New Folder Name Baffle Review

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TO: Participants in LIGO Baffle/Scattering Review

>From LIGO: Barry Barish, Mike Gamble, Larry Jones, Albert Lazzarini, Gary Sanders, Robbie Vogt, Rai Weiss, Stan Whitcomb, Hiro Yamamoto

>LIGO theory associates: Kip Thorne (Caltech), Eanna Flanagan (University of Chicago)

>From GEO: Walter Winkler

>From VIRGO: Jean-Yves Vinet

>From Breault Research Organization: Bob Breault

>From Naval Weapons Laboratory: Hal Bennett

FROM: Kip

DATE: 29 December, 1994 [revised in evening]

I am distributing to you by Federal Express or Campus Mail the following items. They should reach you by Monday or at the latest Tuesday if you are not in California; by Friday in California. I also am sending by electronic mail this memo and the Tentative Agenda. I would welcome suggestions about the agenda.

1. A Tentative Agenda [one sheet, two sides]

2. ''Elementary geometric considerations of light baffles in a tube'' by Rai Weiss, July 5, 1988. A brief discussion of the philosophy of of baffling and a calculation of the number of baffles needed based on baffle geometry.

3. ''Assessment of proposed change in the LIGO baffles'': An April 1, 1993 memo from Rai Weiss to Stan Whitcomb and Bill Althouse, which describes (under "proposed") the present LIGO baffle configuration. [one sheet, two sides]

4. ''Optical Properties of the LIGO Beam Tubes'', a memo from Rai Weiss to Bill Althouse, 17 January 1989. This memo computes the attenuation of light that is specularly reflecting its way from one end of an unbaffled beam tube to the other, as a function of the light's inclination angle to the wall. This calculation was the basis for determining the range of inclination angles that must be intercepted by baffles.

SCATTERING NOISE CALCULATIONS AND THEIR CONCLUSIONS:

5. Analytic Calculations:

a. ''Noise Due to Backscatter off Baffles, the Nearby Wall, and Objects at the Far End of the Beam Tube; and Recommended Actions'' by Eanna E. Flanagan and Kip S. Thorne, 2 August 1994.
[It is generally agreed that, with the chosen baffle design, this backscatter is the dominant scattering noise source in LIGO]

b. [Early next week I will send by e-mail or fax an accompanying writeup by Flanagan and me about other noise sources. These two items, 2a and 2b, replace my old, 1989 document ''Light Scattering and Proposed Baffle Configuration for the LIGO'', which contains two serious analytical errors as well as out-of-date numbers for photodiode efficiency and baffle scattering properties]

6. Numerical Calculations:

   a. ''The phase noise analysis from Breault stray light analysis'' by Rai Weiss, 29 December 1994. This document outlines the intensity scattering analyses performed by the Breault Rsearch Organization (''BRO'') and the analysis by Weiss putting phase noise onto the scattered light, to obtain net gravity-wave noise. The final results are shown in the figure at the end of this document

   b. ''Scatter analysis of the basic LIGO configuration,'' BRO Report #2040, 28 August 1992; the basis for the analysis in 6a.

MEASUREMENTS UNDERLYING THE ABOVE SCATTERING CALCULATIONS:

7. Scattering off candidate wall and baffle materials:

   a. ''Backscatter measurements on steel and Martin black'': A January 24, 1993 memo from David Shoemaker and Rai Weiss to the LIGO Vacuum group. [one sheet, two sides]

   b. ''Summary of BRDF and rms roughness measurements made on three steel samples'', BRO Report #2190, by Gary L. Peterson of Breault Research Organization, January 27, 1993.

   c. Measurements by Weiss on a section of CBI beam tube: To come next week.

8. Mirror irregularities and scattering off mirrors:

   a. ''Basis of the optical wavefront specifications'' by Rai Weiss, March 3, 1994

   b. ''Calflat'': Measurements of shape irregularities of a Hughes-Danbury mirror that was made for use as a calibration flat for the AXAF optics; it was made with a special lapping system to minimize low spatial frequency errors (in the range relevant to our beam tube scattering), but it is not especially good at high spatial frequencies. It is not superpolished.

