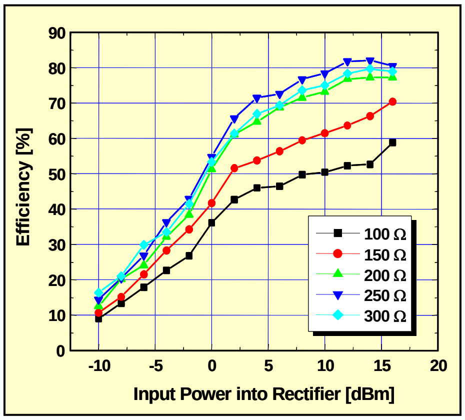
Self-Biased Receive System Using Sector Antenna

Rectenna Efficiency



Overall Efficiency

$$\eta_o = \frac{\text{dc output power}}{\text{incident RF power}} = \frac{V^2/R_{Load}}{P_A}$$

➢Up to **82%** efficiency at the optimum load resistance of 250Ω for 14dBm input power

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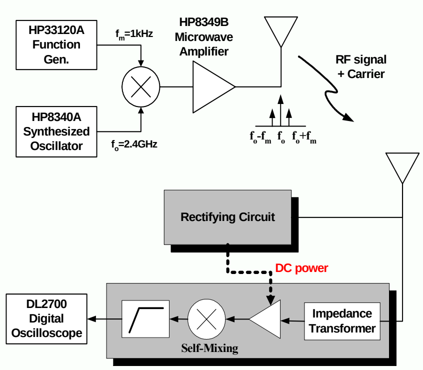
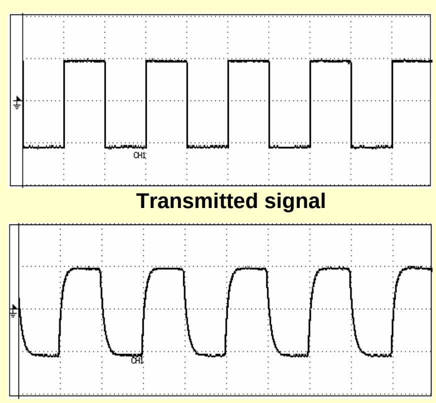
Self-Biased Receive System Using Sector Antenna

Digital Data Receiving





Transmitted signal

Received signal

•1-kHz digital data in the ASK format

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