7.5A REVIEW OF SPECIFIC ANTENNA CONFIGURATIONS: AN ESTIMATE OF COST AND PERFORMANCE VERSUS FREQUENCY FOR A SIMPLE $(10\lambda)^2$ CLEAR-AIR RADAR ANTENNA ARRAY

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INTRODUCTION

At the present time there is widespread interest in building operational clear-air radar wind profilers. The choice of operating frequency and antenna configuration for these profilers is currently under discussion. In this report we compare the cost and performance of a $(10\lambda)^2$ antenna array versus operating frequency over the range 30 to 400 MHz. To simplify the comparison the array beam will be fixed (no steering) and the array will be uniformly fed (no tapering). We consider both Yagi and coaxial collinear (COCO) cable antennas in this comparison, although other configurations (Franklin arrays, printed dipole arrays, fixed dish-type antennas, etc.) may be competitive. We assume that the array is driven by a typical 50 kW peak power, 1 kW average power transmitter located at the array edge when calculating feedline power-handling requirements and when comparing system performance. For this comparison we chose an array aperture of $(10\lambda)^2$ since a one-way beam width of 5° (∿ 3.5° 2-way) or less is desirable to limit beam-spreading effects.

YAGI ARRAY

The following table gives the gain (with respect to a dipole), effective aperture, and boom length for 3, 5, 6, 12 and 17 element Yagi antennas. These values were taken from NBS Technical Note 688 (VIEZBICKE, 1976). The table also gives the effective aperture of a coaxial cable dipole $\lambda/4$ above ground. The right-hand column of the table gives the number of antennas required to fill a $(10\lambda)^2$ aperture.

A survey of the cost of good quality Yagi antennas in the frequency range from 30 to 400 MHz shows that the cost to fill a $(10\lambda)^2$ aperture at a given frequency is about constant for 5- to 17-element Yagis (for example at 144 MHz 6-element Yagis cost \$50 x 71 (Table 1) = \$3,550 and 17-element Yagis cost \$100 x 35 (Table 1) = \$3,500). For cost comparison we take an 8 x 8 array of 6 to 7 element Yagis to fill the $(10\lambda)^2$ aperture. Boom lengths of 6 to 7 element Yagis are 1.2 to 1.5λ long (12 to 15 meters at 30 MHz) and would cause mounting problems at frequencies below 50 MHz. The increased element height might also enhance ground clutter problems with respect to elements located closer to the ground. It is probably logical to use a larger number of shorter Yagis (fewer elements) in the lower VHF band although the cost of feedline and connectors would be higher than given in this report.

We have assumed a simple branch feed for the 8 x 8 Yagi array, with feedline extending to a building at the edge of the array. The curves in the upper part of Figure 1 show the array component costs versus frequency. Curve A gives the antenna costs only, curve B includes baluns at \$10 each and antenna mounts at \$20 each. Curve C gives the total array cost using feedline consisting of a combination of RG-213 and RG-218 polyethylene dielectric coaxial cable and connectors, and curve D gives the array cost when 1/2" and 7/8" foam dielectric cable (foamflex) is used for the feedline. The loss (in dB) versus frequency for the two types of feedlines are compared at the bottom of Figure 1. The relative performance of the arrays using the two feedline types is considered later in this report.

Table 1.

NUMBER OF YAGI ELEMENTS	BOOM LENGTH	GAIN	AE	NUMBER TO FILL $(10\lambda)^2$ ARRAY
3	$.4\lambda$	5.1	$.67\lambda^2$	149
5	$.8\lambda$	8.3	$1.1\lambda^2$	91
6	1.2λ	10.5	$1.4\lambda^2$	71
12	2.2λ	17.0	$2.2\lambda^2$	46
17	3.2λ	21.9	$2.9\lambda^2$	35
Coaxial cable dipole $1/4\lambda$ above ground			$.17\lambda^2$	588

COAXIAL CABLE DIPOLE ARRAY

The coaxial-collinear (COCO) antenna constructed of RG-213 cable has been described by BALSLEY and ECKLUND (1972) and has been used in a variety of antenna arrays since that time. The advantages of the COCO antenna include low cost, simplicity, portability, and a single feed point for up to 48 dipole elements. The major disadvantage seems to be antenna loss (2 dB for a 48-element RG-213 antenna at 50 MHz). For this comparison we take an array of 16 strings consisting of 36 dipoles each to fill the $(10\lambda)^2$ aperture. The COCO antennas are made from RG-213 cable and when comparing performance we assume 2 dB antenna loss at all frequencies even though the loss may be lower than 2 dB at frequencies above 50 MHz.

