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A stacked Yagi antenna for APT reception

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ABSTRACT. The paper describes design and construction of an antenna system with two Yagi arrays stacked to have high gain and directivity. The antenna can be rotated both in azimuth and elevation and used to track a weather statellite by remote control using torque drive motors.

1. Introduction

Orbiting weather satellites with Automatic Picture Transmission (APT) capability transmit earth cloud cover pictures, which are received at ground stations as the satellite passes within radio range of the station. The transmission is in the space research band of 135-138 mc, the transmitter having a power output of about 5 watts. The ground antenna has to reach the satellite and receive the VHF f-m signal with video information amplitude modulated on a sub-carrier. A high gain and highly directive aerial which can be kept constantly pointed towards the orbiting satellite is essential. The paper describes a steerable antenna for APT reception constructed at Delhi with available components and material. High gain and directivity is obtained by stacking two long Yagi arrays. A remotely controlled motor drive for steering the antenna both in azimuth and elevation has been provided.

2. General description

The steerable antenna unit consists of two Yagi arrays, a supporting pedestal, azimuth and elevation drive assemblies and a control panel. The antenna is installed on the flat roof of a building (Fig. 1) and is operated from the console (Fig. 2) located in a room below.

2.1. *Yagi arrays* — The two Yagi arrays consisting of 14 elements each constitute the antenna assembly and are attached to a cross arm by diagonal supporting rods. The cross arm passes through and is locked to the rotating axis of the elevation drive mechanism.

Each array is 8·6 metres long. The boom is a brass tube 30 mm in diameter with the elements consisting of 3·2 mm diameter rods fixed on it.

2·2 *Supporting pedestal* — The supporting pedestal is designed to provide good weather protection for the azimuth and elevation drive assemblies. Easily removeable covers provide ready access to the various units.

The antenna assembly design is such that it is dynamically balanced. The motors merely supply the frictional torque.

Mechanically driven position indicators are provided on the azimuth and elevation housing for azimuth and elevation indication respectively, Selsyn transmitters for remote indication are directly geared to the turn-table and the cross arm.

A cable wrap is provided for the rotation of the cable inside the pedestal. Two separate limit switches give warning indication at the limits of the cable travel in either clockwise or counter clockwise direction.

2.3. *Drive assemblies* — The azimuth and elevation drive assemblies consist of gear drive mechanisms coupled to limit switches and synchro read-out devices. The antenna drive motors are synchros which are coupled to torque transmitters that can be driven in either direction. The rotor windings are energised by 230 V, 50∼ single phase supply. The rotors of both azimuth and elevation torque transmitters can be rotated either manually by handwheels or by a bidirectional 230 V, single phase 50∼ motor. The synchros drive their related antenna axis through a chain of reduction gears. The indicator synchros are connected to the output shafts through another gear chain.

2·4. *Control panel* (*Fig. 2*) — The panel consists of controls with corresponding indicators to show the antenna positions in azimuth and elevation.

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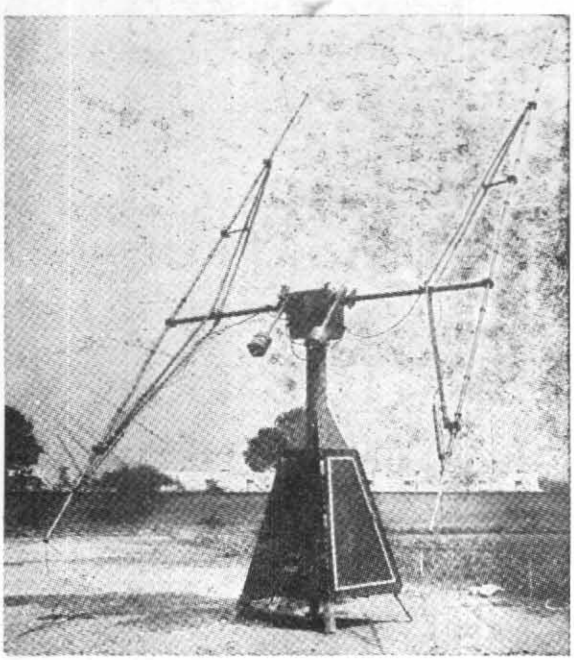

Fig. 1

Separate press button switches are used for the operation and direction control of elevation and azimuth drive motors. Speed control is obtained through a foot operated clutch which couples the motor to the respective drive unit. The operating controls have been so positioned as to allow easy access from a sitting position. A horizontal writing surface is provided for the operator.

The position of the antenna is indicated on circular scales. The elevation angle is displayed on two circular scales, one calibrated in degrees from 0 to 90° and another in tenths of a degree. Azimuth orientation is similarly displayed with the scales calibrated in degrees from 0 to 360° and in tenths of a degree respectively.

