LIGO-T880070-00-R

#37

List of 3/1/89

Estimate of Receiver Gas Load

Michael Burka

23 December 1988

Each LIGO antenna will consist of vacuum chambers, which house the receiver components, and vacuum pipes, which connect the chambers. The pipes will be kept at vacuum indefinitely, and the gas load of the pipes has been addressed in a study by Livas and Moore.[1] This memo addresses the gas load of the vacuum chambers and the receivers which they contain.

Our approach will be to estimate the outgassing characteristics of each type of object or material which will be present in the chambers, and then to estimate the quantities of each which will be present. The most likely mode of operation will be to not perform a high temperature bake of the chambers with material installed, because such a procedure risks mirror contamination. This assumption is reflected in the values assumed for material outgassing. The principal sources of outgassing are as follows:

stainless steel The chamber walls will be made of stainless steel. The water outgassing rate of stainless steel cleaned with hot water has been measured[2] with the VTF to be 5×10^{-9} Torr-l/s-cm^2 after 10 hours and 5×10^{-10} Torr-l/s-cm^2 after 100 hours. It has been proposed that the chambers will be ten feet in height, and that the vertex chamber will be fourteen feet in diameter and the other chambers six feet in diameter. Chambers of these dimensions have internal surface areas of 6.9×10^5 cm^2 and 2.3×10^5 cm^2, respectively. Table 1 summarizes the outgassing properties of the empty chambers.

[1]Jeffrey C. Livas and Boude C. Moore, *Ligo Vacuum System Study.*

[2]Boude Moore, Report at the Ligo Project Review, 15 December 88.

Chamber	Gas load after 10 hours (Torr-l/s)	Gas load after 100 hours (Torr-l/s)
14 Foot tank	3.5×10^{-3}	3.5×10^{-4}
6 Foot tank	1.2×10^{-3}	1.2×10^{-4}

Table 1. Empty chamber gas load

glass Mirrors and beamsplitters will be made of glass, probably fused silica. O'Hanlon[3] lists the outgassing rate of Pyrex to be 1.6×10^{-10} Torr-l/s-cm^2 after ten hours, and the outgassing rate of fused silica is not likely to be very different. The largest glass component is a mirror. An 8" diameter by 4" thick blank has a surface area of 1.3×10^3 cm^2 and a gas load of 2.1×10^{-7} Torr-l/s. A question that remains to be answered is the outgassing of the dielectric coatings that will be applied to the mirror. One might expect that the coatings will behave just like bare glass, because the outermost layer is usually SiO_2. However, the layers are thin and might be permeable. If the underlying high index layers are volatile, then this could be a larger gas load. This needs to be investigated. Also, the outgassing properties of electrically conductive coatings which are needed in some suspension designs are unknown.

wire and cable We have measured the outgassing properties of both 24 gauge teflon insulated wire and RG178 coaxial cable. They are roughly the same, both in dimension and in outgassing rate. Wires which have been baked and then allowed to rehydrate at atmosphere for five days show an outgassing rate which is between 3.9×10^{-9} and 8.4×10^{-9} Torr-l/s-cm^2 after 24 hours in vacuum. The uncertainty stems from uncertainty in the pumping speed and pressure gauge calibration. Water was the dominant outgassing constituent. A middle value of 6×10^{-9} Torr-l/s-cm^2 will be assumed. The wires used in the test had diameters of 0.15 cm. If the wires are of 10 foot length, then the total area of a wire is 150 cm^2, and the gas load of a single wire is 9×10^{-7} Torr-l/s. In the rest of this analysis, the term "wire" will be used to refer to both single wires and RG178 coax.

feedthroughs The coaxial feedthroughs used at MIT are a special variety

[3] John F. O'Hanlon, *A User's Guide to Vacuum Technology,* 1980.

