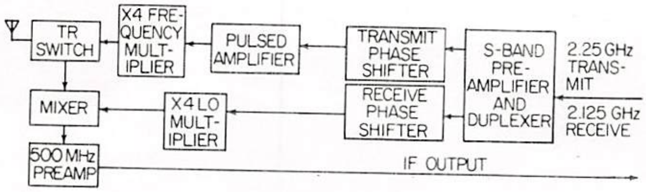

MERA block diagram is typical of solid-state corporate-fed modules.

Its 604 active-element array is corporate-fed by a stripline manifold structure. Low-level, coherent S-band energy is distributed to each module element. In the module, the rf is phase-shifted by 4-bit diode phase shifters, amplified, multiplied x4 and radiated by dipole elements at X-band.

The 9.0-GHz returns signal is mixed with an 8.5-GHz LO in a Schottky barrier-diode balanced mixer. The i-f difference is amplified at 500 MHz and the 604 module outputs are combined in a stripline summing network. Pulse compression techniques are employed to get an effective peak power of approximately 30 kW.

The over-all system is patterned after conventional terrain-following, ground-mapping radar systems. The contract, valued at just under $3-million, was completed in October, 1969. Further testing, to gather both antenna and systems data, is being conducted at the Texas Instrument's Equipment Group in Dallas.

RASSR (Reliable Advanced Solid State Radar) is the next generation of solid-state phased arrays following MERA. A single system is being built by Texas Instruments for the Air Force Avionics Laboratory under a $7-million contract awarded in October, 1969.

The 1880-element array will be corporate-fed at L-band and multiplied to X-band for transmission. Under the present configuration, one rf module will house two open-ended ridged waveguide antennas. The module block diagram will follow the same general configuration as that of MERA. Elements will be arranged on a triangular grid. Key features of RASSR will be a projected MTBF of greater than 500 hours; digital signal processing, making use of new LSI technology; coherent rf generation that is compatible with doppler processing; frequency agility and multimode operation.

The 34-inch aperture is expected to provide 37.5-dB transmit gain and 35.5-dB receive gain. The system noise figure requirements are 10 dB.

MAIR (Molecular Airborne Intercept Radar) was an X-band study program sponsored by the Naval Air Systems Command, Washington, D.C. The purpose was primarily to determine the feasibility of producing a multi-mode airborne array radar. Air-to-air radar capability, requiring much more transmit power than other ground-mapping and search modes, was a primary goal.

Two parallel efforts began in 1967, each with $70,000 funding. They produced slightly different configurations. The Westinghouse Systems Development Division, Baltimore, designed a corporate-fed active-element array. Raytheon, with Microwave Associates supplying the array elements, designed a passive-element reflective array.

Late in April, 1970, proposals to build twenty rf modules to meet MAIR system requirements were submitted to the Navy. These proposals answered the Naval Air Systems Command RFQs sent to nine companies.

Westinghouse proposed an rf module somewhat similar in block-diagram configuration to the MERA module. However, the Westinghouse module features rf peak powers of several watts, a high duty cycle in a pulse doppler mode, and bandwidths of greater than 5% at the 1-dB levels. The company plans to top the 7.5-dB receive noise figure requirements and use a receive i-f of higher than 500 MHz.

The proposed antenna element has variable polarization and is designed to operate in an array environment that scans in both planes to angles much greater than ±50 degrees.

Phased array technology promises many applications

Advancing technologies make phased arrays more useful for present applications, and pave the way for additional ones. Circular array technology is being developed for use on ship superstructures, but the present frequency-scanned planar arrays are improving also.

With advances in solid-state technology, applications in space are beginning to look very attractive. And with increased space activity, communications arrays that conform to aircraft structures will become more important.

Interviews with industry specialists show that these are among the applications being actively considered:

Circular and cylindrical arrays

The radiation pattern of a linear or planar array degrades primarily as a cosine function of the scan angle from broadside. For applications where 360° coverage is required, (such as some shipboard radars), a circular or cylindrical array is often desirable. Primary performance advantages of this type array are a result of its symmetry:

- All beam positions are effectively at broadside, so performance as a function of scan angle is not degraded.
- The requirement for data transfer from one planar array surface to another surface is eliminated.

