Partially Adaptive Phased Array Fed Cylindrical Reflector Technique For High Performance Synthetic Aperture Radar System

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Introduction: Spacebome microwave radar instruments demand a high-performance antenna with a large aperture to address key science themes such as climate variations and predictions and global water and energy cycles. For example, to measure freeze thaw dynamics, snow characteristics, and soil moisture as a seasonal constraint on weather dynamics and hydrological processes requires: 1) a synthetic aperture radar (SAR) antenna with multi-frequency capability (LE-band) [13, 2) high-performance wide-angle scanning for wide ground swath coverage [1]-[2], and 3) multi-polarization operations. Particularly challenging in the specifications for the technical requirements of the antenna is to maintain radiation patterns with low sidelobe levels over wide scan angles in the across track direction, and to obtain the appropriate antenna beamwidth and directivity for a field of view from nadir, **so** that a ground swath size is properly illuminated. Presented in this paper is a novel antenna design technique to achieve and enhance the capabilities for such an instrument. A cylindrical reflector fed with a partially adaptive phased array feed is proposed. It is shown that high-versatility reflector patterns are obtained with amplitude and phase control of only the edge elements, partially adaptive, in the array.

In particular, we demonstrate that the reflector pattern sidelobe levels can be monotonically reduced with amplitude and phase control of only the feed's edge elements in the array. We show that proper amplitude and phase excitations of the feed array edge elements can be used effectively to provide specific sidelobe cancellation in the reflector pattern. We found that a steeper sidelobe envelope (low sidelobe levels) is obtained if the specific sidelobe cancellation in the pattern is chosen to be near the peak of the main beam. Additionally, a different sidelobe envelope can be obtained simultaneously to the left and right side of the peak of the beam. It is found that the impact of sidelobe cancellation is pronounced on widening the antenna beamwidth if the specific sidelobe cancellation is chosen adjacent to the main beam peak. This property is needed for SAR observations closer to nadir. These unique characteristics are demonstrated for wide-angle scanning. Sample results are given to illustrate the effectiveness of this partially adaptive technique, and help guide trade-offs in instrument design.

Antenna Analysis and Geometry: The philosophical notion driving this work is based on two principles: The first is that for a properly optimized phased-array feed located along the focal line of the antenna, the radiation pattern performance of the reflector can be limited to the array feed pattern (mirror image) [13, particularly in the scan plane *y-z* shown in Figure 1. The second is that the far-field sidelobes of the feed edge elements are approximately equal in width to the sidelobes of the feed-array itself. Hence, the edge elements are able to cancel a specific sidelobe in the phased-array feed pattern [3]-[5]. Consequently, the sidelobe cancellation in the array will occur at an angle coinciding with the reflector. Consider a cylindrical reflector with a super-quadric projected aperture that is illuminated by a linear array with N+l feed elements as shown in Figure 1. The cross-section of the cylindrical reflector is a parabola with diameter D. The antenna has a focal length-to-diameter ratio of 0.4, to keep the antenna assembly compact. The array is located along the reflector focal line in the y-z plane. The excitation coefficient for each element, with the exception **of** the edge elements, has the form $a_n e^{jn\alpha}$ for $-N/2 + 1 \leq n \leq N/2 - 1$, where a_n is the amplitude and α is the progressive phase between the elements to scan the antenna beam. The edge element excitation coefficient has the form $w\, e^{j\varphi} = a_{\pm N/2}\, e^{\pm jN/2\alpha}\,(1+ce^{j\pm\delta})$, where c and δ are, respectively, the amplitude scale factor and the phase shift necessary for cancellation of a specific sidelobe in the array pattern. The type of radiation of each element (element pattern) is considered to be of the form $\cos^q(\theta)$. The total field due to this array is the sum of the element fields. Hence, the array factor can be written

$$AF(\theta) = a_{-\frac{N}{2}}(1+ce^{-j\delta})\,e^{-j\frac{N}{2}(\beta d\sin\theta+\alpha)} + a_{\frac{N}{2}}(1+ce^{j\delta})\,e^{j\frac{N}{2}(\beta d\sin\theta+\alpha)} + \sum_{n=-\frac{N}{2}+1}^{\frac{N}{2}-1} a_n e^{jn(\beta d\sin\theta+\alpha)}$$

