SPEED UP OF NEAR-FIELD PHYSICAL 01'1'1(3 SCATTERING CALCULATIONS BY USE OF THE SAMPLING THEOREM*

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A *bstract* - Physical optics scattering calculations performed on the NASA Deep Space Network (DSN) 34-meter beam-waveguide antennas at Ka-band (typically five surfaces) requires approximately 12 hours CPU time on a Cray Y-MP2 computer—excessive in terms of resource utilization. The calculations are done two mirrors at a time, The sampling theorem is used to reduce the number of points on the second surface; tbe points are obtained by performing a physical optics integration over the first surface. The number of points required by subsequent physical optics integrations is obtained by interpolation. Time improvements on the order of 2 to 4 were obtained for typical scattering pairs.

INTRODUCTION

The analysis of the 34m beam-waveguide antennas of the Jet Propulsion Laboratory/NASA 's Deep Space Network requires physical optics scattering calculations to be performed over at least five scattering surfaces. For analysis up to X-band, the computers available could easily handle calculations of this size and complexity. However, with the shift to Ka-band to support future deep space, missions, computational times increased by a factor of about 16. Computational times of 12 hours on a Cray Y-MP2 single. processor computer arc. typical. With limited computer availability, job turnaround could approach 1 week per calculation.

This paper presents a method to reduce the overall time by a factor of 4 or more for a typical pair of scattering surfaces and by a factor of 2 for the overall antenna system. The sampling the.orem is used to speed up the physical optics calculations.

METHOD

The method used to analyze the 34111 antennas consisted of performing a physical optics integral ion over the currents on the first scattering surface to get the currents on the. second surface. Using these new currents on the second surface, the process is repeated to obtain the currents on the third surface, continuing utilization of pairs of surfaces until the complete antenna has been analyzed. Since each surface is of comparable size, and if the current resolution in any direction is N, then N^2 physical optics integrations on the first surface are required for each of the N^2 cur-rent points on the second scattering surface. This implies N^4 operations and is the real driver for the computational time.

1 f the number of points evaluated on the second surface can be reduced significantly and replaced by interpolation to obtain the necessary N^2 points required bya subsequent physical optics calculation, then the computational time will approach that of N^2 operations on the first surface. The physical optics integral is composed of two basic parts, the current term and the kernel or exponential term. The current term is typically a slowly varying function of position, while the kernel varies rapidly as a function opposition and observation point. The kernel is the driver that determines the number of integration points in subsequent i ntegrati on. '1 'he approach is to employ the sarn p] ing theorem to determine the number of surface points necessary to define the surface currents on the second surface, and then to use an integration algorithm to obtain the number of points required by the rapidl y varying, but easil y evaluated kernel.

A key problem is to define a sampling function that could be used to determine the sampling frequency. A uniform distribution on a source surface produces the narrowest field pattern over an observation surface, and any deviations from a uniform distribution broadens the patterns. Thus the patterns produced by a uniform distribution should have the highest frequency and should be a conservative estimator of the sampling frequency. The pattern distribution from a uniform distribution is Sin(u)/(u). If this distribution is evaluated on the sampling surface. and the size of the surface in u,v space is $2 \cdot u_m = 4\pi X_m \mathrm{Sin}\theta_m/\lambda$ and the period is 2π, the function frequency is $B = 2 X_m \mathrm{Sin}\theta_m/\lambda$, where X_m is half the size of the source aperture and θ_m is the angle subtended by the sampling surface. Since the sampling theorem requires sampling at twice tile highest frequency, the number of samples is $N = 4 X_m \mathrm{Sin}\theta_m/\lambda + 1$. Since the fields on the sampling surface arc not a strictly bami-limited function, an 18 percent oversampling was used, Although the Sin(u)/(u) function is based on a far-field derivation, it still gives a good estimate for the sampling frequency on sampling surfaces in the near-ficlti for typical source aperture fields.

Sine functions arc used to do the interpolations, and since the Sin(u)/(u) field function is defined on a spherical surface, the sampling must also be done on a spherical surface. In addition, the origin of the spherical surface is at the field function phase center, which is also the center of a surface containing the uniform distribution, In general, however, the reflector surfaces

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arc not spherical, and the center of the sou rcc aperture may not be the phase center of any scattered fields. To accommodate non-spherical snrfaccs, the surface of interest is enclosed by two spherical surfaces, with the origins of the lwo surfaces at the phase center of the scattered fields. If the phase center (Jots not coincide with the center of the source aperture, an equivalent source aperture is constructed al the phase center, and this is the geometry that is used to calculate the sampling parameters. A radius from the center of the equ i valent source aperture (phase center) is constructed to the interpolation point on the surface of interest and made to intercept the two spherical surfaces. Interpolated fields arc computed on the two spherical surfaces at the intersection points of the radius, then a radial interpolation is performed to obtain the interpolated field point on the surface of interest. Since a near-field interpolation is required, terms of the order l/R and $1/R^2$ arc used, This process is repeated until all the currents that arc required for subsequent physical optics calculations have been calculated.