Limitations in design and construction of these arrays are

- Mathematical analysis and synthesis of the circular array is more complex than the planar array.
- Implementation of a feed system for the circular array is generally more difficult.

Two approaches in solving the feed problem have been studied at the Naval Electronics Lab (NEL) in San Diego, a group looking for techniques in designing circular arrays for shipboard applications. Their general approach uses 128 elements in a circular array. One-fourth or 32 of these elements are used at any one instant to form a beam.

Vector-transfer feed

This method is a modification of the corporate feed system for planar arrays. Coherent power is divided 32 ways, with each output controlled by 3-bit phase shifters. Each of the 32 phased outputs is then electronically switched through equal line length cables and routed to each of 4 radiating elements separated by 90° in the array. A full 128-element array can then be scanned by properly phasing any 32 consecutive elements.

R-2R Parallel-plate lense feed

A second feed method used at NEL is the R-2R parallel plate lens. The lens consists of two circular plates of radius R (see diagram). Spacing between the parallel plates is limited to less than one-half wavelength so that only the electric-field component perpendicular to the plates is propagated. The lens is excited and tapped by simple probes into the region between the plates.

Consider a case where the lens is fed at point A in the diagram. The rf energy is then distributed to the opposite side of the parallel plate region, where it is fed through equal length transmission lines to the array elements. If the array element radiators are located on a ring of radius 2R, then the phase of the radiators is such that a plane wave is propagated into space.

According to J. Provincher, Head of the microwave antenna branch at NEL, "this feed system allows very low sidelobe patterns and broadband performance. For applications requiring narrow beams in azimuth and fan beams in elevation (IFF), and broad bandwidth (EW), these arrays look promising."

An interesting feed method was studied by NEL where two, three and four probes were excited at one time. By varying the inputs at these probes, an amplitude taper could be controlled at the lens output. "Using this technique,"

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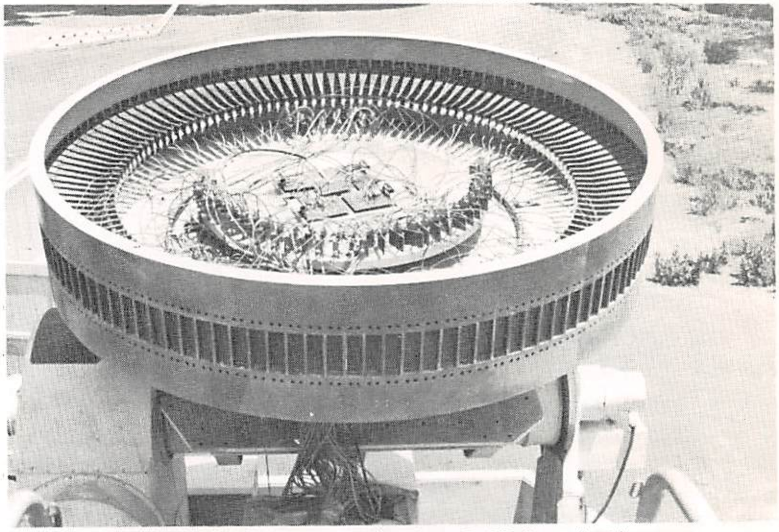
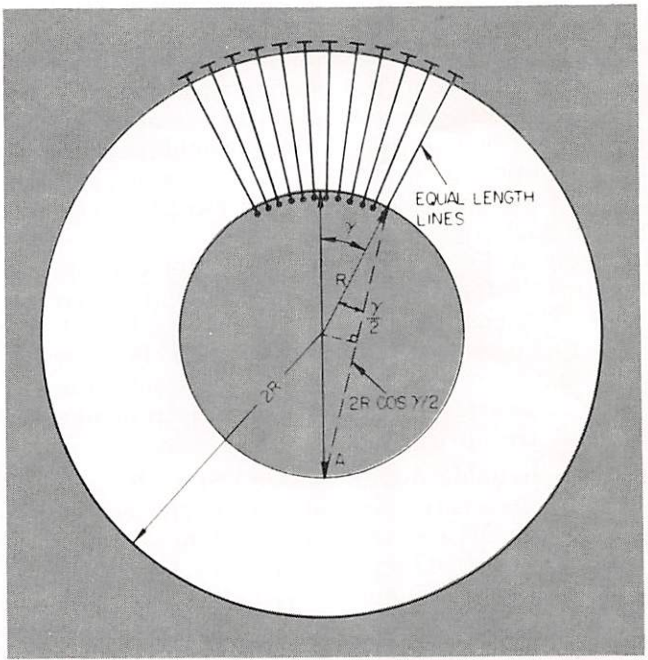
Naval Electronics Laboratory Photo

