RECENT ADVANCES IN AIR TRAFFIC CONTROL RADARS

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This paper describes recent improvements in microwave radars used for air traffic control. These improvements have been designed to increase the target-to-clutter ratio so that adaptive thresholding can be used to give a very low false alarm rate and high probability of detection even when the aircraft target is in the presence of strong clutter.

Studies [1] show that detection suffers when three types of clutter returns are strong; namely, ground clutter, weather clutter or angels. Angels have been almost universally identified as bird flocks. Under certain terrain and propagation conditions, second-time-around clutter can also be a problem. Here ground returns from the second to last transmitted pulse are received from targets beyond the nonambiguous range. These may be from mountains or from the ground when anomolous propagation conditions occur.

Meaningful improvements in this class of radar can be conveniently grouped as shown in Table I. We will briefly discuss each of the three classes listed.

I. RADAR PARAMETERS

Decreasing the radar cell by the use of pulse compression or narrower antenna beams causes the radar to be considerably more complicated since more resolution cells must be processed and it is difficult to achieve the required dB improvement in target-to-clutter ratio. For instance, decreasing effective pulse length from 500 feet to 5 feet gives 20 dB improvement but requires excessive bandwidth (~100 MHz) in already overcrowded radar bands.

As regards siting, it is common practice to site ASRs at low elevations (~25 to 35 ft) to take advantage of the shielding effect of nearby buildings and terrain to prevent the reception of longer range (< 10 to 20 nmi) clutter. This is effective but it also cuts off the possibility of detecting low elevation aircraft at longer ranges.

It has also been common practice to raise the peak of the elevation antenna beam pattern to reduce the illumination of nearby ground clutter by 15 to 30 dB (see Figure 1). This too has the effect of reducing the detectability of low elevation targets at the longer ranges. A good cure for the longer range problem is to provide dual or multiple beams in elevation on receive so that lower beams can be switched in for long aircraft detection. As illustrated in Fig. 1, however, the near-in (< 20 nmi) clutter will still compete with the aircraft both at low and again at high elevations. Detection in the high elevation clutter region shown in Fig. 1 would be improved by the use of an antenna with higher gain in this region, but the low elevation clutter requires some other solutions.

Circular polarization can be relied upon to produce about 15 dB reduction in rain return. A more effective method of reducing both weather and bird clutter is to lower the operating frequency as depicted in Fig. 2.

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For frequencies less than about 600 MHz neither rain nor birds are a problem.

II. MAINTAINING SIGNAL CORRELATION

Under the second major category of improvements, we find the use of large dynamic range, linear receivers. It is well established[2] and shown in Fig. 3 that limiting in the receiver causes a great reduction in the available improvement factor (improvement in target-to-clutter ratio in the MTI processor). Limiting or any nonlinearity in the receiver causes the generation of intermodulation products and a broadening of the spectrum of both target and clutter returns. Their spectra should be kept as narrow as possible for efficient separation using filters.

Since mechanical scanning also broadens these spectra (decorrelates returns from pulse to pulse) it would also help to step scan the antenna so that all pulses to be processed together are collected while the antenna is stationary. This can be accomplished using electronically scanned antennas.

To keep second-time-around clutter signals well correlated requires the use of a fixed interpulse period and a radar coherent from pulse to pulse. Such a radar might employ a klystron transmitter rather than the usual magnetron-coho radar system. In order to use a fixed PRF and still avoid blind speeds, multiple PRFs may be used rather than staggered PRFs. In multiple PRF operation two or more groups of pulses are employed sequentially each of a constant PRF within the group but different PRFs from group to group.

To maintain coherence in target and clutter signals the radar must use fully coherent transmitters and receivers, two channel (quadrature) video and digital signal processing. Digital handling of signals is the only means known of accurately storing data while maintaining wide dynamic range over more than a few pulses.

III. IMPROVED FILTERING AND THRESHOLDING

Finally, under the third category in Table I we call for processing of more pulses. All pulses during a dwell time contain useful signals for filtering purposes. If not enough pulses are available to filter out the clutter one should consider extending the dwell time by using multiple receive antennas or other techniques.