Red light indicators give warning for limiting the rotation in azimuth. The clockwise lamp glows when the antenna cable in the pedestal has been rotated nearly to its limit in the clockwise direction from its central position. The counter clockwise lamp gives a similar warning.

3. Design considerations

An array using parasitic elements has substantially unidirectional characteristics and a relatively simple electrical configuration. It has therefore been used in the antenna system which has to be rotated to aim the beam in any desired direction.

3.1. *Principle*—The signal in the 125 — 138 mc band received from the satellite is fed to the receiver from the aerial *via* a coaxial cable and matching unit. The driven element of the array is connected to the coaxial cable through a balun section which is mounted on the boom very near the driven element. The signal from each of the two cables from the two arrays is combined at the T junction. The T junction is connected to a matching unit which transforms the junction impedance to match with that of the feeder coaxial cable connected to the receiver.

3·2. *Gain and directivity* — The 14 element array is used for increasing gain and directivity. It consists of a reflector, a driven element and twelve directors. Two identical parasitic arrays have been stacked for additional directivity and gain.

The bays are spaced 3·35 meters apart which is much greater than a wavelength; hence the coupling between the bays is slight. The phasing line between the two bays is a coaxial line connected to a coaxial T junction. The impedance at the mid point becomes approximately half that of the individual bays.

3·3. *Polarisation* — The satellite antenna radiates in a pattern similar to that of a dipole. The polarisation components range from circular to linear and are dependent on the position of the satellite. It is therefore desirable to have random linear polarisation characteristics in the ground antenna. This has been achieved by radial displacement of the individual director elements in the Yagi arrays, providing reception for all angles of polarisation.

3·4. *The array elements* — The elements in a directive array is a half-wave dipole. The resonant length of an ungrounded antenna element is shorter than a half wave length and is given by—

$$L_{(\mathrm{cm})} = \frac{14998\cdot 7\, K}{f\,(\mathrm{Mc})}$$

where, the factor K is dependant on the thickness of the conductor and the frequency at which it is used . The value of K for a free space half wave length of 1·07 metres, a diameter of 3·17 mm and a frequency of 137 mc is 0.97.

The driven element is the one which is connected to the receiver through a transmission line. The parasitic elements consisting of the reflector and directors are connected to the driven element through electromagnetic coupling and have no direct connection to the receiver. The parasitic element acts as a director when its tuning is adjusted to the high frequency side of the resonance and as a reflector when the tuning is adjusted to the low frequency side of the resonance. Proper tuning is accomplished by adjusting the length of the elements. The element lengths for elements having a length/diameter ratio of 200 to 400 and with element spacings from $0 \cdot 1$ to $0 \cdot 2\ \lambda$ are given by—

$$\text{Driven element length (cm)} = \frac{14478}{f\ (\text{Mc})}$$

$$\text{Director element length (cm)} = \frac{13868 \cdot 4}{f\ (\text{Mc})}$$

and

$$\text{Reflector element length (cm)} = \frac{15240}{f\ (\text{Mc})}$$

The spacing and length of the 14 elements in the Yagi array is shown in Fig. 3.

3.5. *The driven element* — The feed point impedance and bandwidth of the long Yagi array depends almost entirely on the two or three parasitic elements closest to the driven element, because those further from the driven element are relatively loosely coupled to it. The resistance at the centre of a simple dipole-fed driven element for the long Yagi is about 18 Ω. A folded dipole has been used as driven element. This not only facilitates feeding but also steps up the terminal impedance. For the conductor diameter ratio $dr/dl = 1$ the feed point impedance is increased four times and becomes 72 Ω so that a 75 Ω coaxial line can be directly connected to it, without requiring any other matching arrangement. Also, for the arrangement used, the spacings between the conductors is not critical and thus requirements for construction are not rigid.

3.6. *The balancing device* — The balancing device used for coupling the unbalanced coaxial line to the balanced centre fed folded dipole element of the antenna array consists of a detuning sleeve which is essentially an air insulated quarter wave coaxial line with the sleeve constituting the outer conductor and the outside of the coaxial line being the inner conductor. Because the impedance at the open end is very high, the unbalanced voltage on the coaxial line cannot cause much current to flow on the outside of the sleeve. Thus the sleeve acts like a choke coil in isolating the remainder of the line from the antenna. The diameter of the coaxial detuning sleeve is large compared with the diameter of the cable it surrounds. The sleeve is symmetrically placed with respect to the centre of the antenna element so that it is equally coupled to both sides.

3.7. *Matching section* — The impedance at the coaxial T junction with the two arrays becomes 36Ω, *i.e.*, approximately half that of individual cables. The impedance transforming properties of a quarter wave transmission line have been utilised in matching this mid-point impedance of the antenna bays to the characteristic impedance of the coaxial line which is 50Ω.