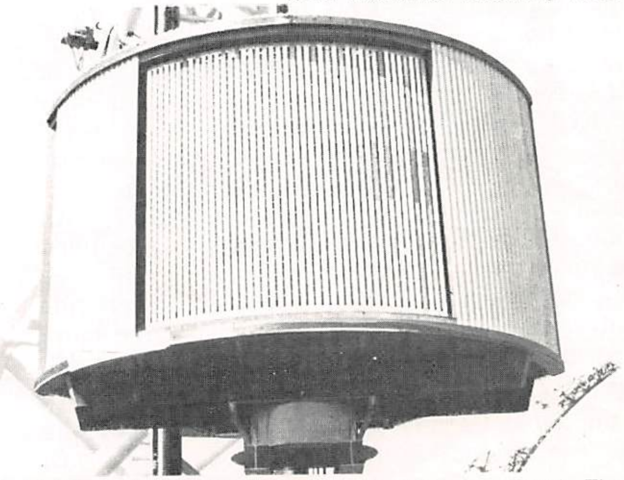


Circular array of 128 elements showing R-2R lens in the center. S-band elements are mounted on 4 foot radius. This antenna has a 20% bandwidth.



R-2R lens geometry forms a planar wavefront.

Naval Electronics Laboratory Photo



1344-Element cylindrical array operates at S-band. The 42 columns are mounted on an eight foot radius.

said Provincher, "26 dB sidelobes were obtained in the antenna pattern. With the multiple probe feed, monopulse processing information is also available."

Engineers at NEL have extended these circular array techniques to cylindrical arrays. A 1344-element S-band array is presently being constructed using the vector-transfer feed approach with open-ended waveguide radiating elements. Implementation of all of the phase shifters is not yet complete.

This test array will not be a complete cylinder, but enough of the circular arc will be implemented to allow a small sector of scanning. This antenna is believed to be the first cylindrical array of its size.

Frequency scanning arrays

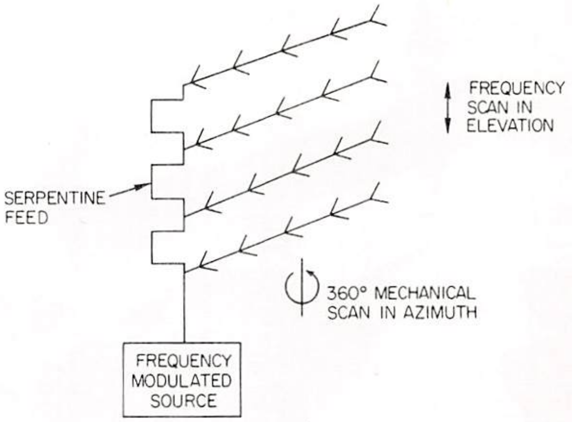
A hybrid array system that scans mechanically in azimuth and frequency scans in elevation has found considerable use by the Navy for shipboard applications. These antennas replace fixed-feed reflectors for long range surveillance radars. Frequency scanned arrays provide inertia-less scan in a relatively simple and economic manner. By continuous mechanical scanning in a 360° horizontal plane and frequency scanning in elevation, three-dimensional data is obtained for high data rate hemispherical coverage. A typical configuration for this planar system is shown.

A serpentine waveguide feed excites one end of multiple rows of waveguide. Each waveguide then radiates energy through slotted waveguide elements. Elevation scan is accomplished by changing the frequency and thereby changing relative phase of the rf energy as it leaves the serpentine feed.

This method has been well proven for both tactical ground based and shipboard surveillance radars. The Hughes AN/SPS-52 and the ITT Gilfillan AN/SPS/48 are production examples of systems used aboard ships.

