

EXTENDING THE OBSERVABLE ZENITH ANGLE OF FAST USING AN OFFSET FEED

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Abstract. The five hundred meter aperture spherical radio telescope is will use an active spherical reflector. When the zenith scan angle is changed, the illuminated part of the reflecting surface is made to fit a paraboloid of revolution in real time by active control. The maximum zenith scan angle $|\psi_{\max}|$ of FAST is 30° under conditions of the geometry selected in order that the feed does not illuminate the ground. The result of this paper shows that the maximum zenith scan angle $|\psi_{\max}|$ can be extended to 69° by offsetting the feed.

Keywords: radio telescope, maximum zenith scan angle, offset-fed

1. Introduction

The Five hundred meter Aperture Spherical radio Telescope (FAST) is a giant karst-based radio telescope (Qiu, 1998; Peng *et al.*, 1996). It differs from the 305 m Arecibo telescope (Kildal *et al.*, 1994) in that FAST will have an active spherical reflector. This active reflector consists of many elementary hexagonal segments having an open width of L m. When zenith scan angles are changed the illuminated part of the reflecting surface is made to fit a paraboloid of revolution in real time by active control. The radius R of the spherical surface of FAST is 300 m, and the opening D of the spherical surface is 520 m diameter. The diameter d of the aperture illuminated by the feed is 300 m, the focal length of the paraboloid will be $F = 0.467R$. The maximum zenith scan angle $|\psi_{\max}|$ of the FAST is 30° under conditions of the selected geometry to ensure that the feed pattern does not illuminate the ground. For angles $|\psi_{\max}|$ larger than 30° , there are the following two problems:

1. Part of the power radiated by the feed system will illuminate the ground. The spillover will reduce the gain of the antenna and increase the thermal noise produced by radiation from the ground.
2. The area of the illuminated aperture will reduce, which will influence the electrical performance of the antenna.



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The problems can be overcome by an offset feed for the active reflector to extend the angle $|\psi_{\max}|$. An offset-fed also influences the electric performance of the antenna. This paper investigates the dependence of the electric performance of the antenna on the zenith scan range of FAST when the angle $|\psi_{\max}|$ is extended by an offset-fed.

2. Limit on Extended Zenith Scan Ranges of FAST by Offset Feed

The maximum zenith scan angle $|\psi_{\max}|$ of FAST extended by an offset feed is limited by the following three factors.

1. **The maximum adjustable distance δ_{\max} of the elementary spherical units along the radial direction.** When the angle $|\psi_{\max}|$ is extended from 30° to $30^\circ + \psi_0$ by an offset feed, the opening angle of the asymmetrically illuminated area is supposed to remain 60° , regardless of whether it can be realized by the same feed. The area would in fact be part of a new paraboloid with its apex at the intersection of the major optical axis and the spherical surface. The diameter of this (imaginary) paraboloid becomes d' , where $d' = 2R \sin |\psi_{\max}| = 2R \sin(30^\circ + \psi_0) \geq 300$ m. So, the distance δ_{\max} must be increased and it increases quickly with increasing angle $|\psi_{\max}|$. For example, when the angle $|\psi_{\max}|$ of FAST is extended from 30° to 45° by an offset feed, the distance δ_{\max} increases from 0.7 m to about 6.5 m. It is very difficult to realize such a large adjustment distance δ_{\max} through engineering, or the cost will be very expensive.
2. **Paraboloid antenna focal ratio limit on the angle $|\psi_{\max}|$.** When an offset feed is used, the focal length of the paraboloid is supposed to still be $F = 0.467R$, hence, the dependence of the parabolic antenna focal ratio F/d' on the angle $|\psi_{\max}|$ is $F/d' = 0.2335/\sin |\psi_{\max}|$. When the angle $|\psi_{\max}| \geq 69^\circ$, the ratio $F/d' \leq 0.25$ and the antenna changes from a paraboloid of long focal length to one of short focal length. When $F/d' < 0.25$ there are two bad electric current regions on the parabolic surface. The direction of one component of the current in one region is opposite to that of the current in the other region. The field radiated by them is of opposite phase at the maximum radiation direction of the antenna. So, it is clear there will be reduced performance of the antenna when the ratio $F/d' < 0.25$. Hence, the angle $|\psi_{\max}|$ of FAST can be at most extended by an offset feed to 69° .
3. **Influence of offset feed on antenna gain.** After implementation of an offset feed, the following two factors will influence the antenna gain. First, the area of the reflecting surface to be illuminated is supposed to still be a circle of 300 m diameter, but the effective aperture of the antenna is changed into an ellipse (dotted line), see Figure 1b. The antenna gain will reduce as the effective aperture decreases. Second, the subtended angle 2ϕ (see Figure 1a.) of the illuminated aperture at the phase center of the feed reduces rapidly with the

