MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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A HIGH PERFORMANCE, LOW COST, AIR TRAFFIC CONTROL RADAR

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ABSTRACT

Recent improvements in the technology of electronically switched antennas and digital signal processing make possible a relatively high performance, low cost, surveillance radar. The radar described employs an electronically step-scanned, cylindrical antenna together with an advanced digital signal processor to give superior MTI performance at an estimated cost of less than half the present S-band ASRs.

The radar output consists of narrowband, digital target reports free of false alarms, suitable for transmission over telephone lines. Remote radar operation using digital, bright, scan-history displays becomes practical as does easy incorporation of beacon and direction finder outputs along with digitally generated video maps.

The complete absence of moving parts, the low power transmitter and the largely solid-state construction will provide high reliability and low maintenance costs.

These techniques are most easily and economically implemented in the UHF band, but a similar L-band radar can be designed with somewhat increased complexity and cost.

The techniques and background studies employed in the design of the proposed radar evolved over a period of three or four years as a result of work for the Air Force under Contract F19628-73-C-0002. Some of these techniques are being applied to improve the MTI performance of the ASR under FAA Contract DOT-FA71WAI-242.

Accepted for the Air Force
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A HIGH PERFORMANCE, LOW COST, AIR TRAFFIC CONTROL RADAR

I. INTRODUCTION AND SUMMARY

It is now possible to design a relatively high performance surveillance radar that is capable of providing reliable clutter-free detection of aircraft at a lower cost than was previously possible. For illustrative purposes we have described a system design suitable for use at the smaller airports where general aviation aircraft operations predominate and the tower does not have an ARTS-III or ARTS-II (TRACON) system. Other variations of this basic design would be suitable for typical ASR and ARSR application.

The proposed radar design is based upon techniques which have been analyzed and verified in an experimental radar design at Lincoln Laboratory for a different application. It employs an electronically step-scanned, cylindrical antenna and an advanced digital signal processor to give superior MTI performance. In production, the cost of this new radar is estimated to be less than 50% of the cost of a standard ASR.

It is proposed that the radar operate at UHF to insure that birds and weather do not produce false targets and at UHF it is practical to construct an efficient phased array antenna at low cost. An alternate L-band version of this basic radar could also be employed, but it would be slightly more complex and costly. Digital processing of the radar signal leads naturally to a digital, bright, scan-history display suitable for use in an airport tower cab. Because the digital processor output can be fed over conventional telephone lines, traffic at a remote airfield can be inexpensively displayed at an enroute center. In addition, a strobe corresponding to the output of a VHF or UHF direction finder can be incorporated on the display to indicate the aircraft in communication with the controller.

The complete absence of moving parts, the low power transmitter and the largely solid-state construction will provide high reliability and low maintenance.

Finally, the digital display will allow the easy addition of data from a beacon system such as ATCRBS or DABS for easy expansion to sites with a larger percentage of beacon-equipped aircraft.

In the sections that follow we will first describe the need for an inexpensive radar and show its requirements. We then discuss the very important matter of frequency choice. The proposed radar is described in some detail followed by an outline of the development plan for the radar.

II. NEED FOR AN INEXPENSIVE RADAR, REQUIREMENTS

The role of primary radar varies with the density of aircraft in the terminal area and the degree to which these aircraft are equipped with operating beacons. Several of the largest terminal control areas forbid the entrance of nonbeacon-equipped aircraft. Here radar is used to detect intruders and those with malfunctioning beacons. Also, it has been demonstrated (at Atlanta) that radar returns can supplement beacon returns by filling in when, on occasion, the beacon return is missing. This is usually due to beacon antenna shadowing when the aircraft is in a turn or lobing in the interrogator antenna pattern.

At the very opposite extreme there are hundreds of terminals which must handle a very high percentage of nonbeacon-equipped aircraft. For these terminals radar could be a valuable tool for traffic management. Unfortunately, the cost of a typical ASR radar installation has limited its use to about 130 airports. There are about 600 airports which handle commercial flights and several thousand that handle general aviation, a large number of which have control towers and many even have instrument landing systems. The traffic at many outlying airfields is handled remotely from enroute centers solely on the basis of pilot position reports. Since cost limits their use, it is quite clear that the first requirement for a radar for smaller airports is low cost, as long as it is consistent with adequate performance. Maintenance should not be overlooked when considering the overall cost. A radar which fails infrequently and is easy to repair can reduce ownership costs appreciably. For this reason a radar with no moving parts, with a relatively low power transmitter and built with essentially all solid-state circuits is preferred to older style radars.

Aircraft detection and aircraft location requirements should be comparable with the best present ASR's except for range which need be only 20 nmi One set of parameters for this class of radar is shown in Table I.

TABLE I

Aircraft Size	Small, single-engine aircraft
Range	20 nmi maximum
Elevation Angle Coverage	1 to 30°
Maximum Altitude	20,000 ft.
Azimuth Accuracy	0.5 deg
Update Time	Four sec maximum
Blind Speeds	None, except for aircraft with radial velocities less than three knots

All of these requirements should be met in the presence of ground clutter, precipitation clutter and angels (birds).

Because small airports cannot afford a separate IFR room, it is imperative that the radar be capable of operation in the tower cab. This necessitates a bright display.

If the radar is to operate from remote sites and the cost is to be kept low, an expensive microwave link is undesirable. The transmission of data from the radar to the display should use telephone lines. This would allow radar operation and thus traffic control at a remote airfield by personnel at an en-route center. This seems particularly desirable in safely handling the relatively small number of commercial aircraft at several hundred presently unequipped airports.

A further requirement in keeping with the low cost aspect of the radar is that the output of other equipment such as VHF/UHF direction finding and the output of beacon systems such as ATCRBS and DABS can be easily incorporated into the display. This can be done by requiring a digital display processor with extra capability to handle these other sensor outputs. This growth capability should be planned into the radar so that it can grow gracefully with increasing air traffic.

Once a digital display processor (small general purpose computer) has been specified, it is natural to ask it to supply range rings and simple video maps.

III. CHOICE OF OPERATING FREQUENCY

Choice of the correct operating frequency is critical to the design of a high performance, inexpensive ASR. In this section, consideration is first given to the relative sizes of clutter and target returns as a function of frequency. Next, we discuss the feasibility of using an electronically step-scanned antenna with its very narrow ground clutter spectrum. This is followed by an exposition of the Doppler ambiguity, blind speed problem and how it disappears at lower frequencies. Consideration is given to the superior elevation coverage achievable using a step-scanned antenna at lower frequencies.

A. Moving Clutter and Aircraft Sizes

The fundamental limitation on ASR performance is almost always related to the radar's subclutter capabilities, its ability to see targets in clutter. Thus, we desire frequencies at which the radar cross sections of desired targets are enhanced and the clutter cross sections are reduced. Figure 1 shows a summary of aircraft and moving clutter cross section data as a function of frequency. For rain we have assumed a 1.5 degree fan beam at a maximum range of 20 nmi. It is quite clear that the aircraft return is maintained at the same or larger size as the frequency decreases whereas the type of moving clutter, precipitation and birds, decreases in size. The clutter sizes shown are mean values so that an approximately 15 dB ratio between target and clutter is required for automatic detection. The dashed line in the figure at 600 MHz is the highest frequency where rain and birds are not considered a problem. Below 600 MHz the radar need not even use circular polarization to combat rain. Also, below this frequency there is a good separation between the size of aircraft and bird returns so that a threshold based on target size will effectively eliminate the birds without affecting aircraft detection. It is generally desirable to avoid having to use circular polarization because (a) aircraft when viewed broadside produce a large specular reflection on linear polarization which is lost when

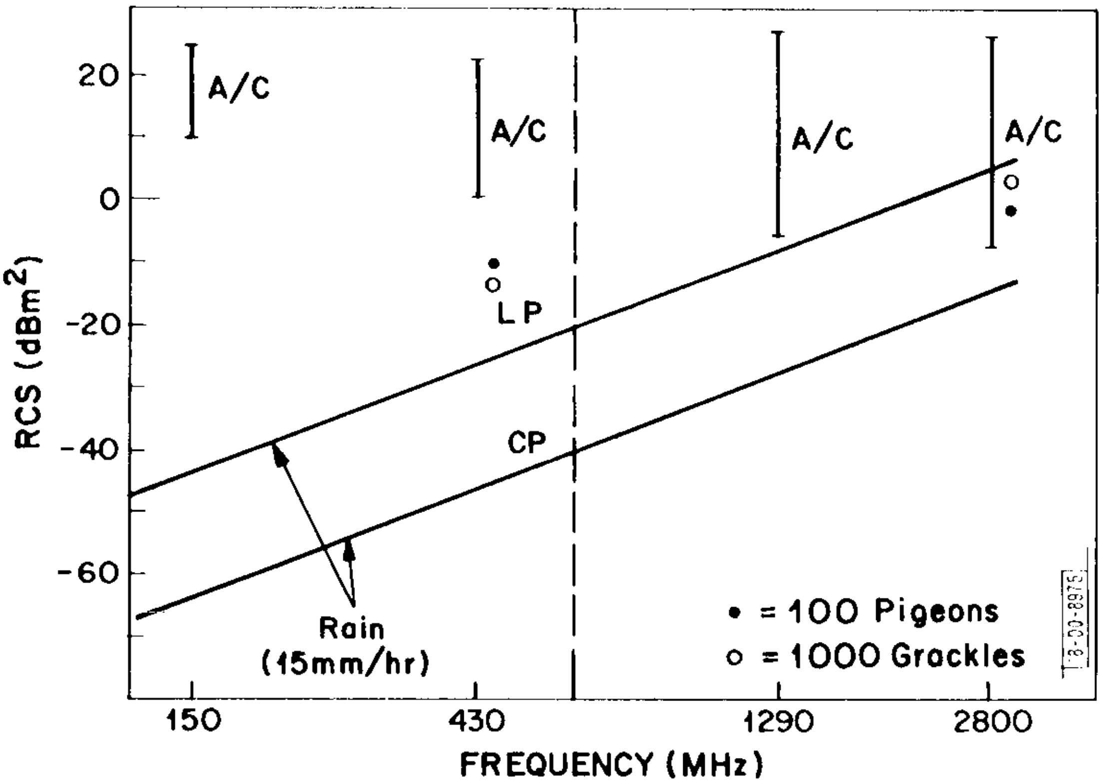

Fig. 1. Radar cross section of aircraft (A/C) and moving clutter (rain and birds) as a function of frequency (Ref. 1).