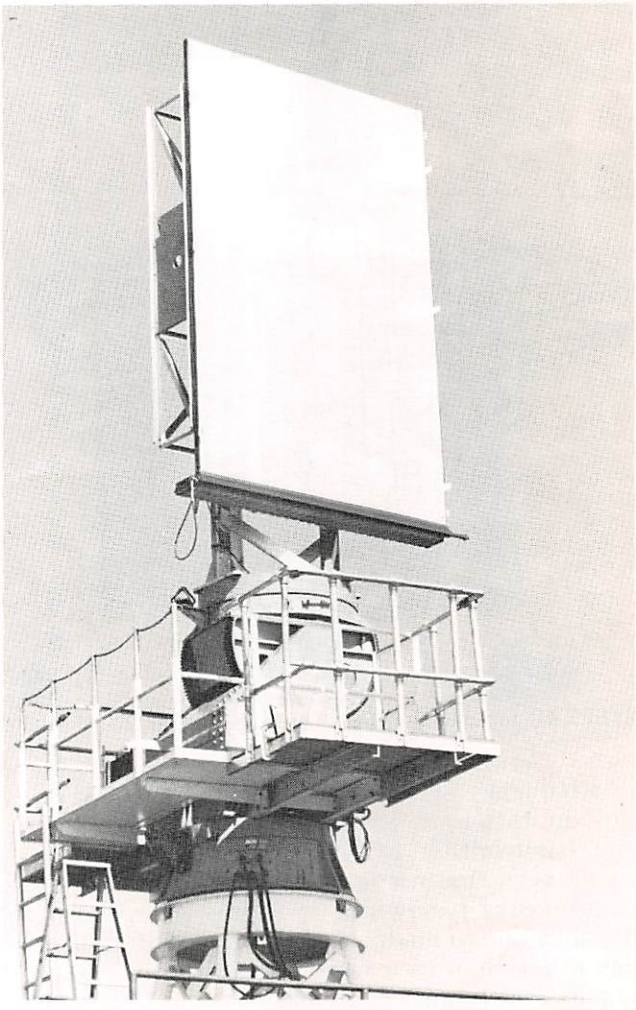
According to Irving Hammer, associate director of engineering at ITT Gilfillan, Van Nuys, Calif., this is a most economical method for solving the surveillance radar problem because of its relatively simple and proven design. Lack of complex hardware also increases reliability in this type of system.

Another important application for these hybrid antennas is in precision approach radar systems to handle large aircraft volume at airfields. One technology program at Gilfillan began in 1967 to develop an X-band planar array frequency scanned ±10 degrees in azimuth and phase scanned ±7 degrees in elevation. The program is being developed for the Navy/Marine Corps at Patuxent Naval Air Station, Md.



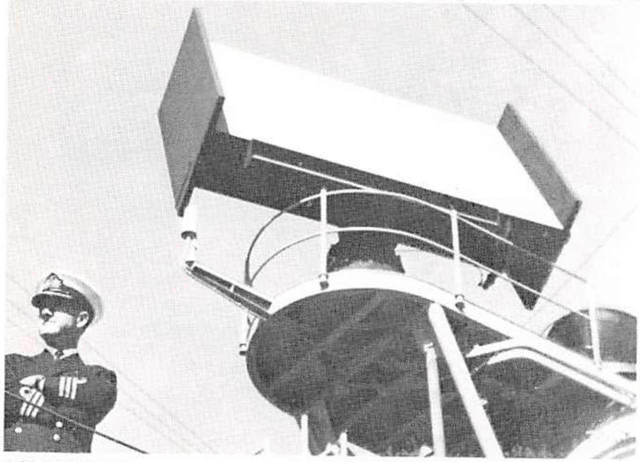
Hybrid array uses frequency and mechanical scan to minimize costs.

