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CORNING GLASS WORKS
ELECTRO-OPTICS DEPARTMENT
RALEIGH, NORTH CAROLINA

IMPROVED SCREEN FOR REAR-PROJECTION VIEWERS

Technical Report No. - 40

Date — April 25, 1969

Period Covered — March 28, 1969
to
April 25, 1969

STAT

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TECHNICAL REPORT NO. 40

1. Scattering Screens for Subjective Testing

Eight $12^1/8" \times 15^1/8"$ screens of good quality have been delivered to the sponsoring agency for subjective evaluation. Table I lists the eight sample screens, along with a possible set of independent variables of the experiment. Two types of scattering layer were employed, having glass-binder volume ratios of 0.57 and 1.0. The axial gain values fall in three groups typified by the approximate values 3.5, 5, and 6. Four different substrate transmittances were selected as shown.

The properties of the scattering layer alone were measured and appear in the left side of Table II. The axial gain B(0) is the same as in Table I. Brightness variation within 45° of the axis is $V_{45} = [B(0)-B(45)]/[B(0)+B(45)]$ and a similar definition holds for V_{30}. The fraction of incident parallel radiant power transmitted into a 45° half-angle cone is T_{45}. Similarly T_{90} and T_{30} represent efficiencies of transmittance into the forward hemisphere and a 30° half-angle cone, respectively. The diffuse reflectance R_D is measured as the fraction of the incident parallel beam power diffusely reflected into a hemisphere. The right-hand half of the table lists complete screen properties calculated, except in the case of α_T, from the scattering layer properties and the substrate transmittance T_s. These quantities give an approximate description of screen performance in that no corrections have been made for variation of T_s as a function of the angle at which a given ray passes through the substrate, or for the effects of refraction of the rays upon leaving the substrate. These effects could change the values by 5 — 10%. The trapped light ratio α_T was directly measured on the assembled screens. All screens have an antireflection coating on the substrate surface facing the observer. This reduces specular reflection from the glass-air value of approximately 4% to well

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below 0.5% throughout most of the visible spectrum, for angles of incidence up to 30°. Figure I shows the coating firm's (Optical Coating Laboratory, Inc., Santa Rosa, California) measurement of the reflection spectrum of one of our coated plates.

1.1 Scattering Layer Properties

The AQ Series and AR Series screens of Tables I and II belong to a large group of trial screens having the same layer composition but varying in layer thickness. Table III lists these screens, their scattering layer properties, the substrate transmittances, and the trapped light ratios for some of the larger ones. Screens AQ-9, 10, 19, 21, 22 and AR-24, 25, 26 were cast with the $13^1/2$" knife while the remainder in Table III were cast with the 2" knife. The scattering data from Table III are represented by the smooth curves of Figures 2 — 5. The individual points plotted in these figures represent corresponding data for the candidate screens for subjective evaluation. The x's represent data for AL-4 and AL-5.

1.1.1 Efficiency

The curves of T_{90}, T_{30}, and T_{45} in Figs. 4 and 5 show an unexpected dropoff at high gains. Microscopic observation revealed a qualitative change in the character of the scattering layer as it was made thinner — a network of dark crevices appeared. This is also accompanied by an increase in diffuse reflectance. The behavior of screens AL-4 and AL-5, which have a low binder content and a thin layer, is consistent with this structural change also. AL-4 and AL-5 are significantly less efficient and more diffusely reflecting than the AQ and AR type. Of all the glass particle screens we have fabricated, the

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AQ — AR Series are the most efficient in the axial gain region of interest. They are 75 — 80% as efficient as the theoretical thin screens treated in P-19-30 which, as pointed out earlier (P-19-39), are intrinsically more efficient.

1.1.2 Resolution

The dry thickness of the AQ — AR Series is 3 — 4 mils and, contrary to expectations, mainly volume scattering is involved. The resolution, however, estimated qualitatively by the contact method, does not appear to decrease rapidly with increasing thickness. All the candidate samples appeared to have acceptable contrast at 10 li/mm. Scintillation occurs in all these screens and is undoubtedly a factor in degrading the resolution. Modulation transfer functions have yet to be measured.

1.1.3 Brightness Distribution Curves

The brightness gain $B(\theta)$ as a function of angle is tabulated for the candidate screens in Table IV. The normalized gain $B(\theta)/B(0)$ is plotted in Figures 6 — 8.

1.2 Trapped-Light and Ambient-Light Properties of Assembled Screens.

The right-hand half of Table II lists the quantity $R_D T_s^2$, which is a good approximation to the effective diffuse reflectance for ambient light. All candidate screens except AL-4 thus have an effective diffuse reflectance less than 5%.

The trapped light ratio α_T was measured on the full-size assembled screens. The efficacy of substrate absorption in reducing trapped light is evident from the tabulated values.

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Table I

Values of the independent variables, glass-binder volume ratio, axial gain, and substrate transmittance, for the eight screens submitted for subjective testing.

Sample	Scatter Layer		Substrate Trans.
	glass vol. / binder vol.	Axial Gain B(0)	T_s
AQ-18	0.57	3.54	69
AQ-11	0.57	3.96	46
AQ-17	0.57	3.39	33
AQ-20	0.57	3.12	22
AR-28	0.57	6.14	69
AR-27	0.57	6.07	46
AL-4	1.0	5.3	69
AL-5	1.0	5.19	46

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Table II

Measured scattering properties of the scattering layer and performance parameters for the assembled rear-view screens submitted for subjective testing.

Sample	Scattering Layer Only							Complete Rear-View Screen					
	B(0)	$V_{\%}45$	$V_{\%}30$	$T_{\%}90$	$T_{\%}45$	$T_{\%}30$	$R_{\%}D$	$T_{\%}s$	$B(0)T_s$	$T_{\%}45$	$T_{\%}30$	$R_{D\%}T_s^2$	$\alpha_{\%}T$
AQ-18	3.54	51	34	66	47	30	9.5	69	2.45	32	21	4.5	0.63
AQ-11	3.96	56	38	68	49	32	10.7	46	1.82	23	15	2.3	0.133
AQ-17	3.39	50	36	64	45	29	9.5	33	1.12	15	10	1.03	0.081
AQ-20	3.12	46	29	62	45	28	9.5	22	0.69	10	6	0.46	0.062
AR-28	6.14	72	54	73	57	41	9.5	69	4.23	39	28	4.5	0.24
AR-27	6.07	70	53	74	59	41	9.5	46	2.78	27	19	2.0	0.086
AL-4	5.30	72	62	56	39	26	20	69	3.66	27	18	9.5	0.74
AL-5	5.19	72	62	54	38	26	20	46	2.39	17	12	4.2	0.135

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Table III

Scattering layer properties, substrate transmittances, and selected trapped light ratios for AQ and AR series screens.