circular polarization is employed (this specular reflection becomes important when trying to see aircraft at near zero radial velocity) and (b) the radar is unnecessarily complicated by the presence of circular polarization because of the necessity to either provide receiving channels for each polarization or a mechansim for switching between circular and linear polarizations.

B. Electronic Step-Scan Antenna

An electronically step-scanned antenna is highly desirable for incorporation in an ASR because it reduces the spectral width of the ground clutter return to a narrow band. It is so narrow in fact that it is possible to completely separate the aircraft with slow velocities from the ground clutter. This is illustrated in Figure 2 which is the spectral output of a 435 MHz radar using an electronically step-scanned, circular array antenna. Notice that all of the ground clutter appears in one of the filter outputs and that the aircraft competes only with receiver noise. The subclutter visibility of the radar is limited only by the size of clutter the radar can handle and this, in turn, is limited only by the dynamic range of available analog-to-digital converters.

Although not entirely ruled out at S-band, these cylindrical arrays are easier to build at lower frequencies and the large aperture they provide substantially reduces the required transmitter power, which in turn permits all the antenna switching to be accomplished with solid-state components. Cylindrical arrays have been used in a few radars at UHF and one is being designed for ATCRBS use at L-band by Hazeltine.

C. Doppler Ambiguities

The difficulties that pulsed MTI radars have with Doppler ambiguities and blind speeds are well known. Figure 3 depicts a number of targets as seen

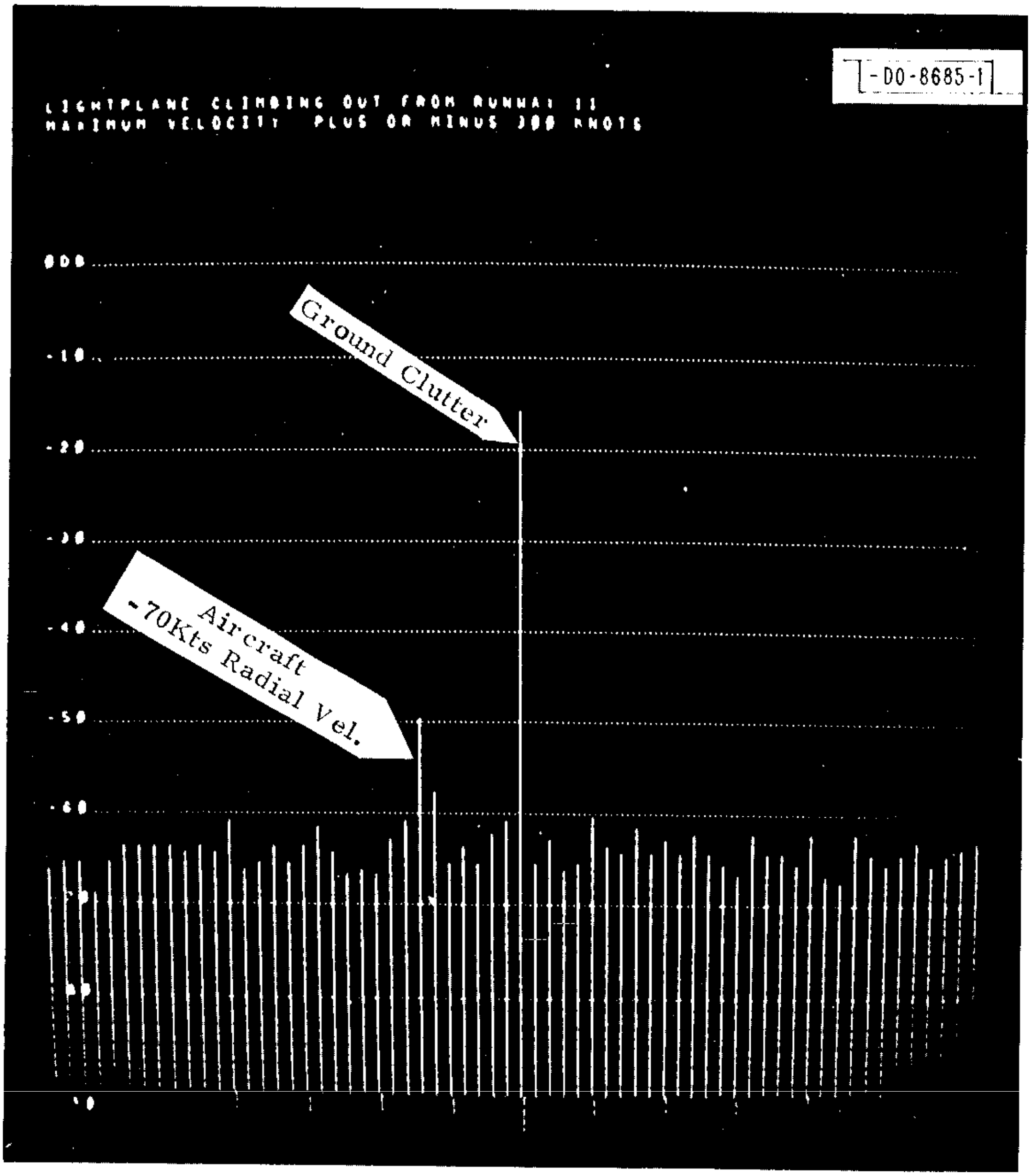

Fig. 2. Doppler spectrum of ground clutter and light single engine aircraft as observed by a UHF radar employing an electronically step-scanned antenna.

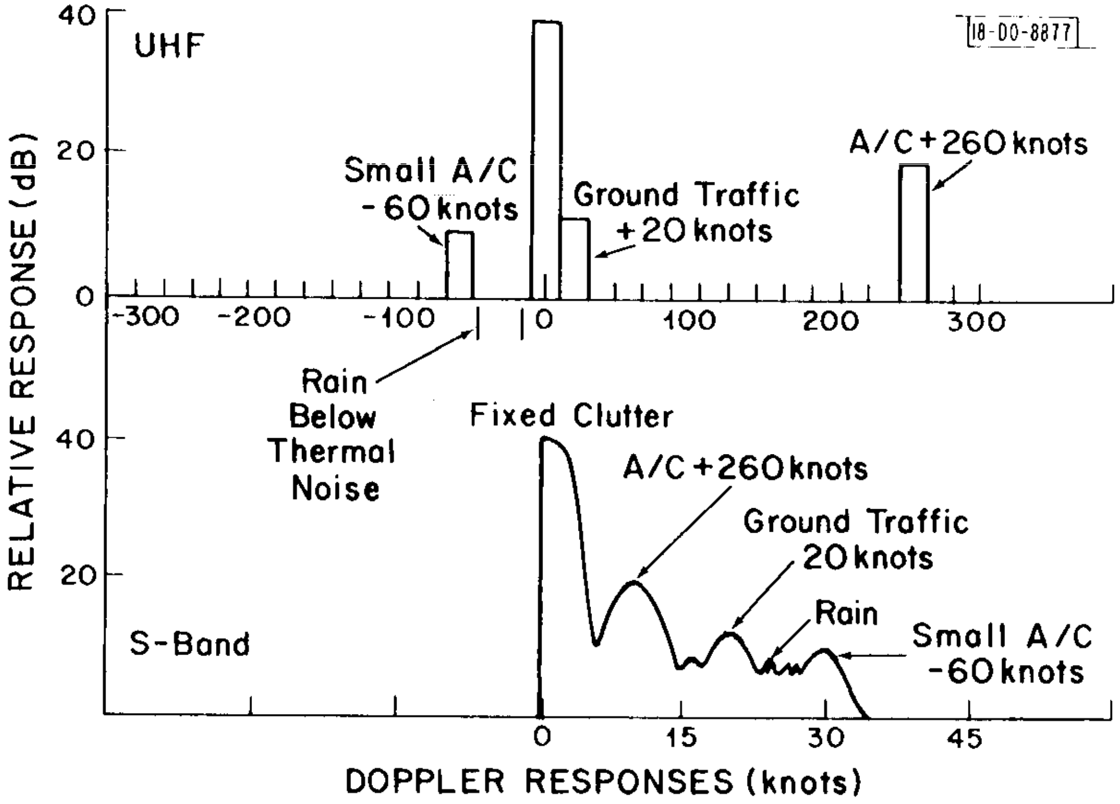

Fig. 3. Doppler domain responses of an S-band and a UHF radar to a typical environment.

in the Doppler domain by radars at UHF and S-band. Consider, for example, a radar running at 2800 MHz and 1000 pulses per second. Because of spectrum folding inherent in a sampled (pulsed) radar, all targets will appear to have radial velocities in the range between ± 52 knots. The first blind speed will be at least 104 knots. A target with a radial velocity component of 124 knots will produce the same Doppler response as one with a radial velocity of 20 knots. This is a liability because it precludes separating slow targets from fast ones by filtering in the Doppler domain. Hence, airplanes may be relatively undetectable in range azimuth cells which contain slow moving traffic on the ground or moderate rain.