9. ''Spatial Uniformity of Silicon Photodiodes'' by Brian Lantz, 14 November 1994. These measurements are one underpinning for the conclusion that recombination of scattered light with the main beam at the photodiode is unimportant compared to recombination at a cavity mirror.

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REVIEW of LIGO BAFFLE DESIGN AND LIGHT SCATTERING IN BEAM TUBE
January 6 and morning of January 7, 1995
Room 114 East Bridge, Caltech, Pasadena, CA

Tentative Agenda
Begin Each Morning at 9:00AM
Indicated Times Include Discussion

Preliminaries:

20min Overview of Issues --- Kip Thorne

40min The Present Baffle and Beam Tube Designs
LIGO --- Larry Jones
VIRGO --- Jean-Yves Vinet
GEO --- Walter Winkler

Issues Underlying Scattering Calculations [brief presentations by some or all of the indicated people, followed by a general discussion]:

45min Mirror Irregularities and Light Scattering from Mirrors: Measurements; Theory; 1/\theta^2 Approximation for dP/d\Omega; Reciprocity Relation for Scattering Out of and Into Main Beam
--- Rai Weiss
--- Jean-Yves Vinet
--- Walter Winkler
--- Eanna Flanagan [Reciprocity Relation]

45min Surface Roughness, Specular Reflectivity, BRDF & Scattering Cross Sections for beam-tube materials [small incidence angle] and for candidate baffle materials [large incidence angle]: measurements and theory
--- Rai Weiss
--- Bob Breault
--- Jean-Yves Vinet
--- Walter Winkler
--- Hal Bennett???
--- Eanna Flanagan

45min Beam Tube and Baffle Vibrations
--- Larry Jones [seismic spectra at LIGO sites]
--- Mike Gamble [normal mode analysis of LIGO beam tube]
--- Eanna Flanagan [phase noise put onto scattered light that scatters or diffracts off vibrating baffles and scatters or reflects off vibrating walls]
--- Jean-Yves Vinet
--- Walter Winkler

15min Photodetector Spatial Inhomogeneities, and the Unimportance?? of Recombination of Scattered Light Into the Main Beam at the Photodetector Compared to Recombination at a Cavity Mirror
--- Rai Weiss
--- Kip Thorne

Scattering Calculations:

60min Overview of the Calculations and Final Answers for the Gravitational-Wave Noise h(f) from the Dominant Scattering Paths

LIGO --- Kip Thorne
VIRGO --- Jean-Yves Vinet
GEO --- Walter Winkler

Details of scattering calculations assuming Full Decoherence. Each scattering path will be discussed individually and fully before turning to the next one. Some or all of the following people to make presentations on each issue...

--- Bob Breault
--- Rai Weiss
--- Eanna Flanagan
--- Kip Thorne
--- Jean-Yves Vinet
--- Walter Winkler

30min Specular Reflection from One End of the Tube to the Other, Evading All Baffles

30min Backscatter off Baffles

20min Backscatter off Near Wall

15min Backscatter off Objects at Far End of Vacuum System

30min Single Diffraction off Baffles

10min Diffraction Aided Reflection

45min Coherent Scattering Effects and Their Control [most especially in single diffraction]; Mechanisms of Decoherence

---Eanna Flanagan
---Kip Thorne

30min Special Scattering Noise Effects for Special Interferometer Configurations:

Delay Lines
--- Walter Winkler

Dual Recycled Interferometers
--- ???

30min Scattering Noise and its Control in Instrumentation Chambers

---Jean-Yves Vinet
---Rai Weiss
---Walter Winkler

60min Concluding Discussion:
Is the present LIGO baffle design adequate? optimal?
What changes should be considered?
What further studies should be done before freezing the design?

