Short Course on Electronically Scanned Reflectarrays - Real-Beam Radar

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Overview

Introduction

- **Function**: Radars sense angle, range and velocity of (moving) scatterers in the environment [1–4].

FMCW radar: FM ranging

- Range:

$$R = c\frac{T_c}{2}\frac{\Delta f}{f_m}$$

- Velocity:

$$v = \frac{\mathrm{d}\,R}{\mathrm{d}\,t}$$

Pulse-Doppler radar: pulse-delay ranging

- Range:

$$R = c\frac{\Delta t}{2}$$

- Velocity:

$$v = \frac{f_D \lambda_0}{2}$$

- Blind zone:

$$R_b = c\,(\tau_p + t_s)/2$$

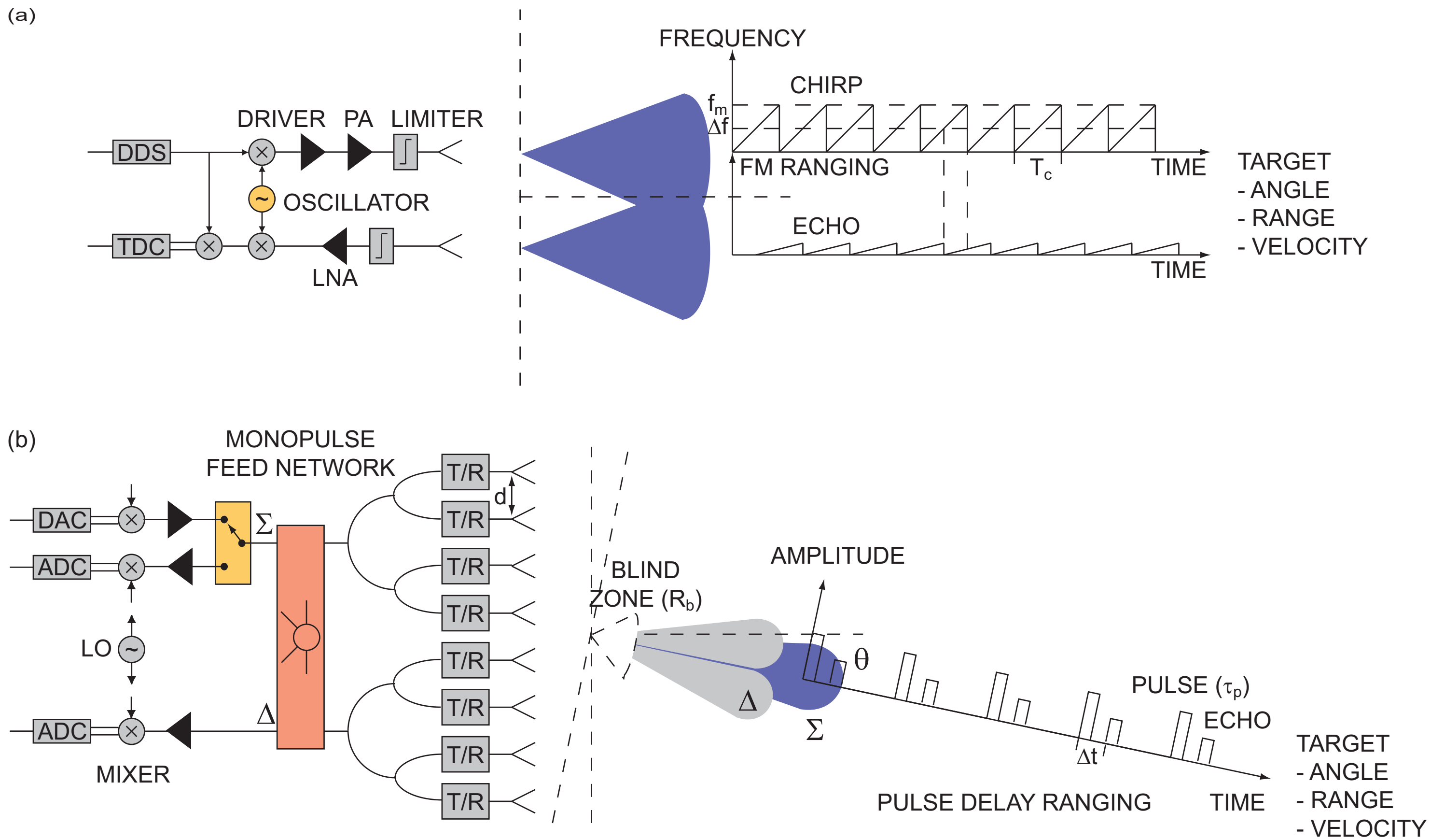

Figure 1: (a) A monostatic frequency modulated continuous wave (FMCW) radar. (b) A monostatic monopulse-Doppler radar based on an RF beamforming active electronically scanned array.

Radar Antennas

- **Function**: direction of arrival (DOA) sensing through field of view sampling with a directive antenna [5–9]
- Mechanically scanned antenna (M-Scan radar)
  - **Advantages**:
    - Cooling: no need for aperture cooling
    - Cost
    - Scan volume (gimbal), wide field of view
  - **Advantages**:
    - Scan rate
    - Scan volume (focal plane scanning [10]), limited field of view due to comatic aberration
    - Size, weight and wind resistance (Meshed reflectors have lower weight and wind resistance, but higher surface losses.)

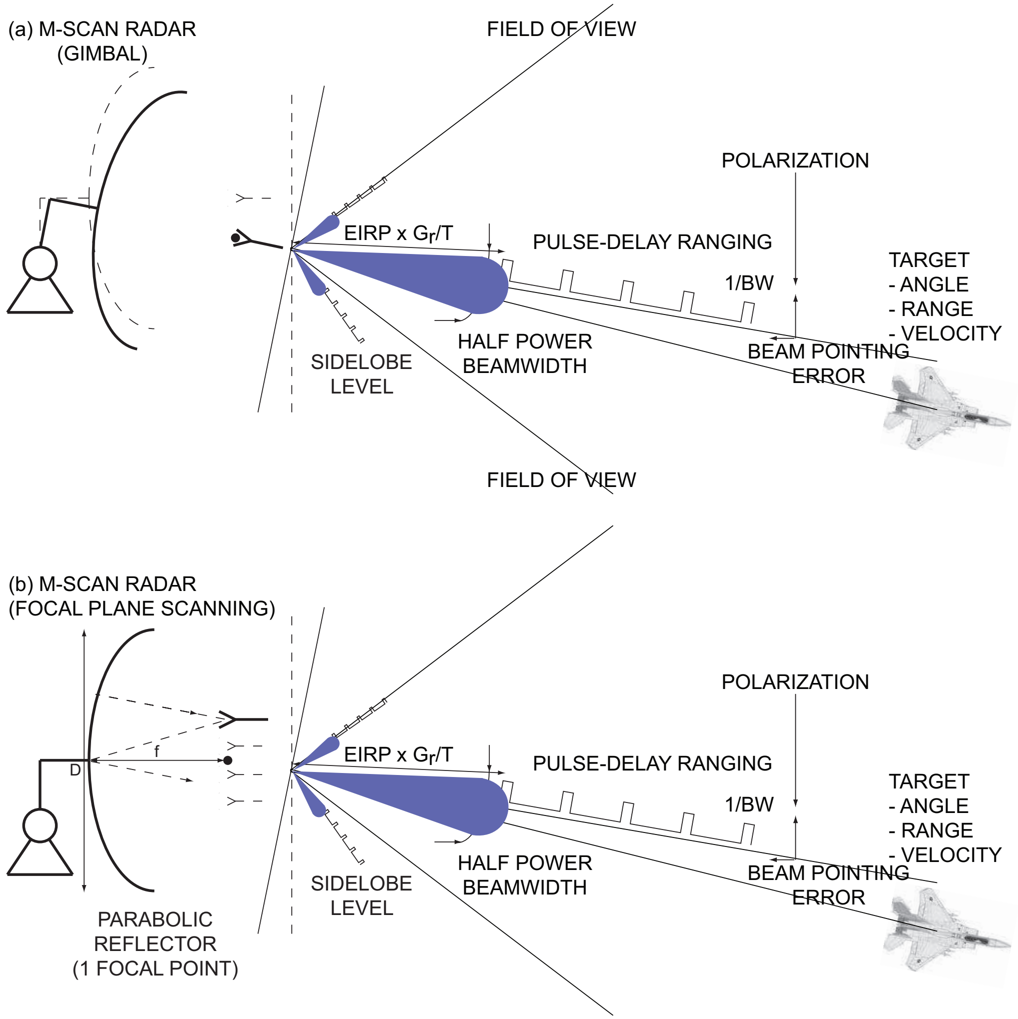

Figure 2: (a) M-Scan radar (gimbal) (b) M-Scan radar (focal plane scanning).