Staggering the prf changes the apparent Doppler and can shift the blind speeds but it does not relieve the ambiguity problem.

A radar operating at a 600 MHz carrier frequency and 1000 pulses per second will have its first blind speed at approximately 485 knots and unambiguous target velocities up to 242+ knots. The unambiguous speed will increase with decreasing frequency. At UHF there is no need to stagger the prf to avoid blind velocities for aircraft normally encountered in the terminal area. This further simplifies the radar.

D. Vertical Coverage

ASR radars, being located on airports, are usually surrounded by flat ground or water. Hence, reflections from the ground can have a marked effect upon the vertical coverage. The subclutter performance of such radars can be enhanced by setting the antenna low enough so that the first maximum of the interference pattern is significantly higher than the ground clutter. However, other constraints, like the need to see over hangars and other obstructions, often require that the antenna be considerably higher.

Where the antenna height is chosen appropriately the ground reflection can be employed to provide nearly optimum vertical coverage. Examples of achievable elevation patterns are given in Section IV (see Figure 10).

E. Frequency Allocations

We have determined that for consistently good results and for ease of implementation that the radar carrier frequency should be below 600 MHz. We consider two possibilities for frequency allocations to this type of radar service; namely, bands which are presently allocated for radar location and the possibility of using one or more UHF TV channels.

In the western hemisphere the band of frequencies from 420 to 450 MHz is allocated for radio location by international treaty. Representative radars presently operating in this band include the FPS-85 at Eglin Air Force Base, many SPS-40's on various Navy ships, the BMEWS radar, and experimental radars (such as the electronically step-scanned LRDR and the Millstone Hill radars at Lincoln Laboratory). The radar proposed here can operate with a three dB bandwidth of half a megahertz. Hence, it would seem that several channels might be made available in the 30 MHz between 420 and 450.

Several years ago the band of frequencies from 470 MHz to 980 MHz was set aside for UHF television channels. It was the hope that opening up 70 channels would make television abundantly available to many communities and tend to offset the monopoly that big networks have on television programming. Today it is generally agreed that this experiment has failed. Consider the following facts.

Occupancy of the 70 UHF TV channels is very light, whereas there is an average of 50 television stations on each of the VHF TV channels (channel 2 through 13). On the 69 UHF TV channels there is a total of 435 stations for an average of slightly more than six TV stations per channel. In addition to channel 37 which is reserved for radio astronomy there are no less than 13 UHF TV channels which are not used at all. In the band below 602 MHz there are six UHF TV channels which are used by 10 or fewer stations (see 1972 broadcasting yearbook).

Two possibilities suggest themselves, either a TV channel could be cleared nationwide by moving all the occupants to nearby channels or the radars could share channels with TV stations,using geographical separation to prevent harmful interference.

There is a precedent for this sort of thing. In Los Angeles, land mobile radio operations are carried out with the approval of the FCC on UHF TV channels 14 and 20.

We speculate that there will be very few applications for additional use of the UHF channels by TV stations. This is partly because most of the stations now on UHF are losing money, but more importantly,the emerging solid-state cable TV distribution technology offers a much better way to distribute the video signals in all but the most thinly populated areas. Cable offers more channels and much better picture quality than can be had over the air.

In view of all of the above, we foresee a more or less gradual erosion of UHF TV channels for other services and think there is strong technical justification for operating ATC radars at UHF (400 - 800 MHz).

F. Alternate L-band Radar

In the event that UHF frequencies do not become available, a somewhat more complicated radar can be designed for L-band (~1300 MHz). An electronically step-scanned antenna could still be employed. An antenna of the same complexity as that proposed for the UHF radar would be three times smaller in both dimensions. To maintain the same power aperture product (and thus the same rate of volume search), the power needs to be nine times as great as UHF. A larger more complicated antenna could be substituted instead.

Another factor is the increase in rain backscatter as seen in Figure 1. At L-band, the radar must either employ circular polarization or a Doppler filter bank with mean level thresholding of each filter in the bank. This adds complexity to either the cylindrical antenna or the signal processing, thus increasing system costs.

We see from the above discussion that as the operating frequency increases above about 600 MHz for the same performance the radar becomes more complicated and also more expensive.

IV. DESCRIPTION OF RADAR

This section describes in some detail the configuration of a modern, relatively inexpensive, electronically step-scanned radar. From the above discussion we see that a UHF frequency is highly desirable. Since the present UHF radar band is 420 to 450 MHz, we have chosen to describe the radar in this band. Higher frequencies, at least up to 600 MHz, could be used with no change in performance.

Figure 4 shows the principal parts and Figure 5 is an artist's conception of the radar. Each of these is described in detail in the sections below. Table II is a list of parameters chosen for the radar.

A. Transmitter/Receiver

In contrast to conventional ASR radars the required transmitter power is very low; only 25 kW peak, 25 watts average. At this power level the transmitter can be designed conservatively to provide high reliability. It uses the only electron tubes in the radar other than the CRT display tube. The transmitter is completely coherent, which is simple to accomplish at UHF.

The receiver has two channels for the sum and difference monopulse signals. Each is identical and employs identical sensitivity time control (STC) so that the detection threshold setting represents a fixed target size in square meters. In this way, aircraft will be detected but not angels (birds).

B. Antenna

A cylindrical, electronically step-scanned antenna is employed because it eliminates the spectral broadening of the ground clutter return caused by the motion of a mechanically scanned antenna. The resulting intrinsic clutter spectrum due to the motion of the trees in the wind is so narrow that the clutter can be completely filtered out leaving only receiver noise to compete with the aircraft return.

Other reasons for choosing a cylindrical array are its simplicity, reliability and low cost. It also provides a large aperture thus reducing the average power requirement. The poor accuracy normally associated with its relatively

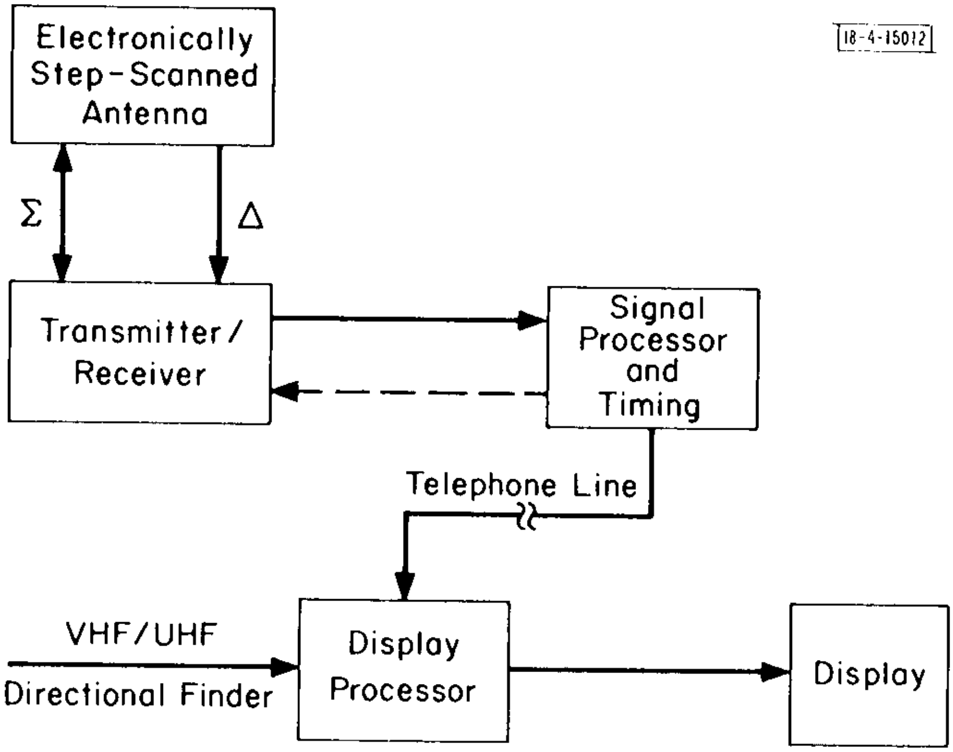

Fig. 4. Block diagram of radar system.