BATCH START

STAPLE
OR
DIVIDER

30 Sept 97

Version 7 (Final)

Baffle Numbers and Locations at Livingston: Short Table
Part B: Mid Point to End Station
[by Kip Thorne, 06 October 1996 & 27 September 1997]
[based on analyses by Eanna Flanagan and Kip Thorne]

At Livingston the total numbers of baffles are:

FS Baffles: 426
NS Baffles: None

FS Baffles from Midpoint to End Station of Each Arm: 107

The following table shows the locations of the baffles and of the field welds in each of the two identical arms at Livingston, as Computed on 25 June 1996 using the Mathematica Notebooks "BaffleLocations5" and "TableGeneration1", and as augmented with separations and tolerances on 06 October 1996 using the Mathematica Notebook "ToleranceTable", and as modified so max tolerance is 0.10m and then printed out using the Mathematica Notebook "ToleranceTable4" on 30 September 1997:

The columns are as follows:

Column 1: "Number" -- Baffle's identifying number, or
"FW" for field weld (girth seam)

Column 2: "Location" -- Distance of baffle vertex or field weld from the beam tube axes vertex, in meters [Nominal Value]

Column 3: "Type" -- Baffle type

Column 4: "Lean" -- The direction the baffle face leans:
"T" -- toward the beam tube axes vertex
"A" -- away from the beam tube axes vertex

Column 5: "Butt" -- This column identifies baffles that butt up against an avoidance zone:
"E-GV": -- end of baffle's base butts up against a gate valve
"V-GV": -- vertex of baffle butts up against a gate valve
"V-AZ": -- vertex of baffle butts up against the edge of a field-weld avoidance zone
"E-AZ": -- end of baffle's base butts up against

edge of a field-weld avoidance zone
"V-PP": -- vertex of baffle butts up against the edge of a port-pump avoidance zone
THE GATE-VALVE ABUTTMENTS [FS BAFFLES 107 and 213] ARE MANDATORY, AS ARE THE AZ ABUTTMENTS OF ALL FS BAFFLES FROM BAFFLE 107 THROUGH 140; all other abuttments are nominal

Column 6: "Previous Field Weld" -- The previous, adjacent field weld and the present baffle

Column 7: "Seprn" -- Separation of the previous, adjacent field weld from the vertex of the present baffle [Nominal Value; in meters]

Column 8: "Next Field Weld" -- The present baffle and the next, adjacent field weld

Column 9: "Seprn" -- Separation of the next, adjacent field weld from the vertex of the present baffle [Nominal Value; in meters]

Column 10: "BafflePair" -- The pair of baffles whose separation is given in the next column

Column 11: "Seprn" -- Separation of the baffle vertices for the pair in the previous column; in meters

Column 12: "Tol" -- Tolerance on the separation [the separation can be larger than that of the previous column by no more than this amount; it can be smaller by any desired amount]

Number	Location	Type	Lean	Butt	Previous Field Weld	Seprn	Next Field Weld	Seprn	Baffle Pair	Seprn	Tol
FW	2017.430										
107	2018.560	FS	T	E-GV	{FW, 107}	1.130	{ 107, FW}	16.870			
FW	2035.430										
FW	2051.990										
108	2052.320	FS	T	E-AZ	{FW, 108}	0.329	{ 108, FW}	19.480			
FW	2071.800										
FW	2091.610										
109	2091.940	FS	T	E-AZ	{FW, 109}	0.329	{ 109, FW}	19.480			
FW	2111.430										
FW	2131.240										
110	2131.570	FS	T	E-AZ	{FW, 110}	0.330	{ 110, FW}	19.480			