Radar Antennas

- **Function**: direction of arrival (DOA) sensing through field of view sampling with a directive antenna [5–9]
- Electronically scanned array (E-Scan radar)
  - **Advantages**:
    - Digitization-enabled (ABF, STAP) multiple simultaneous modes: air-to-air (search), air-to-surface (GMTE, GMTI), EW (ECCM, ECM, ESM), ...
    - Inertialess and instantaneous scanning: lightweight platforms, short reaction times and more time-on-target during search mode, ...
    - EIRP $\times$ G_r/T: high Tx power, low Rx sidelobe levels
    - Multiple simultaneous Rx channels: multi-target tracking (AESA), monopulse tracking, SLB, ...
    - RCS reduction
    - Reliability: graceful degradation due to use of solid-state power amplification (AESA)

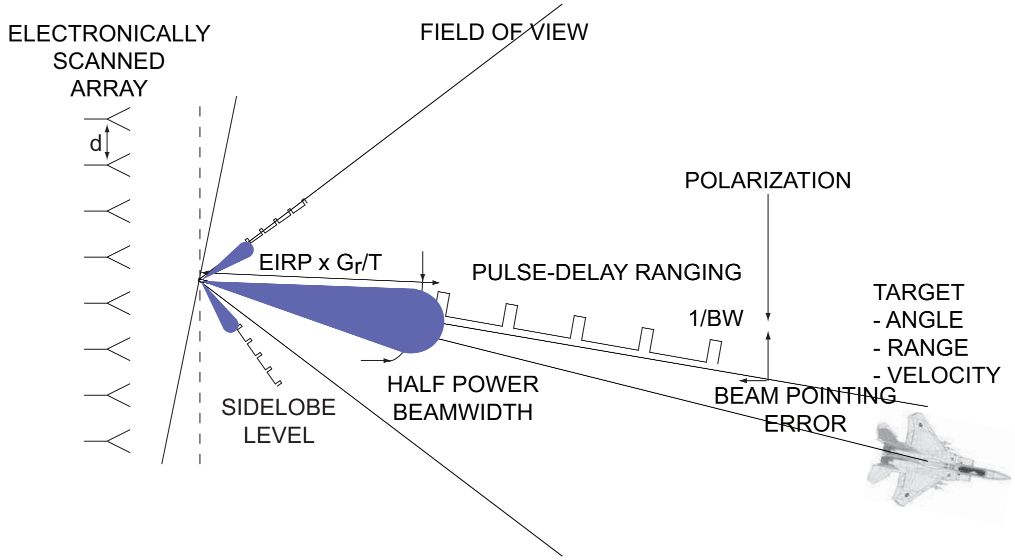

Figure 3: An electronically scanned array.

Radars: References

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[4] M. A. Richards, J. A. Scheer, and W. A. Holm, *Principles of Modern Radar*. SciTech Publishing, 2010.

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[6] ——, "Phased arrays - Part II: Implementations, applications, and future trends," *IEEE Trans. Microwave Theory Tech.*, vol. 50, no. 3, pp. 688–698, March 2002.

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High-Precision Direction-of-Arrival Sensing

The monopulse technique:

□ **Function**: Four-quadrant monopulse comparators are the proverbial cross hairs of a tracking radar. They increase the angular accuracy to a fraction of the beamwidth by comparing echoes, which originate from a single pulse and which are received in three concurrent and spatially-orthogonal channels, being the sum channel, Σ, the azimuth-difference channel, Δ_{AZ}, and the elevation-difference channel, Δ_{EL}. A four-quadrant monopulse comparator can be readily implemented by illuminating an electronically scanned reflectarray with a monopulse feed horn [1–5].

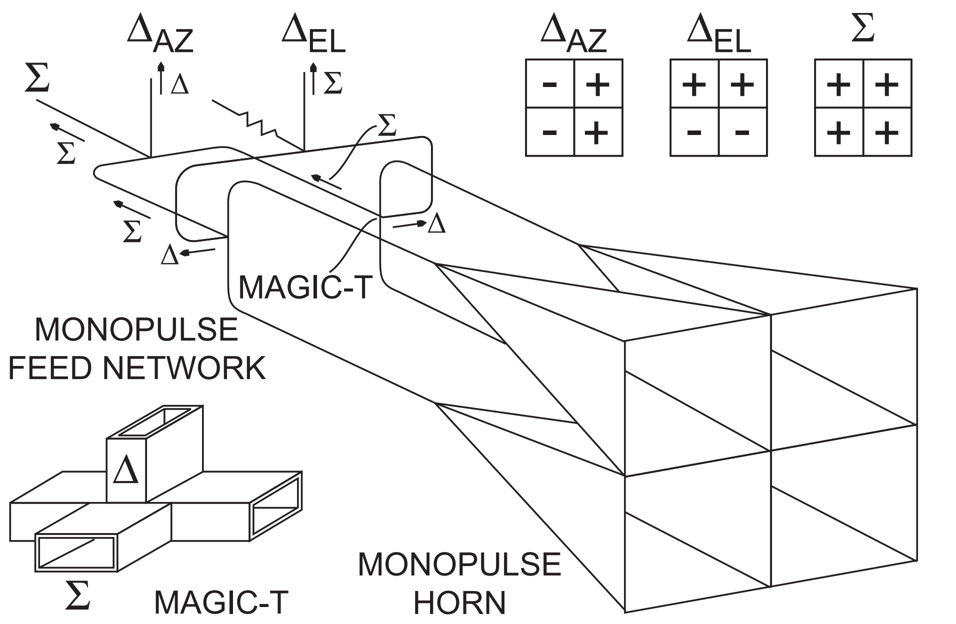

Figure 4: A four-horn square feed, connected to waveguide monopulse feed network.

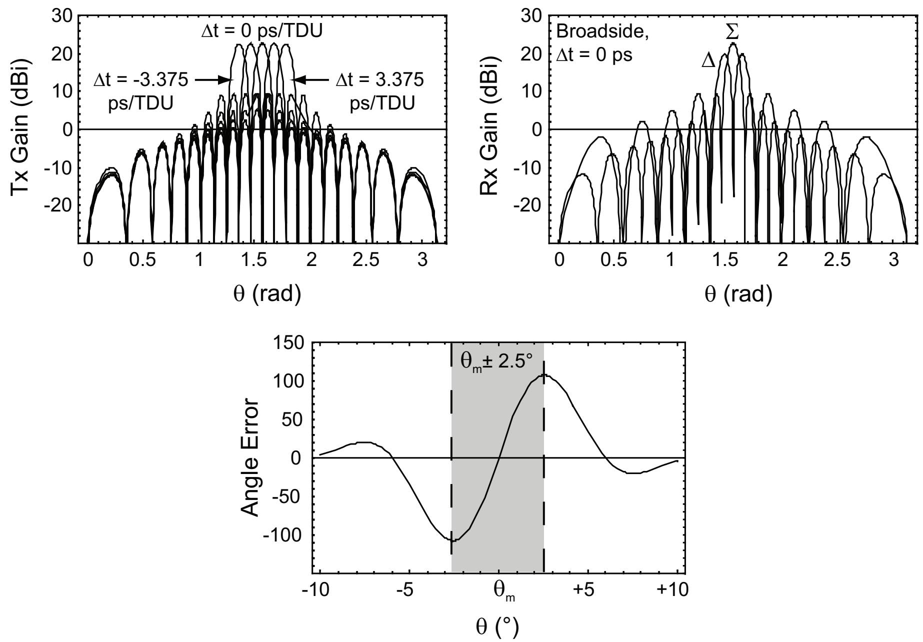

Figure 5: The monopulse error: $e = k\,\frac{\vec{\Sigma}\cdot\vec{\Delta}}{||\vec{\Sigma}||}$, in which k is the AGC factor, which is used to normalize e.

The monopulse technique:

- **Function**: Four-quadrant monopulse comparators are the proverbial cross hairs of a tracking radar. They increase the angular accuracy to a fraction of the beamwidth by comparing echoes, which originate from a single pulse and which are received in three concurrent and spatially-orthogonal channels, being the sum channel, Σ, the azimuth-difference channel, Δ_{AZ}, and the elevation-difference channel, Δ_{EL}. A four-quadrant monopulse comparator can be readily implemented by illuminating an electronically scanned reflectarray with a monopulse feed horn [1–5].

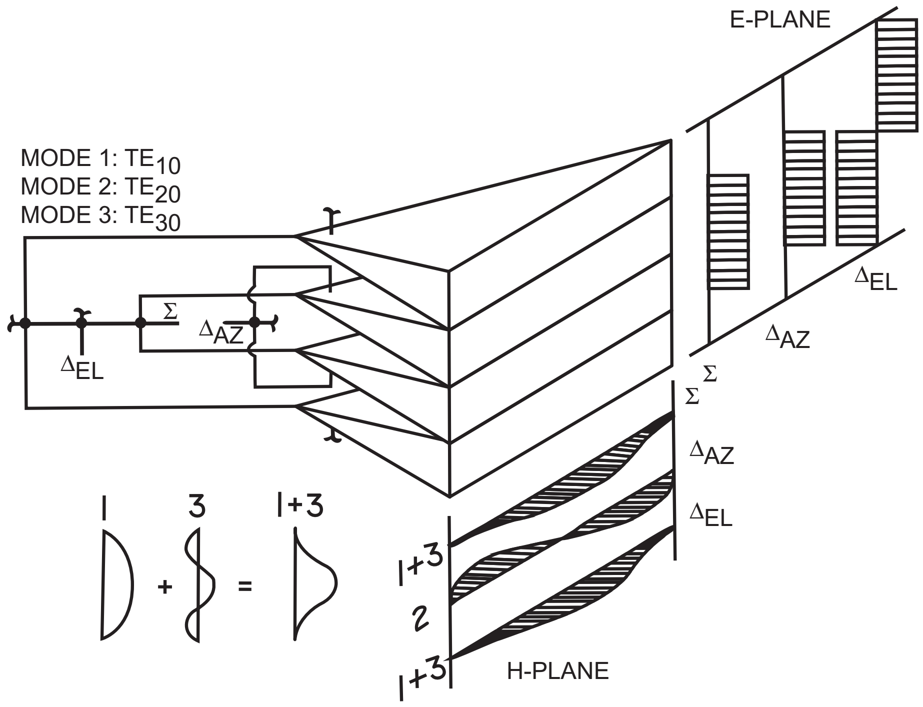

Figure 6: A four-horn triple-mode feed [1, 2].