Sample	Wet Layer Thickness Mil	B(0)	V_{45} %	V_{30} %	T_{90} %	T_{45} %	T_{30} %	R_D %	T_s %	α_T %
AQ-1	3	12.59	89	81	68	55	43	8.1	97	
2	3	12.30	89	80	68	55	43	9.1	47	
3	5	9.48	81	66	79	65	47	6.2	47	
4	5	9.86	84	67	78	64	48	6.2	97	
5	7	6.88	76	55	76	59	42	8.1	97	
6	7	5.76	69	52	74	54	36	8.1	47	
7	9	4.15	52	37	70	53	33	8.3	47	
8	9	3.57	51	33	69	48	31	8.3	97	
9	8.7	4.32	59	42	68	50	33	7.8	97	3.3
10	8.7	4.56	62	43	70	51	34	7.8	47	0.11
12	11	2.98	42	28	66	44	27	9.7	97	
13	11	2.90	40	29	64	43	26	9.7	47	
14	10	3.28	49	31	66	46	28	8.8	47	
15	10	3.43	46	31	68	48	30	8.8	97	
19	11	3.00	44	28	64	44	26	10.3	97	4.9
21	12	2.46	37	26	59	38	23		47	
22	12	3.01	44	28	64	44	27		97	
AR-1	11	4.98	62	48	71	52	34		47	
2	11	5.84	69	50	74	57	39		97	
3	9	6.30	71	53	74	59	41		47	
4	9	6.88	73	55	77	61	43		97	
5	10	5.36	63	48	75	55	36		47	
6	10	5.38	65	46	76	57	38		97	
7	12	3.56	46	33	70	48	29		47	
8	12	3.98	54	36	71	52	33		97	
9	12	3.92	49	35	73	50	32		71	
10	9	5.08	61	44	74	57	39		47	
11	9	5.36	64	46	76	59	40		97	
12	10	5.85	67	49	76	59	40		47	

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Sample	Wet Layer Thickness Mil	B(0)	V_{45} %	V_{30} %	T_{90} %	T_{45} %	T_{30} %	R_D %	T_s %	α_T %
13	10	5.29	63	44	74	57	37		97	
14	11	4.73	63	41	74	55	36		47	
15	11	4.67	59	44	72	53	35		97	
16	12	4.18	54	35	72	53	33		47	
17	12	3.18	43	29	69	47	28		97	
18	9	5.54	64	45	78	60	41		47	
19	9	6.05	69	50	76	59	41		97	
20	8	7.51	75	57	78	62	44	8.3	47	
21	8	7.03	74	57	78	60	43	8.3	97	
22	9	6.40	69	50	80	64	44	9.3	47	
23	9	6.12	67	50	78	61	41	9.3	97	
24	9	7.61	76	59	78	61	44	9.3	97	
25	9	7.30	74	59	76	60	42	9.3	47	
26	9	7.30	75	58	78	62	44	9.3	47	

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Table IV

ANGULAR GAIN FUNCTION FOR SAMPLE AQ-18

FRACTION OF POWER INSIDE 90 DEGREES = 66 PER CENT

FRACTION OF POWER INSIDE 45 DEGREES = 47.2 PER CENT

BRIGHTNESS VARIATION = +- 51 PER CENT

FRACTION OF POWER INSIDE 30 DEGREES = 29.5 PER CENT

BRIGHTNESS VARIATION = +- 34 PER CENT

SPECULAR TRANSMITTANCE = .0

ANGLE K= θ	I[K]	GAIN[K] = B(θ)	B(θ)/B(0)
0	1.05	3.543	1.00
5	0.966	3.273	0.922
10	0.867	2.969	0.837
15	0.763	2.665	0.752
20	0.653	2.345	0.661
25	0.553	2.058	0.578
30	0.45	1.754	0.494
35	0.369	1.518	0.428
40	0.299	1.316	0.371
45	0.238	1.136	0.320
50	0.191	1.004	0.2835
55	0.15	0.883	0.249
60	0.118	0.793	0.222
65	0.088	0.704	0.1985
70	0.059	0.58	0.1635
75	0.038	0.5	0.141
80	0.012	0.234	0.066
85	0.00	0.00	0.0
85	0.00	0.00	0.0

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FRACTION OF POWER INSIDE 90 DEGREES = 33 PER CENT

FRACTION OF POWER INSIDE 45 DEGREES = 23.9 PER CENT

BRIGHTNESS VARIATION = +- 56 PER CENT

FRACTION OF POWER INSIDE 30 DEGREES = 15.4 PER CENT

BRIGHTNESS VARIATION = +- 38 PER CENT

SPECULAR TRANSMITTANCE = 0

ANGLE K= θ	I[K]	GAIN[K] = B(θ)	B(θ)/B(0)
0	0.95	1.92	1.0
5	0.872	1.769	0.92
10	0.788	1.617	0.841
15	0.676	1.415	0.736
20	0.564	1.213	0.632
25	0.467	1.041	0.543
30	0.372	0.869	0.452
35	0.295	0.728	0.3785
40	0.237	0.627	0.326
45	0.188	0.536	0.279
50	0.152	0.477	0.248
55	0.12	0.423	0.22
60	0.096	0.389	0.2025
65	0.077	0.367	0.191
70	0.055	0.324	0.1682
75	0.027	0.212	0.113
80	0.007	0.084	0.0438
85	0.00	0.00	0.00
85	0.00	0.00	0.0

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FRACTION OF POWER INSIDE 90 DEGREES = 31. PER CENT

FRACTION OF POWER INSIDE 45 DEGREES = 21.8 PER CENT

BRIGHTNESS VARIATION = +- 50 PER CENT

FRACTION OF POWER INSIDE 30 DEGREES = 13.9 PER CENT

BRIGHTNESS VARIATION = +- 36 PER CENT

SPECULAR TRANSMITTANCE = 0

ANGLE K= θ	I[K]	GAIN[K] = B(θ)	B(θ)/B(0)
0	0.95	1.644	1.0
5	0.907	1.575	0.956
10	0.837	1.471	0.895
15	0.724	1.298	0.788
20	0.601	1.108	0.656
25	0.48	0.917	0.558
30	0.39	0.779	0.4715
35	0.319	0.675	0.41
40	0.26	0.588	0.358
45	0.224	0.547	0.332
50	0.191	0.515	0.313
55	0.15	0.453	0.2755
60	0.115	0.398	0.242
65	0.079	0.323	0.196
70	0.053	0.268	0.166
75	0.032	0.214	0.13
80	0.007	0.072	0.0438
85	0.00	0.00	0.0
85	0.00	0.00	0.0