called Pave connectors. They contain a low-outgassing epoxy which is their principal gas load. We have measured an outgassing rate of 4.6×10^{-7} Torr-l/s-cm^2 for this epoxy after three hours of pumping. A typical feedthrough with thirty coax capacity has an area of 128 cm^2, for a gas load of 5.9×10^{-5} Torr-l/s. The single wire feedthroughs contain no epoxy, and their gas load is negligible.

pusher coils The magnetic pusher coils contain many turns of wire. The MIT prototype pushers use 750 turns of 4.5 mil enamel wire with an average turn radius of 0.6 inch, so the surface area of wire on each coil is roughly 130 cm^2. If we assume that the wire outgasses at the same rate as the teflon insulated signal wire, then the gas load of a single pusher coil after 10 hours is 1.9×10^{-6} Torr-l/s. There is a significant source of uncertainty in this estimate, in that the outgassing rate of enamel wire may be different from teflon. Thus, the outgassing of pusher coils needs to be measured.

optical fibers For purposes of estimation, we will assume that each fiber is ten feet long and outgasses at the same rate as 24 gauge teflon insulated wire.

motors A measured upper limit for the gas load of a vacuum-prepped motor is 4×10^{-6} Torr-l/s after eight hours of pumping. The motor is a Globe model 43A107-1 with a continuous torque of 40 ounce-inches. Vacuum preparation consisted of disassembling and degreasing the gearbox, replacing gearbox bearings with Bartemp[4] bearings, and dismantling the motor and replacing its bearings with Bartemps.

Other materials will be present in such small quantities that they need not be considered in gas load calculations. Although they are expected to have low gas loads, such components as Faraday isolators and Pockel cells should be checked in the near future so that there are no surprises.

The next step is to estimate what each tank will contain. The mirror stations (end, mid and non-vertex central stations) will contain the fewest components. The following table estimates the contents of a typical mirror

[4]Bartemp is a trademark of Barden Corp. A Bartemp bearing is a dry bearing with a molybdenum disulfide impregnated teflon race.

station. The numbers are the best guesses of the author, but they are obviously just guesses, because the specific receiver design has not yet been completed.

System	Component	No. of wires
Mirror	8 Sensors	16
	6 Motors	12
	6 Pushers	12
	6 Fibers	0
Pointing system	2 Detectors	10
	8 Motors	16
	2 Fibers	0

Table 2. Contents of a mirror station

The gas load of sensors and detectors is assumed to be negligible. They are included in Table 2 in order to get an estimate of the wire count. The outgassing tally for a mirror station is shown below. Gas load values at 100 hours are extrapolated from the measured and the reference data assuming a 1/t time dependence.

Component	Gas load after 100 hours (Torr-l/s)
Chamber wall	1.2×10^{-4}
1 Mirror	2.1×10^{-8}
14 Motors	4.5×10^{-6}
6 Pushers	1.1×10^{-6}
66 Wires	1.4×10^{-5}
1 Coax feedthrough	1.8×10^{-6}
8 Optical fibers	1.7×10^{-6}
Total Gas Load	1.4×10^{-4}

Table 3. Gas load in a mirror station

The beamsplitter chamber contains a large number of suspended components. The gas load of the components is likely to be dwarfed by the gas load of the wires which are needed to control the suspended platforms. A recent schematic of the beamsplitter chamber drawn by Ron Drever shows 136 control modules. Each control module contains an l.e.d., a detector, and a pusher. We assume that each of the three elements requires two wires, and we guess that there will be thirty motors with two wires each. Perhaps one-fourth of the wires will be coax, requiring 8 Pave connectors. The gas load after 100 hours, summarized below, is 3.6×10^{-4} Torr-l/s.

Component	Gas load after 100 hours (Torr-l/s)
Chamber wall	1.2×10^{-4}
30 Motors	9.6×10^{-6}
136 Pushers	2.6×10^{-5}
876 Wires	1.9×10^{-4}
8 Coax feedthroughs	1.4×10^{-5}
Total Gas Load	3.6×10^{-4}

Table 4. Gas load in a beamsplitter station

Table 5 shows the situation for the vertex chamber, which contains the components of a beamsplitter station plus two mirror stations.