FW	2151.050									
FW	2170.860									
111	2171.190	FS	T	E-AZ	{FW,	111}	0.329	{ 111,	FW}	19.480
FW	2190.670									
FW	2210.490									
112	2210.820	FS	T	E-AZ	{FW,	112}	0.330	{ 112,	FW}	19.480
FW	2230.300									
FW	2250.110									
113	2250.440	FS	T	E-AZ	{FW,	113}	0.329	{ 113,	FW}	19.480
FW	2269.920									
FW	2289.730									
114	2290.060	FS	T	E-AZ	{FW,	114}	0.330	{ 114,	FW}	19.480
FW	2309.550									
FW	2329.360									
115	2329.690	FS	T	E-AZ	{FW,	115}	0.329	{ 115,	FW}	19.480
FW	2349.170									
FW	2368.980									
116	2369.310	FS	T	E-AZ	{FW,	116}	0.329	{ 116,	FW}	19.480
FW	2388.790									
FW	2408.610									
117	2408.940	FS	T	E-AZ	{FW,	117}	0.329	{ 117,	FW}	19.480
FW	2428.420									
FW	2448.230									
118	2448.560	FS	T	E-AZ	{FW,	118}	0.329	{ 118,	FW}	19.480
FW	2468.040									
FW	2487.850									
119	2488.180	FS	T	E-AZ	{FW,	119}	0.330	{ 119,	FW}	19.480
FW	2507.670									
FW	2527.480									
120	2527.810	FS	T	E-AZ	{FW,	120}	0.329	{ 120,	FW}	19.480
FW	2547.290									
FW	2567.100									
121	2567.430	FS	T	E-AZ	{FW,	121}	0.329	{ 121,	FW}	19.480
FW	2586.910									
FW	2606.730									
122	2607.060	FS	T	E-AZ	{FW,	122}	0.329	{ 122,	FW}	19.480
FW	2626.540									
FW	2646.350									
123	2646.680	FS	T	E-AZ	{FW,	123}	0.330	{ 123,	FW}	19.480
FW	2666.160									
FW	2685.970									
124	2686.300	FS	T	E-AZ	{FW,	124}	0.329	{ 124,	FW}	19.480
FW	2705.790									
FW	2725.600									
125	2725.930	FS	T	E-AZ	{FW,	125}	0.329	{ 125,	FW}	19.480
FW	2745.410									

FW	2765.220											
126	2765.550	FS	T	E-AZ	{FW, 126}	0.329	{ 126, FW}	19.480				
FW	2785.030											
FW	2804.850											
127	2805.180	FS	T	E-AZ	{FW, 127}	0.329	{ 127, FW}	19.480				
FW	2824.660											
FW	2844.470											
128	2844.800	FS	T	E-AZ	{FW, 128}	0.330	{ 128, FW}	19.480				
FW	2864.280											
FW	2884.090											
129	2884.420	FS	T	E-AZ	{FW, 129}	0.329	{ 129, FW}	19.480				
FW	2903.910											
FW	2923.720											
130	2924.050	FS	T	E-AZ	{FW, 130}	0.329	{ 130, FW}	19.480				
FW	2943.530											
FW	2963.340											
131	2963.670	FS	T	E-AZ	{FW, 131}	0.329	{ 131, FW}	19.480				
FW	2983.150											
FW	3002.970											
132	3003.300	FS	T	E-AZ	{FW, 132}	0.330	{ 132, FW}	19.480				
FW	3022.780											
FW	3042.590											
133	3042.920	FS	T	E-AZ	{FW, 133}	0.329	{ 133, FW}	19.480				
FW	3062.400											
FW	3082.210											
134	3082.540	FS	T	E-AZ	{FW, 134}	0.330	{ 134, FW}	19.480				
FW	3102.030											
FW	3121.840											
135	3122.170	FS	T	E-AZ	{FW, 135}	0.329	{ 135, FW}	19.480				
FW	3141.650											
FW	3161.460											
136	3161.790	FS	T	E-AZ	{FW, 136}	0.329	{ 136, FW}	19.480				
FW	3181.270											
FW	3201.090											
137	3201.420	FS	T	E-AZ	{FW, 137}	0.330	{ 137, FW}	19.480				
FW	3220.900											
FW	3240.710											
138	3241.040	FS	T	E-AZ	{FW, 138}	0.329	{ 138, FW}	19.480				
FW	3260.520											
FW	3280.330											
139	3280.660	FS	T	E-AZ	{FW, 139}	0.329	{ 139, FW}	19.480				
FW	3300.150											
FW	3319.960											
140	3320.290	FS	T	E-AZ	{FW, 140}	0.329	{ 140, FW}	19.480				
FW	3339.770											
141	3358.170	FS	T		{FW, 141}	18.400	{ 141, FW}	1.410	{ 140, 141}	37.880	0.10	