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FRACTION OF POWER INSIDE 90 DEGREES = 30 PER CENT

FRACTION OF POWER INSIDE 45 DEGREES = 21.9 PER CENT

BRIGHTNESS VARIATION = +- 46 PER CENT

FRACTION OF POWER INSIDE 30 DEGREES = 13.4 PER CENT

BRIGHTNESS VARIATION = +- 29 PER CENT

SPECULAR TRANSMITTANCE = 0

ANGLE K=0	I[K]	GAIN[K] = B(θ)	B(θ)/B(0)
0	1.02	1.511	1.0
5	0.936	1.393	0.922
10	0.867	1.304	0.863
15	0.773	1.185	0.784
20	0.686	1.082	0.714
25	0.58	0.948	0.626
30	0.485	0.83	0.55
35	0.401	0.726	0.48
40	0.329	0.637	0.422
45	0.267	0.559	0.369
50	0.211	0.487	0.322
55	0.159	0.411	0.272
60	0.112	0.332	0.2195
65	0.079	0.277	0.186
70	0.047	0.204	0.135
75	0.024	0.137	0.0906
80	0.007	0.062	0.0410
85	0.00	0.00	0.0
85	0.00	0.00	0.0

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GLASS SAMPLE NUMBER 2

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ANGULAR GAIN FUNCTION FOR SAMPLE AR-28

FRACTION OF POWER INSIDE 90 DEGREES = 73 PER CENT

FRACTION OF POWER INSIDE 45 DEGREES = 57.3 PER CENT

BRIGHTNESS VARIATION = +- 72 PER CENT

FRACTION OF POWER INSIDE 30 DEGREES = 40.6 PER CENT

BRIGHTNESS VARIATION = +- 54 PER CENT

SPECULAR TRANSMITTANCE = 0

ANGLE K=0	I[K]	GAIN[K] = B(θ)	B(θ)/B(0)
0	1.0	6.141	1.0
5	0.926	5.711	0.931
10	0.778	4.851	0.790
15	0.618	3.93	0.64
20	0.470	3.132	0.507
25	0.363	2.456	0.399
30	0.26	1.842	0.3135
35	0.193	1.443	0.235
40	0.149	1.197	0.195
45	0.115	1.003	0.163
50	0.086	0.819	0.1332
55	0.066	0.707	0.1153
60	0.051	0.623	0.103
65	0.037	0.541	0.088
70	0.027	0.492	0.0801
75	0.016	0.379	0.0618
80	0.011	0.384	0.06255
85	0.002	0.142	0.02308
90	0.00	0.00	0.0

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FRACTION OF POWER INSIDE 90 DEGREES = 36 PER CENT

FRACTION OF POWER INSIDE 45 DEGREES = 28.4 PER CENT

BRIGHTNESS VARIATION = +- 70 PER CENT

FRACTION OF POWER INSIDE 30 DEGREES = 19.8 PER CENT

BRIGHTNESS VARIATION = +- 53 PER CENT

SPECULAR TRANSMITTANCE = 0

ANGLE K=0	I[K]	GAIN[K] = B(θ)	B(θ)/B(0)
0	1.0	2.949	1.00
5	0.936	2.772	0.939
10	0.808	2.418	0.818
15	0.652	1.99	0.675
20	0.479	1.504	0.510
25	0.353	1.15	0.3395
30	0.268	0.914	0.31
35	0.205	0.737	0.25
40	0.161	0.619	0.2095
45	0.123	0.512	0.1735
50	0.089	0.409	0.1385
55	0.066	0.34	0.115
60	0.056	0.331	0.112
65	0.044	0.308	0.1043
70	0.029	0.253	0.0856
75	0.013	0.146	0.04942
80	0.002	0.041	0.0121
85	0.00	0.00	0.0
85	0.00	0.00	0.0

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FRACTION OF POWER INSIDE 90 DEGREES = 56 PER CENT

FRACTION OF POWER INSIDE 45 DEGREES = 38.6 PER CENT

BRIGHTNESS VARIATION = +- 72 PER CENT

FRACTION OF POWER INSIDE 30 DEGREES = 26.3 PER CENT

BRIGHTNESS VARIATION = +- 62 PER CENT

SPECULAR TRANSMITTANCE = 0

ANGLE K=0	I[K]	GAIN[K] =B(θ)	B(θ)/B(0)
0	1.01	5.295	1.0
5	0.907	4.77	0.901
10	0.65	3.46	0.654
15	0.454	2.464	0.466
20	0.319	1.782	0.337
25	0.245	1.415	0.2675
30	0.208	1.258	0.2378
35	0.156	0.996	0.1885
40	0.138	0.944	0.1781
45	0.115	0.856	0.164
50	0.099	0.807	0.1525
55	0.084	0.768	0.1451
60	0.069	0.728	0.1378
65	0.06	0.749	0.1408
70	0.047	0.721	0.1365
75	0.029	0.582	0.11
80	0.007	0.218	0.0412
85	0.00	0.00	0.0
85	0.00	0.00	0.0

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ANGULAR GAIN FUNCTION FOR SAMPLE AL-5

FRACTION OF POWER INSIDE 90 DEGREES = 26 PER CENT

FRACTION OF POWER INSIDE 45 DEGREES = 18.6 PER CENT

BRIGHTNESS VARIATION = +- 72 PER CENT

FRACTION OF POWER INSIDE 30 DEGREES = 12.6 PER CENT

BRIGHTNESS VARIATION = +- 62 PER CENT

SPECULAR TRANSMITTANCE = 0

ANGLE K= θ	I[K]	GAIN[K] = B(θ)	B(θ)/B(0)
0	0.98	2.515	1.00
5	0.877	2.258	0.896
10	0.63	1.642	0.654
15	0.449	1.193	0.474
20	0.324	0.885	0.352
25	0.24	0.68	0.271
30	0.199	0.59	0.2345
35	0.164	0.513	0.204
40	0.13	0.436	0.173
45	0.112	0.406	0.1612
50	0.099	0.395	0.157
55	0.087	0.39	0.155
60	0.059	0.302	0.12
65	0.046	0.282	0.114
70	0.035	0.265	0.1052
75	0.018	0.174	0.069
80	0.00	0.00	0.0
80	0.00	0.00	0.0
80	0.00	0.00	0.0

