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Relationship between Stepper Motor Step-angle and Satellite Dish Antenna Diameter and Beam-Width

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Abstract: - This study is a part of a research of designing a Satellite Dish Antenna Positioning System using stepper motors for adjusting azimuth, elevation and polarization angles. This paper aims to find a general relationship between the step-angle of the stepper motor and the satellite dish antenna diameter and beam-width. This relationship insures that the dish antenna directed within the HPBW when it position to any satellite within the range.

***Keywords:** - HPBW Half-Power Beam-Width, Stepper motor Step-angle, antenna step-angle*

I. INTRODUCTION

Open-loop control system combines between simplicity and low cost. To add effectiveness feature to the system or to improve efficiency of it, you must find a relationship between the system components. So they will be compatible with each other.

The main feature lets the stepper motor to be the optimum choice for open-loop motion control system, is that's the load position controlled by a predetermined number of digital pulses send to the motor driver from the control unit (controller).

To implement the stepper motor in this application, a relationship must be obtained between step-angle of the stepper motor, and the diameter and Beam-Width of the intended dish antenna.

II. THE PARABOLIC REFLECTOR AND HPBW

Parabolic reflectors are widely used in satellite communications systems to enhance the gain of antenna. The reflector provides a focusing mechanism which concentrates the energy in a given direction. The most commonly used form of parabolic reflector has a circular aperture, as shown in figure (1) [3].

Figure (1): a parabolic reflector

This is the type seen in meany home installations for the reception of TV signals. The circular aperture configuration is referred to as paraboloidal reflector [3].

A fundamental relationship exists between the power gain of an antenna and its effective aperture is

$$\frac{\mathrm{Area_{eff}}}{\mathrm{G}} = \frac{\lambda^2}{4\pi} \longrightarrow (1)$$

Where

$$Area_{eff} = \eta Area_{physical} \longrightarrow (2)$$

The illumination efficiency η is usually a specified number, and it can range between about 0.5 and 0.8 of course, it cannot exceed unity, and a conservative value often used in calculation is 0.55.

The gain and beam-width of the paraboliodal antenna are as follows: The physical area of the aperture plane is

$$Area_{physical} = \frac{\pi D^2}{4} \longrightarrow (3)$$

From the relationships given by equations (1) and (2), the gain is

$$G = \frac{4\pi}{\lambda^2}\eta\, Area_{physical} \longrightarrow (4)$$

$$= \eta\left(\frac{\pi D}{\lambda}\right)^2 \longrightarrow (5)$$

The radiation pattern for the paraboloidal reflector has a major lobe (Half-Power Beam-Width) and a number of side-lobes as shown in the figure (2) [3].

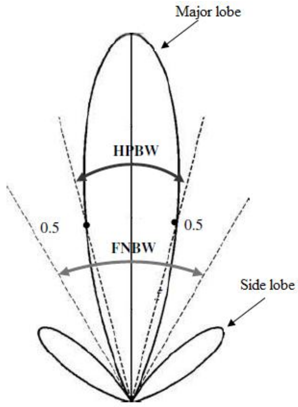

Figure (2): illustrate the Half Power Beam-Width

Useful approximate formulas for the half-power beam-width (HPBW) and the first null beam-width the (FNBW) are [3,4]:

$$HPBW = 70\frac{\lambda}{D} \longrightarrow (6)$$

$$FNBW = 2HPBW \longrightarrow (7)$$

III. THE AZIMUTH AND ELEVATION ANGLES

The azimuth angle a_z is the angle at which the earth station's desk is pointing at the horizon, whereas the elevation angle θ is the angle by which the antenna bore sight must be rotated to lock on to the satellite [1]. The azimuth and elevation angles, collectively called the *look angles*. The look angles are the coordinates to which an earth station antenna must be pointed to communicate with a satellite [1].

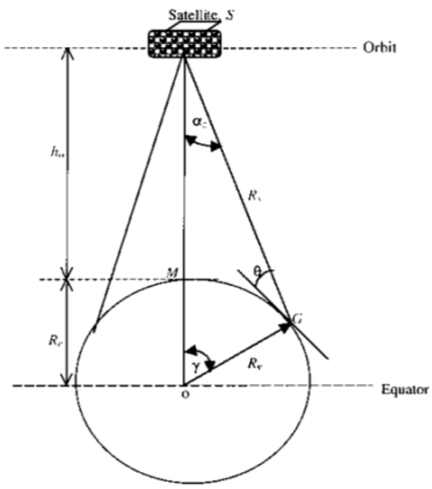

Figure (3): Geometry of look angles

The elevation angle θ can be calculated using this equation

$$\theta = tan^{-1}\left(\frac{cos\Delta cos L_{ET} - ({R_e}/{r})}{\sqrt{1 - cos^2\Delta\, cos^2 L_{ET}}}\right) deg \longrightarrow (8)$$

and the azimuth angle a_z using this one

$$a_z = 180 + tan^{-1}\left(\frac{tan\,\Delta}{sin\,L_{ET}}\right)\, deg \longrightarrow (9)$$

Where:
θ = elevation angle of satellite from the earth station.
L_{ET} = latitude of the earth station. This value is positive for latitudes in the Northern Hemisphere (i.e., north of the equator) and negative for the Southern Hemisphere (i.e., south of the equator).
L_{SAT} = latitude of the satellite.
Δ = difference in longitude between the earth station and the satellite.
r = radius of the orbit = OM + MS = $R_e + h_0$.