FW	3359.580										
FW	3379.390										
142	3393.940	FS	T		{FW, 142}	14.550	{ 142, FW}	5.263	{ 141, 142}	35.770	0.10
FW	3399.210										
FW	3419.020										
143	3427.720	FS	T		{FW, 143}	8.699	{ 143, FW}	11.110	{ 142, 143}	33.770	0.10
FW	3438.830										
FW	3458.640										
144	3459.610	FS	T	E-AZ	{FW, 144}	0.964	{ 144, FW}	18.850	{ 143, 144}	31.890	0.10
FW	3478.450										
145	3489.530	FS	T		{FW, 145}	11.080	{ 145, FW}	8.733	{ 144, 145}	29.930	0.10
FW	3498.270										
146	3517.800	FS	T		{FW, 146}	19.530	{ 146, FW}	0.279	{ 145, 146}	28.270	0.10
FW	3518.080										
FW	3537.890										
147	3544.500	FS	T		{FW, 147}	6.608	{ 147, FW}	13.200	{ 146, 147}	26.700	0.10
FW	3557.700										
148	3569.720	FS	T		{FW, 148}	12.010	{ 148, FW}	7.798	{ 147, 148}	25.220	0.10
FW	3577.510										
149	3593.530	FS	T		{FW, 149}	16.020	{ 149, FW}	3.792	{ 148, 149}	23.820	0.10
FW	3597.330										
150	3616.030	FS	T		{FW, 150}	18.710	{ 150, FW}	1.107	{ 149, 150}	22.500	0.10
FW	3617.140										
FW	3636.950										
151	3637.280	FS	T	E-AZ	{FW, 151}	0.330	{ 151, FW}	19.480	{ 150, 151}	21.250	0.10
FW	3656.760										
152	3657.730	FS	T	E-AZ	{FW, 152}	0.964	{ 152, FW}	18.850	{ 151, 152}	20.450	0.10
FW	3676.570										
153	3676.900	FS	T	E-AZ	{FW, 153}	0.330			{ 152, 153}	19.180	0.10
154	3695.210	FS	T				{ 154, FW}	1.174	{ 153, 154}	18.310	0.10
FW	3696.390										
155	3712.480	FS	T		{FW, 155}	16.090	{ 155, FW}	3.719	{ 154, 155}	17.270	0.10
FW	3716.200										
156	3728.760	FS	T		{FW, 156}	12.570	{ 156, FW}	7.245	{ 155, 156}	16.290	0.10
FW	3736.010										
157	3744.130	FS	T		{FW, 157}	8.115	{ 157, FW}	11.700	{ 156, 157}	15.360	0.10
FW	3755.820										
158	3758.610	FS	T		{FW, 158}	2.791			{ 157, 158}	14.490	0.10
159	3772.280	FS	T				{ 159, FW}	3.357	{ 158, 159}	13.660	0.10
FW	3775.630										
160	3785.160	FS	T		{FW, 160}	9.531	{ 160, FW}	10.280	{ 159, 160}	12.890	0.10
FW	3795.450										
161	3797.320	FS	T		{FW, 161}	1.874			{ 160, 161}	12.160	0.10
162	3808.780	FS	T				{ 162, FW}	6.473	{ 161, 162}	11.460	0.10
FW	3815.260										
163	3819.600	FS	T		{FW, 163}	4.340			{ 162, 163}	10.810	0.10