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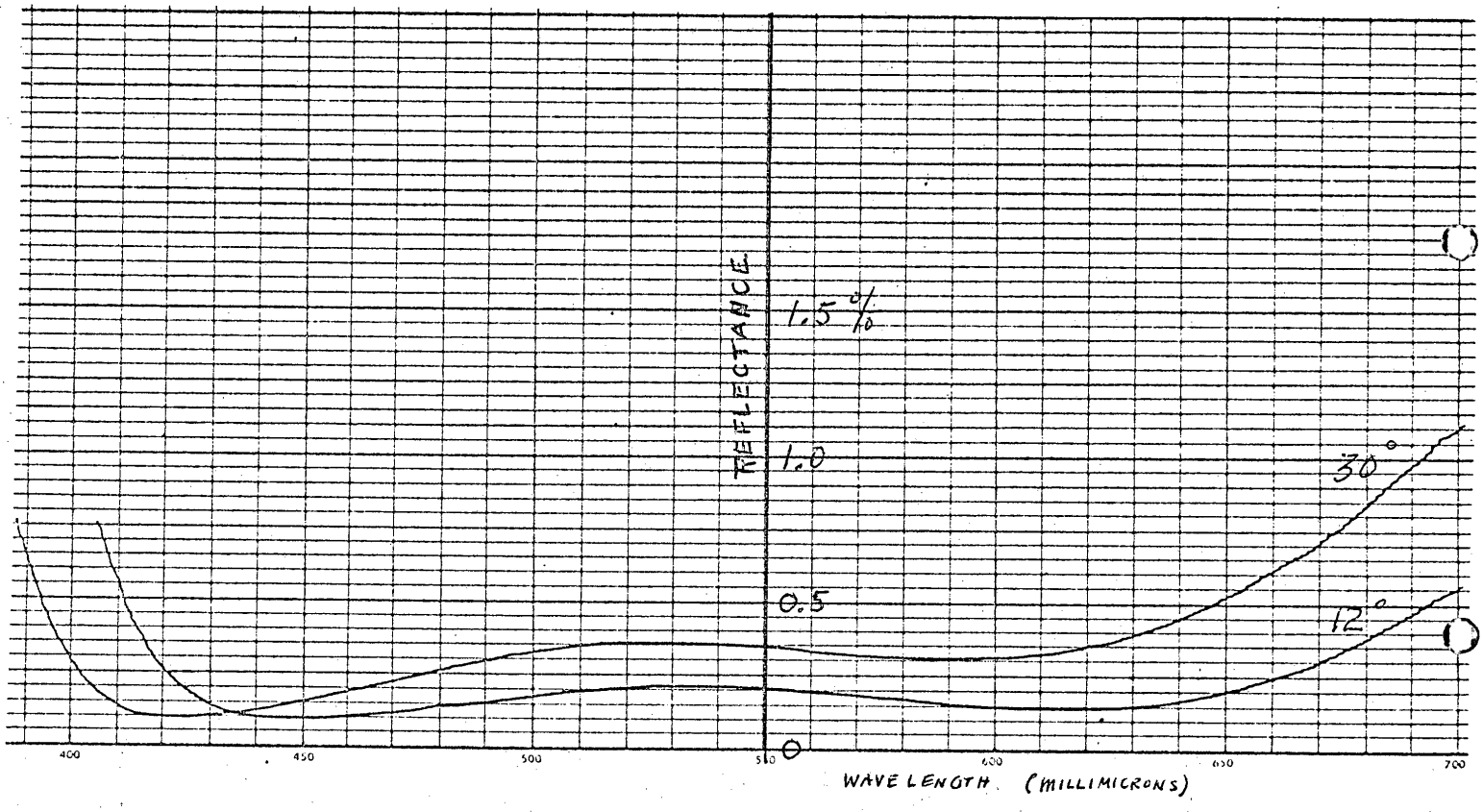

Figure 1. Typical reflection spectrum for antireflection coatings applied to observer side of screens submitted for subjective testing. Lower curve is for 12° angle of incidence, upper curve for 30°.

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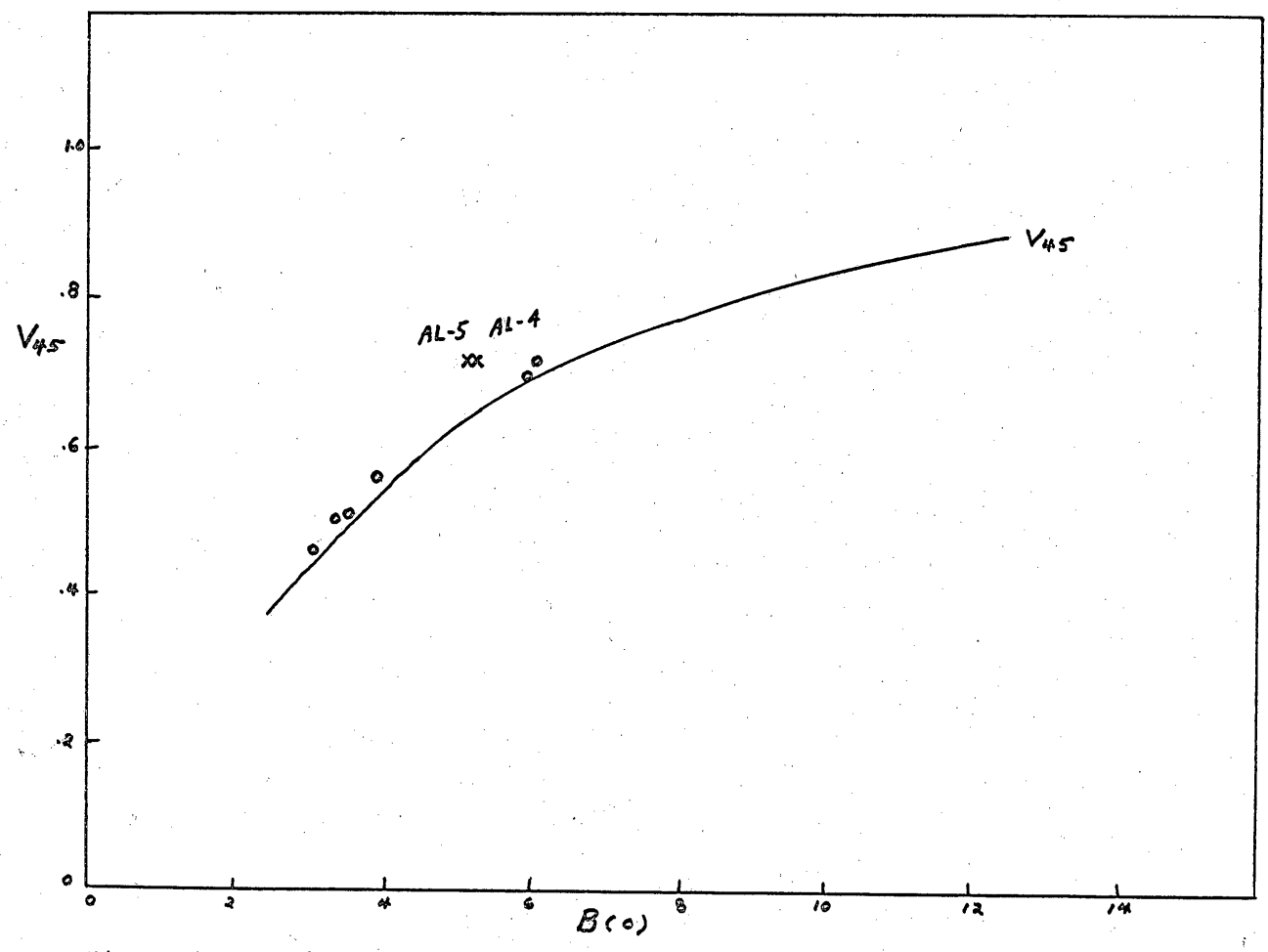