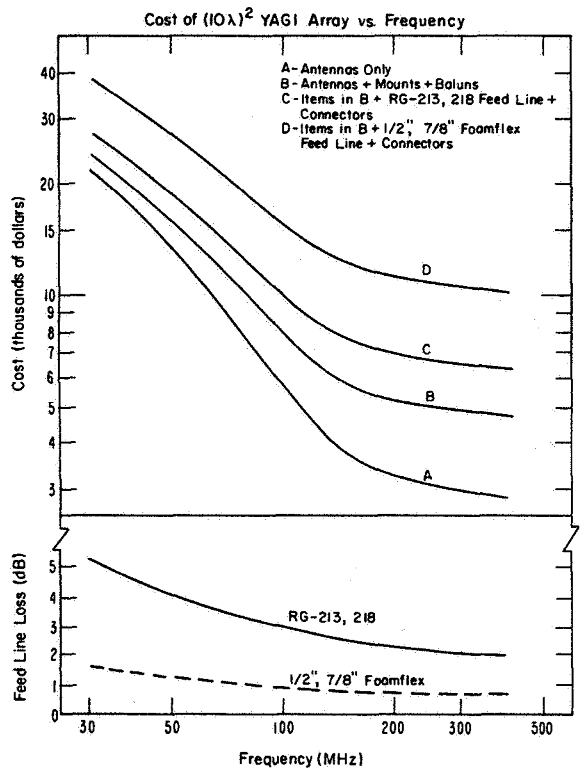

Figure 1.

The COCO antenna costs shown in Figure 2 include RG-213 cable, support rope, support posts, clips and ground wire at \$2.15/meter. The interchange of inner and outer cable conductors between dipoles costs \$1.50 for materials and \$6.65 for labor. Baluns cost \$10 each. Curve A shows the $(10\lambda)^2$ array cost versus frequency using RG-218, RG-213 feedline and curve B shows the cost for 1/2" and 7/8" foamflex feedline. Feedline loss (in dB) versus frequency for the two types of feedline are shown at the bottom of Figure 2. Curves AA and BB give the cost of $(10\lambda)^2$ arrays using RG-213, RG-218 feedline (AA) and foamflex feedline (BB) less the labor cost of \$6.65/dipole for interchanging the inner and outer cable conductors. The antenna cost curves in Figure 2 are dashed above 200 MHz because manufacturing tolerance problems may increase costs at higher frequencies.

ESTIMATED PERFORMANCE OF $(10\lambda)^2$ ARRAYS

The relative performance of the Yagi and COCO $(10\lambda)^2$ arrays using the two types of feedlines considered in the previous sections has been calculated by using the radar detectability equation given in BALSLEY and GAGE (1982). The equation has been modified by replacing the temperature term in the denominator by $[cbT_S + (1-b)\,T_C + b(1-c)\,T_A + T_R]$ where T_S = sky temperature, T_C = feedline temperature, T_A = resistive antenna temperature, T_R = receiver noise temperature, b = feedline transmission coefficient, c = antenna radiating efficiency. For these calculations T_C and T_A were set to 290°, T_R was 120°K (1.5 dB noise figure) and maximum, minimum and typical values for T_S were taken from KRAUS (1966). The 2-dB COCO antenna loss was accounted for by setting c = .63. Antenna loss of 0.5 dB (c = .89) was used for the Yagi array. Average transmitted power was set to 1 kW at all frequencies, height resolution was set to 1 km, and minimum detectability was set at 3 dB. The radio refractive turbulence structure constant (C_n^2) was taken as $10^{-(15.5+.2z)}$ where z = height in km. This value ($C_n^2 = 10^{-18}$ at 12.5 km) was found by NASTROM et al. (1982) to be typical of quieter conditions observed at Poker Flat, Alaska. The