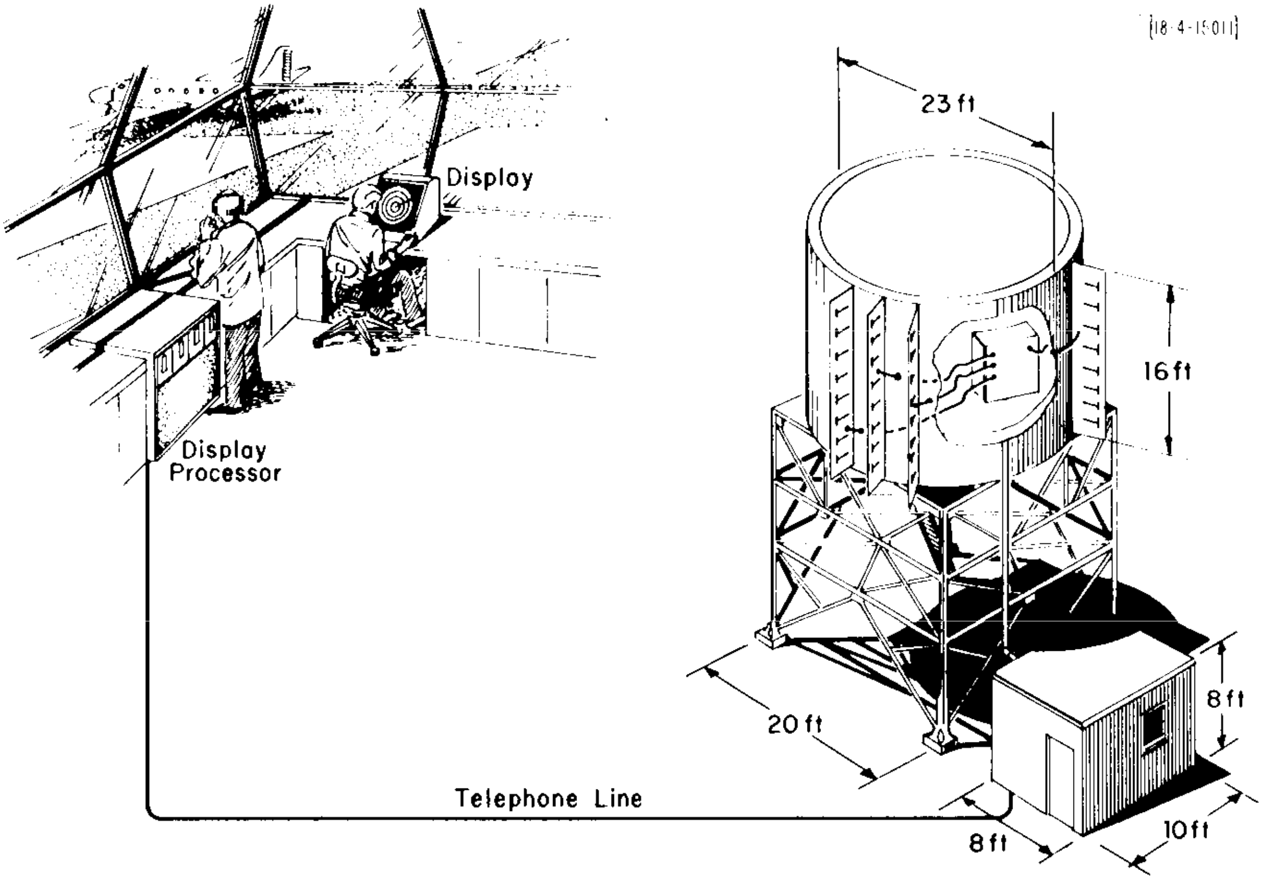

Fig. 5. Artist concept of radar.

TABLE II
RADAR PARAMETERS

Frequency	435 MHz
Transmitter Waveform	
Range Resolution	1/6 nmi
Pulse Width	2 μsec
Peak Power	25 kW
PRF	500 Hz
Dwell Time	0.062 sec
Scan Time	4 sec
Antenna (Electronically Step-Scanned)	
Diameter	23 ft
Height	16 ft
Gain	23 dB
Azimuth Beamwidth (3 dB one way)	6.7 deg
Elevation Coverage	1 to 30 deg
Number of Azimuth beams	64
Azimuth Accuracy (monopulse)	0.5 deg
Number of Antenna Switches	100
Assumed Target Size	0.5 m^2
Receiver Noise Figure	2 dB
System Losses (attenuation plus signal processing)	14 dB
Signal Processing: DC removal on eight pulses plus noncoherent integration	
Telephone Remoting Capability	240 targets/scan
Display Processor:	
Memory	8000 words
Cycle Time	0.8 μsec
Add Time	1.6 μsec
Display	
Character Generation	
Vector and Circle Generation	
Refresh Rate	30/sec

wide azimuth beamwidth is overcome by employing monopulse techniques. The 23-ft. diameter was chosen with azimuth accuracy in mind. Much longer range radars (as for ARSR service) with more severe azimuth accuracy requirements can be built by increasing the antenna's diameter.

Figure 6 shows the RF circuit for the antenna. Twenty-four columns of radiating elements are excited out of a total of 64. The required excitation is derived using a 1:24-way power divider together with lengths of cable to correct the phase of each column so that a plane wave is radiated from the circular structure. Practically any excitation desired can be achieved with this arrangement including separately generated sum and difference patterns. Monopulse performance can be optimized and low sidelobes can be achieved on both the sum and difference patterns.

The array is steered by commutating the twenty-four excitation signals around the cylinder using a matrix of diode transfer switches (100 switches). Switching speeds of a few microseconds are typical. Individual switches designed for this service at UHF have been tested to at least 5 kW peak power on 3 μsec pulses of 0.03 duty factor so are very conservatively rated for the radar under consideration.

Figure 7 shows a 32-element cylindrical antenna of this type presently being used in another radar application.

A semicircular antenna employing 96 radiating columns has also been built and operated over a year with no down time. This array antenna provides excellent radiation patterns (Figure 8). It is steered with a switch matrix similar to Figure 6.

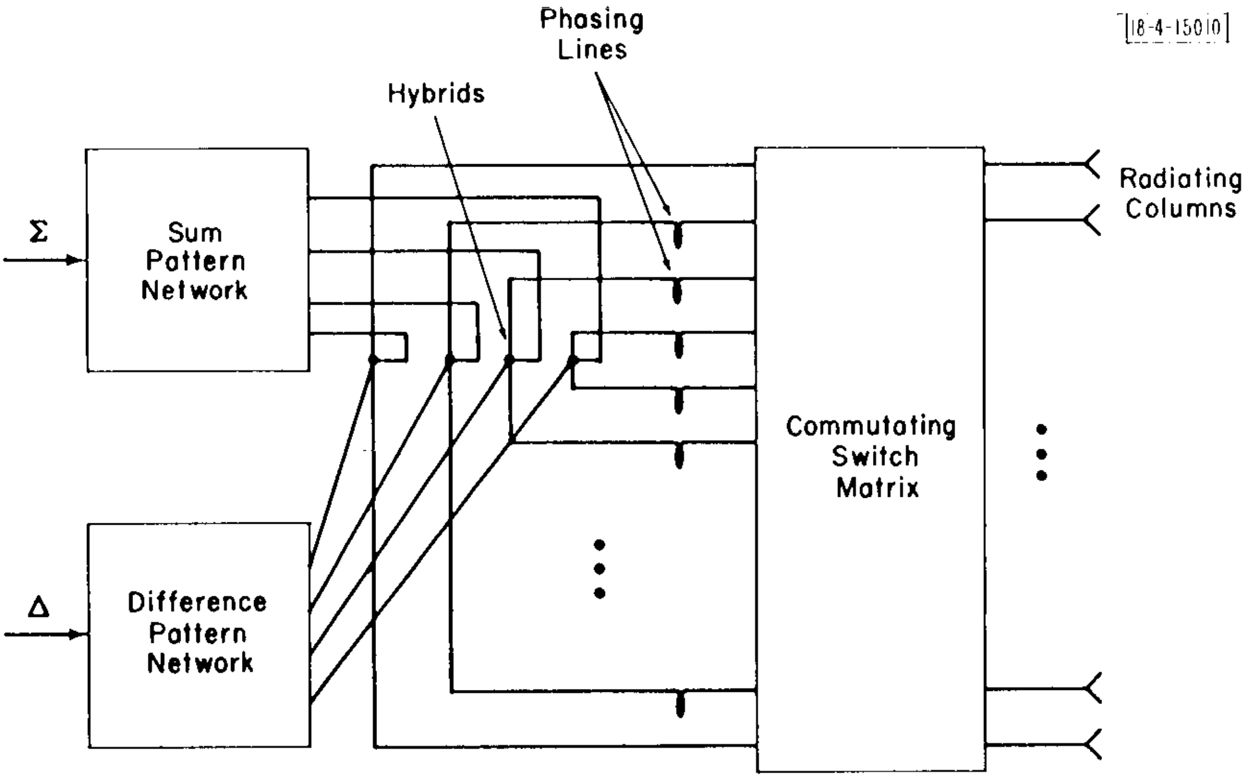

Fig. 6. Details of antenna circuit.