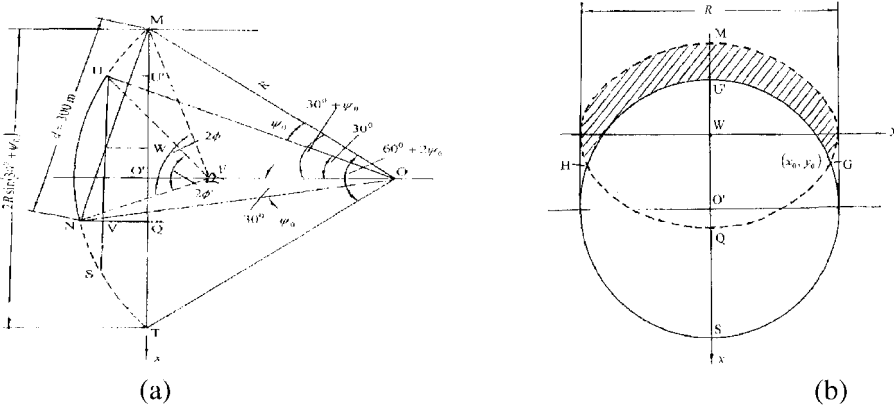


Figure 1. The effective aperture of the antenna.

increase of the angle $|\psi_{\max}|$. For example, when the angle $|\psi_{\max}|$ of FAST is extended from 30° to 45° by an offset feed, the subtended angle 2ϕ decreases from 112.69° to 107° . Hence, the spillover of the feed increases quickly and the antenna gain will be reduced. Now dependence of the antenna performances on the angle $|\psi_{\max}|$ will be calculated.

3. Dependence of the Antenna Performance on the Maximum Zenith Scan Angle

3.1. DEPENDENCE OF THE ANTENNA GAIN ON THE ANGLE

The distance $|\delta_{\max}|$ is limited to 0.70 m to reduce cost. The factors, except that of the feed spillover, which have influence on the antenna gain are supposed to be same. As shown in Figure 1b, when the angle $|\psi_{\max}| \leq 30^\circ$, the effective aperture of the antenna is the solid circle whose area is S_0 . When the angle $|\psi_{\max}| > 30^\circ$ and the distance δ_{\max} is not limited, the effective aperture of the antenna is the dotted ellipse shown in Figure 1b whose area is S_e . As the angle $|\psi_{\max}| > 30^\circ$ and the distance δ_{\max} is limited to 0.70 m, the area of the effective aperture of the antenna is $S_e - S_s$ where S_s is the area of the shadow shown in Figure 1b. The segments located in the shadow should be adjusted at random in order that the power reflected from the shadow is not received by the feed. The reduced value of the antenna gain is ΔG for the angle $|\psi_{\max}|$ that is extended by the offset feed, and

$$\Delta G = \Delta G_1 + \Delta G_2 \text{ (dB)} \tag{1}$$

where ΔG_1 is the contribution of the decreased antenna effective aperture to the value ΔG and

$$\Delta G_1 = \begin{cases} 101g \left(\frac{S_e}{S_o} \right) \text{ (dB), the } \delta_{\max} \text{ is not limited} \\ 101g \left(\frac{S_e - S_s}{S_o} \right) \text{ (dB), the } \delta_{\max} \text{ is limited to 0.70 m} \end{cases}$$