164	3829.800	FS	T				{ 164, FW}	5.273	{ 163, 164}	10.200	0.10
FW	3835.070										
165	3839.420	FS	T		{FW, 165}	4.346			{ 164, 165}	9.619	0.10
166	3848.490	FS	T				{ 166, FW}	6.394	{ 165, 166}	9.072	0.10
FW	3854.880										
167	3857.050	FS	T		{FW, 167}	2.163			{ 166, 167}	8.557	0.10
168	3865.120	FS	T						{ 167, 168}	8.071	0.10
169	3872.730	FS	T				{ 169, FW}	1.966	{ 168, 169}	7.612	0.10
FW	3874.690										
170	3879.910	FS	T		{FW, 170}	5.214			{ 169, 170}	7.179	0.10
171	3886.680	FS	T						{ 170, 171}	6.771	0.10
172	3893.070	FS	T				{ 172, FW}	1.440	{ 171, 172}	6.387	0.10
FW	3894.510										
173	3899.090	FS	T		{FW, 173}	4.584			{ 172, 173}	6.024	0.09
174	3904.770	FS	T						{ 173, 174}	5.681	0.09
175	3910.130	FS	T				{ 175, FW}	4.188	{ 174, 175}	5.359	0.08
FW	3914.320										
176	3915.180	FS	T		{FW, 176}	0.866			{ 175, 176}	5.054	0.08
177	3919.950	FS	T						{ 176, 177}	4.767	0.07
178	3924.450	FS	T						{ 177, 178}	4.496	0.07
179	3928.690	FS	T						{ 178, 179}	4.240	0.06
180	3932.690	FS	T				{ 180, FW}	1.443	{ 179, 180}	4.000	0.06
FW	3934.130										
181	3936.460	FS	T		{FW, 181}	2.329			{ 180, 181}	3.772	0.05
182	3940.020	FS	T						{ 181, 182}	3.558	0.05
183	3943.370	FS	T						{ 182, 183}	3.356	0.05
184	3946.540	FS	T						{ 183, 184}	3.165	0.04
185	3949.520	FS	T						{ 184, 185}	2.985	0.04
186	3952.340	FS	T				{ 186, FW}	1.604	{ 185, 186}	2.816	0.04
FW	3953.940										
187	3954.990	FS	T		{FW, 187}	1.052			{ 186, 187}	2.656	0.04
188	3957.500	FS	T						{ 187, 188}	2.505	0.03
189	3959.860	FS	T						{ 188, 189}	2.362	0.03
190	3962.090	FS	T						{ 189, 190}	2.228	0.03
191	3964.190	FS	T						{ 190, 191}	2.101	0.03
192	3966.170	FS	T						{ 191, 192}	1.982	0.02
193	3968.040	FS	T						{ 192, 193}	1.869	0.02
194	3969.800	FS	T				{ 194, FW}	0.699	{ 193, 194}	1.763	0.02
FW	3970.500										
195	3971.470	FS	T	E-AZ	{FW, 195}	0.964			{ 194, 195}	1.663	0.02
196	3972.940	FS	T						{ 195, 196}	1.472	0.10
197	3974.330	FS	T						{ 196, 197}	1.394	0.10
198	3975.650	FS	T						{ 197, 198}	1.319	0.10
199	3976.900	FS	T						{ 198, 199}	1.249	0.10
200	3978.080	FS	T						{ 199, 200}	1.182	0.09
201	3979.200	FS	T						{ 200, 201}	1.119	0.09

202	3980.260	FS	T						{ 201, 202}	1.060	0.08
203	3981.270	FS	T						{ 202, 203}	1.003	0.08
204	3982.210	FS	T						{ 203, 204}	0.950	0.07
205	3983.110	FS	T						{ 204, 205}	0.899	0.07
206	3983.960	FS	T						{ 205, 206}	0.851	0.06
207	3984.770	FS	T						{ 206, 207}	0.806	0.06
208	3985.530	FS	T						{ 207, 208}	0.763	0.06
209	3986.250	FS	T						{ 208, 209}	0.722	0.05
210	3986.940	FS	T						{ 209, 210}	0.683	0.05
211	3987.590	FS	T						{ 210, 211}	0.647	0.05
212	3988.200	FS	T				{ 212, FW}	0.301	{ 211, 212}	0.612	0.04
FW	3988.500										
213	3988.750	FS	T	V-GV	{FW, 213}	0.255			{ 212, 213}	0.556	0.04