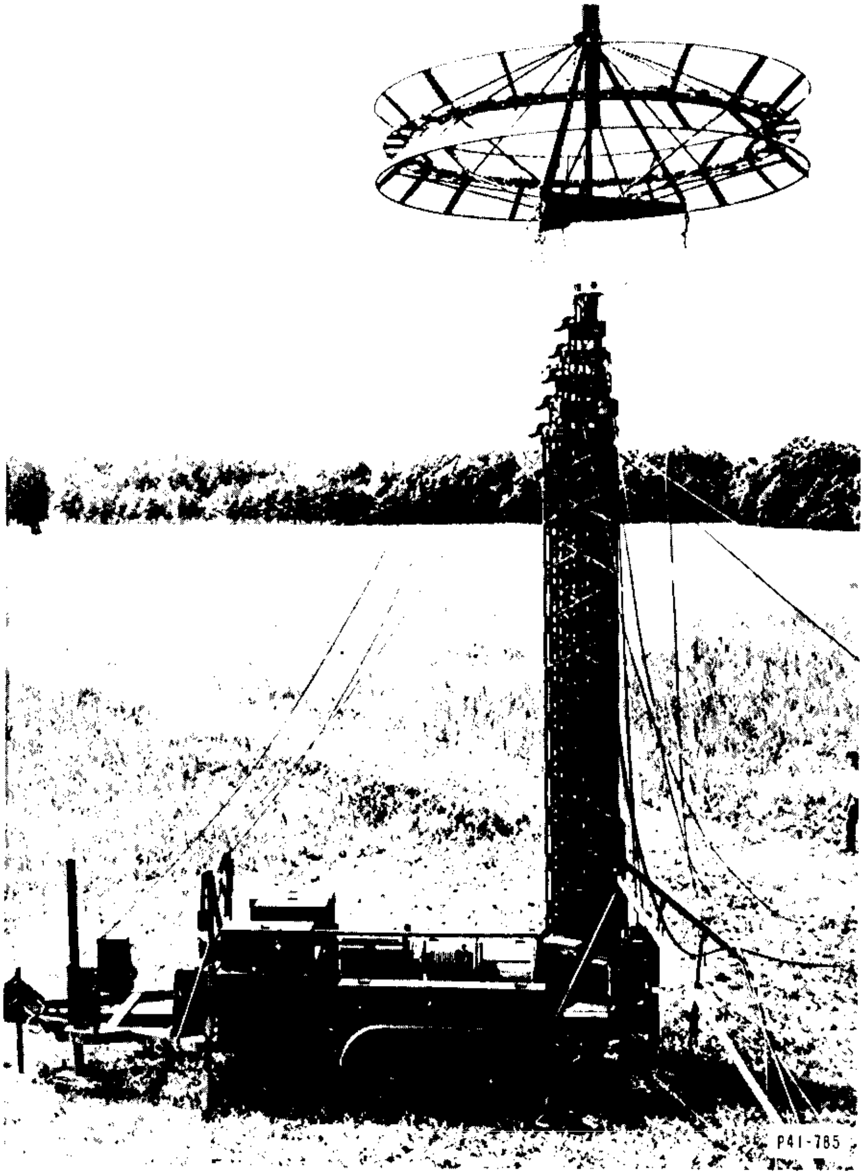

Fig. 7. 32-element cylindrical antenna.

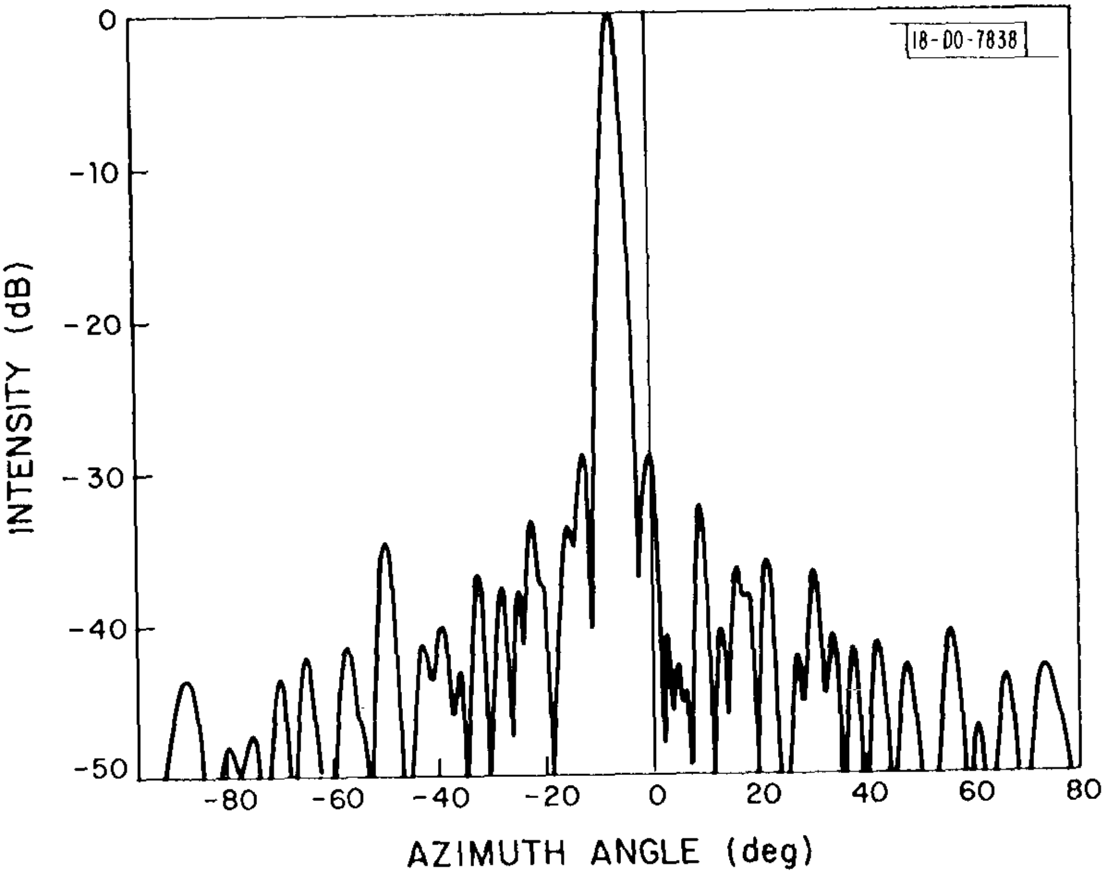

Fig. 8. Typical beam pattern UHF circular array.

One of these switches is shown in Figure 9. Note that there are no adjustments. Although these switches were assembled by hand, the design is suitable for more or less automatic production as thick film or thin film hybrid microwave integrated circuits. The Lincoln semicircular array radar uses almost 200 of these switches and, except for a couple of burn-in failures when it first was turned on, there have been no switch failures in more than a year of operation. When a fault does occur in one of the switches, it is very simple to locate and correct. A mode can be built into the radar which automatically checks the switches and indicates the location of the fault.

The antenna aperture height of 16 ft. will allow a sufficient number of radiating elements in elevation to provide a very desirable vertical coverage pattern. Typical computed vertical coverage diagrams for various heights over a ground plane are shown in Figure 10. The nonmoving antenna can be mounted atop airport buildings or nearby hills to give improved low elevation coverage, an approach which heretofore was not acceptable because the clutter rejecting capability of previous radar designs was inadequate.

C. Signal Processing

The proper approach to signal processing involves two important steps. First, it is important to keep the target and clutter signals well correlated. The reason for this is that well correlated signals have the narrowest possible spectrum and are thus easier to separate using filters. Steps employed in this radar to maintain correlation of the signals are: (a) the antenna is step-scanned to eliminate the decorrelation caused by antenna scanning motion, (b) a fully coherent transmitter with a high degree of stability is employed so that even the second-time-around clutter returns are very well correlated,