Component	Gas load after 100 hours (Torr-l/s)
Chamber wall	3.5×10^{-4}
2 Mirrors	4.2×10^{-8}
58 Motors	1.9×10^{-5}
148 Pushers	2.8×10^{-5}
1008 Wires	2.1×10^{-4}
10 Coax feedthroughs	1.8×10^{-5}
16 Optical fibers	3.5×10^{-6}
Total Gas Load	6.3×10^{-4}

Table 5. Gas load in the vertex chamber

The 100 hour gas loads and pumping speeds necessary to achieve a pressure of 10^{-7} Torr after 100 hours are shown in Table 6.

Chamber type	Gas Load (Torr-l/s)	Pumping Speed (l/s)
Mirror station	1.4×10^{-4}	1.4×10^{3}
Beamsplitter station	3.6×10^{-4}	3.6×10^{3}
Vertex station	6.3×10^{-4}	6.3×10^{3}

Table 6. Summary of chamber gas loads

As seen in the tables above, the dominant contributions to the gas load are the chamber walls and the wires. It may be possible to reduce the overall gas load by using thinner wires. If 30 gauge wire is used instead of the 24 gauge wire installed in the MIT prototype, then the surface area of each wire is reduced by a factor of 3. If half of the wires can be so reduced, then the 100 hour gas loads of the beamsplitter and vertex stations are 3.0×10^{-4} and 5.6×10^{-4} Torr-l/s, respectively.

In summary, the estimates above are very rough. Work on the outgassing properties of stainless steel is continuing under Boude Moore. We need to undertake investigation of ways to reduce the outgassing of wires, either by finding a better insulating material, or by determining which wires can be made thin. There are components which have not been vacuum tested, such as Faraday isolators and coated mirrors. We need to test these, lest there be some surprises in the future. If there are materials which outgas profusely that will have to be used in LIGO, then they need to be identified. A summary of types of material appears in Table 7. Tables 8, 9, and 10 show the pressure at 10 hours and 100 hours for the three types of chambers with pumping speeds of 1000 liter/s, 3000 liter/s, and 10000 liter/s, respectively.

Material	Outgassing rate at 100 hours (Torr-l/s-cm^2)	Surface area in vertex tank (cm^2)	Gas load at 100 hours (Torr-l/s)
Stainless steel	5×10^{-10}	6.9×10^{5}	3.5×10^{-4}
Teflon	1.4×10^{-9}	1.5×10^{5}	2.1×10^{-4}
Epoxy	1.4×10^{-8}	1.3×10^{3}	1.8×10^{-5}

Table 7. Summary of outgassing materials

Chamber	P at 10 hours (Torr)	P at 100 hours (Torr)
Mirror	1.4×10^{-6}	1.4×10^{-7}
Beamsplitter	3.6×10^{-6}	3.6×10^{-7}
Vertex	6.3×10^{-6}	6.3×10^{-7}

Table 8. Chamber pressures with 1000 liter/s pump

Chamber	P at 10 hours (Torr)	P at 100 hours (Torr)
Mirror	4.7×10^{-7}	4.7×10^{-8}
Beamsplitter	1.2×10^{-6}	1.2×10^{-7}
Vertex	2.1×10^{-6}	2.1×10^{-7}

Table 9. Chamber pressures with 3000 liter/s pump

Chamber	P at 10 hours (Torr)	P at 100 hours (Torr)
Mirror	1.4×10^{-7}	1.4×10^{-8}
Beamsplitter	3.6×10^{-7}	3.6×10^{-8}
Vertex	6.3×10^{-7}	6.3×10^{-8}

Table 10. Chamber pressures with 10000 liter/s pump

The words in this receiver gas load estimate are those of the author, but much of the data has been supplied by Nelson Christensen, Jeff Livas, and Boude Moore.

