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GEO 600

1.1 A bit of history

GEO 600 is a British / German gravitational-wave detector (see Grote
for the LIGO Scientific Collaboration (2008)) located in Germany close
to the city of Hannover. GEO evolved from a collaboration between
the groups working on the Garching 30 m and the Glasgow 10 m pro-
totypes. In 1989 these groups proposed to build an underground 3 km
gravitational-wave detector, 'GEO', in the Harz mountains in northern
Germany (Leuchs et al. (1987) and Hough et al. (1989)). Although re-
viewed positively, a shortage of funds on both ends, in the British Science
and Engineering Research Council and after the German reunification
also in the German funding bodies, made the realization of this large
project impossible. The collaborators decided to try obtaining funds for
a shorter detector and compensate for the shortness by implementing
more advanced techniques. A suitable stretch of land to build a 600 m
instrument was found 20 km south of the city of Hannover, owned by
the Universität Hannover and the state of Lower Saxony. Funding could
finally be obtained from PPARC (Particle Physics and Astronomy Re-
search Council), MPG (Max-Planck Gesellschaft), BMFT (Bundesmin-
isterium für Forschung und Technologie), and the State of Lower Sax-
ony. The construction of GEO 600 started on September 4th 1995. The
following years were busy with the construction of the infrastructure
and the vacuum system, which got finished in 1998 just before the im-
plementation of suspension systems and optics started. The two input
Mode Cleaners (see below) of GEO 600 were operative in 1999. GEO 600
was equipped with medium quality test optics in 2001 in order to gain
experience with the handling and installation of 5 kg optics suspended
from wires just several times the thickness of a hair. Two of the mir-

rors were already 'monolithically' suspended by thin glass fibres. At the same time the principal investigators of GEO and LIGO signed a memorandum of understanding, agreeing on the sharing and joint analysis of data acquired by the instruments. The first stable operation of the Power Recycled interferometer was achieved in December 2001 immediately followed by a short coincidence test run with the LIGO detectors (Willke et al. (2004)), testing the stability of the system and getting acquainted with data storage and exchange procedures. The first scientific data run, again together with the LIGO detectors was performed in August and September of 2002, where GEO 600 achieved a duty cycle (percentage of time taking science data) of 97%. The work on implementation of Signal Recycling (see below) and the exchange of all temporary optics for the final, monolithically suspended ones concluded with another joint data run in fully dual recycled mode at the end of 2003 and into 2004. As the sensitivity of all detectors improved, the collaborative data runs were extended in length, culminating in the 5th data run lasting from November 2005 to October 2007. This data run, where also the Virgo detector participated, concluded the operation of the first generation of gravitational-wave detectors.

1.2 GEO 600 techniques

To achieve a sensitivity comparable to the larger LIGO (Sigg for the LIGO Scientific Collaboration (2008)) and Virgo detectors (Acernese et al. (2008)) GEO600 had to use techniques to increase the sensitivity that were not planned for the first generation of the other instruments, like Signal Recycling, multiple-stage pendulums with monolithic suspension, and electro-static actuators.

In the early 1990s when the decision on the optical layout of GEO 600 had to be made, Signal Recycling (Meers (1988)) and Resonant sideband extraction (Mizuno et al. (1993a))were just being developed in the Garching laboratories around the 30 m prototype (Mizuno et al. (1993b) and Heinzel et al. (1996)). Optical delay lines had shown severe problems with scattered light in the experiments (Winkler (1983)). Arm cavities in combination with Dual Recycling, a combination of Power Recycling (Schnier et al. (1997)) and Signal Recycling (Strain and Meers (1991) or Freise et al. (2000)) was considered to be too immature in terms of robust control schemes for all relevant degrees of freedom to be used in GEO 600. Hence the choice fell on a Michelson interferometer with folded

arms, giving an effective arm length of 1200 m, and Dual Recycling (see figure 1.2).

The lasers used in the prototypes at that time were stabilized Ar^+ lasers with a wavelength of 514 nm. These 'dinosaurs' consuming tens of kW to produce a few Watts of noisy laser light, were replaced in the large-scale interferometers by the just evolving solid state Nd:YAG lasers, which have a much higher efficiency (see Kane and Byer (1985) or Frede et al. (2004)) and are inherently much more stable. The longer wavelength of 1064 nm also relaxed the requirements on mirror surface accuracy and micro roughness. In the 1990s these lasers showed good power stability only at frequencies in the MHz range. A modulation technique, which shifted the laser power stability requirements from the detection band into the radio frequency range was used for generating the gravitational wave signal and with it the error signal for controlling the differential length of the interferometer arms. The GEO team decided to use Schnupp (Schnupp (1988) modulation for this purpose. Phase modulating the light before it enters the interferometer in combination with slightly different arm lengths (13.5 cm in the case of GEO 600) yields a signal at the modulation frequency. The amplitude of this signal depends on the deviation from the 'dark fringe' (the operation point of destructive interference at the output port) and hence gives an error signal for controlling the differential length degree of freedom and also yields the GW signal. The same modulation sidebands are also used to create error signals for an automatic alignment system as described in Grote et al. (2004). In the first generation all gravitational wave detectors used this read-out scheme, which is called RF- (Radio Frequency) or heterodyne-readout.