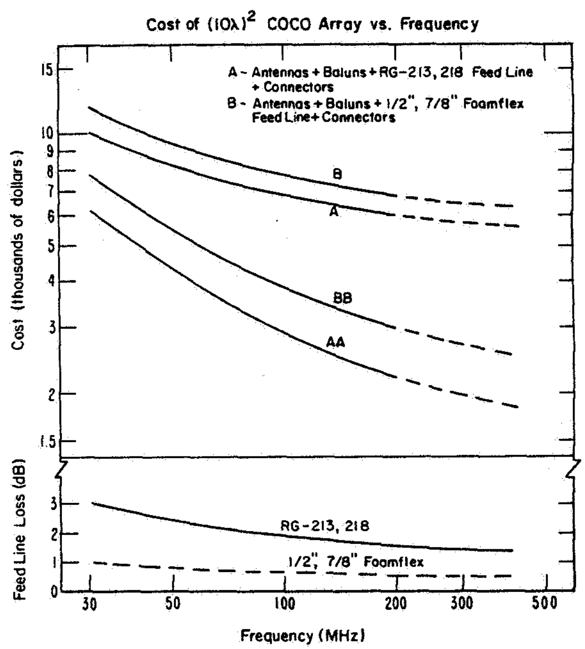

Figure 2.

lowest value of C_n^2 observed at 12.5 km was $\sim 3 \times 10^{-19}$ and ranged up to 3×10^{-17} under strong wind conditions. The detectability equation was solved for maximum height for usable signal-to-noise for the $(10\lambda)^2$ arrays discussed in the previous sections. Figure 3 gives maximum height versus frequency for Yagi (solid curve) and COCO (dashed curve) arrays, calculated using foamflex feedline for maximum, minimum and typical sky temperatures for the Northen Hemisphere. Figure 4 shows the curves for both types of feedline for both antenna types using typical sky temperatures.

The data from Figures 1, 2 and 4 are combined in Figures 5 and 6 to show the cost/height relationship versus frequency for Yagi arrays (Figure 5) and COCO arrays (Figure 6). Each figure gives the relationship for both foamflex and RG-218, RG-213 feedline with frequency indicated at spot values near the thin lines that link the curves for the two types of feedlines. The curves for foamflex feedline in Figures 5 and 6 are combined in Figure 7 to give a more direct comparison of the Yagi and COCO cost/height relationship. At frequencies below about 100 MHz the COCO array has a large cost advantage over the Yagi array with only a 0.5 km loss in maximum observing height. Above 144 MHz all combinations cost $12,000 or less and the height difference is 1 km or more ($\sim$ 1.5 km at 420 MHz). The Yagi array curve is dashed from 30 to 50 MHz since boom length would be too long for the 8 x 8 array considered in this comparison. The COCO array curve is dashed above 200 MHz since it may be difficult to manufacture COCO elements with the required precision above this frequency. Although operating frequencies above 200 MHz seem at a disadvantage for either type of array, at 420 MHz it would be possible to nearly double the effective aperture by using 64 17-element Yagis with larger spacing. The 3.2λ boom length (2.25 meters) would be no problem from a height standpoint, increased antenna costs would be $2,500 and increased feedline costs would be minimal. The maximum observable height would increase to 13.5 km (indicated by the circled X in Figure 7).