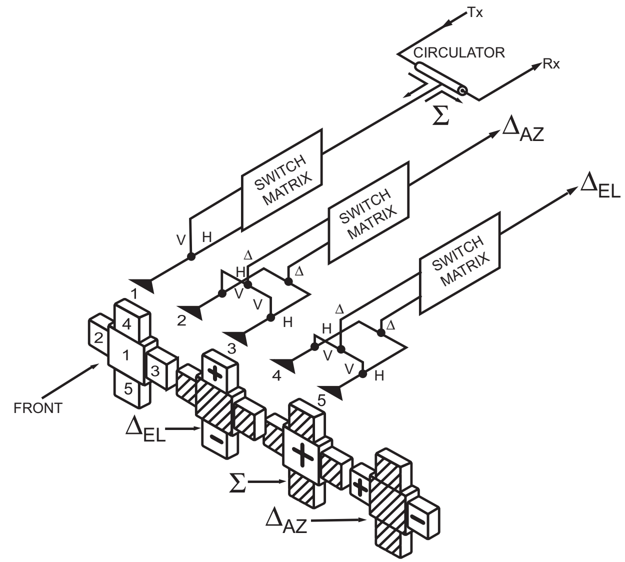

Figure 7: Five-horn feed with coupling to both linear-polarization components, which are combined by the switch matrix to select horizontal, vertical, or circular polarization [5].

High-Precision Direction-of-Arrival Sensing: References

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RF Beamforming Passive Subarrays

Passive Subarrays

- **Function**: Adding 2-D electronic scanning to 1-D RF beamforming AESA (or PESA) [1–4]
- **Advantages**:
  - Cost: lower compared to AESA solution
  - Size: feasible at Ka-band ($\lambda_0/2$ @ 35 GHz = 4.3 mm)
- **Disadvantages**:
  - EIRP, EIRP $\times$ G$_r/T$:
    - lower compared to AESA solution
    - f(N, θ_{MAX}), in which N is the # of antennas per passive subarray and $\pm\theta_{MAX}$ is the field of view

    A 38 GHz example is given; assume:

    - Aperture coupled microstrip antennas: η= 90%
    - Distributed loaded-line RF MEMS TTD phase shifters: 6.75 ps/dB, P_{MAX} = 500 mW
    - Wilkinson power dividers: IL = 0.3 dB

    N_{OPT} = 8 (θ_{MAX} = 34°): EIRP = 40 W (sufficient for Tx-only array), G$_r/T$ = 0.036 1/K (insufficient for Rx-only and T/R array)

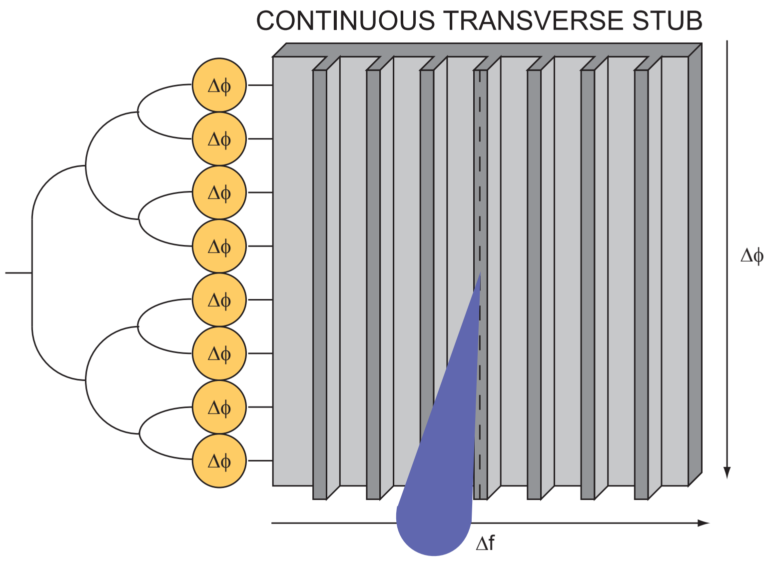

Figure 8: Stick-assembled continuous transverse stub fed by a passive subarray [1].

Passive Subarrays

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  - Size: feasible at Ka-band ($\lambda_0/2$ @ 35 GHz = 4.3 mm)
- **Disadvantages**:
  - EIRP, EIRP $\times$ G$_r/T$:
    - lower compared to AESA solution
    - f(N, θ_{MAX}), in which N is the # of antennas per passive subarray and $\pm\theta_{MAX}$ is the field of view

A 38 GHz example is given; assume:

- Aperture coupled microstrip antennas: η= 90%
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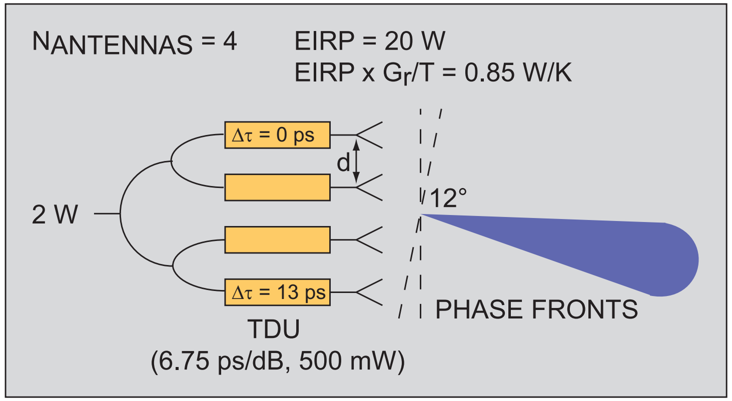

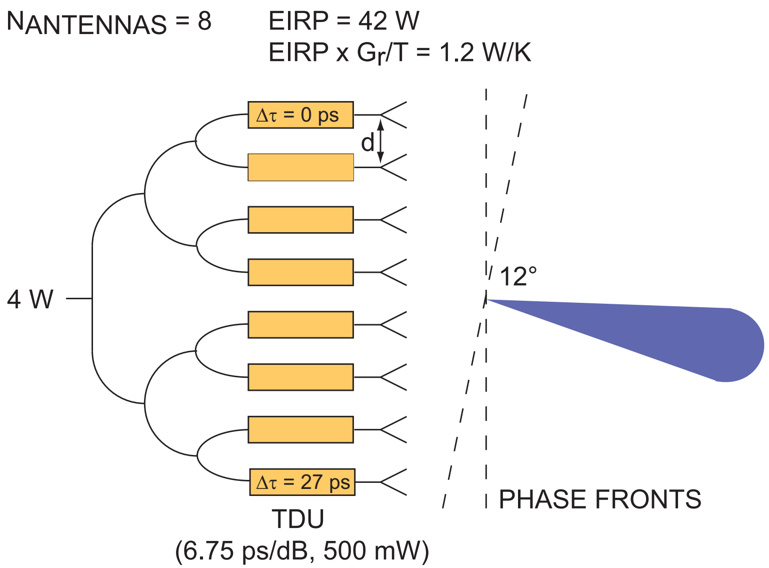

Figure 9: EIRP, EIRP $\times$ G$_r/T$ of RF MEMS passive subarray

Passive Subarrays

- **Function**: Adding 2-D electronic scanning to 1-D RF beamforming AESA (or PESA) [1–4]
- **Advantages**:
  - Cost: lower compared to AESA solution
  - Size: feasible at Ka-band ($\lambda_0/2$ @ 35 GHz = 4.3 mm)
- **Disadvantages**:
  - EIRP, EIRP $\times$ G$_r/T$:
    - lower compared to AESA solution
    - f(N, θ_{MAX}), in which N is the # of antennas per passive subarray and $\pm\theta_{MAX}$ is the field of view

    A 38 GHz example is given; assume:

    - Aperture coupled microstrip antennas: η= 90%
    - Distributed loaded-line RF MEMS TTD phase shifters: 6.75 ps/dB, P_{MAX} = 500 mW
    - Wilkinson power dividers: IL = 0.3 dB

    N_{OPT} = 8 (θ_{MAX} = 34°): EIRP = 40 W (sufficient for Tx-only array), G$_r/T$ = 0.036 1/K (insufficient for Rx-only and T/R array)

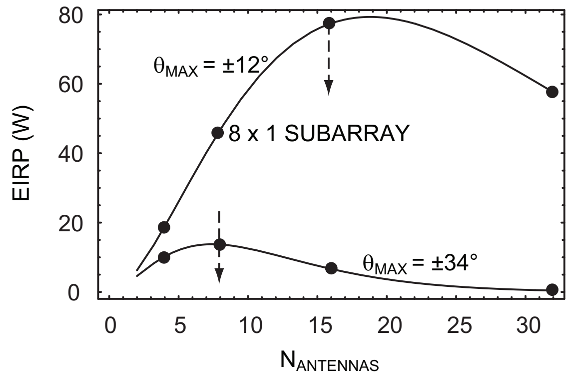

Figure 10: EIRP of RF MEMS passive subarray

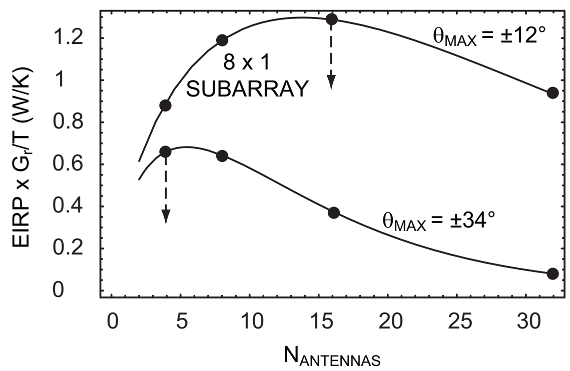

Figure 11: EIRP $\times$ G$_r/T$ of RF MEMS passive subarray

Passive Subarrays: Examples

Figure 12: Tikhomirov NIIP's X-band Irbis-E radar is a multi-mode hybrid electronically scanned array radar developed for the Sukhoi 35BM fighter aircraft (Western countries all but use AESA nose-cone radars).