ΔG_2 is the contribution of the incremental spillover of the feed to the value ΔG . When the feed pattern is assumed to have the form $E(\phi) = \cos^n(\phi/2)$,

$$\Delta G_2 = \{101g[1 - \cos^{(2n+1)}(\phi/2)]\} + 0.4496, \quad \delta_{\max} \text{ is not limited}$$

$$\Delta G_2 = 101g \left\{ 1 - \frac{1}{2} [\cos^{(2n+1)}(\phi/2) + \cos^{(2n+1)}(\phi'/2)] \right\} + 0.4496 \text{ (dB),}$$

δ_{\max} is limited to 0.7 m

Under the conditions of the geometry selected for FAST

$$\begin{aligned} \phi &= 30^\circ + \frac{1}{2} \left\{ \sin^{-1} \left[\frac{0.533 \sin(60^\circ - |\psi_{\max}|)}{\sqrt{1.284 - 1.066 \cos(60^\circ - |\psi_{\max}|)}} \right] \right. \\ &\quad \left. + \sin^{-1} \left[\frac{0.533 \sin |\psi_{\max}|}{\sqrt{1.284 - 1.066 \cos |\psi_{\max}|}} \right] \right\} \\ \phi' &= \frac{1}{2} \left\{ 116.3^\circ - |\psi_{\max}| + \sin^{-1} \left[\frac{0.533 \sin(60^\circ - |\psi_{\max}|)}{\sqrt{1.284 - 1.066 \cos(60^\circ - |\psi_{\max}|)}} \right] \right\} \end{aligned}$$

According to formula (1), as $n = 8.2$ (the edge taper of the paraboloid is -11 dB) and the distance δ_{\max} is limited to 0.70 m and the zenith scan angle regions are respectively extended to $\pm 40^\circ$, $\pm 45^\circ$, $\pm 50^\circ$ and $\pm 55^\circ$ by the offset feed, the corresponding decrease in the antenna gain is 1.22 dB, 2.03 dB, 3.02 dB and 4.23 dB, respectively.

3.2. INFLUENCE OF THE ANGLE ON THE ANTENNA PATTERNS

The angle $|\psi_{\max}|$ can be extended by the offset feed, which will also influence the antenna pattern. For the frequencies, f , of 1 GHz, 2 GHz and 5 GHz and the angles $|\psi_{\max}|$ of 30° , 55° respectively, the parameters of the patterns of the E plane and H plane of the antenna are detailed in Table I.

4. Conclusion

From what is said above, the zenith scan region can be extended by an offset feed, but the antenna performance will be reduced whether the distance δ_{\max} is limited or not. If the distance δ_{\max} is limited, the antenna performance is reduced more quickly, so we have to accept a reduction in the antenna performance in exchange for extending the zenith scan region. The calculated results show that

TABLE I
The parameters of the patterns

$ \psi_{\max} $ f (GHz)	30°				55°			
	2β		ξ (dB)		2β		ξ (dB)	
	E	H	E	H	E	H	E	H
1.0	5.4'	5.4'	-37.2	-37.2	4.78'	6.56'	-33.0	-23.1
2.0	2.7'	2.7'	-37.2	-37.2	2.39'	3.28'	-33.0	-23.1
5.0	1.08'	1.08'	-37.2	-37.2	0.96'	1.31'	-33.0	-23.1

2β : Half-power beam width.

ξ : First side lobe.

E: E plane.

H: H plane.

- The paraboloid focal ratio F/d' must be larger than 0.25 to avoid bad currents in the paraboloid and hence, the maximum zenith scan angle $|\psi_{\max}|$ of FAST can be only extended through to 69° by an offset feed under the conditions of the geometry selected.
- When the distance δ_{\max} is limited to 0.70 m and the maximum zenith scan angles $|\psi_{\max}|$ are extended to 40° , 45° , 50° , 55° and 60° , the corresponding decrease in the antenna gain is by 1.2 dB, 2.0 dB, 3.0 dB, 4.2 dB and 5.7 dB, respectively.
- The side lobes of the antenna pattern will increase with the increase of the zenith scan regions. When the maximum zenith scan angles $|\psi_{\max}|$ are extended from 30° to 50° , the side lobes of the patterns at H plane increase from -37.2 dB to -23.1 dB.

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