RESULTS

Figure 1 shows the accuracy of the sampling approach. in the center of the figure the geometry of a test case is illustrated which includes a pair of parabolic mirrors such as arc used on a typical 34m beam-wavcgui(ic antenna. The first parabola is the source apert urc. The second parabola is the sampling surface on which a reduced set of fields arc calculated and then interpolated to obtain the total set of fields and hence currents required by physical optics. The curves shown in the figure arc for the fields calculated by performing a physical optics integration over the currents on the second parabola (sampling surface), One curve uses currents calculated using the sampling theorem and the other curve is based on the currents being computed using physical optics integration for all current points. As can be seem, the two curves arc essentially identical over 40 dB. The differences arc primarily in the sidelobe region. 1 lowever, the sidelobe regions do not illuminate subsequent scattering surfaces and therefore arc of no interest in this particular application. If the sidelobe regions arc of interest, then the sampling frequency would have to be increased (additional over sampling). This would increase the computation time and the advantage of using the sampling theorem would be reduced.

Figure 2 is a summary of the lime improvement for a calculation on a 34 m beam-wavcguir.ic antenna at Ka-band. The actual antenna has several flat mirrors that were not included in the analysis. (The removal of these flat mirrors produces the geometry shown in the figure, where one mirror appears to be located in front of the main reflector; the actual antenna however, dots not have a mirror in front of the main reflector.) The results arc shown by mirror pairs, the first mirror being the source mirror and the second mirror being the sampling mirror. The first mirror set shows a time. improvement of 4,39 for the sampling approach over a non-sampling approach. Moving along by onc mirror, the second mirror set shows an improvement of 1.69 by using sampl ing. The difference in time between the two cases is easily accounted for, The sampling frequency is based on the size of the source. aperture and the subtended angle produced by the sampling surface. In the second case the two mirrors arc closer together, increasing the subtended angle and in turn requiring a higher sampling frequency. The third set of mirrors showed an improvement of 2.88, giving an overall improvement up to and including the subreflector of a factor of 2.73. The sampling theorem was not applied to the main reflector calculation, so an improvement factor of 1.0 was assigned. Including the main reflector, a net improvement of 2.05 was obtained, reducing computat ion time, from 11.55 hours 105.64 hours.

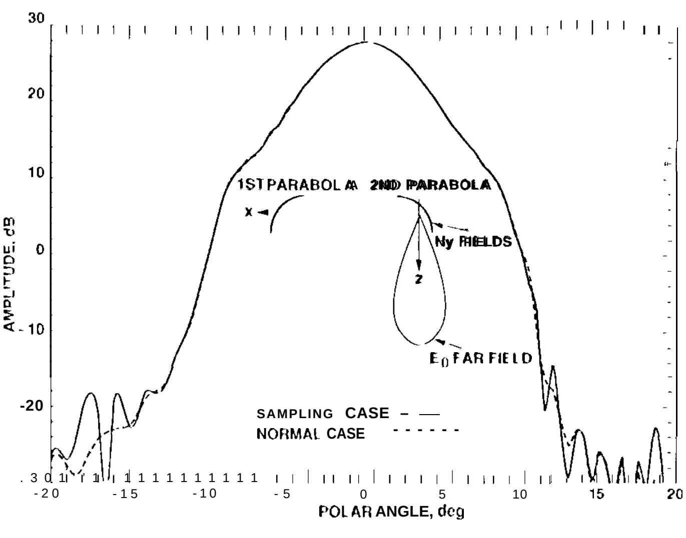
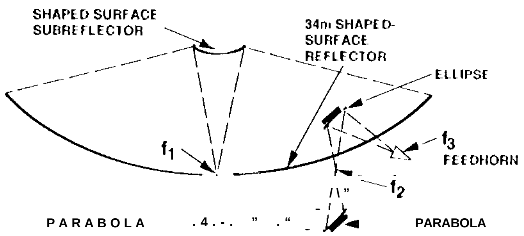


Fig. 1. E-0 far-field component, parabola/parabola, ϕ = O.



GEOMETRY	INTEGRATION POINTS PER AXIS, 1ST/2ND SURFACE	POINTS PER WAVELENGTH	TIME SAMPLING, minutes	TIME NORMAL, minutes	TIME RATIO
ELLIPSE/PARABOLA	340'270	1/1	6443	283.00	4.39
PARABOLA/PARABOLA	270'270	1/1	107.54	181.32	1.69
PARABOLA/SUBREFLECTOR	270'200	1/0.5	3288	94,72	288
SUEI101AL			204.S5 (341h)	55904 (932h)	273
SUBREFLFC1OR'MAIN	20024	0.5/..	133.82	133 B?	1.00
TOTAL			33867 (5.64h)	69286 (11.55h)	205

Fig. 2. 1}SS-13 34111 beam-waveguide antenna analysis schematic and summary (Ka-band).