A major improvement is the use of near-optimum filtering. Once the transmitter and antenna parameters for a radar design have been chosen and it is agreed to use a linear receiver, a certain weighted sum of the signals from each radar resolution cell will maximize or optimize the target-to-clutter ratio for any given radial target velocity. The improvement factor to be expected from this optimum filter as a function of target velocity for a typical Airport Surveillance Radar (ASR) is shown in Fig. 4. This should be compared to Fig. 3 to note the tremendous improvement possible using optimum filtering against ground clutter. The combination of step-scanning and optimum filtering is depicted in Fig. 5, showing even more improvement around zero and the multiple blind speeds.

The word near-optimum filtering is found in Table I because it is found that usually, although not always, a bank of optimum filters covering all target velocities requires an excessive amound of hardware. In particular, too many multiplies are required. It is usually possible to find a set of filters which approximates the optimum set and comes within 1.0 dB or so of the optimum curve. For instance, a three-pulse canceller followed by an eight sample Discrete Fourier Transform is a suitable near-optimum filter bank for the conditions shown in Fig. 4. For a step-scanned antenna (Fig. 5) the Discrete Fourier Transform is the optimum filter.

So far we have only discussed filtering against ground clutter. Weather clutter is characterized by a spectral width corresponding to about 17 knots and a mean Doppler which varies with wind conditions and the direction the antenna is pointing. An optimum filter could be built to combat weather clutter but it would necessitate the measurement and storage of the time-varying covariance matrix of the total clutter present in each resolution cell. This generally requires more computation and memory than is economically feasible to use in the signal processor.

A practical solution to the thresholding problem is to use a regularly updated ground clutter map to develop a threshold for zero velocity ground clutter and so called mean-level thresholding on each filter in the near-optimum filter bank. In mean-level thresholding the clutter signals are added for a number of range gates on either side of the one being examined for a target. The threshold is a multiple of this number.

Two types of radars are being demonstrated using the above principles. The first is a UHF radar employing a step-scan antenna, and the second an S-band radar with parameters similar to ASRs in common use but containing a klystron instead of a magnetron transmitter. Excellent performance against all types of clutter can be achieved using either type of radar.

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REFERENCES

[1] C. E. Muehe, et al., "Concepts for Improvement of Airport Surveillance Radars," Project Report ATC-14, M.I.T. Lincoln Laboratory (26 February 1973).

[2] W. W. Shrader, "MTI Radar," RADAR HANDBOOK, Chapter 17, M.I. Skolnik, Editor, McGraw-Hill Book Company (1970).

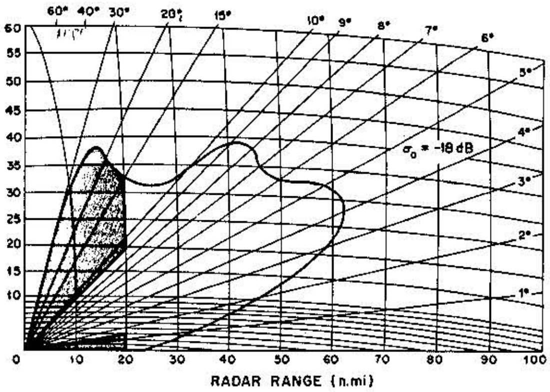
TABLE I

I. Radar parameter changes which increase the target-to-clutter ratio at the input of the radar.
   - A. Reduction in clutter cell size by decreasing resolution in range, azimuth or elevation.
   - B. Siting.
   - C. Modification of receiving antenna pattern as a function of range.
   - D. Use of circular polarization against rain.
   - E. Use of a lower operating frequency.

II. Improvements to maintain or improve the correlation from pulse to pulse of both target and clutter returns.
   - A. Use large dynamic range, linear receiver.
   - B. Use two-channel (quadrature) video.
   - C. Use fully coherent transmitters and receivers.
   - D. Use step-scan antenna.
   - E. Use multiple PRF instead of staggered PRF.
   - F. Use digital signal processing.

III. Improve filtering and thresholding.
   - A. Use adequate number of pulses.
   - B. Use near-optimum filtering.
   - C. Use adaptive thresholding, ground clutter map, mean-level thresholding.

FIGURES



COVERAGE OF ASR-7 RADAR AGAINST A 2-M² TARGET

Figure 1 - Vertical Coverage of a Typical S-band ASR in Detecting a Two-Square-Meter Target. Detection in the Shaded Areas is Spotty because of Competition with Ground Clutter.