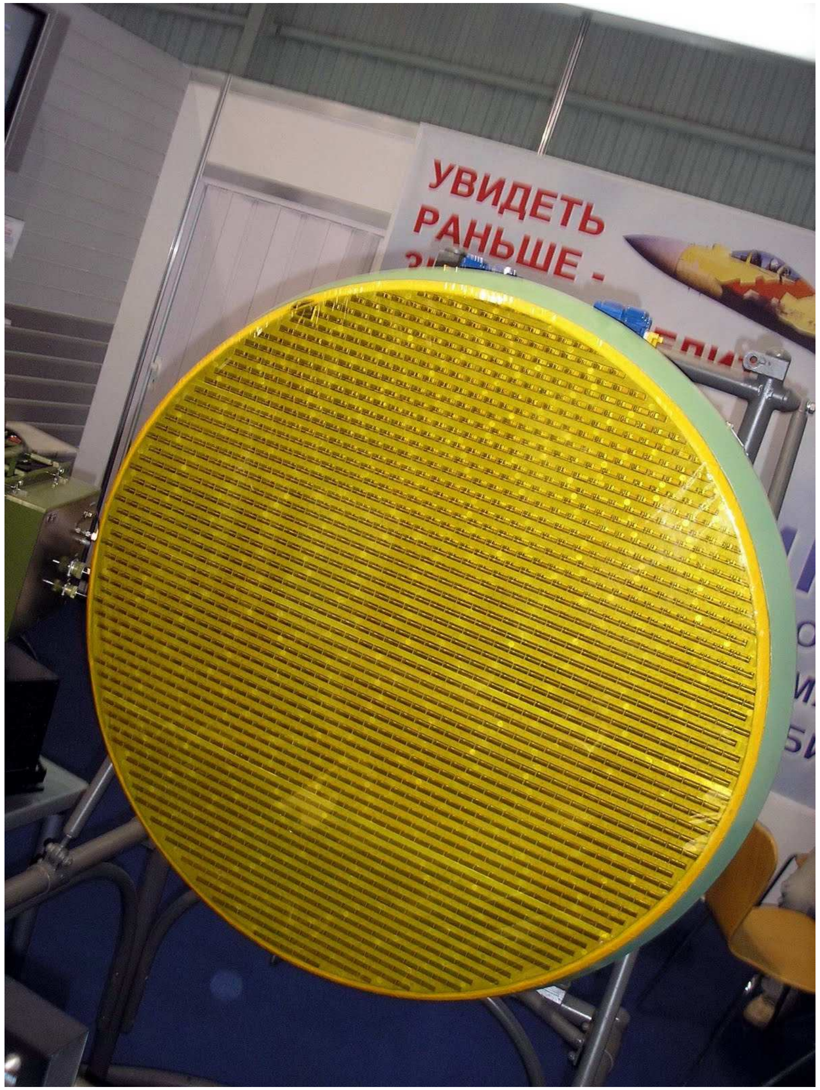

Figure 13: Tikhomirov NIIP's X-band Irbis-E radar.

Passive Subarrays: References

[1] C. Quan, J. J. Lee, B. M. Pierce, and R. C. Allison, "Wideband 2-D electronically scanned array with compact CTS feed and MEMS phase shifters," U.S. Patent 6,822,615, February 25, 2003.

[2] Raytheon technologies promise to improve radar affordability. [Online]. Available: http://investor.raytheon.com/phoenix.zhtml?c=84193&p=irol-newsArticle&ID=1176149

[3] B. Pillans, "RF MEMS (WFW01 workshop presentation)," in *European Microwave Week , Paris, France*, Sept. 29, 2010.

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RF Beamforming PESA Subsystems

- **Principle of Operation**: A lens array captures an unbounded wave, (TTD) phase shifts and reradiates the guided wave [1–4].
- **Advantages**:
  - Bandwidth: TTD-capable
  - Beam pointing error (3b $< \tilde{P} <$ 4b)
  - Monopulse-capable
  - No feed blockage, protrusion (Cassegrain)
  - Polarimetric
- **Disadvantages**:
  - Beam steering controller on the outside
  - Size and weight (brick assembly)
  - Spill-over loss (Tx) and noise (Rx)
- **Examples**:
  - Radant [3]

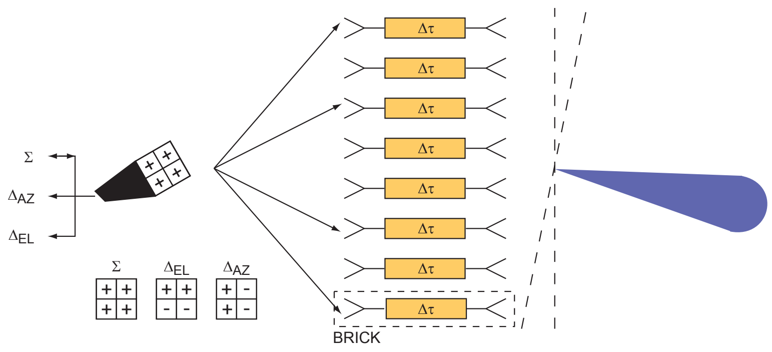

Figure 14: An UWB lens array is illuminated by a four-quadrant monopulse horn.

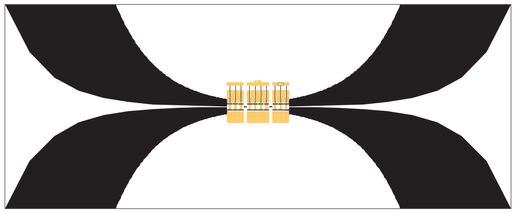

Figure 15: A *differential* UWB lens array brick (DETSA – slotline RF MEMS TTD phase shifter – DETSA)

Wideband Brick Assembled Lens Arrays

- **Principle of Operation**: A lens array captures an unbounded wave, (TTD) phase shifts and reradiates the guided wave [1–4].
- **Advantages**:
  - Bandwidth: TTD-capable
  - Beam pointing error (3b $< \tilde{P} <$ 4b)
  - Monopulse-capable
  - No feed blockage, protrusion (Cassegrain)
  - Polarimetric
- **Disadvantages**:
  - Beam steering controller on the outside
  - Size and weight (brick assembly)
  - Spill-over loss (Tx) and noise (Rx)
- **Examples**:
  - Radant [3]

Figure 16: Radant's X-Band RF MEMS electronically scanned lens array has a 0.4 square meter aperture area. It contains 25,000 RF MEMS switches [3].

Wideband Brick Assembled Lens Arrays: Patents

US005598172A

United States Patent [19] **Chekroun**

[11] **Patent Number: 5,598,172**
[45] **Date of Patent: Jan. 28, 1997**

[54] **DUAL-POLARIZATION MICROWAVE LENS AND ITS APPLICATION TO A PHASED-ARRAY ANTENNA**

[75] Inventor: **Claude Chekroun**, Gif sur Yvette, France

[73] Assignee: **Thomson - CSF Radant**, Les Ulis, France

[21] Appl. No.: **799,785**

[22] Filed: **Nov. 5, 1991**

[30] **Foreign Application Priority Data**

Nov. 6, 1990 [FR] France 90 13708

[51] **Int. Cl.**^{6} **H01Q 19/06**; H01Q 15/02
[52] **U.S. Cl.** **343/754**; 343/756; 343/909
[58] **Field of Search** .... 343/754, 756, 343/909, 911 R, 913

[56] **References Cited**

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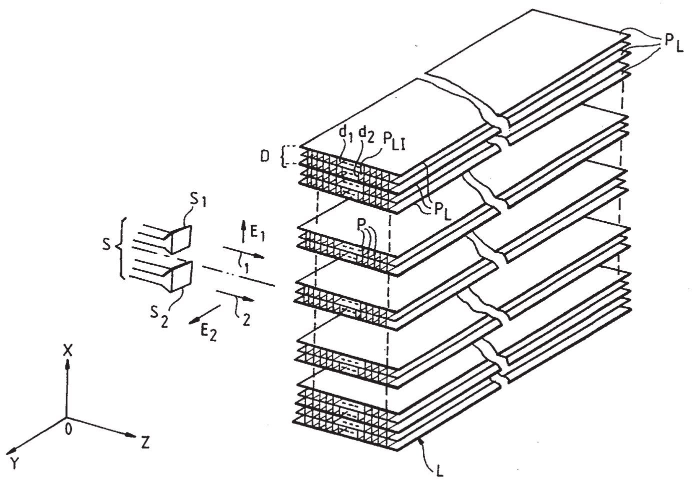
4,975,712	12/1990	Chen	343/754
5,001,495	3/1991	Chekroun	343/754
5,081,465	1/1992	Collignon	343/754

Primary Examiner—Gregory C. Issing
Attorney, Agent, or Firm—Pollock, Vande Sande & Priddy

[57] **ABSTRACT**

A microwave lens of the type described in the French patent No. 2,469,808 is adapted to operate with two crossed polarizations. To this end, each of the phase-shifting channels of the lens is subdivided into two subchannels, each of them being assigned to one of said polarizations. Each subchannel includes, in addition to phase-shifting panels, means for rotating by 90° the polarization of the incident wave and impedance matching means.

12 Claims, 8 Drawing Sheets



US006822615B2

(12) **United States Patent** **Quan et al.**

(10) **Patent No.: US 6,822,615 B2**
(45) **Date of Patent: Nov. 23, 2004**

(54) **WIDEBAND 2-D ELECTRONICALLY SCANNED ARRAY WITH COMPACT CTS FEED AND MEMS PHASE SHIFTERS**

(75) Inventors: **Clifton Quan**, Arcadia, CA (US); **Jar J. Lee**, Irvine, CA (US); **Brian M. Pierce**, Moreno Valley, CA (US); **Robert C. Allison**, Rancho Palos Verdes, CA (US)

(73) Assignee: **Raytheon Company**, Waltham, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 64 days.