BATCH START

STAPLE
OR
DIVIDER

LIGO-T880070-00-R

Estimate of Receiver Gas Load

Michael Burka

23 December 1988

Each LIGO antenna will consist of vacuum chambers, which house the receiver components, and vacuum pipes, which connect the chambers. The pipes will be kept at vacuum indefinitely, and the gas load of the pipes has been addressed in a study by Livas and Moore.[1] This memo addresses the gas load of the vacuum chambers and the receivers which they contain.

Our approach will be to estimate the outgassing characteristics of each type of object or material which will be present in the chambers, and then to estimate the quantities of each which will be present. The most likely mode of operation will be to not perform a high temperature bake of the chambers with material installed, because such a procedure risks mirror contamination. This assumption is reflected in the values assumed for material outgassing. The principal sources of outgassing are as follows:

stainless steel The chamber walls will be made of stainless steel. The water outgassing rate of stainless steel cleaned with hot water has been measured[2] with the VTF to be 5×10^{-9} Torr-l/s-cm^2 after 10 hours and 5×10^{-10} Torr-l/s-cm^2 after 100 hours. It has been proposed that the chambers will be ten feet in height, and that the vertex chamber will be fourteen feet in diameter and the other chambers six feet in diameter. Chambers of these dimensions have internal surface areas of 6.9×10^5 cm^2 and 2.3×10^5 cm^2, respectively. Table 1 summarizes the outgassing properties of the empty chambers.

Chamber	Gas load after 10 hours (Torr-l/s)	Gas load after 100 hours (Torr-l/s)
14 Foot tank	3.5×10^{-3}	3.5×10^{-4}
6 Foot tank	1.2×10^{-3}	1.2×10^{-4}

Table 1. Empty chamber gas load

[1] Jeffrey C. Livas and Boude C. Moore, *Ligo Vacuum System Study*.
[2] Boude Moore, Report at the Ligo Project Review, 15 December 88.

glass Mirrors and beamsplitters will be made of glass, probably fused silica. O'Hanlon[3] lists the outgassing rate of Pyrex to be 1.6×10^{-10} Torr-l/s-cm^2 after ten hours, and the outgassing rate of fused silica is not likely to be very different. The largest glass component is a mirror. An 8" diameter by 4" thick blank has a surface area of 1.3×10^3 cm^2 and a gas load of 2.1×10^{-7} Torr-l/s. A question that remains to be answered is the outgassing of the dielectric coatings that will be applied to the mirror. One might expect that the coatings will behave just like bare glass, because the outermost layer is usually SiO_2. However, the layers are thin and might be permeable. If the underlying high index layers are volatile, then this could be a larger gas load. This needs to be investigated. Also, the outgassing properties of electrically conductive coatings which are needed in some suspension designs are unknown.

wire and cable We have measured the outgassing properties of both 24 gauge teflon insulated wire and RG178 coaxial cable. They are roughly the same, both in dimension and in outgassing rate. Wires which have been baked and then allowed to rehydrate at atmosphere for five days show an outgassing rate which is between 3.9×10^{-9} and 8.4×10^{-9} Torr-l/s-cm^2 after 24 hours in vacuum. The uncertainty stems from uncertainty in the pumping speed and pressure gauge calibration. Water was the dominant outgassing constituent. A middle value of 6×10^{-9} Torr-l/s-cm^2 will be assumed. The wires used in the test had diameters of 0.15 cm. If the wires are of 10 foot length, then the total area of a wire is 150 cm^2, and the gas load of a single wire is 9×10^{-7} Torr-l/s. In the rest of this analysis, the term "wire" will be used to refer to both single wires and RG178 coax.

feedthroughs The coaxial feedthroughs used at MIT are a special variety called Pave connectors. They contain a low-outgassing epoxy which is their principal gas load. We have measured an outgassing rate of 4.6×10^{-7} Torr-l/s-cm^2 for this epoxy after three hours of pumping. A typical feedthrough with thirty coax capacity has an area of 128 cm^2, for a gas load of 5.9×10^{-5} Torr-l/s. The single wire feedthroughs contain no epoxy, and their gas load is negligible.