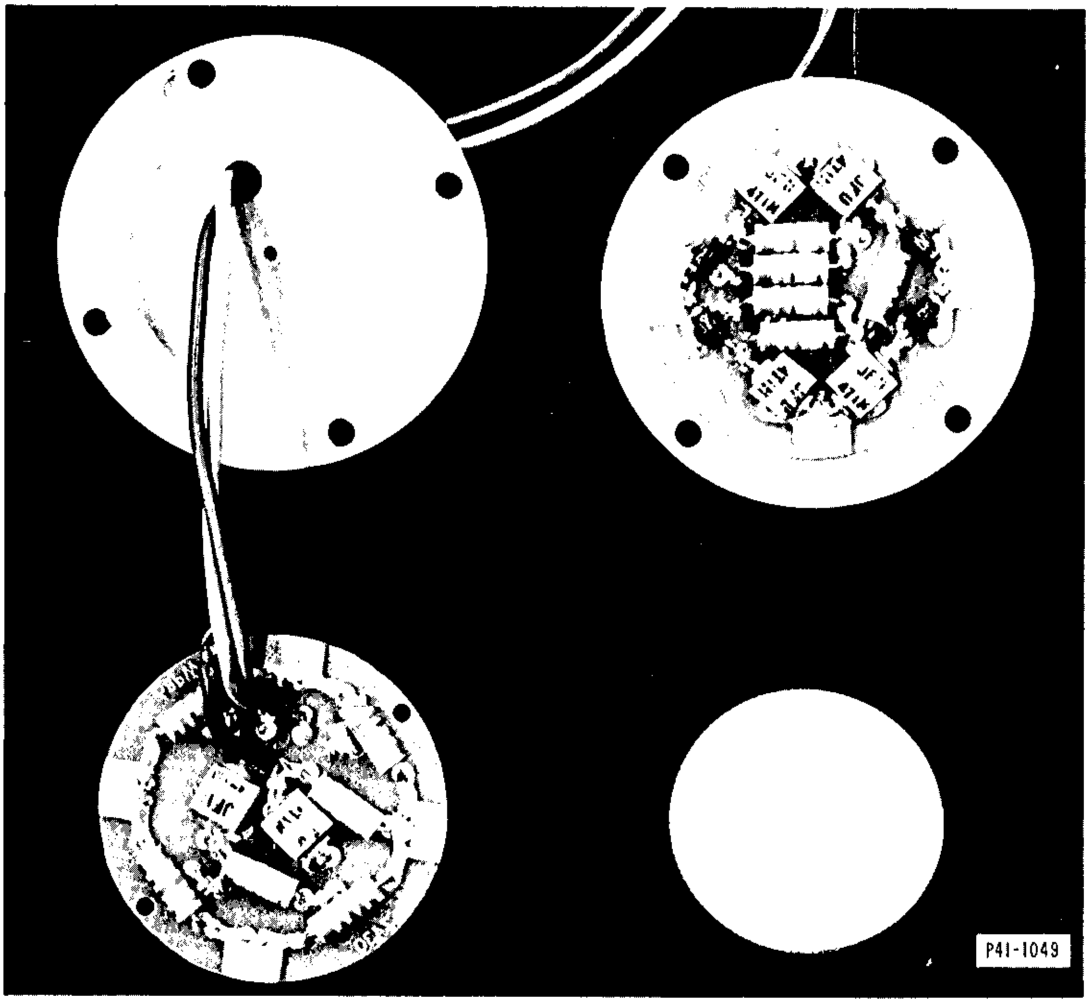

Fig. 9. Diode switch used for pointing cylindrical array antenna.

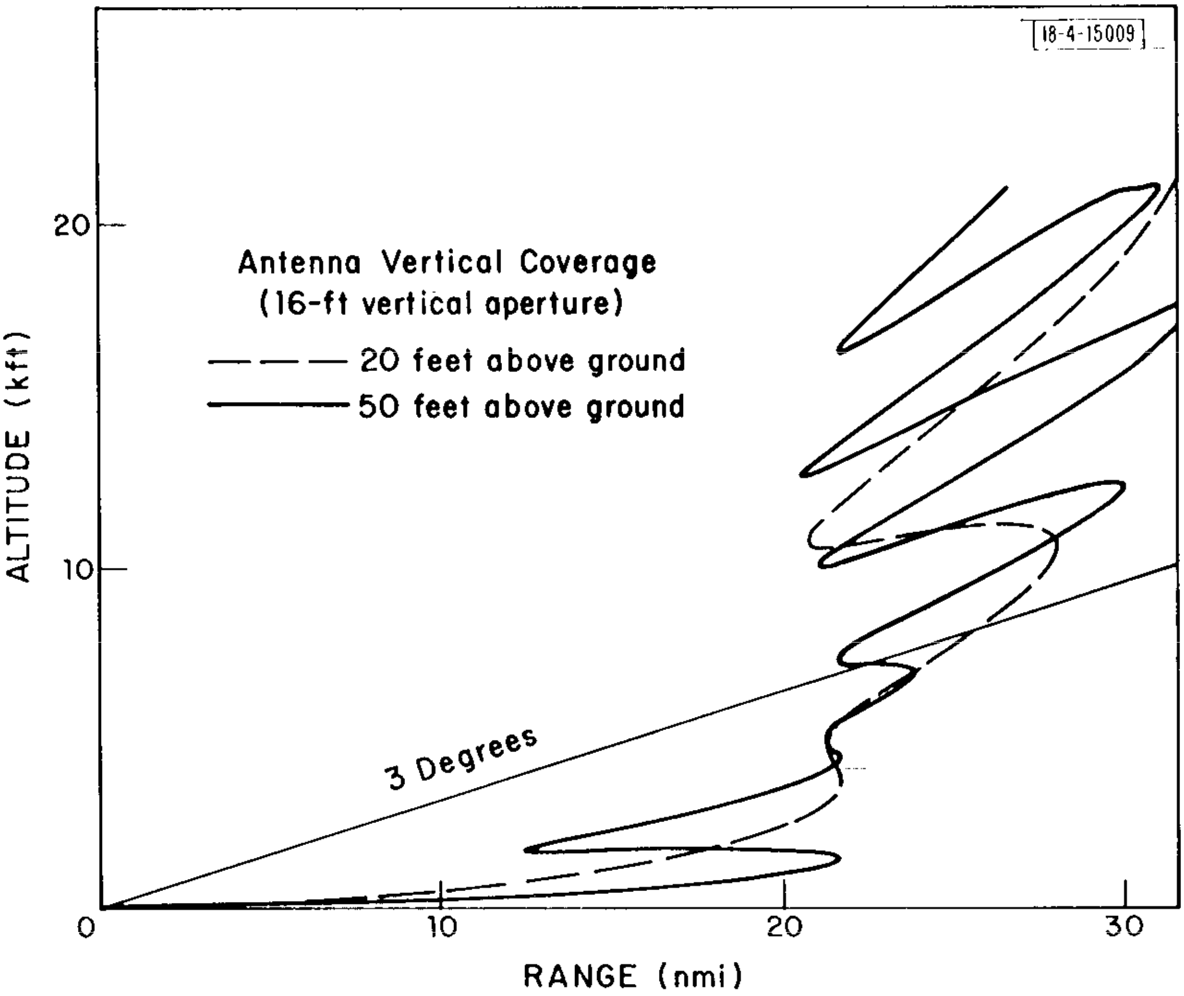

Fig. 10. Vertical coverage of antenna.

and (c) a receiver is provided which is linear over the entire range of the analog-to-digital (A/D) converters. Any nonlinearity introduced in the receiver spreads the clutter spectrum making it difficult to separate clutter from targets. As an example, the limiting and detection process used in conventional S-band ASR's is largely responsible for its relatively poor improvement factor (see Figure 12). In addition, (d) the A/D converters employed have the greatest dynamic range (10-bit) commercially available so that even very large clutter signals will not limit and, thus, become decorrelated.

The second step in our approach to signal processing is to use a form of processor which is as close as is economically feasible to the theoretically optimum signal processor[2]. Given a set of samples of the target plus clutter signal and knowing the form of the target signal and the correlation of the clutter samples, there exists a theoretically optimum way of weighting and adding this set of signal samples to produce the highest ratio of target to clutter at the output of the signal processor. We call this an optimum processor.

Having gone through the steps outlined above to maintain maximum correlation, we find that the clutter signals are practically perfectly correlated. The width of this clutter line (the so called intrinsic spectrum) is determined by the wind blowing trees and foliage in the clutter patch. The width is very small compared to the prf employed and it varies with wind velocity.

If we consider the clutter spectrum as a true line spectrum, the optimum processor is a discrete Fourier transform (DFT) using all of the 32 signal samples collected during the radar dwell time. For economy in the signal processor, we chose a slightly nonoptimum processor made by simply removing the DC from each of the two quadrature video channels over sets of eight signal samples, and then noncoherently integrating the results. The improvement curve for this simpler processor has identically the same shape as for an eight-pulse optimum processor and only suffers a noncoherent integration loss of about 2.5 dB compared to the optimum processor. It is, however, much simpler to construct since it has no multipliers, only adders and subtractors.

The signal processor (see Figure 11) receives and stores the returns on eight successive pulses in a shift register. All eight samples from a given range gate are added coherently and the result divided by eight to obtain the mean. The mean then is subtracted from each sample. The magnitude of the eight differences are added together. This is a noncoherent integration of the detected signals. Successive groups of eight are dealt with in the same way until all the pulses on one azimuth (32) are processed. The antenna beam is then set to a new azimuth.

The resulting improvement in signal-to-clutter ratio is shown in Figure 11. Notice the high value of improvement factor out to maximum velocities of interest (no blind speeds). The target is competing with noise (not clutter) in the central velocity region and the STC and threshold are set to detect all targets above about 0.5 m^2.

So called tangential targets with low components of radial velocity present a side view to the radar. Typically, a large specular return of at least 30 m^2 cross section occurs off the side of the aircraft. Thus, the tangential aircraft will be seen down to 18 dB below the top of the curve in Figure 13.