(21) Appl. No.: **10/373,936**

(22) Filed: **Feb. 25, 2003**

(65) **Prior Publication Data**

US 2004/0164915 A1 Aug. 26, 2004

(51) **Int. Cl.**^{7} **H01Q 3/00**
(52) **U.S. Cl.** **343/754**; 342/376
(58) **Field of Search** 343/753, 754; 342/368, 369, 372, 376

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,160,519	A	*	12/2000	Hemmi	343/754
6,421,021	B1	*	7/2002	Rupp et al.	343/753
6,677,899	B1	*	1/2004	Lee et al.	342/376

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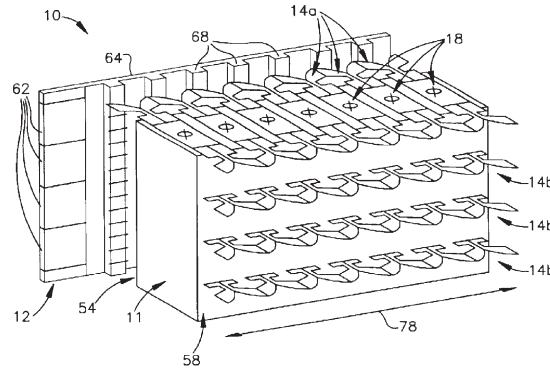
Primary Examiner—Michael C. Wimer
(74) *Attorney, Agent, or Firm*—Leonard A. Alkov; Karl A. Vick

(57) **ABSTRACT**

A microelectromechanical system (MEMS) steerable electronically scanned lens array (ESA) antenna and method of frequency scanning are disclosed. The MEMS ESA antenna includes a wide band feedthrough lens and a continuous transverse stub (CTS) feed array. The wide band feedthrough lens includes first and second arrays of wide band radiating elements and an array of MEMS phase shifter modules disposed between the first and second arrays of radiating elements. The continuous transverse stub (CTS) feed array is disposed adjacent the first array of radiating elements for providing a planar wave front in the near field. The MEMS phase shifter modules steer a beam radiated from the CTS feed array in two dimensions.

14 Claims, 5 Drawing Sheets



Wideband Brick Assembled Lens Arrays: References

[1] C. Chekroun, "Microwave phase shifter and its application to electronic scanning," U.S. Patent 4,320,404, February 24, 1981.

[2] ——, "Dual-polarization microwave lens and its application to a phased-array antenna," U.S. Patent 5,598,172, November 05, 1991.

[3] J. J. Maciel, J. F. Slocum, J. K. Smith, and J. Turtle, "MEMS electronically steerable antennas for fire control radars," *IEEE Aerosp. Electron. Syst. Mag*, vol. 22, no. 11, pp. 17–20, November 2007.

[4] K. Van Caekenberghe and T. Vähä-Heikkilä, "An analog RF MEMS slotline true-time-delay phase shifter," *IEEE Trans. Microwave Theory Tech.*, vol. 56, no. 9, pp. 2151–2159, September 2008.

Resonant Tile Assembled Reflectarrays

- **Principle of operation**: A tunable impedance surface reflects an unbounded wave in a desired direction by tuning the surface impedance (reactance) of unit cells in order to obtain a linear reflection phase shift progression over the surface [1–6].
- **Advantages**:
  - Beam steering controller on the backside
  - EIRP $\times$ G$_r/T$: higher than for a brick-assembled lens or reflectarray
  - Monopulse-capable
  - Size and weight (tile-assembly)
- **Disadvantages**:
  - Bandwidth: resonant
  - Beam pointing error (1b $< \tilde{P} <$ 2b)
  - Feed blocking, protrusion (Cassegrain)
  - (Single Polarized)
  - Spill-over loss (Tx) and noise (Rx)

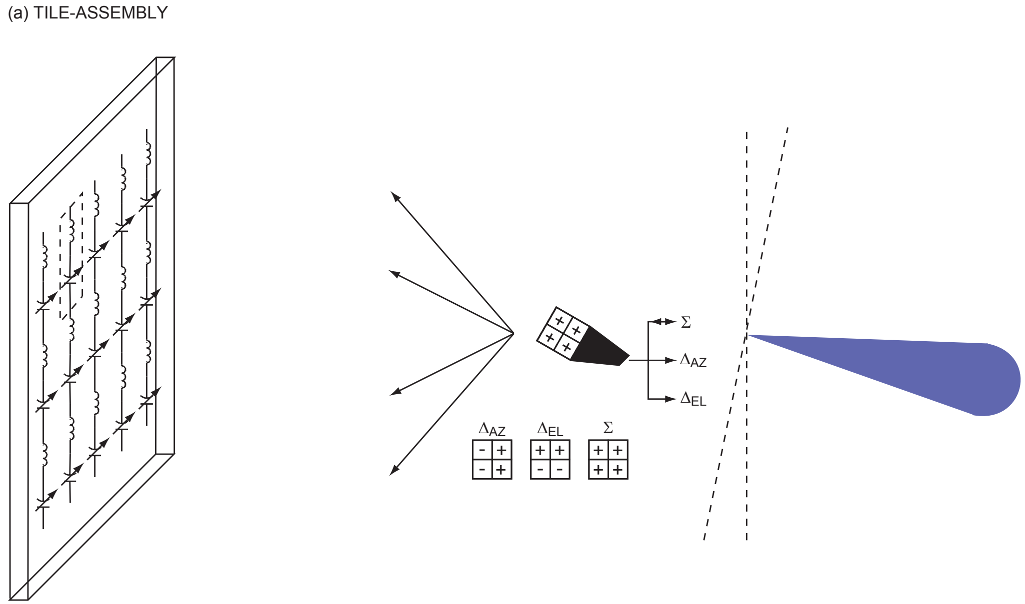
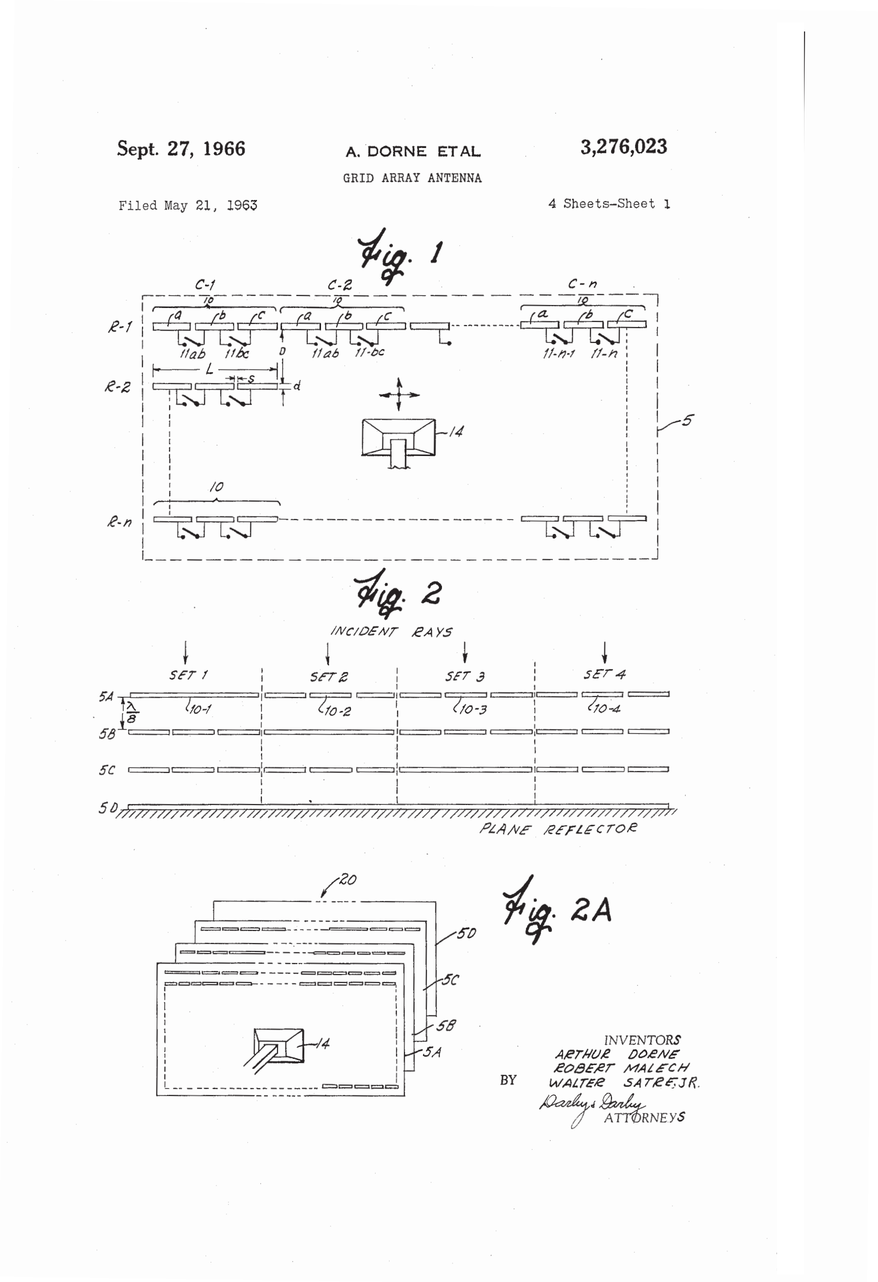
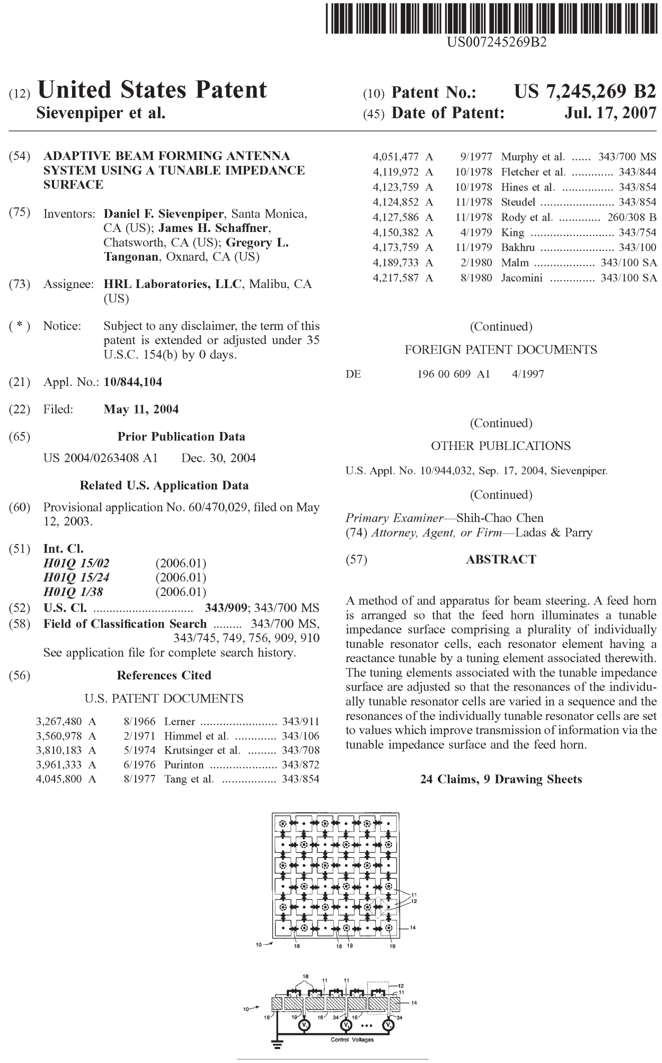