Where d is the inter-element spacing, $\beta=2\pi/\lambda$, and the term in the above equation

$$ce^{-j\delta}a_{-\frac{N}{2}}\,e^{-j\frac{N}{2}(\beta d\sin\theta+\alpha)} + ce^{j\delta}a_{\frac{N}{2}}\,e^{j\frac{N}{2}(\beta d\sin\theta+\alpha)}$$

represents the cancellation field due to the feed-edge elements. **As** an illustration for a specific sidelobe cancellation m, at an angle θ_i, the parameters c and δ (for $a_n=1$) can easily shown to be

$$c = \frac{|F(\theta_i)|}{2}; \qquad \delta = (m+1)\pi - \frac{N}{2}(\beta d\sin\theta_i+\alpha)$$

in **which**

$$F(\theta_i) = \sum_{n=-\frac{N}{2}}^{\frac{N}{2}} e^{jn(\beta d\sin\theta_i+\alpha)}; \qquad \theta_i = \arcsin\frac{1}{\beta d}\left[\pm\pi\frac{2(m+1)}{N+1} - \alpha\right]$$

In order to determine the reflector performance, we have used in our simulation implementation a diffraction analysis technique based on a physical optics (PO) approximation of the current distribution on the reflector surface. We consider the illumination of the array feed of the reflector to be generated by each element. With respect to individual feed elements in the array, the main reflector is considered to be in the far zone or far-field region. But with respect to the entire array, the main reflector may be considered in the near zone. Thus, the radiated far-field pattern of the reflector impinged by the incident field of the array can be obtained from the following expression assuming e^{jwt} time dependence:

$$\vec{E}(u,v) = -jk\eta\frac{e^{-j\beta r}}{4\pi r}\left[\bar{\bar{I}} - \hat{r}\hat{r}\right].\vec{T}(u,v); \text{ and } \vec{T}(u,v) = \iint_{S'} \vec{I}(\vec{r}')e^{j\beta wz'}e^{j\beta(ux'+vy')}dx'dy'$$

Where $\hat{r} = u\hat{x}+v\hat{y}+w\hat{z}$, $\vec{r}' = x'\hat{x}+y'\hat{y}+z'\hat{z}$, $u=\sin\theta\cos\phi$, $v=\sin\theta\sin\phi$, $w=[1-(u^2+v^2)]^{1/2}=\cos\theta$, and I is the unit 3x3 dyadic matrix, $\eta=120\pi$, S' is the projected aperture in the x-y plane, and $\vec{I}(\vec{r}') = \vec{J}(r')\sqrt{1+\left(\frac{\partial f}{\partial x'}\right)^2+\left(\frac{\partial f}{\partial y'}\right)^2}$ is the PO current where f describes the reflector surface $f(x,y)=z$.

The projected aperture boundary of the antenna in x-y plane is represented analytically as a super-quadric curve $\left|\frac{x'}{a}\right|^n + \left|\frac{y'}{b}\right|^n = 1$, where a, b are the semi-axes in the x and y direction respectively [13, and n is the parameter that provides the capability to control the shape of the curvature corners as shown in Figure lb.

Results and Discussions: Consider the cylindrical reflector geometry shown in Figure 1 with a 41-element array feed polarized in the vertical direction y. The length of the feed array at L-band (1.26 GHz) is equal to the diameter of the reflector, 6 **m,** and the inter-element spacing is 0.63 λ. The scan beam is realized by phase progression of the elements with the exception of the edge elements in the array. The amplitude and phase excitation, $w\, e^{j\varphi}$, of the edge elements is computed for different sidelobe cancellation in the phased array feed. Figures 2a and b show the resulting reflector performance for sidelobe cancellation at ±23.98° and ±16.87° respectively. It is evident from the figure that a steep sidelobe envelope is obtained when the sidelobe cancellation is chosen closer to the peak of the beam. Similar observations are obtained for the scan beam as depicted in Figures 2c and d, and 2e and f for 5° and 10" scans respectively. It is also shown in Figures 2c, d, and e that different sidelobe level envelopes can be obtained simultaneously with respect to the peak. Figure 2f demonstrates, in particular, the ability to control the sidelobe level on one side of the antenna pattern while retaining the other side intact.