Figure 2. Brightness variation V_{45} versus axial gain for the AQ and AR Series screens. Solid curves represent the average of the data from Table III. Individual points represent data for candidate screens of Table II.

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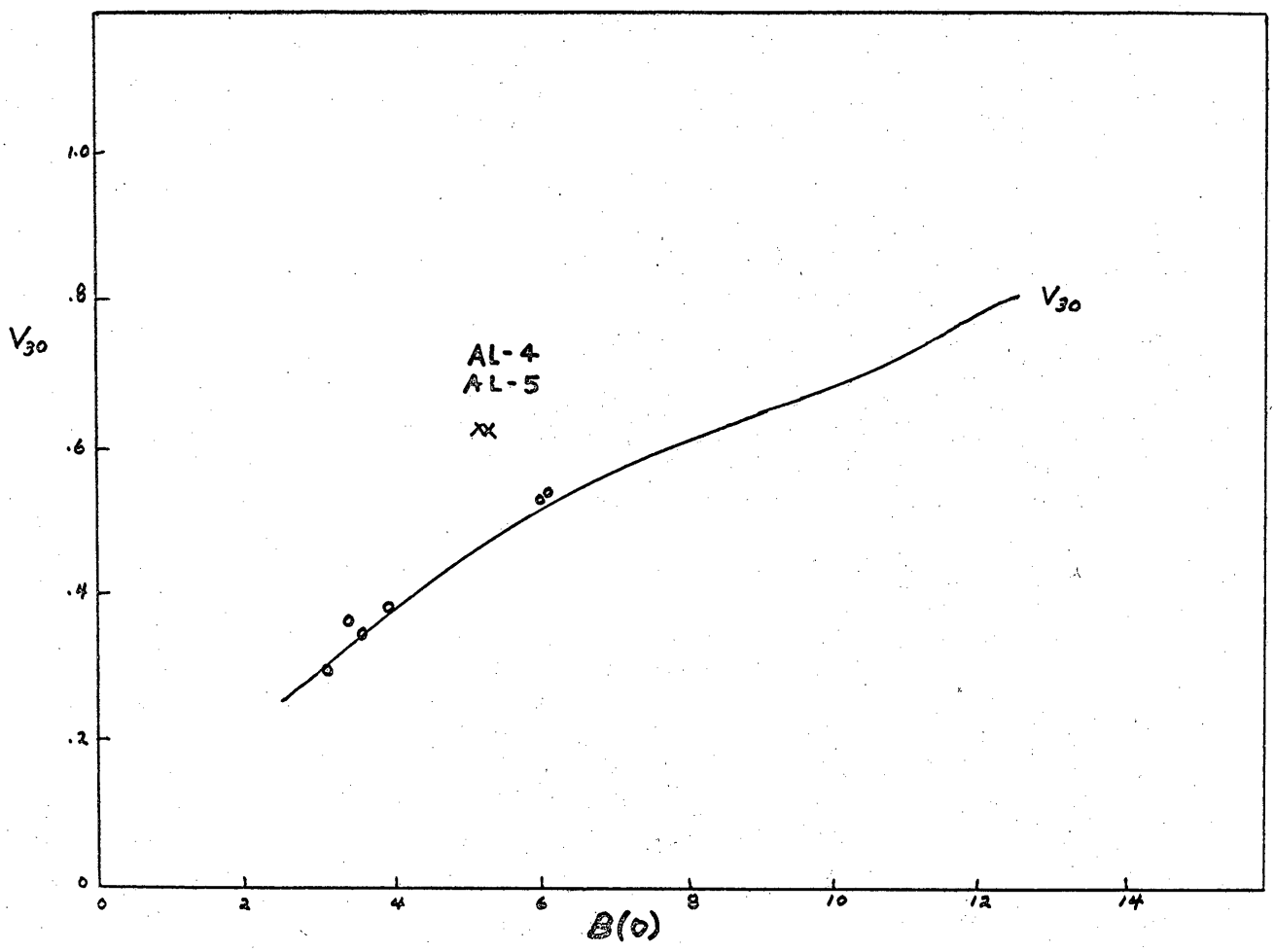

Figure 3. Brightness variation V_{30} versus axial gain for the AO and AR Series screens. Solid curves represent the average of the data from Table III. Individual points represent data for candidate screens of Table II.