pusher coils The magnetic pusher coils contain many turns of wire. The MIT prototype pushers use 750 turns of 4.5 mil enamel wire with an average turn radius of 0.6 inch, so the surface area of wire on each coil is roughly 130 cm^2. If we assume that the wire outgasses at the same rate as the teflon insulated signal wire, then the gas load of a single pusher coil after 10 hours is 1.9×10^{-6} Torr-l/s. There is a significant source of uncertainty in this estimate, in that the outgassing rate of enamel wire may be different from teflon. Thus, the outgassing of pusher coils needs to be measured.

[3] John F. O'Hanlon, *A User's Guide to Vacuum Technology*, 1980.

optical fibers For purposes of estimation, we will assume that each fiber is ten feet long and outgasses at the same rate as 24 gauge teflon insulated wire.

motors A measured upper limit for the gas load of a vacuum-prepped motor is 4×10^{-6} Torr-l/s after eight hours of pumping. The motor is a Globe model 43A107-1 with a continuous torque of 40 ounce-inches. Vacuum preparation consisted of disassembling and degreasing the gearbox, replacing gearbox bearings with Bartemp[4] bearings, and dismantling the motor and replacing its bearings with Bartemps.

Other materials will be present in such small quantities that they need not be considered in gas load calculations. Although they are expected to have low gas loads, such components as Faraday isolators and Pockel cells should be checked in the near future so that there are no surprises.

The next step is to estimate what each tank will contain. The mirror stations (end, mid and non-vertex central stations) will contain the fewest components. The following table estimates the contents of a typical mirror station. The numbers are the best guesses of the author, but they are obviously just guesses, because the specific receiver design has not yet been completed.

System	Component	No. of wires
Mirror	8 Sensors	16
	6 Motors	12
	6 Pushers	12
	6 Fibers	0
Pointing system	2 Detectors	10
	8 Motors	16
	2 Fibers	0

Table 2. Contents of a mirror station

The gas load of sensors and detectors is assumed to be negligible. They are included in Table 2 in order to get an estimate of the wire count. The outgassing tally for a mirror station is shown below. Gas load values at 100 hours are extrapolated from the measured and the reference data assuming a 1/t time dependence.

[4] Bartemp is a trademark of Barden Corp. A Bartemp bearing is a dry bearing with a molybdenum disulfide impregnated teflon race.

Component	Gas load after 100 hours (Torr-l/s)
Chamber wall	1.2×10^{-4}
1 Mirror	2.1×10^{-8}
14 Motors	4.5×10^{-6}
6 Pushers	1.1×10^{-6}
66 Wires	1.4×10^{-5}
1 Coax feedthrough	1.8×10^{-6}
8 Optical fibers	1.7×10^{-6}
Total Gas Load	1.4×10^{-4}

Table 3. Gas load in a mirror station

The beamsplitter chamber contains a large number of suspended components. The gas load of the components is likely to be dwarfed by the gas load of the wires which are needed to control the suspended platforms. A recent schematic of the beamsplitter chamber drawn by Ron Drever shows 136 control modules. Each control module contains an l.e.d., a detector, and a pusher. We assume that each of the three elements requires two wires, and we guess that there will be thirty motors with two wires each. Perhaps one-fourth of the wires will be coax, requiring 8 Pave connectors. The gas load after 100 hours, summarized below, is 3.6×10^{-4} Torr-l/s.

Component	Gas load after 100 hours (Torr-l/s)
Chamber wall	1.2×10^{-4}
30 Motors	9.6×10^{-6}
136 Pushers	2.6×10^{-5}
876 Wires	1.9×10^{-4}
8 Coax feedthroughs	1.4×10^{-5}
Total Gas Load	3.6×10^{-4}

Table 4. Gas load in a beamsplitter station

Table 5 shows the situation for the vertex chamber, which contains the components of a beamsplitter station plus two mirror stations.