ITT Gilfillan Photo



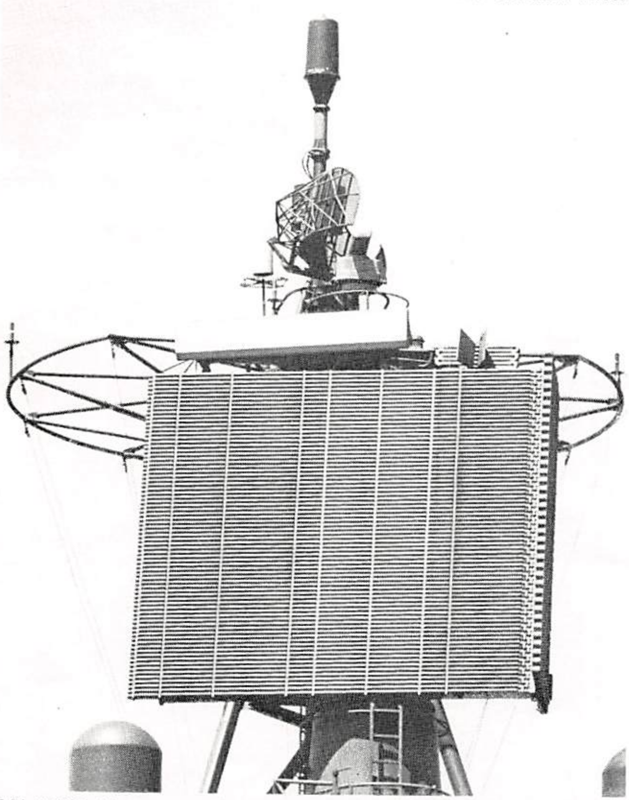
Precision approach radar antenna operates at X-band. It is frequency scanned in elevation and phase scanned in azimuth.

Hughes Aircraft Photo



AN/SPS-52 mounted on Australian warship.

ITT Gilfillan Photo



AN/SPS-48 mounted on mast of USS Sterett.

Frequency scanning has an inherent narrowband limitation in a few systems that require large bandwidths. ECM systems or radars requiring very fine range resolutions are examples. Instantaneous bandwidth is narrow because any sidebands due to modulation get radiated in directions other than cw carrier. As a rule of thumb, the pulsewidth must be at least 3 times the length of the unfolded serpentine feed to avoid degradation in performance.

Spacecraft phased arrays

Requirements for spacecraft phased arrays are quite different from their ground-based counterparts. Their goal is to replace many cumbersome dishes with a single aperture that is instantaneously steerable and wideband enough to include multiple frequency communications bands. Generally, the advantages that the phased array offers the spacecraft includes its ability to:

- Scan inertialessly.
- Form multiple beams with one aperture.
- Adjust sidelobe level.

Since spacecraft systems are primarily communications systems, modulated cw signals are employed rather than the short high energy pulses generally required by radar. According to spokesmen at TRW Systems Group, Redondo Beach, Calif., other considerations that change the design approach for spacecraft arrays are

1) It costs about $10,000 to place one pound of payload on a typical booster such as Titan III C. As long as electronic equipment costs less than this amount, the ultimate design criteria is performance per pound instead of performance per dollar.
2) Narrower scan coverage is generally allowed in spacecraft arrays. Where ±45 degrees scan is a minimum requirement for ground radars, ±10 degrees may be sufficient in a spacecraft to cover all points on the earth. Grating lobes are allowed closer to broadside and element spacing can be made greater than the $\lambda/2$ spacing generally required for ground based arrays. If the spacing is increased to 2λ the number of elements in a planar array is reduced by a factor of 16. The same array gain is then achievable with fewer elements and less weight.
3) With the narrower scan requirements, the element radiator also takes on a different configuration. Rather than the dipole, open ended waveguide, or spiral, that generate a wide element pattern, a helix or similar element can be used to get greater element gain and narrower element patterns.
4) The spacecraft array needs to be very wideband. This is not to handle the high data rates required of some ground based arrays, but to allow relatively narrowband communication on many different channels that may be spaced far apart in frequency. The narrowband selective filtering will be done in the system, not the antenna.
5) Because of their light weight, cw average power characteristics, and projected reliability, solid-state sources are the only real candidates for spacecraft arrays. Although noise figure and efficiencies have deterred this approach in the past, solid-state technology is now at a stage where phased arrays at L- and S-band are expected to find space applications in the early 1970s.

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