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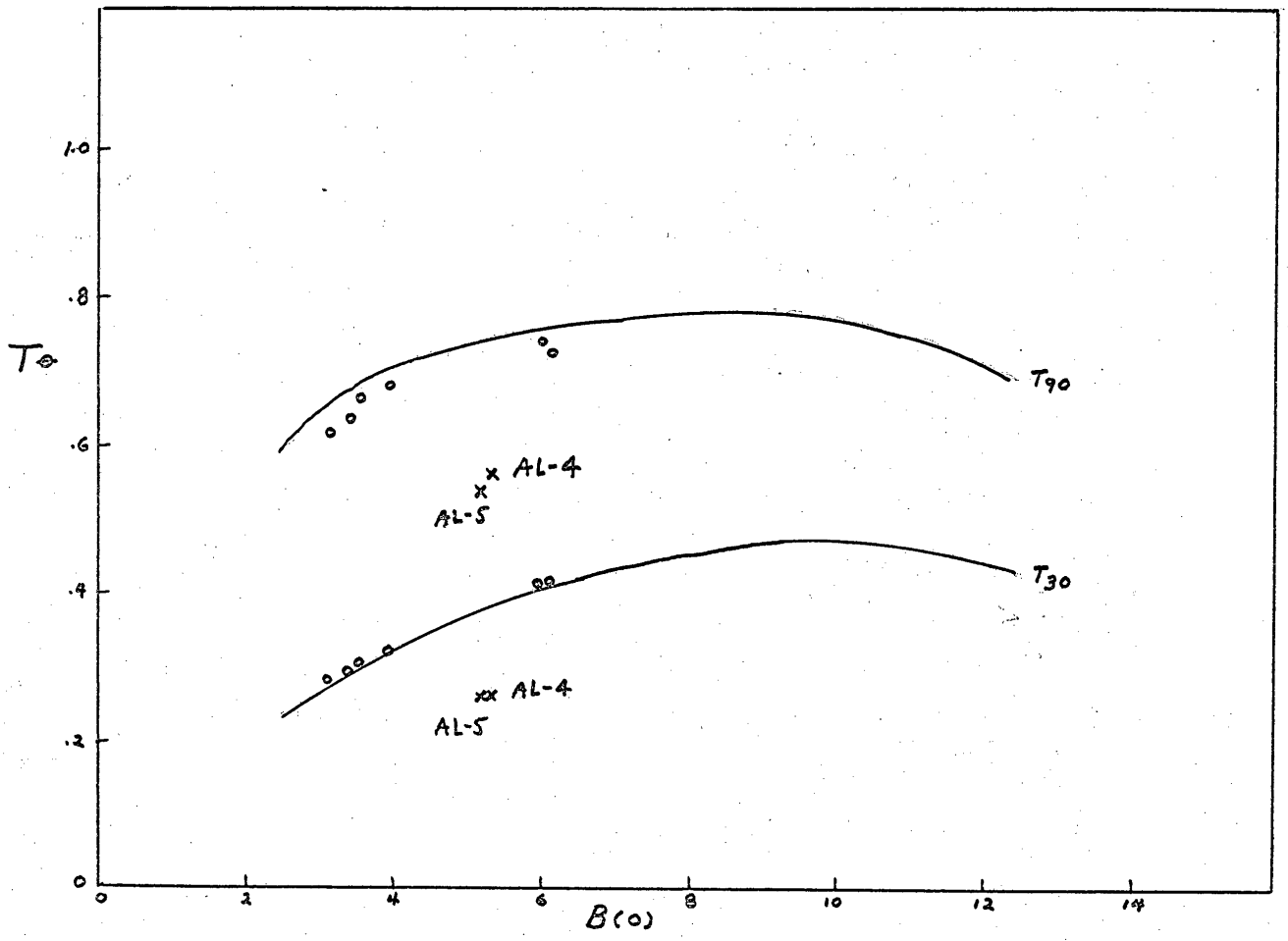

Figure 4. Diffuse transmittance T_{90} into the forward hemisphere and diffuse transmittance T_{30} into the forward 30° half-angle cone for the AQ and AR Series screens. Solid curves represent the average of the data from [illegible] indicate represent data for candidate screens of Table II.

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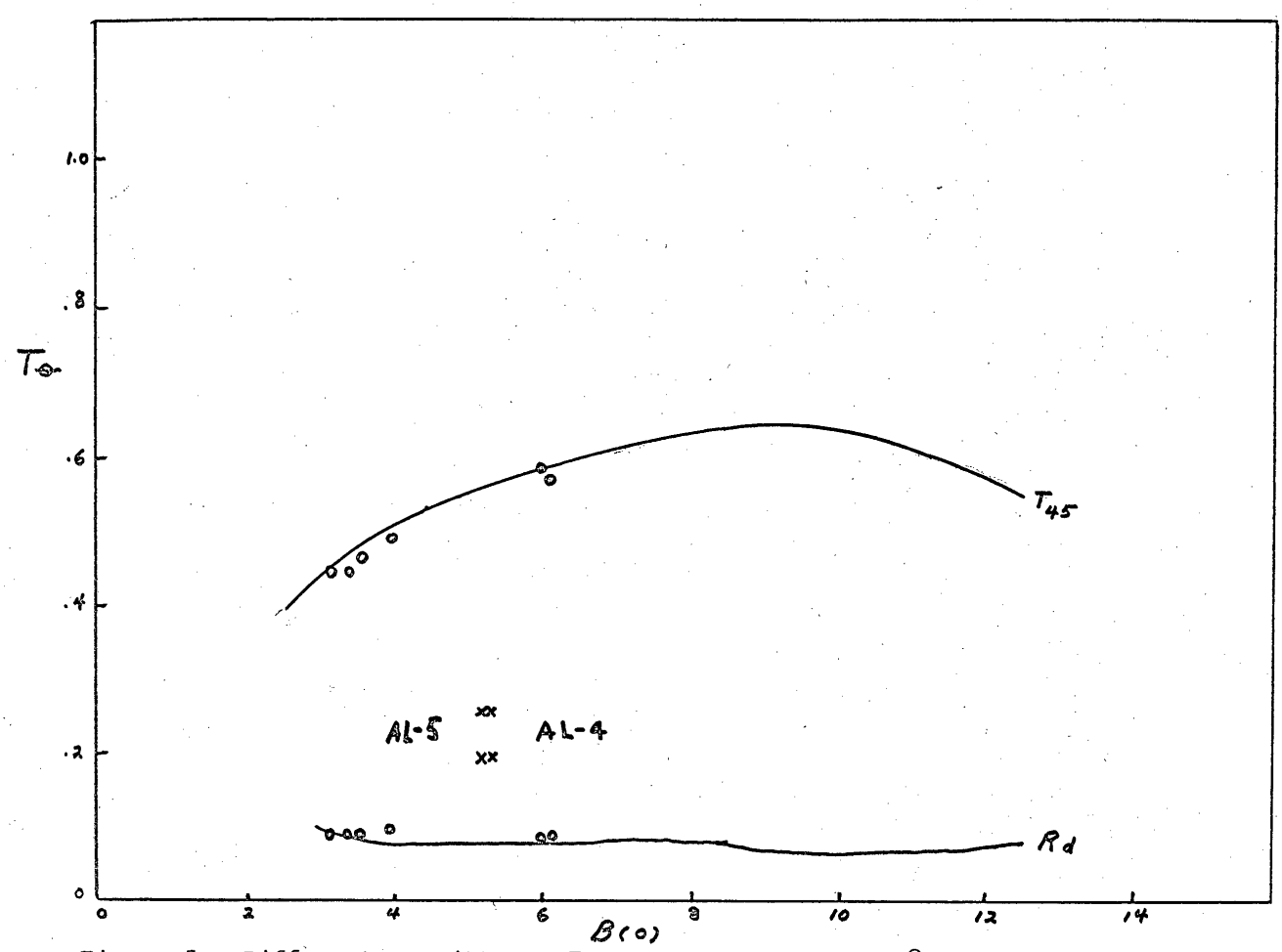