IV. STEPPER MOTORS

The stepper motor is a device used to convert electrical pulses into discrete mechanical rotational movements [5]. Also stepping motor is defined as a device that translates an electrical signal to a change in position of a shaft or other actuator [6].

4.1 Stepper motor type:

There are three basic stepper motor types, Variable-reluctance, Permanent-magnet and Hybrid [2].

4.1.1 Variable-reluctance (VR)

This type of stepper motor has been around for a long time. It consists of a soft iron multi-toothed rotor and wound stator [9].

4.1.2 Permanent Magnet (PM)

Often referred as a "tin can" or "can stack" motor the permanent magnet step motor is a low cost and low-resolution type motor with typical step angles of 7.5^0 to 15^0. PM motors as the name implies have permanent magnets added to the motor structure [9].

4.1.3Hybrid (HB)

The hybrid stepper motor is more expensive then the PM stepper motor but provides better performance with respect to step resolution, torque and speed. Typical step angles for the HB stepper motor range from 3.6^0 to 0.9^0. The hybrid stepper motor combines the best features of both the PM and VR type stepper motor [9].

Where step angle β is the number of degrees a rotor will turn per step. Smaller the step-angle, greater the number of steps per revolution and higher the resolution or accuracy of positioning obtained.

4.2. Connecting stepper motor and antenna:

Different methods are used to connect load (antenna) to the stepper motor. This paper concerned with two methods. The first one is connecting load directly and the second one is connecting load using gears.

4.2.1. Connecting antenna directly

That means the stepper motor step-angle β affect with the same value to the antenna step angle.

$$\alpha = \beta \longrightarrow (10)$$

Where α is the antenna step-angle in (azimuth and elevation).

4.2.2. Connecting antenna using gears

That means the motor Connected to the load indirectly as shown in the fig. (4). Let n_1, n_2 = speeds of 1 and 2, z_1 and z_2 = numbers of teeth on 1 and 2, D_1, D_2 = pitch circle diameters of 1 and 2 [7].

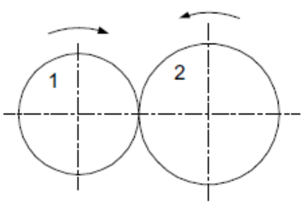

Figure (4): Simple gear connection.

According to Figure (4):

$$\gamma = \frac{n_1}{n_2} = -\frac{z_2}{z_1} = -\frac{D_2}{D_1} \longrightarrow (11)$$

The negative sign signifies that 1 and 2 rotate in opposite directions. The ratio $\gamma = z_2/z_1$ is called the gear ratio [7].

That means the relation between motor step-angle β and the antenna step-angle α given by this equation:

$$\alpha = \gamma\beta \longrightarrow (12)$$

So the smaller gear ratio, greater number of antenna steps per revolution and higher the resolution of positioning obtain.

V. RELATIONSHIPS BETWEEN STEP-ANGLE AND (HPBW AND ANTENNA DIAMETER)

Pointing the antenna to the calculated elevation and azimuth angle means directed the antenna to the 0dB angle which is the center of the antenna beam-width (HPBW).
So the limit of the directional antenna angle which lets the antenna point to the intended satellite and still within the HPBW of the antenna can be given by this equation:

$$limit = (az_{cal} \pm \frac{HPBW}{2})\, deg \longrightarrow (13)$$

Note:

In this application, the parabolic antenna with a circular aperture, the HPBW in the azimuth and elevation are equal. So the equation will be done in one direction (azimuth).
The stepping motor does not offer all calculated positions. It divides the looking radius in to discrete positions base on the step-angle β as mentioned. So the calculated angle maybe aligned with a discrete position or drooped between two discrete positions.
To convert the calculated azimuth angle (az_{cal}) in to number of steps (n):

$$x = \frac{az_{cal}}{\alpha} \longrightarrow (14)$$

Where x= (0…360)/ α
The result x will be one of these:

$$x = n \longrightarrow when\ x \text{ is an integer} \longrightarrow (15)$$
$$x = n \longrightarrow when\ x mod 1 < 0.5 \longrightarrow (16)$$
$$x = n + 1 \longrightarrow when\ x mod 1 \geq 0.5 \longrightarrow (17)$$

Where n is the integer part of x
The pointing azimuth (az_p) must be one of these:

$$az_p = n\alpha \longrightarrow (18)$$

Or

$$az_p = (n+1)\alpha \longrightarrow (19)$$

But at least one of them must be dropped within the antenna beam-width (HPBW) as shown in figure (5).