Figure 17: (a) tile-assembled resonant RF MEMS tunable impedance surface

Resonant Tile Assembled Reflectarrays: Patents





US007245269B2

(12) **United States Patent**
Sievenpiper et al.

(10) **Patent No.:** US 7,245,269 B2
(45) **Date of Patent:** Jul. 17, 2007

(54) **ADAPTIVE BEAM FORMING ANTENNA SYSTEM USING A TUNABLE IMPEDANCE SURFACE**

(75) Inventors: **Daniel F. Sievenpiper**, Santa Monica, CA (US); **James H. Schaffner**, Chatsworth, CA (US); **Gregory L. Tangonan**, Oxnard, CA (US)

(73) Assignee: **HRL Laboratories, LLC**, Malibu, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/844,104**

(22) Filed: **May 11, 2004**

(65) **Prior Publication Data**

US 2004/0263408 A1 Dec. 30, 2004

Related U.S. Application Data

(60) Provisional application No. 60/470,029, filed on May 12, 2003.

(51) **Int. Cl.**
H01Q 15/02 (2006.01)
H01Q 15/24 (2006.01)
H01Q 1/38 (2006.01)

(52) **U.S. Cl.** .... **343/909**; 343/700 MS

(58) **Field of Classification Search** .... 343/700 MS, 343/745, 749, 756, 909, 910
See application file for complete search history.

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Primary Examiner—Shih-Chao Chen
(74) *Attorney, Agent, or Firm*—Ladas & Parry

(57) **ABSTRACT**

A method of and apparatus for beam steering. A feed horn is arranged so that the feed horn illuminates a tunable impedance surface comprising a plurality of individually tunable resonator cells, each resonator element having a reactance tunable by a tuning element associated therewith. The tuning elements associated with the tunable impedance surface are adjusted so that the resonances of the individually tunable resonator cells are varied in a sequence and the resonances of the individually tunable resonator cells are set to values which improve transmission of information via the tunable impedance surface and the feed horn.

24 Claims, 9 Drawing Sheets

Resonant Tile Assembled Reflectarrays: Examples

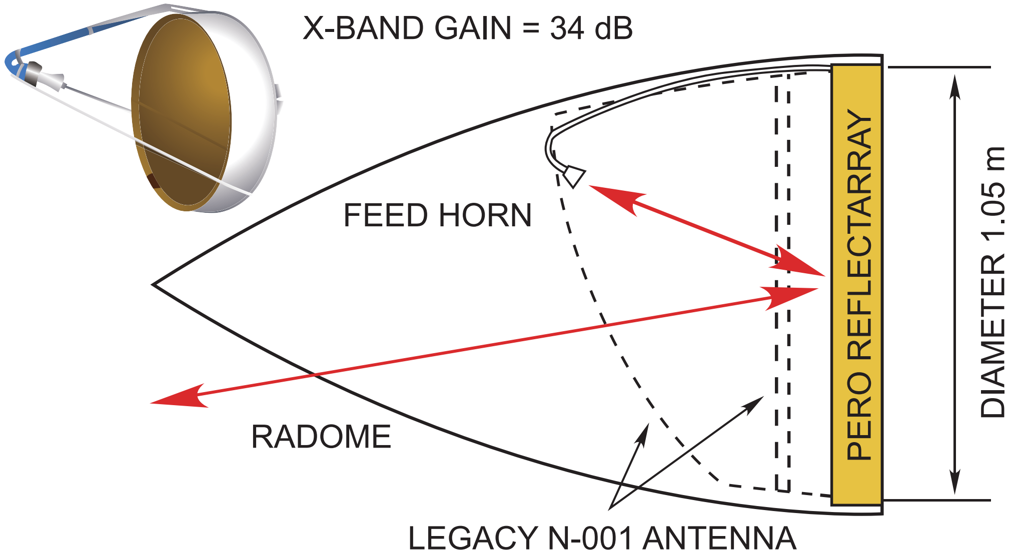

Figure 18: Tikhomirov NIIP's low-weight X-band Pero electronically scanned reflectarray for a Sukhoi 30 fighter aircraft nose-cone radar upgrade (Western countries all but use AESA nose-cone radars).

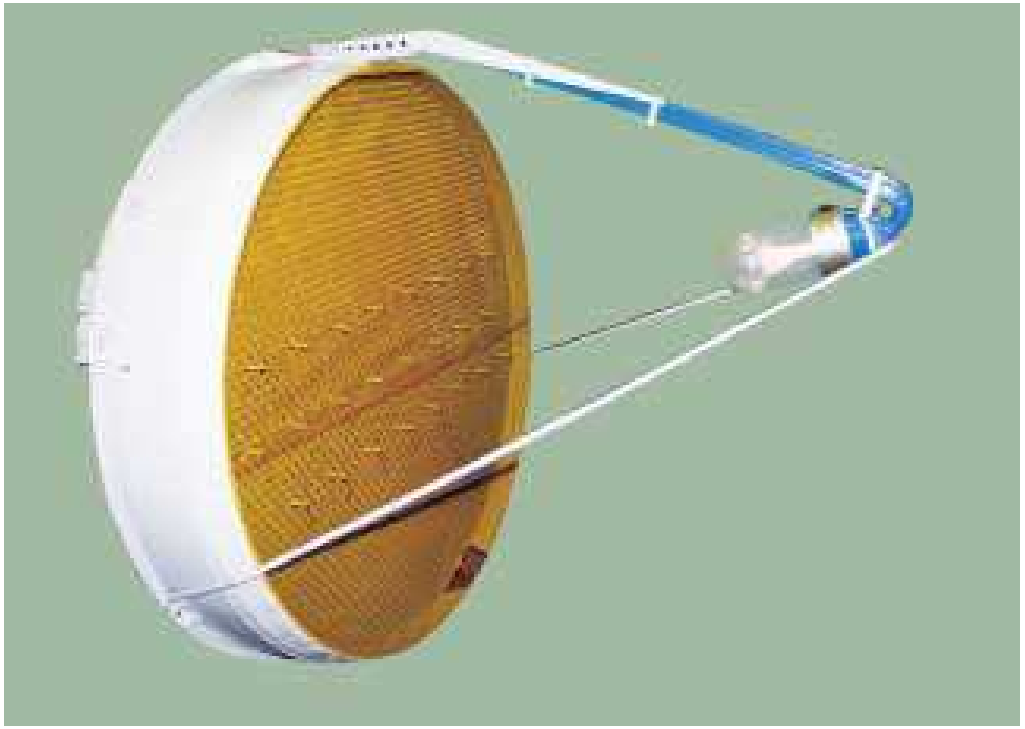

Figure 19: Tikhomirov NIIP's low-weight X-band Pero electronically scanned reflectarray.

Resonant Tile Assembled Reflectarrays: Opportunities

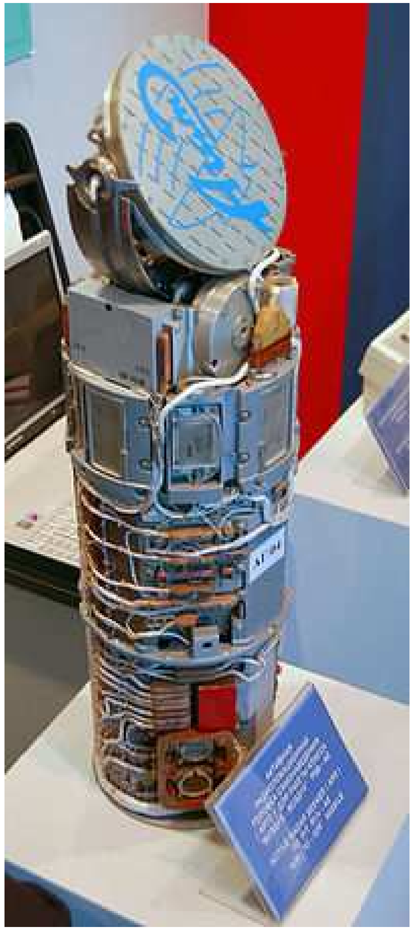

Figure 20: E-Scan radar upgrade for resonant-fed slotted waveguide based M-Scan radars. Shown: Moscow Agat Research Institute X-band 9B-1103M monopulse-Doppler radar active homing head for the Vympel R-77 (RVV-AE) air-to-air missile.