Figure 5. Diffuse transmittance T_{45} into the forward 45° half-angle cone and diffuse reflectance R_D for the AQ and AR Series Screens, versus axial gain. Solid curves represent the average of the data from Table III. Individual points represent data for candidate screens of Table II.

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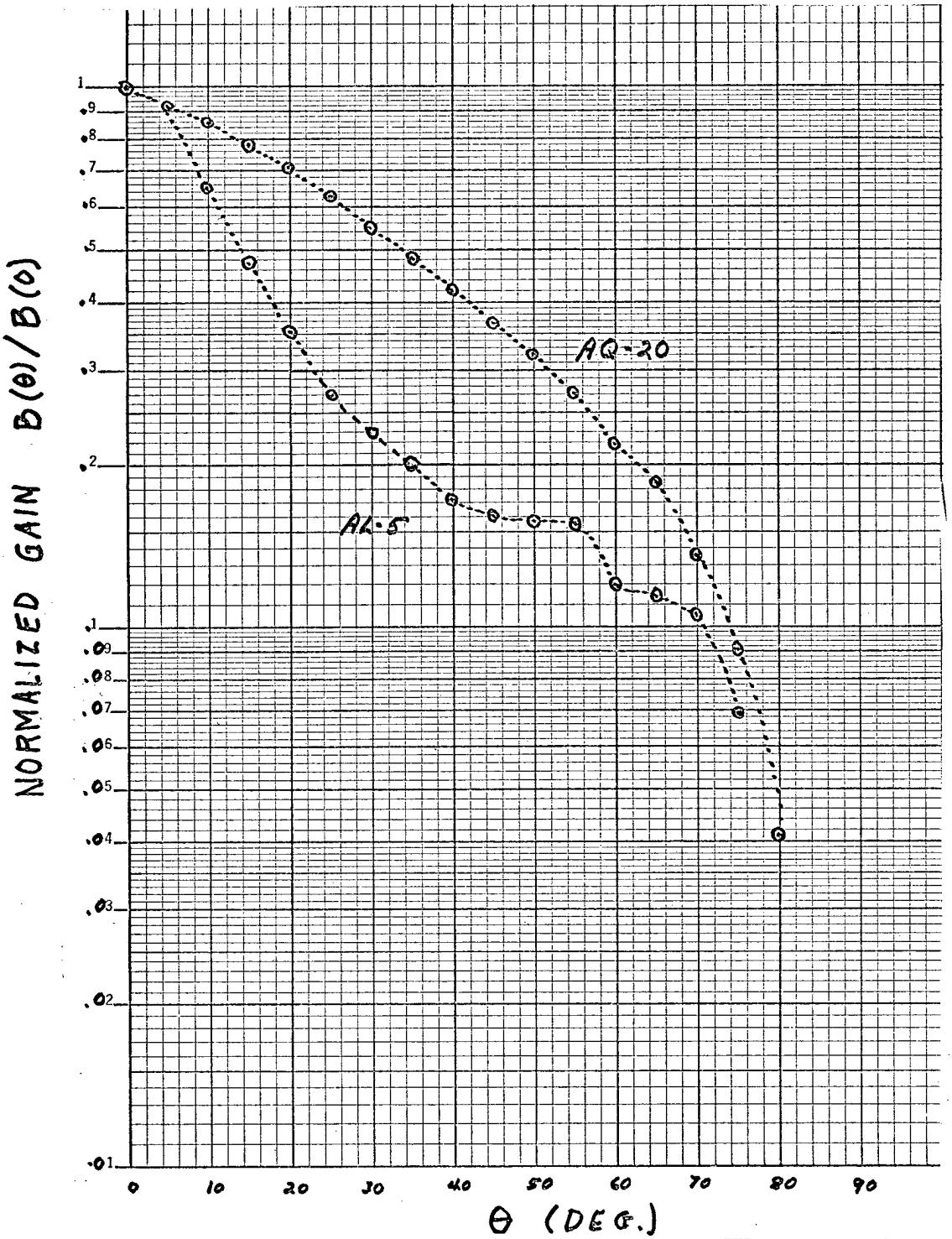

Figure 6. Normalized gain versus angle for candidate screens AQ-20 and AL-5.