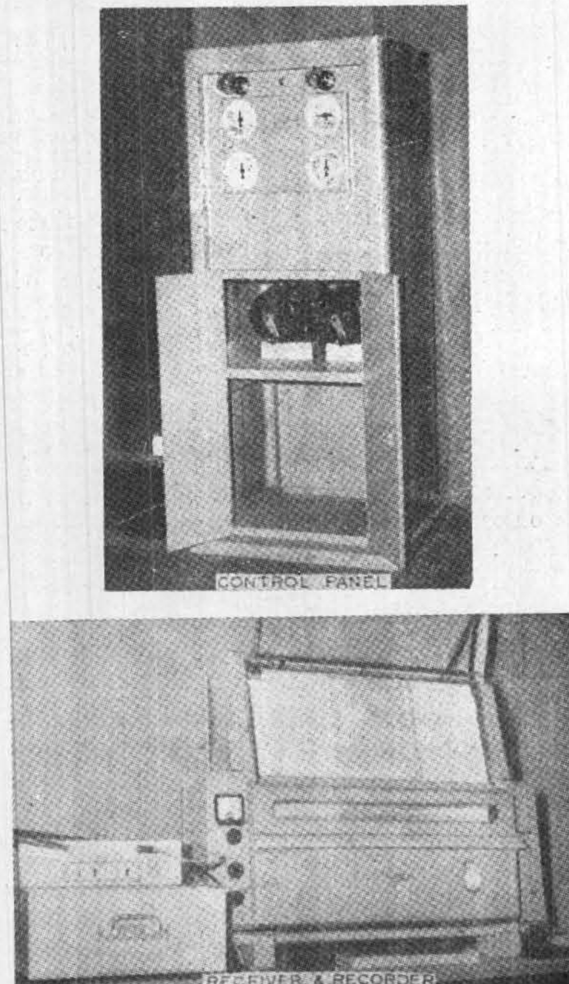

Fig. 2

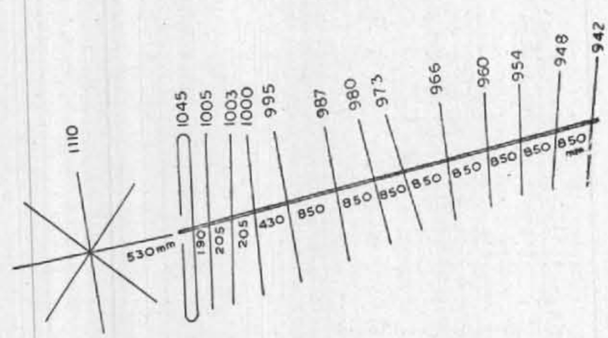

Fig. 3

Yagi array for APT

(All dimensions are in mm)

The input impedance Z_s of a quarter wave line terminated in a resistive impedance Z_R is given by :

$$Z_s = Z_o^2 / Z_R$$

where t Z_o is the characteristic impedance of the line. The inner conductor is silvered outside and the outer conductor is silvered inside. The inner conductor is supported by only three insulating beads at the centre of the outer conductor made of copper tubing. The number of beads is kept to a minimum to reduce losses.

The air insulated coaxial line characteristic impedance is given by—

$$Z_o = 138 \log b/a$$

where Z_o is the characteristic impedance, b the inner diameter of the outer conductor and a the outer diameter of the inner conductor.

The physical length of line is related to its electrical length according to the relation—

$$\text{Length (cm)} = \frac{29992 \cdot 32}{f\,(\text{Mc})} V$$

where, V is the velocity factor which is the ratio of the actual velocity along the line to the velocity in free space and is equal to $0 \cdot 85$ for air insulated coaxial line. Length of the quarter wave line is given by—

$$\text{Length (cm)} = \frac{7498 \cdot 08}{f\,(\text{Mc})} V$$

4. Conclusion

The antenna has been used in conjunction with a preamplifier, a suitable F.M. receiver and a weather chart facsimile recorder modified for recording cloud pictures. APT transmissions from ESSA, NIMBUS and ITOS satellites have been received at New Delhi. Similar equipments have also been installed at Calcutta and Madras.

DISCUSSION

(Presented by G. P. Srivastava)

SHRI V. SRINIVASAN : Has the system of antenna any bearing on the quality and details of the APT pictures ?

SHRI G.P. SRIVASTAVA : Yes. It is one of the factors. The recorder and receiver also contribute to the quality of the picture.

SHRI P.R. SEN GUPTA (Kharagpur) : If it is a narrow beam, antenna distortion may not be much. The resolution is controlled by antenna distortion.

SHRI H. MITRA pointed out that the aerial developed by Poona Instruments Division and that developed by Telecom. Unit, Delhi, were polarised in one direction only. The stacked Yagi is polarised in opposite directions, so that the signal from the satellite polarised in any direction would be more efficiently received than the other two.