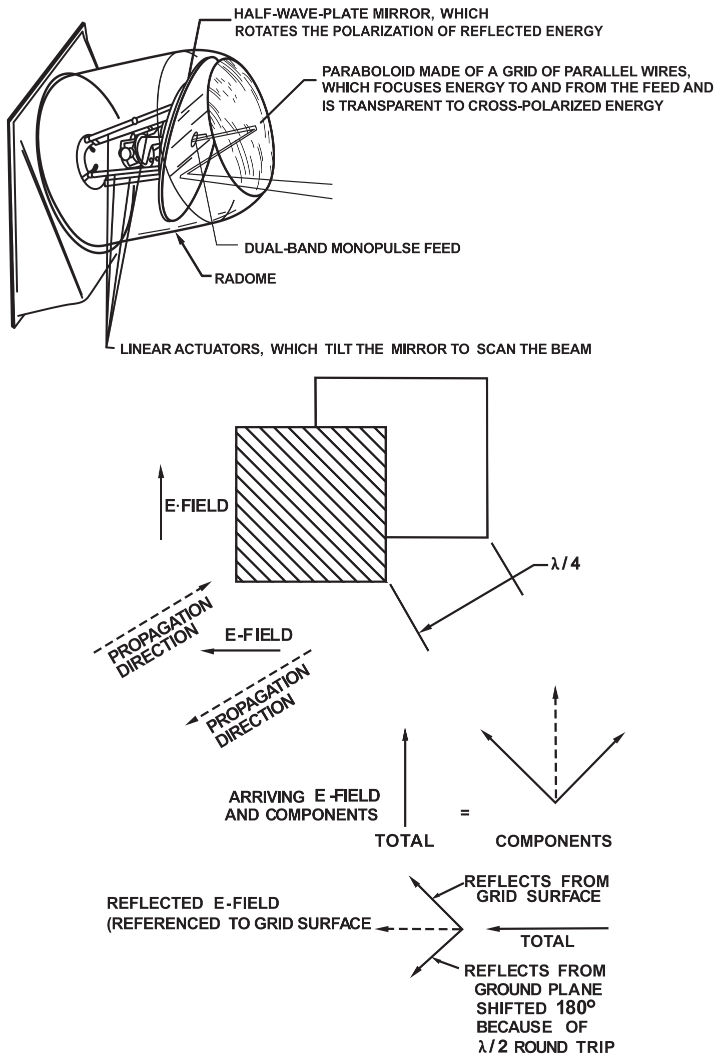

Figure 21: E-Scan radar upgrade for inverse Cassegrain dual reflector antenna based M-Scan radars. Picture recovered from [7].

Wideband Brick Assembled Reflectarrays

- **Principle of operation**: Brick-assembled reflectarrays based on antennas and (TTD) phase shifters capture the unbounded wave, and (TTD) phase shift, reflect, (TTD) phase shift, and reradiate the guided wave [8–14].
- **Advantages**:
  - Bandwidth: TTD-capable
  - Beam pointing error (3b $< \tilde{P} <$ 4b)
  - Beam steering controller on the backside
  - Monopulse-capable
  - Polarimetric
- **Disadvantages**:
  - EIRP $\times$ G$_r/T$: Lower than for a tunable impedance surface, higher than for a lens
  - Feed blocking, protrusion (Cassegrain)
  - Size and weight (brick assembly)
  - Spill-over loss (Tx) and noise (Rx)

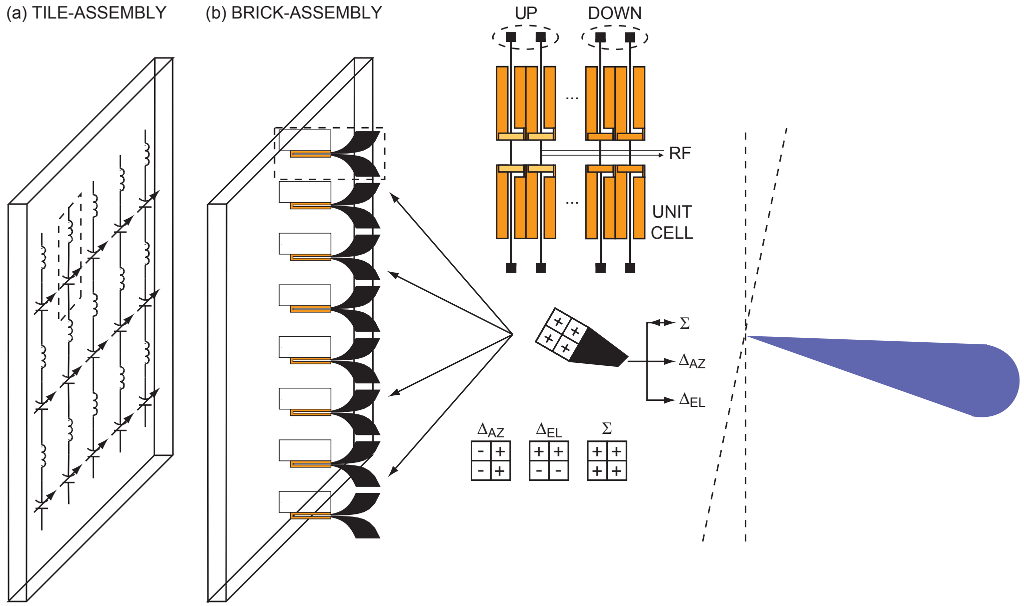

Figure 22: (a) tile-assembled resonant RF MEMS tunable impedance surface, (b) brick-assembled ultra wideband RF MEMS reflectarray, (inset) *differential* RF MEMS slotline TTD reflection phase shifter.

Wideband Brick Assembled Reflectarrays

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  - Spill-over loss (Tx) and noise (Rx)

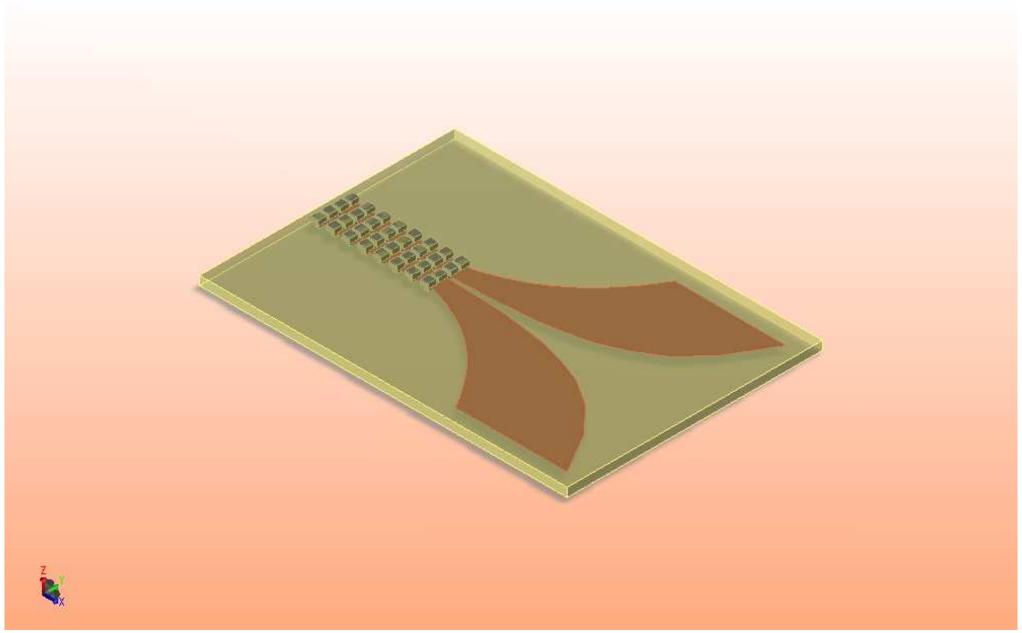

Figure 23: Artist impression of an RF MEMS reflectarray brick with 3:1 bandwidth.

Wideband Brick Assembled Reflectarrays

- **Principle of operation**: Brick-assembled reflectarrays based on antennas and (TTD) phase shifters capture the unbounded wave, and (TTD) phase shift, reflect, (TTD) phase shift, and reradiate the guided wave [8–14].

- **Advantages**:
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  - Monopulse-capable
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- **Disadvantages**:
  - EIRP $\times$ G$_r/T$: Lower than for a tunable impedance surface, higher than for a lens
  - Feed blocking, protrusion (Cassegrain)
  - Size and weight (brick assembly)
  - Spill-over loss (Tx) and noise (Rx)

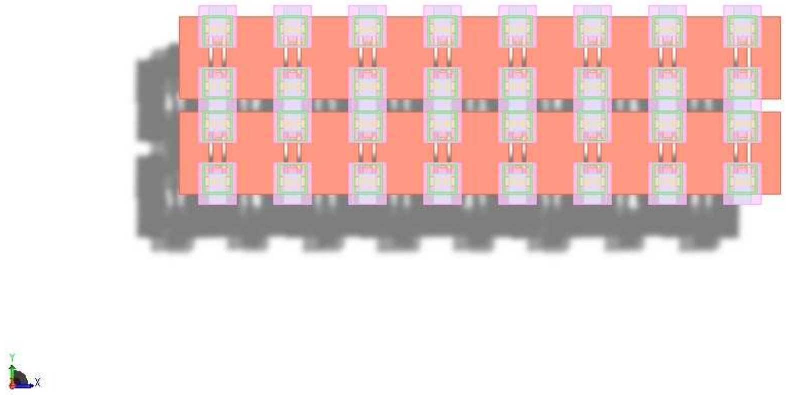

Figure 24: Artist impression of a *differential* slot-line TTD reflection phase shifter based on Radant RMSW200 SPST RF MEMS switches.

United States Patent [11] 3,569,974

[72] Inventor **Willard W. McLeod, Jr.**
Lexington, Mass.
[21] Appl. No. **693,531**
[22] Filed **Dec. 26, 1967**
[45] Patented **Mar. 9, 1971**
[73] Assignee **Raytheon Company**
Lexington, Mass.