A similar observation was made for horizontal polarization. The key advantage of the system **is** that the T/R modules driving the array, with the exception of the edge elements, can be identical, thus affecting a considerable saving in cost for manufacture and testing.

References

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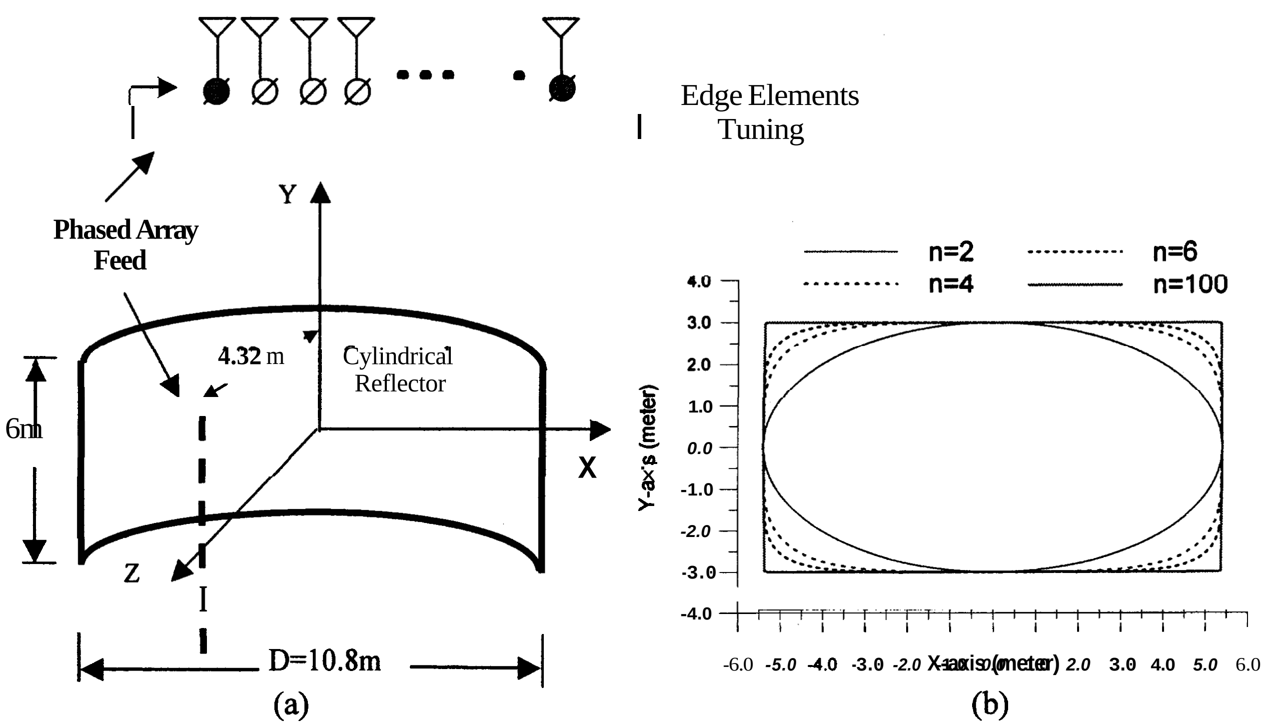

Figure 1. (a) Phased array fed cylindrical reflector, (b) Cylindrical reflector super-quadric projected aperture in ***x-y*** plane.