Component	Gas load after 100 hours (Torr-l/s)
Chamber wall	3.5×10^{-4}
2 Mirrors	4.2×10^{-8}
58 Motors	1.9×10^{-5}
148 Pushers	2.8×10^{-5}
1008 Wires	2.1×10^{-4}
10 Coax feedthroughs	1.8×10^{-5}
16 Optical fibers	3.5×10^{-6}
Total Gas Load	6.3×10^{-4}

Table 5. Gas load in the vertex chamber

The 100 hour gas loads and pumping speeds necessary to achieve a pressure of 10^{-7} Torr after 100 hours are shown in Table 6.

Chamber type	Gas Load (Torr-l/s)	Pumping Speed (l/s)
Mirror station	1.4×10^{-4}	1.4×10^{3}
Beamsplitter station	3.6×10^{-4}	3.6×10^{3}
Vertex station	6.3×10^{-4}	6.3×10^{3}

Table 6. Summary of chamber gas loads

As seen in the tables above, the dominant contributions to the gas load are the chamber walls and the wires. It may be possible to reduce the overall gas load by using thinner wires. If 30 gauge wire is used instead of the 24 gauge wire installed in the MIT prototype, then the surface area of each wire is reduced by a factor of 3. If half of the wires can be so reduced, then the 100 hour gas loads of the beamsplitter and vertex stations are 3.0×10^{-4} and 5.6×10^{-4} Torr-l/s, respectively.

In summary, the estimates above are very rough. Work on the outgassing properties of stainless steel is continuing under Boude Moore. We need to undertake investigation of ways to reduce the outgassing of wires, either by finding a better insulating material, or by determining which wires can be made thin. There are components which have not been vacuum tested, such as Faraday isolators and coated mirrors. We need to test these, lest there be some surprises in the future. If there are materials which outgas profusely that will have to be used in LIGO, then they need to be identified. A summary of types of material appears in Table 7. Tables 8, 9, and 10 show the pressure at 10 hours and 100 hours for the three types of chambers with pumping speeds of 1000 liter/s, 3000 liter/s, and 10000 liter/s, respectively.

Material	Outgassing rate at 100 hours (Torr-l/s-cm^2)	Surface area in vertex tank (cm^2)	Gas load at 100 hours (Torr-l/s)
Stainless steel	5×10^{-10}	6.9×10^{5}	3.5×10^{-4}
Teflon	1.4×10^{-9}	1.5×10^{5}	2.1×10^{-4}
Epoxy	1.4×10^{-8}	1.3×10^{3}	1.8×10^{-5}

Table 7. Summary of outgassing materials

Chamber	P at 10 hours (Torr)	P at 100 hours (Torr)
Mirror	1.4×10^{-6}	1.4×10^{-7}
Beamsplitter	3.6×10^{-6}	3.6×10^{-7}
Vertex	6.3×10^{-6}	6.3×10^{-7}

Table 8. Chamber pressures with 1000 liter/s pump

Chamber	P at 10 hours (Torr)	P at 100 hours (Torr)
Mirror	4.7×10^{-7}	4.7×10^{-8}
Beamsplitter	1.2×10^{-6}	1.2×10^{-7}
Vertex	2.1×10^{-6}	2.1×10^{-7}

Table 9. Chamber pressures with 3000 liter/s pump

Chamber	P at 10 hours (Torr)	P at 100 hours (Torr)
Mirror	1.4×10^{-7}	1.4×10^{-8}
Beamsplitter	3.6×10^{-7}	3.6×10^{-8}
Vertex	6.3×10^{-7}	6.3×10^{-8}

Table 10. Chamber pressures with 10000 liter/s pump

The words in this receiver gas load estimate are those of the author, but much of the data has been supplied by Nelson Christensen, Jeff Livas, and Boude Moore.