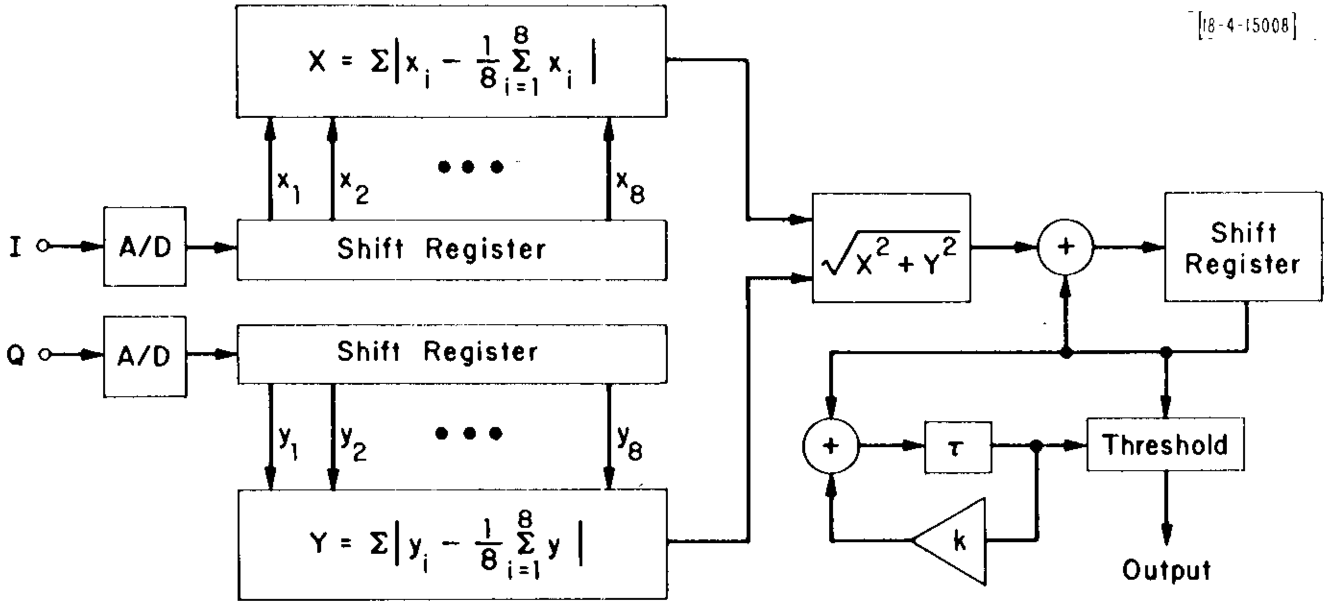

Fig. 11. Digital signal processor.

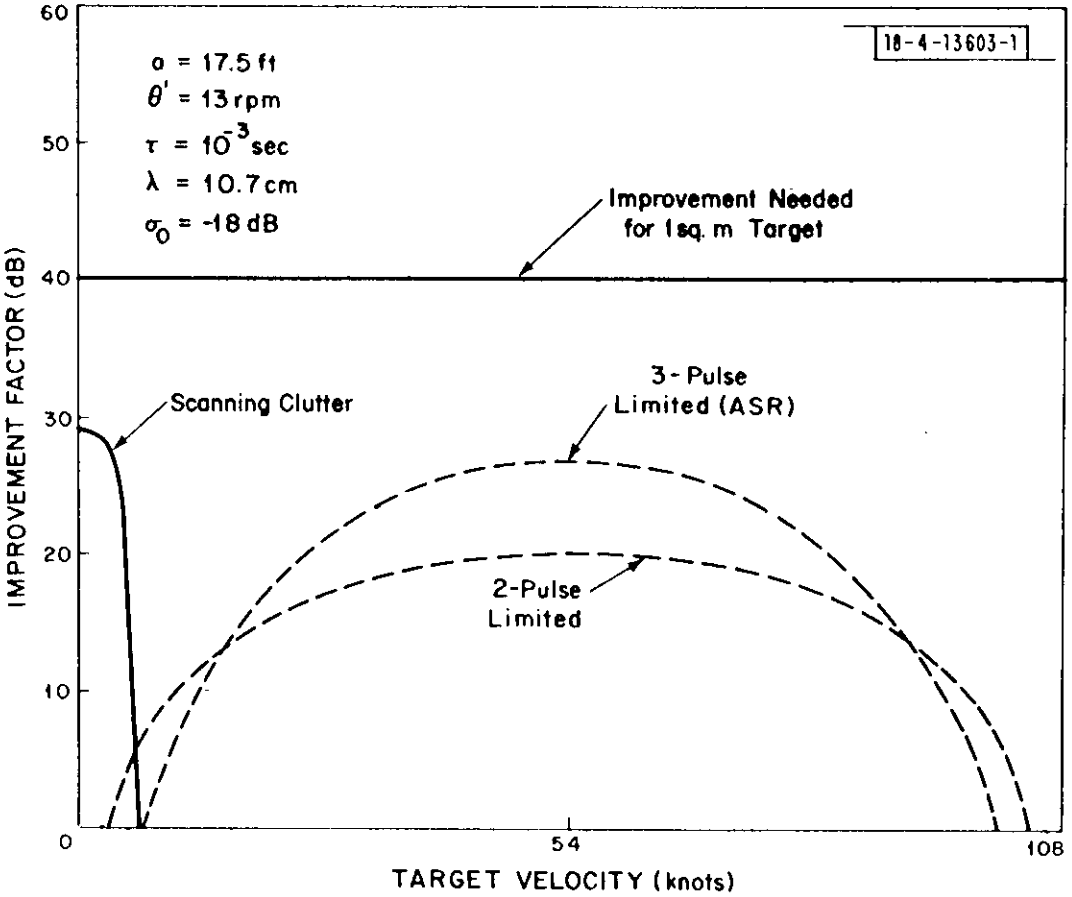

Fig. 12. Performance of S-band cancelers.

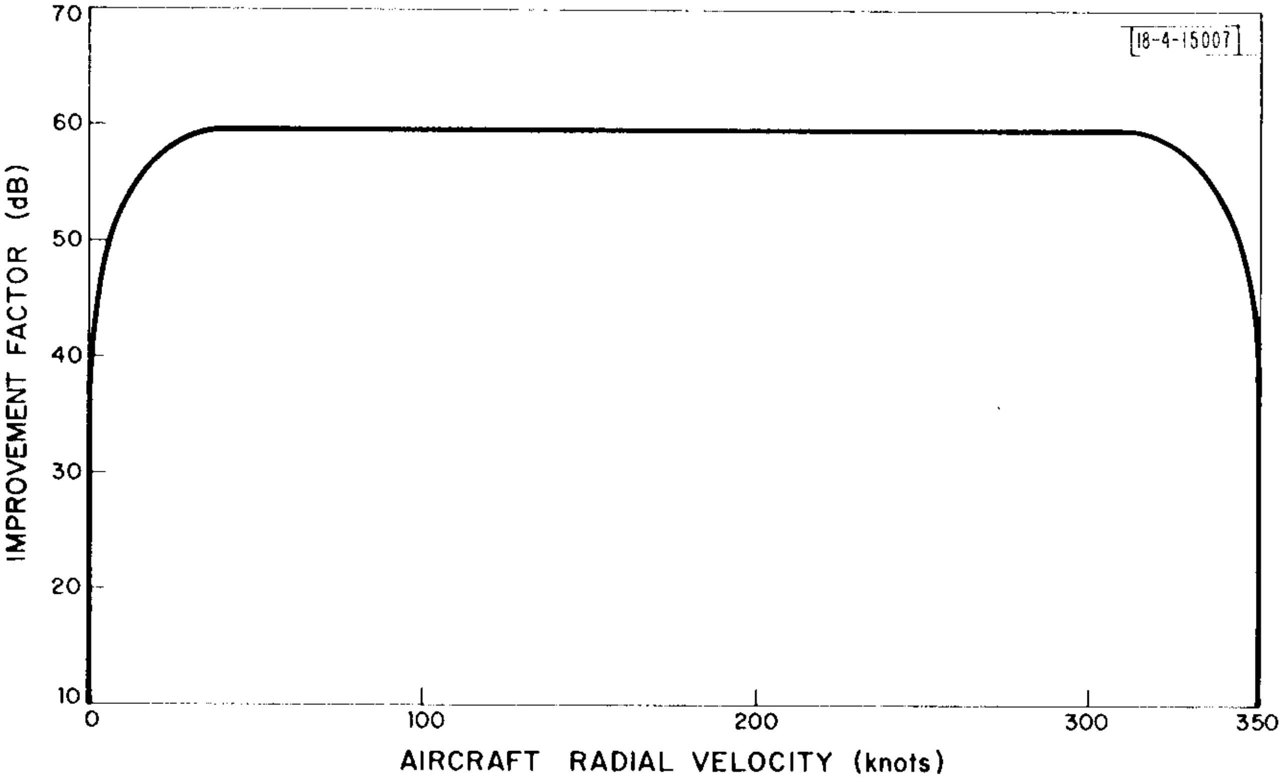

Fig. 13. Velocity performance of radar.

The aircraft at this point has only two knots radial velocity. Even a slow aircraft would be missed on only a few scans as it flies on a tangential course with respect to the radar. When a display is used which constantly displays several previous scans (scan-history display), these few detections are not missed, especially as the controller can observe the tangential velocity of the aircraft. The ability of this radar to see targets with such low radial velocity obviates the need for a ground clutter map further simplifying the radar.

Two other features of this signal processor should be noted. Since the residue at its output consists of receiver noise and target (no clutter) and since the receiver noise is constant, a simple time average can be used to set the threshold for detection.

Occasionally a resolution cell will contain a very large reflecting object (usually man-made). The return will saturate the analog-to-digital converters. Provision can be made in the processor to detect such an overload and the corresponding cell is simply not processed for a target. This will occur for an extremely small percentage of the resolution cells.

Signals at the output of the signal processor are either zero if the threshold was not crossed in the sum channel or else the size of the sum and difference signals in digital form. These are passed on to the display processor along with the azimuth and range of the target.

The number of bits associated with each target report is shown in Table III.

TABLE III

NUMBER OF BITS IN TARGET REPORT

Gross Azimuth	6 bits
Range	7 bits
Sum Signal Magnitude	10 bits
Difference Signal Magnitude	10 bits
	33 bits

Adding a few bits for data identification, parity, etc. we assign 40 bits to a single target report. Using a 2400 bit per second telephone line, a total of 60 targets per second or 240 targets per scan can be reported.

The signal processor also contains the digital timing and control for the radar.

