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USE OF MULTIPLE 4π RADIATION SOURCES FOR QUASI-UNIFORM IRRADIATION OF CIRCULAR SURFACES

by

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ABSTRACT

The problem of optimally locating multiple 4π radiation sources in relation to circular planar targets is addressed, with the constraint that the surface be irradiated with 80% uniformity. The optimum source-location coordinates and the resulting target flux patterns are presented for a number of source arrays. They are compared to the results of a similar study for quasi-uniform irradiation of square surfaces.

I. INTRODUCTION

The uniform irradiation of large surface areas at high fluences is often difficult, or even impossible, with a single source of a strength available with present technology. The use of multiple sources of equal strength may offer one solution, as investigated by Clark and Freiwald¹ who have presented results for the irradiation of square targets. The irradiation of circular targets with multiple sources is the subject of this paper.

II. PROBLEM DESCRIPTION

The following assumptions were made for the problem of circular targets:

- All sources for a given case emit with equal strength.
- All sources are 4π sources - $\phi(r) = S_0/4\pi r^2$.
- All sources emit with the same spectrum.
- The sources have no dimension (point sources).
- All sources are arranged in a plane parallel to the target.

The source-target geometry used in this study is shown in Fig. 1. The source array and target surface plane are circles inscribed in a square with the length of a side being L . Taking the center of the coordinate system as the center of the source array, the source locations can be scaled to the

target dimension L by taking $X_j = \alpha_j L$, $Y_j = \gamma_j L$, and $Z = \beta L$. The total flux at a point x, y, z on the target surface due to all sources is

$$\phi(x, y, z) = \frac{S_0}{4\pi L^2} \sum_{j=1}^N \frac{1}{\left(\frac{x}{L} - \alpha_j\right)^2 + \left(\frac{y}{L} - \gamma_j\right)^2 + \beta^2} \quad (1)$$

Calculations were performed to determine the maximum flux on the target by using the criterion of 80% uniformity and taking advantage of symmetries of the source arrays.

Fig. 1. Source-target geometry.

Fig. 2. Source array patterns.

III. NUMERICAL RESULTS

The source arrays chosen for this study are shown in Fig. 2. For each case shown the number of sources (N) is given with the source pattern.

For each case 376 grid points were used within a chosen symmetry. The calculations were normalized by setting $S_0/L^2 = 1$.

The computational technique used is to choose a value of β and to find the values of α_j and γ_j required for the uniformity criterion, namely:

$$\frac{\phi_{\max} - \phi_{\min}}{\phi_{\max}} \leq 0.2. \quad (2)$$

During this search the source locations are moved symmetrically in the x- and y-direction. After a set of coordinates is found that satisfies Eq. (2), β is used as the iteration variable until the maximum value of the flux averaged over the target surface is found. The uniformity constraint is

maintained at all times during this iteration process.

The results of these calculations for 16 source-array patterns are summarized in Table I. Average flux values at the 376 grid points are given in Column 2; as can be seen, these values increase with increasing N due to the normalization. The most favorable case for a given number of sources is indicated by (*). The most favorable pattern for the circular targets investigated is obtained by placing all the sources uniformly along the circumference of a single circle. This eliminates the hot spot that would be caused if one source were located at the center of the circle. The hot-spot phenomenon can also be seen in arrays with different numbers of sources. However, the addition of a center source to a most favorable pattern always reduces the maximum average flux that can be attained.

The values of α_j and γ_j given in Column 4 of Table I are for the outermost source. Note that γ_j is always zero because the outermost source is always placed on the x-axis. By using these values for the symmetry pattern of Fig. 2 the remaining source locations can be determined. For patterns having sources at more than one radius, the ratio of the radii is 2:1. Column 6 gives the ratio of the average flux from a given case to the average flux from a single source. The ratio in Column 7 provides an indication of the relative effectiveness of the source-array geometries. This ratio, computed by

$$R = \frac{(\phi_{\text{ave}})_N}{N(\phi_{\text{ave}})_1}, \quad (3)$$

represents a gain in the average flux over the single-source case due only to the multiple-source geometry, because the number of sources appears in the denominator of Eq. (3). For example, in Case 16 a gain of 5 is achieved by using 8 sources of strength S_0 over using a single source with strength $8S_0$.

Once a real L and ϕ_{ave} are specified, the required strength, S_0 , per source is found as follows: Calculate $S_0 = (L^2 \phi_{\text{ave}}) / [(\phi_{\text{code}})_{\text{ave}}]$; or calculate S_0 as before for a single source, then divide this source strength by the number in Column 6 to obtain the strength for other cases. The sources should be

placed at $z = \beta L$, $x_j = \alpha_j L$, and $y_j = \gamma_j L$ as per Column 4 and the array patterns given in Fig. 2.

Figures 3 through 18 show field plots of the flux at selected points in a symmetry section of the circular target.

A few comparisons can be made to the results obtained in a study for the irradiation of square surfaces.¹ Figure 19 plots some comparative data for most favorable source patterns with 1, 4, and 8 sources. Note that the average flux in these three cases is higher for the circular targets. However, the ratios of the average flux and of R have a minimum at $N = 4$ sources (with a probable maximum at $N = 1$ source). This result is most probably caused by the less efficient irradiation of the corners of a square target if only a few sources are present. For many sources, the illumination of the two targets will probably be almost identical, i.e., as $N \rightarrow \infty$, $\beta \rightarrow 0$, and the only "difference" will be near the edges.

Table II compares the results for circular and planar targets having varying uniformity. All the circular source geometries generate larger fluxes than the planar ones, as determined previously. Also, in both cases (circular and planar), the flux on the circular target will increase with the relaxing of uniformity criterion, because the radiation sources are closer to the target (β decreases with lower uniformity).