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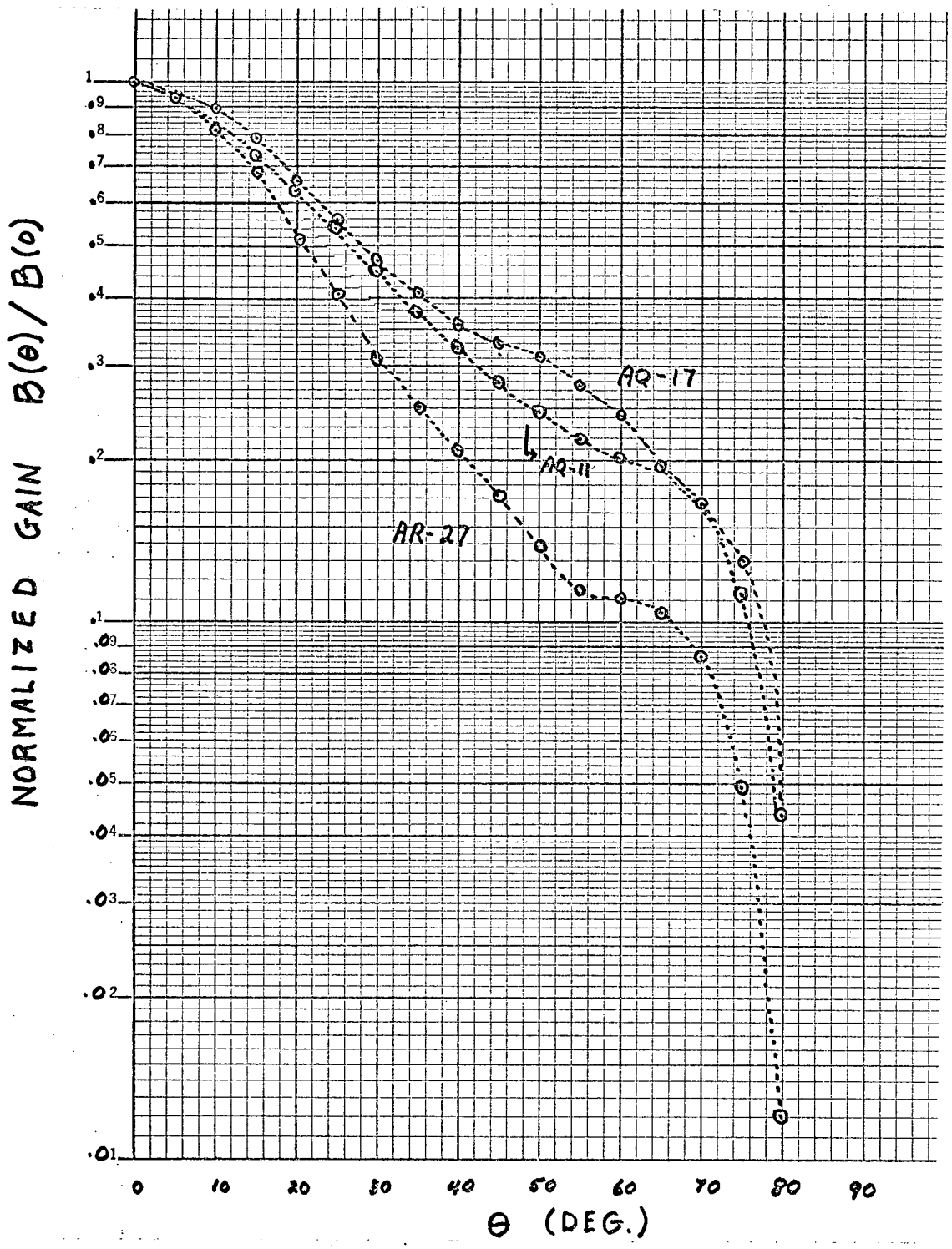

Figure 7. Normalized gain versus angle for candidate screens AQ-17, AQ-11 and AR-27.

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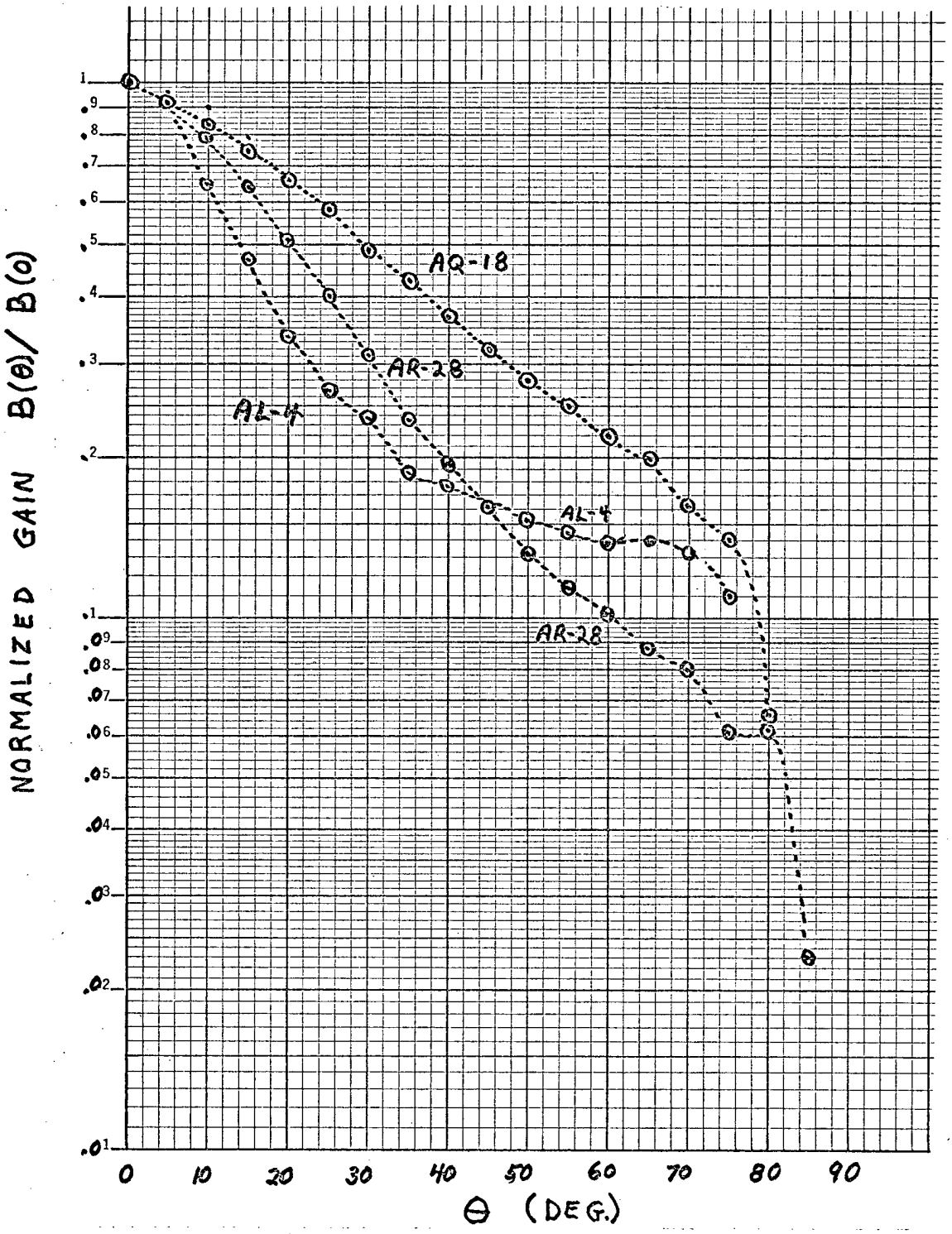

Figure 8. Normalized gain versus angle for candidate screens AQ-18, AR-28 and AL-4.

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