D. Display Processor

The telephone line is connected through a modem into the display processor. This processor is a small computer such as a Nova 800. Its functions are as follows:

1. Coordinate Conversion: the range-azimuth returns are converted to rectangular coordinates by calculating R cos θ and R sin θ. Including data input time, this requires approximately 10 msec/sec for 60 targets even if software multiply is used.

2. Monopulse Azimuth Determination: the difference and sum signal amplitudes are used to correct the gross azimuth by calculating

$$X = R \cos \theta + k\Delta R \sin \theta / \Sigma \qquad \text{and}$$

$$Y = R \sin \theta + k\Delta R \cos \theta / \Sigma$$

where Δ and Σ are the sum and difference amplitudes and k is a constant. These calculations require another 20 msec/sec using software multiply and divide.

3. Target Display Refresh: the computer will be programmed to generate a so called scan-history display. The display is depicted in Figure 12. The most recent report will be a larger circle and the past three to six scans will also be displayed but as smaller circles so the target will appear as a snake with a head and tail. The controller can estimate aircraft speed from the separation of the circles and he can easily follow aircraft maneuvers. This function, using a direct memory access to the display, will require 170 msec/sec of computer time.

4. Range Rings and Video Map: the display will contain internally a vector (straight line) generator and a circle generator in addition to a character generator. Thus, the display processor will be programmed to refresh the display with range rings and a video map showing runway location, VOR stations, obstructions, etc. It is estimated that this will require 70 msec/sec of computer time.

5. VHF or UHF Direction Finder: the model FA-5530 VHF/UHF direction finder gives a very steady output showing the direction of the aircraft calling the tower. Unlike older direction finding sets using goniometers, this set uses an electronically switched set of antennas arranged in a circle. This imparts a Doppler to the incoming signal from which electronics within the direction finder can determine the direction of the aircraft. The apparent direction is very steady and does not vary with voice modulation as did the older direction finders. Where available, the output of this direction finder will be introduced into the display processor and onto the display as a straight line (see Figure 14). This will require less than 10 msec/sec of computer time.

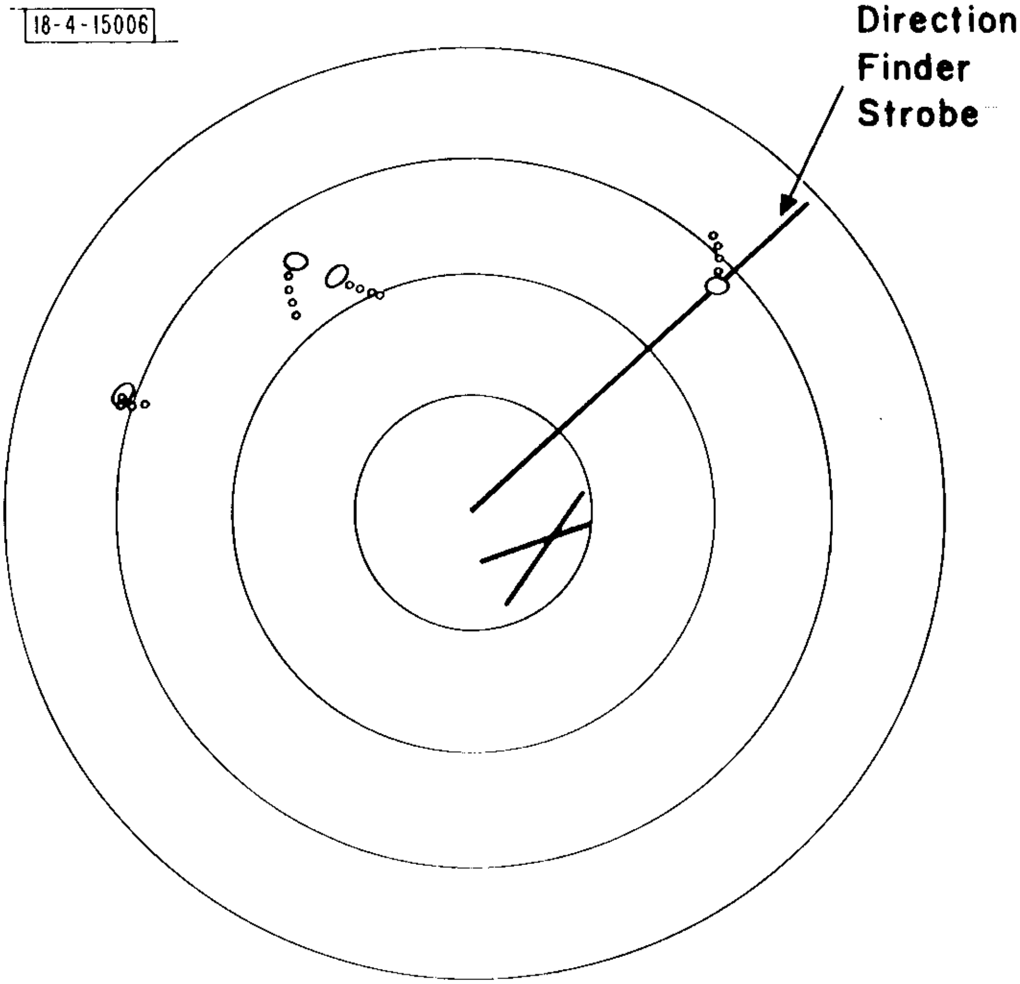

Fig. 14. Typical display.

6. ATCRBS or DABS Output: the total time for all the above functions amounts to less than 280 msec/sec so there is plenty of capacity left to process and display beacon data. With this type of display processor and display, the surveillance sensor system could grow gracefully as the traffic at an airport increased. The cost of the display and its processor would be shared between radar and beacon. The added cost for the other parts of a short range (20 nmi) ATCRBS interrogator is estimated to be less than $50K.

E. Display

The display proper is a 20-inch CRT. The display includes D/A converters for the X, Y and Z axes, a gross beam positioner and a fine beam positioner which generates characters. Besides this the display contains a vector generator to draw straight lines at any angle and a circle generator capable of drawing circles of any size anywhere on the screen. An example of a display with this capability is available as a standard item from Monitor Displays (Fort Washington, Pennsylvania). The only exception is that the Monitor display has a rectangular CRT instead of the desired round shape.

F. Estimated Production Costs

While providing the superior performance described above, this radar would cost less than half the cost of previous ASR's. The low cost comes about because of the use of a low power transmitter employing tetrodes instead of expensive microwave tubes. The antenna is a fixed structure built with much less precision than its S-band counterpart. It uses a set of relatively inexpensive diode switches for scanning. The signal and display processor and the display are all digital and make extensive use of integrated circuits.

They thus take advantage of the recent improvements in digital hardware, particularly in its costs.

Table IV shows the estimated cost of the radar to the FAA in production lots of 50 units. In arriving at these costs, we have assumed that prior to production an experimental model would have been constructed and evaluated and that a contractor would have been separately funded to construct an engineered prototype radar.

TABLE IV

ESTIMATED PRODUCTION COSTS

Transmitter/Receiver	$ 32K
Antenna	45
Signal Processing	21
Display Processor	15
Display	17
Integration and Test	10
	$140K

In estimating Table IV, where a similar unit is available from industry (display processor and display), the firm price for a single unit was used. For the other units, the cost of all of the purchased parts was determined and this was multiplied by a factor of two or three depending on whether these were subassemblies or piece parts. The results were compared with the costs of units of comparable complexity. The biggest doubt concerns the cost of the antenna where we are projecting somewhat cheaper construction techniques than have been used previously for this type of antenna. The production cost of an L-band radar with equivalent performance is estimated to be about 20% larger, primarily due to the increased antenna complexity and transmitter power.

When comparing the cost of this new digital radar with more conventional designs it should be recognized that the performance of the new radar would be substantially superior to that of a scaled down conventional ASR. It would provide improved MTI performance, (freedom from false reports from ground clutter, birds and weather), and it would directly feed either a bright digital display and/or a telephone line to a remote display or center. The radar is also capable of determining the relative velocity of aircraft; a feature not now available in existing radars. All of the above characteristics contribute to provide a radar with the data quality needed by a busy controller and/or a tracking computer.

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13. ABSTRACT

Recent improvements in the technology of electronically switched antennas and digital signal processing make possible a relatively high performance, low cost, surveillance radar. The radar described employs an electronically step-scanned, cylindrical antenna together with an advanced digital signal processor to give superior MTI performance at an estimated cost of less than half the present S-band ASRs.

The radar output consists of narrow band, digital target reports free of false alarms, suitable for transmission over telephone lines. Remote radar operation using digital, bright, scan-history displays becomes practical as does easy incorporation of beacon and direction finder outputs along with digitally generated video maps.

The complete absence of moving parts, the low power transmitter and the largely solid-state construction will provide high reliability and low maintenance costs.

These techniques are most easily and economically implemented in the UHF band, but a similar L-band radar can be designed with somewhat increased complexity and cost.

The techniques and background studies employed in the design of the proposed radar evolved over a period of three or four years as a result of work for the Air Force under Contract F19628-73-C-0002. Some of these techniques are being applied to improve the MTI performance of the ASR under FAA Contract DOT-FA72WAI-242.

14. KEY WORDS

low-cost surveillance radar
digital signal processor
switched cylindrical antenna
ASR
MTI
Air Traffic Control