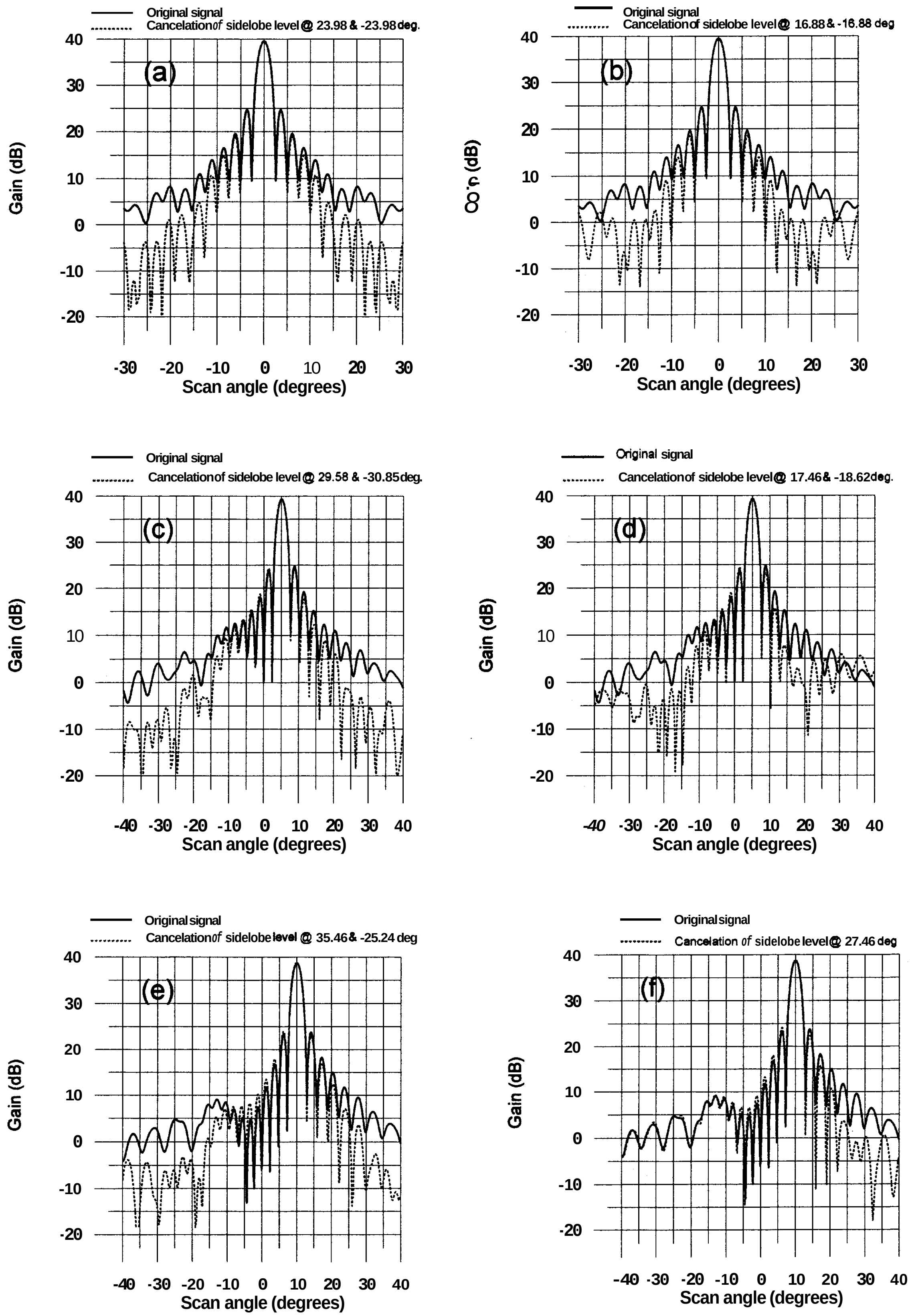

Figure **2.** Effect of amplitude and phase excitation control of the feed edge elements, **w** $e^{j\varphi}$**,** of a phased array fed cylindrical reflector on its scan beam radiation patterns (dotted lines) for, (a) and (b) 0° scan; **(c)** and (d) beam scan to 5°; (e) and (f) beam scan to 10°. Note the solid lines represent the original signal results due to uniform amplitude excitation of all elements in the array, and progressive phase **shift.**