IV. CONCLUSIONS

The method of Clark and Freiwald for the irradiation of square targets has been extended to circular targets. The results show that a gain can be obtained by using N -sources of strength S_0 rather than a single source of strength NS_0 . It also appears (for the few comparisons made) that higher flux averages can be obtained for circular targets than for square ones with the same number of sources, if the circle diameter equals the length of the side of the square. In other words, one can illuminate 78.5% of the area of a square (a circle inscribed in a square) with less total source strength than needed to illuminate an entire square.

Finally, the techniques used are readily modified to suit various geometries and to determine the optimum source locations for various numbers of sources; results can be used to make intelligent tradeoff decisions for a particular target.

REFERENCE

1. R. W. Clark and D. A. Freiwald, "Use of Multiple 4π Radiation Sources for Quasi-Uniform Irradiation of Square Surfaces," Los Alamos Scientific Laboratory report LA-5455-MS (November 1973).

TABLE I
RESULTS OF FLUX CALCULATIONS FOR IRRADIATION OF CIRCULAR PLANAR TARGETS

Case	(1) Number of Sources	(2) (ϕ_{code}) ave	(3) $\frac{\phi_{max} - \phi_{min}}{\phi_{max}}$	(4) α_j, γ_t Outer Sources	(5) β	(6) $\frac{\phi_{code} \text{ case } x}{\phi_{code} \text{ case } 1}$	(7) R
1*	1	0.0735	20.00%	0, 0	1.00	1.00	1.00
2*	3	0.427	19.87	0.5, 0	0.54	5.81	1.94
3	4	0.409	19.96	0.64, 0	0.69	5.56	1.39
4*	4	0.833	19.89	0.48, 0	0.39	11.33	2.83
5	5	0.661	19.88	0.64, 0	0.55	8.99	1.80
6*	5	1.335	19.80	0.45, 0	0.32	18.16	3.63
7	6	1.003	19.93	0.61, 0	0.45	13.65	2.27
8*	6	1.900	19.99	0.44, 0	0.27	25.85	4.31
9	6	1.354	19.92	0.70, 0	0.34	18.42	3.07
10	7	1.473	14.98	0.59, 0	0.36	20.04	2.86
11	7	0.928	20.00	0.89, 0	0.53	12.63	1.80
12*	7	2.435	18.93	0.44, 0	0.24	33.13	4.73
13	8	2.109	19.91	0.56, 0	0.29	28.69	3.59
14	8	1.524	19.81	0.75, 0	0.38	20.73	2.59
15	8	2.134	19.77	0.70, 0	0.28	29.03	3.63
16*	8	2.954	18.42	0.43, 0	0.23	40.19	5.02

*Most favorable case for the given number of sources.

Fig. 3. Target fluence field grid plot, Case 1.

Fig. 5. Target fluence field grid plot, Case 3.

Fig. 4. Target fluence field grid plot, Case 2.

Fig. 6. Target fluence field grid plot, Case 4.

Fig. 7. Target fluence field grid plot, Case 5.

Fig. 8. Target fluence field grid plot, Case 6.

Fig. 9. Target fluence field grid plot, Case 7.

Fig. 10. Target fluence field grid plot, Case 8.

Fig. 11. Target fluence field grid plot, Case 9.

Fig. 12. Target fluence field grid plot, Case 10.

Fig. 13. Target fluence field grid plot, Case 11.

Fig. 14. Target fluence field grid plot, Case 12.

Fig. 15. Target fluence field grid plot, Case 13.

Fig. 16. Target fluence field grid plot, Case 14.

Fig. 17. Target fluence field grid plot, Case 15.

Fig. 18. Target fluence grid plot, Case 16.

Fig. 19. Comparative data of circular and planar targets.

TABLE II
COMPARATIVE STUDY OF CIRCULAR AND PLANAR TARGETS WITH VARYING UNIFORMITY

N	$(\phi_{\text{code}})_{\text{ave}}$	α, γ	β	Uniformity (%)	Geometry
1	0.08707	0	0.87	60	Square
1	0.05898	0	1.09	70	Square
1	0.03649	0	1.42	80	Square
1	0.01692	0	2.13	90	Square
1	0.1727	0	0.62	60	Circle
1	0.1182	0	0.77	70	Circle
1	0.07349	0	1.0	80	Circle
1	0.03364	0	1.51	90	Circle
3	0.8678	0.35	0.36	60	Circle
3	0.6290	0.42	0.43	70	Circle
3	0.4267	0.50	0.54	80	Circle
3	0.2360	0.67	0.74	90	Circle
4	1.171	0.34	0.27	60	Square
4	0.9509	0.36	0.32	70	Square
4	0.6976	0.41	0.39	80	Square
4	0.5083	0.43	0.51	90	Square
4	1.475	0.36	0.28	60	Circle
4	1.154	0.40	0.33	70	Circle
4	0.8312	0.48	0.39	80	Circle
4	0.5147	0.59	0.52	90	Circle
6	2.894	0.37	0.20	60	Circle
6	2.396	0.40	0.23	70	Circle
6	1.900	0.44	0.27	80	Circle
6	1.329	0.51	0.34	90	Circle
8	2.946	0.40	0.19	60	Square
8	2.391	0.42	0.23	70	Square
8	1.723	0.46	0.30	80	Square
8	0.9818	0.55	0.45	90	Square
8	4.419	0.38	0.16	60	Circle
8	3.736	0.41	0.18	70	Circle
8	2.954	0.43	0.23	80	Circle
8	2.158	0.47	0.30	90	Circle