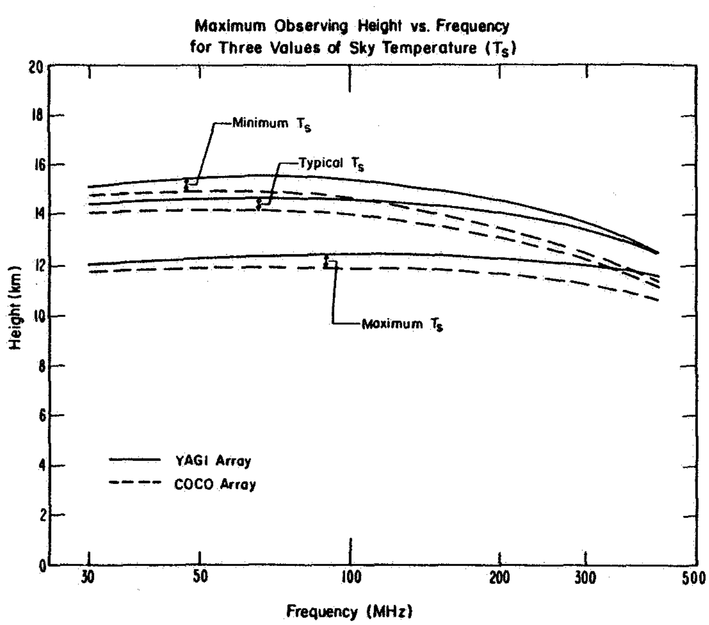

Figure 3.

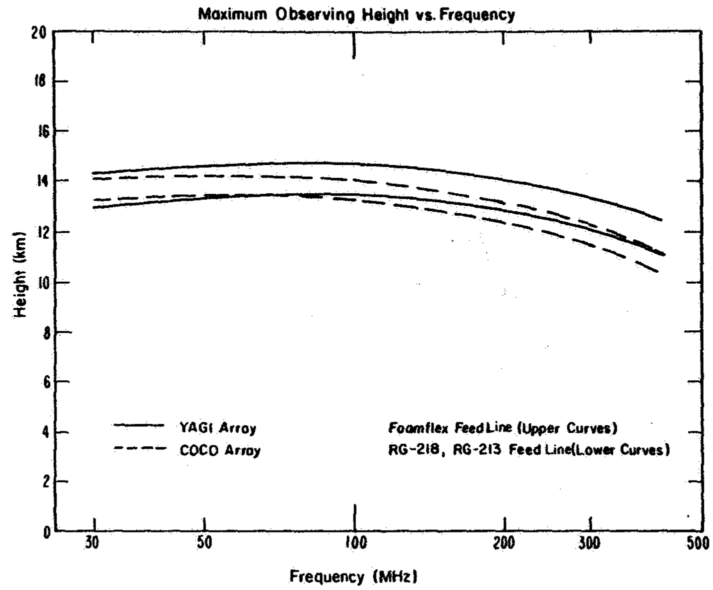

Figure 4.

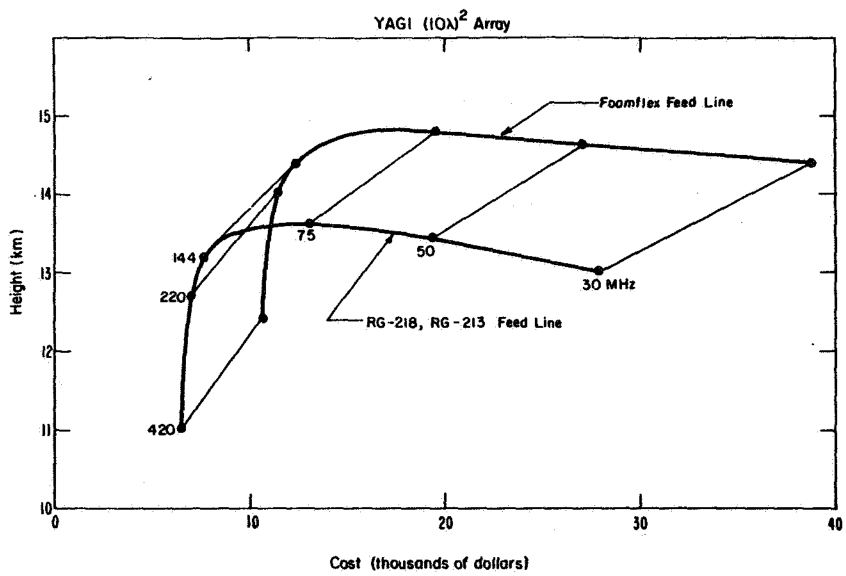

Figure 5.