[54] **DUAL POLARIZATION MICROWAVE ENERGY PHASE SHIFTER FOR PHASED ARRAY ANTENNA SYSTEMS**
12 Claims, 12 Drawing Figs.

[52] **U.S. Cl.** **343/754,** 333/21, 333/24.1, 333/24.3, 333/98, 343/756, 343/778, 343/854
[51] **Int. Cl.** **H01p 1/16,** H03h 5/12, H01g 19/06
[50] **Field of Search** .... 343/754—756, 854, 778, 909 (Cursory); 333/24.1, 24.3, 21 (A), 21

[56] **References Cited**

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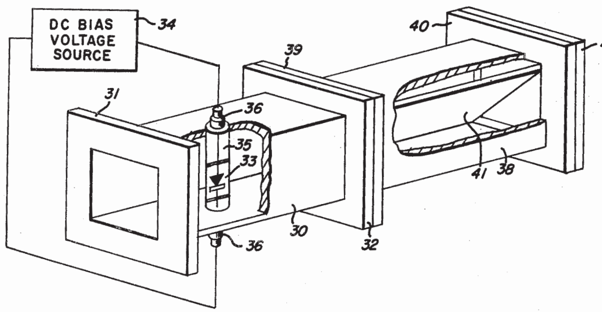
Nolen, J. C., " Phased Array Polarization Agility" IEEE Trans. on Antennas & Propagation, Vol. AP— 13, 1965 pp. 820— 821

Primary Examiner—Eli Lieberman
Assistant Examiner—Wm. H. Punter
Attorneys—Harold A. Murphy, Joseph D. Pannone and Edgar O. Rost

ABSTRACT: A phase shifter is disclosed for supporting dual orthogonal polarization modes of propagated microwave energy in tactical electrically beam scanning phased array antenna systems of the optically fed reflector type. Reentrant single port antenna array elements provide a predetermined electrical phase shift of linear as well as circular polarized energy. Incident waves received by each element oriented in one plane of polarization, for example, a vertical wave, will be electrically shifted and launched after traversal of the device as, illustratively, a horizontally oriented wave. Each element incorporates a circular polarizer as well as reflective termination member together with solid state phase shifting means.



United States Patent [19]

Chekroun

[11] **4,320,404**
[45] **Mar. 16, 1982**

[54] **MICROWAVE PHASE SHIFTER AND ITS APPLICATION TO ELECTRONIC SCANNING**

[75] Inventor: **Claude Chekroun,** Bures Sur Yvette, France
[73] Assignee: **Societe d'Etude du Radant,** Orsay, France
[21] Appl. No.: **237,642**
[22] Filed: **Feb. 24, 1981**

Related U.S. Application Data

[63] Continuation of Ser. No. 971,546, Dec. 20, 1978.

[30] **Foreign Application Priority Data**

Dec. 20, 1977 [FR] France 77 38354

[51] **Int. Cl.**[3] **H01Q 3/26**
[52] **U.S. Cl.** **343/854;** 343/754; 343/786
[58] **Field of Search** 343/854, 754, 756, 909, 343/755, 757, 778; 333/21, 24.1, 24.3, 98

[56] **References Cited**

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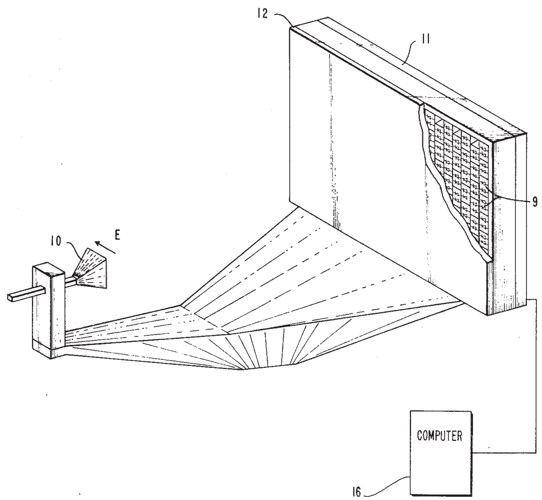
Primary Examiner—David K. Moore
Attorney, Agent, or Firm—Finnegan, Henderson, Farabow, Garrett and Dunner

[57] **ABSTRACT**

A plurality of metallic wire conductors are fitted in shunt along a shorted wave guide parallel to a dielectric field of electromagnetic wave incident to the wave guide. At least some of the wires have diodes mounted on them such that selective biasing of the diodes renders these wires discontinuous and causes a controlled phase shift of the incident wave.

10 Claims, 6 Drawing Figures



Wideband Brick Assembled Reflectarrays: References

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- **Principle of operation**: It is a cascade of a single pole N throw (SPNT) switch and a beamformer (beamforming matrix or lens or reflector based focal plane scanner [1–4]).
- **Advantages**:
  - Bandwidth: TTD-capable, if based on focal plane scanner (parabolic reflector, Luneburg or Rotman lens)
- **Disadvantages**:
  - Bandwidth: coupler limited, if based on beamforming matrix (Blass, Butler, Nolen)
  - Beam pointing error: high, B beam positions versus 2^{2P-1} beam positions for (TTD) phase shifter based ESA
  - EIRP $\times$ G$_r/T$: P_T limited by linearity and cold-switched power handling of SPNT switch. G lowered by insertion loss (IL) of SPNT switch and beamformer.
  - Field of view: related to f/D (IL, size)
  - Not monopulse-capable

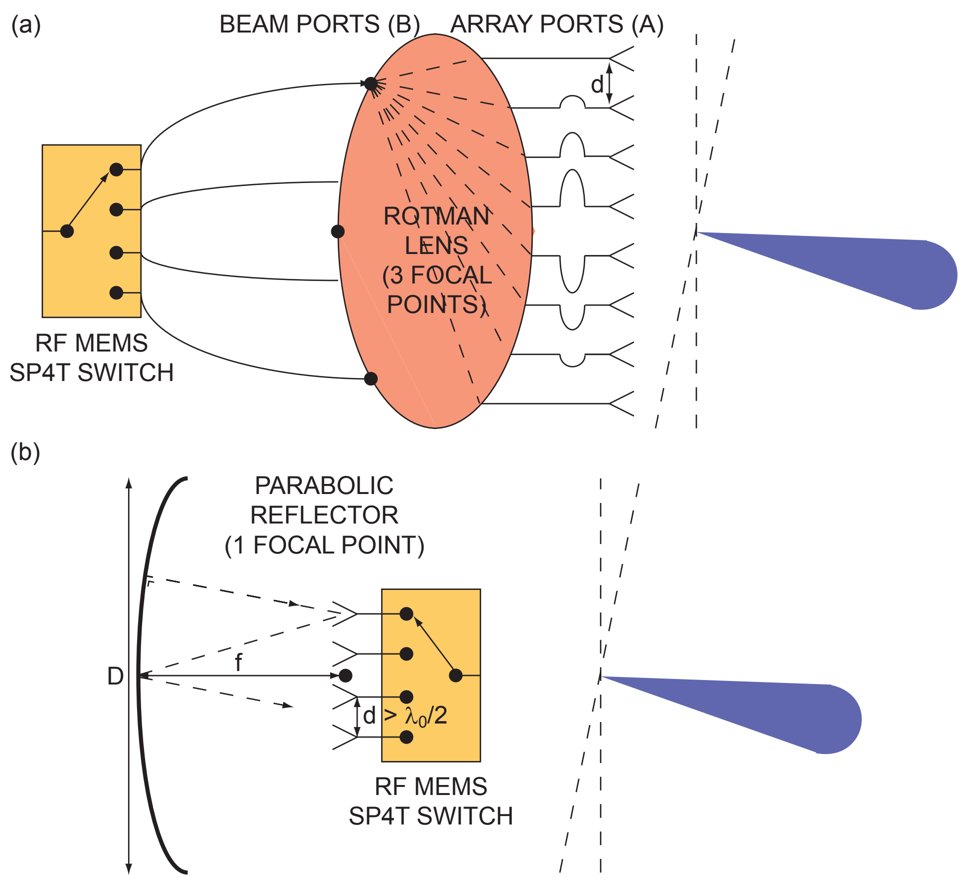

Figure 25: Switched beamformers based on an RF MEMS single pole 4 throw (SP4T) switch and a focal plane scanner: (a) the Rotman lens based focal plane scanner, (b) parabolic reflector based focal plane scanner.

Switched Beamformers

- **Principle of operation**: It is a cascade of a single pole N throw (SPNT) switch and a beamformer (beamforming matrix or lens or reflector based focal plane scanner [1–4]).
- **Advantages**:
  - Bandwidth: TTD-capable, if based on focal plane scanner (parabolic reflector, Luneburg or Rotman lens)
- **Disadvantages**:
  - Bandwidth: coupler limited, if based on beamforming matrix (Blass, Butler, Nolen)
  - Beam pointing error: high, B beam positions versus 2^{2P-1} beam positions for (TTD) phase shifter based ESA
  - EIRP $\times$ G$_r/T$: P_T limited by linearity and cold-switched power handling of SPNT switch. G lowered by insertion loss (IL) of SPNT switch and beamformer.
  - Field of view: related to f/D (IL, size)
  - Not monopulse-capable

Figure 26: KNIRTI's Sorbtsiya H/I-band radar jamming ECM pod for the Sukhoi 34 fighter aircraft features a Luneburg lens based focal plane scanner.

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Radomes

RF MEMS Radomes

- **Primary function**: Protection of ESA against adverse environmental conditions
- **Secondary functions**:
  - Calibration [1]
  - (Tunable) Frequency selective surface (FSS) [2]
  - Limiter
  - (Reconfigurable) Polarization transformer [3]
  - Shutter (RCS control) [4]

Figure 27: Radome [5] (Photo of APAR radome, Thales, Hengelo, The Netherlands)

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