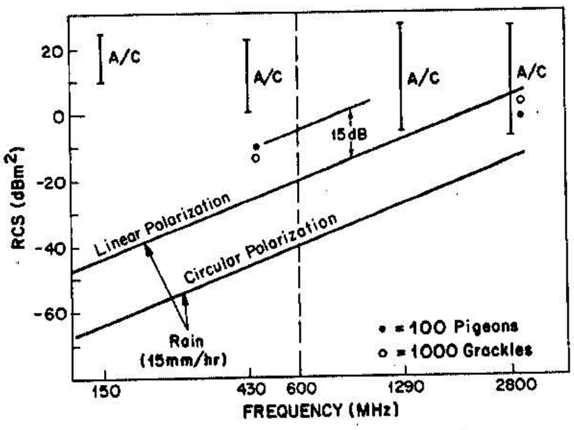


Figure 2 - Radar Cross Section (RCS) of Aircraft (A/C), Rain and Bird Flocks vs. Operating Frequency.

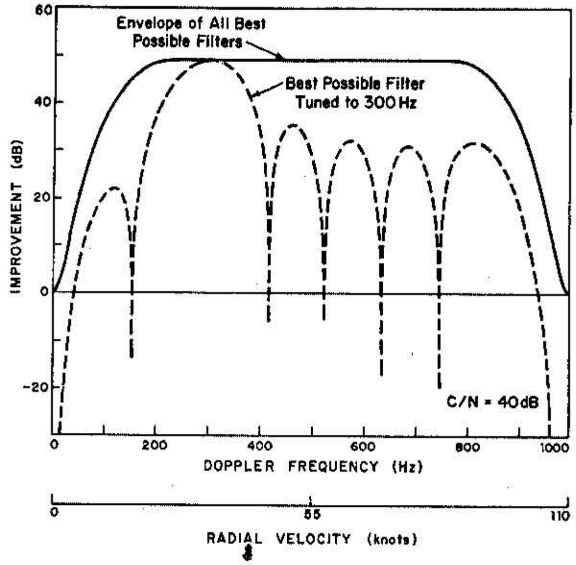


Figure 4 - Improvement Factor vs. Target Velocity for Optimum Signal Processor and Rotating Antenna. Parameters are the same as Figure 3.

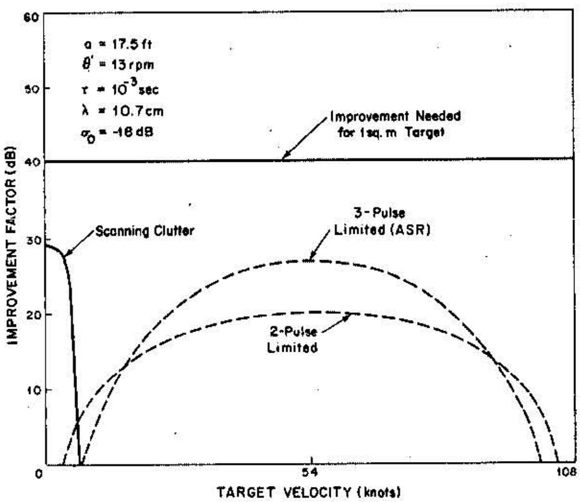


Figure 3 - Improvement Factor vs. Target Velocity for MTI Cancellers Following Limiting-type Receivers. Typical ASR Parameters are Assumed.

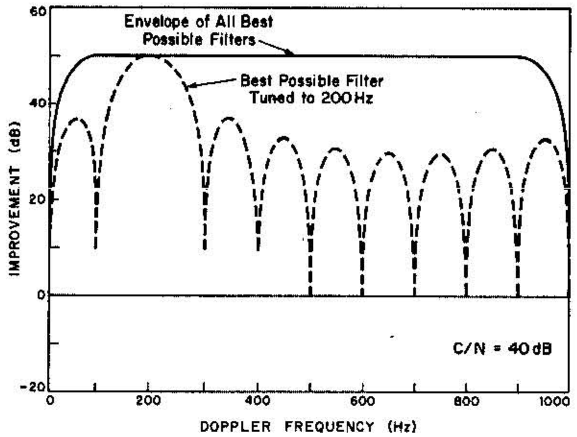


Figure 5 - Improvement Factor vs. Target Doppler for Optimum Signal Processor when using a Step-Scan Antenna.