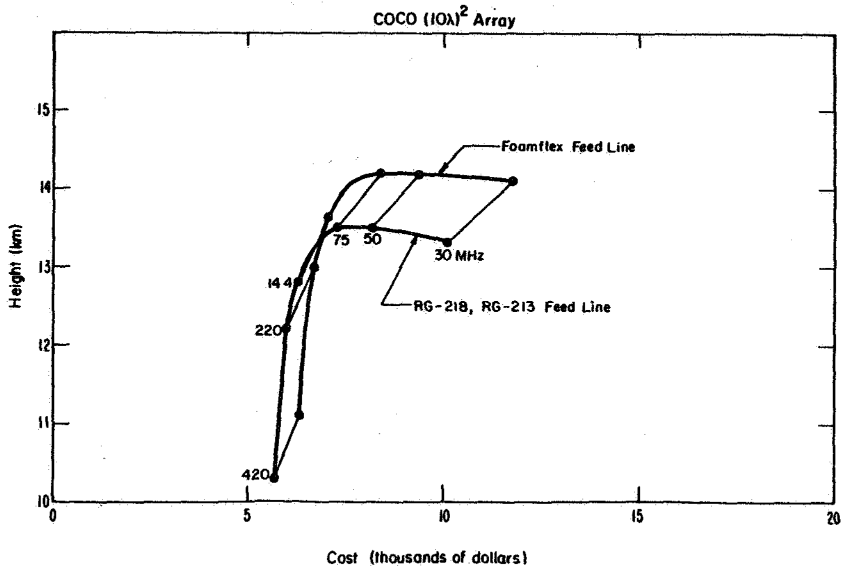

Figure 6.

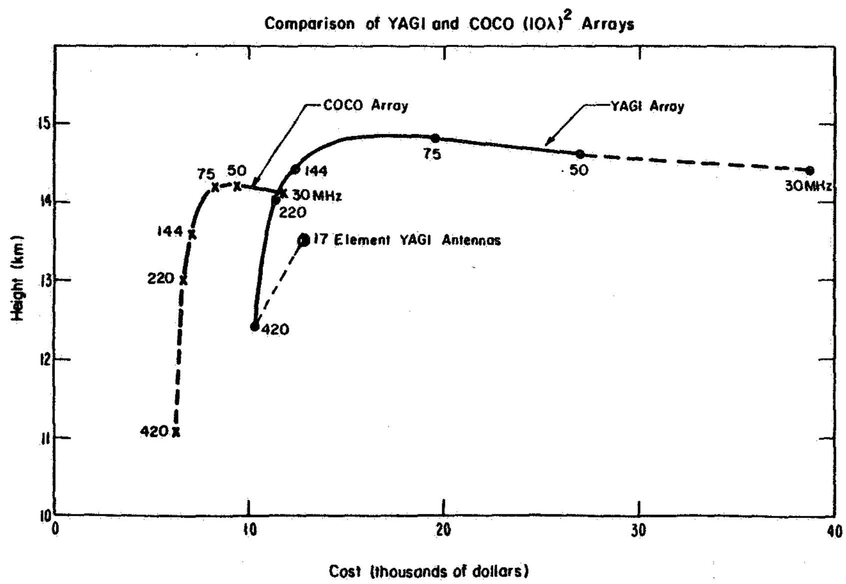

Figure 7.

SUMMARY

In this report we have compared costs and performance for $(10\lambda)^2$ Yagi and COCO arrays suitable for use in clear-air radar systems. In general the COCO antennas seem to have a clear cost advantage below 100 MHz with only a slight corresponding loss in performance due to loss in the antenna elements. At frequencies above 150 MHz the YAGI arrays have a larger performance gain for somewhat higher costs. The curves presented in this report can be used to determine the relative performance gain for dollar cost when choosing operating frequency, antenna type and feedline type for a $(10\lambda)^2$ array. The maximum observing heights shown in Figures 3 through 7 were calculated using values of C_n^2 typical of relatively quiet conditions; under high wind conditions the heights could increase by over 5 km.

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