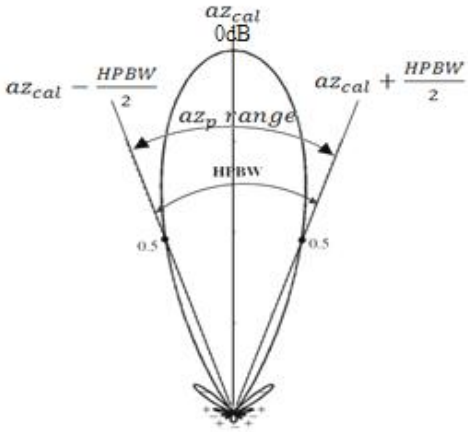

Figure (5) illustrates the limit of az_p

That means:

$$n\alpha \geq az_{cal} - \frac{HPBW}{2} \quad deg \longrightarrow (20)$$

Or

$$(n+1)\alpha \leq az_{cal} + \frac{HPBW}{2} \text{ deg} \longrightarrow (21)$$

By Multiplying equation (20)*(-1) we find:

$$-n\alpha \leq -az_{cal} + \frac{HPBW}{2} \; deg \longrightarrow (22)$$

By adding equation (21) to (22) we find:

$$\alpha \leq 2 * \frac{HPBW}{2} \text{ deg} \longrightarrow (23)$$

Or

$$\alpha \leq HPBW \text{ deg} \longrightarrow (24)$$

That means the antenna step-angle α must be less than or equal to the Half-Power Beam Width (HPBW) of the intended antenna. According to equation (6), also the diameter of the antenna is a function of antenna steps-angle(α) .

$$\alpha \leq 70\frac{\lambda}{D} \text{ deg} \longrightarrow (25)$$

6. Results:

For connecting antenna directly, according to equation (10), equations (24) and (25) can be rewritten as follow:

$$\alpha = \beta \leq HPBW \text{ deg} \longrightarrow (26)$$

$$\alpha = \beta \leq 70\frac{\lambda}{D} \text{ deg} \longrightarrow (27)$$

Also in connecting antenna using gears, according to equation (12), equations (24) and (25) can be rewritten as follow:

$$\alpha = \gamma\beta \leq HPBW \text{ deg} \longrightarrow (28)$$

$$\alpha = \gamma\beta \leq 70\frac{\lambda}{D} \text{ deg} \longrightarrow (29)$$

Figure (6) illustrates a relationship between antenna step-angle α and antenna diameter D for receiving a KU-Band downlink frequency 12GHz satellite signal.

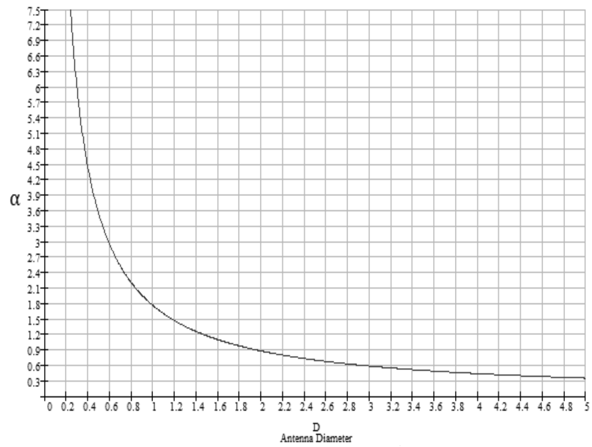

Figure (6): illustrate the relation between antenna diameter and step-angle

As the figure illustrates, in the direct connection if we use hybrid stepper motor which has a 1.8° step-angle as an example, and operate it in a full-step operation mode, then the antenna diameter must be less than or equal to 1 meter. Also when it operates in a half-step operation mode (this switching sequence double the resolution of the stepper motor by causing the rotor to move half the distance it does when the full-step switching sequence is used [8]) producing a 0.9° step-angle, then the antenna diameter must be less than or equal to 2 meters.

Also when we connect antenna using gears, for example permanent magnet stepper motor which has 7.5° step-angle with gears which has a 0.125 gear ratio, results in a 0.938° antenna step-angle. So the antenna diameter will be less than or equal to 1.9 meters, as illustrates in figure (6).

VI. CONCLUSION

From the results we can say that the step-angle of the stepper motor limits the diameter of the antenna that can be used when we connect them directly and vice-versa.

Connecting motor using gear to the antenna lets the design more flexible. By this way we can use stepper motor with less resolution and adjusting resolution of antenna step-angle by calculating the optimum gear- ratio (base on the HPBW and antenna diameter).

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