1.2.1 Power Recycling

In GEO 600 the light source is a master/slave 12 W Nd:YAG laser with a wavelength of 1064 nm (Zawischa et al. (2002)). Two subsequent optical resonators, the Mode Cleaners, with a finesse of about 2000 each, filter the light to lower the spatial fluctuations and reduce the higher order transversal optical modes (Gossler et al. (2003)), before the beam is injected into the interferometer through modulators and Faraday isolators (see figure 1.2). In order to optimize the signal-to-shot-noise ratio the light power in the interferometer arms has to be as high as possible. Whereas the other large GW detectors use optical cavities in the interferometer arms to increase the light power, in conjunction with a

relatively low power recycling factor, in GEO 600 the power is resonantly enhanced only in the Power Recycling cavity, with a high power recycling factor of about 1000. In this scheme the full light power in the interferometer arms (or more precisely in the one interferometer arm) has to traverse the beam splitter. The residual absorption in the beam splitter substrate leads to a local heating, which results in a thermal lens (Winkler et al. (1991) and Hild; et al. (2006)). This thermal lens limits the maximum light power level that can be used in GEO 600 to about 10 kW. Up to 2009 the power level used at the beam splitter was about 3 kW.

1.2.2 Signal Recycling

Similar to Power Recycling (where the carrier power being reflected by the interferometer back to the input port is resonantly enhanced) an additional Recycling mirror in the interferometer output can resonantly enhance the signal sidebands. The bandwidth and centre frequency of the Signal Recycling cavity are determined by the reflectivity and microscopical position of the Signal Recycling mirror, respectively. In GEO 600 a transmission of the mirror of 2% and a detuning from carrier resonance of about 2.2 nm was used until mid 2009. This resulted in a bandwidth (FWHM) of about 700 Hz and a detuning frequency of 530 Hz. A resulting sensitivity curve is shown in figure 1.1.

1.2.3 Seismic isolation and triple pendulum suspensions

For isolating the mirrors from ground motion GEO 600 uses a triple pendulum suspension system (Plissi et al. (2000) and Husman et al. (2000)). In places where fast actuation on the mirrors is required an almost identical reaction pendulum is suspended next to the main pendulum chain. In the main interferometer **E**lectro **S**tatic **D**rive actuators are used (Hewitson et al. (2007)). These allow low-noise fast actuation directly at the mirror without sacrificing the high mechanical quality factors of the mirrors and without inducing environmental magnetic noise coupling by the use of magnets. For the upper two stages of the pendulums, at lower frequencies but larger actuation ranges, magnet-coil actuators are being used. The motion of the upper mass with respect to the holding frame is sensed with shadow sensors and the signal is fed back (with appropriate filtering) to the magnet-coil actuators to dampen the mechanical resonances of the suspension.

The lowest stage of the GEO suspension is made in a quasi-monolithic way by suspending the mirror from the penultimate mass via four fused silica fibres of $\approx 210\,\mu m$ diameter, which are welded to little fused silica plates, which in turn are bonded to the mirror sides using a hydro-catalysis bonding technique ((Sneddon et al. (2003)). The internal modes of the fibres themselves are slightly dampened by a coating of amorphous Teflon to ease the requirements of the length control loops (Gossler et al. (2004)).

1.3 The status in late 2009

From January 2006 to September 2009 GEO 600 collected almost 1000 days of scientific data. The first 21 month, called S5 (the fifth scientific run of the LIGO Scientific Collaboration) GEO 600 took data together with the LIGO detectors and partly with the Virgo detector. The last part of the data taking period, called 'Astrowatch', which started in November 2007, covered the downtime of the LIGO (L1 and H1) and Virgo detectors during their upgrading period to the 'enhanced' versions. A part of the time during the Astrowatch period was set aside for noise investigations and experiments preparing future upgrades. Even with
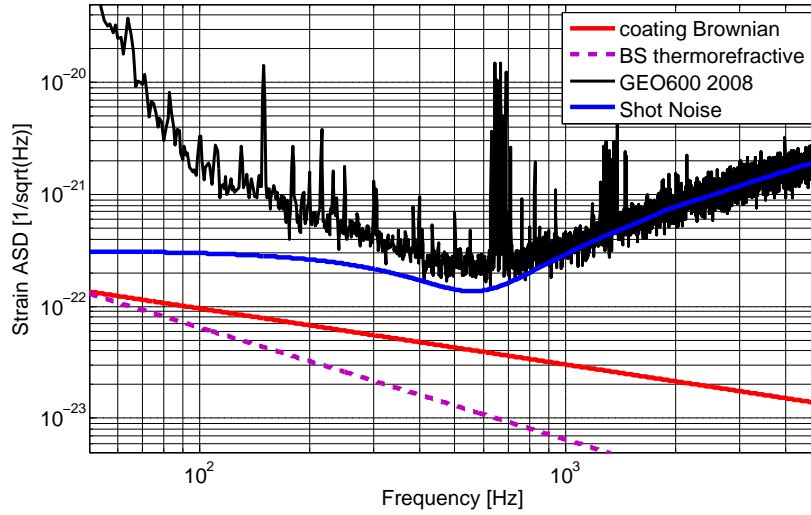

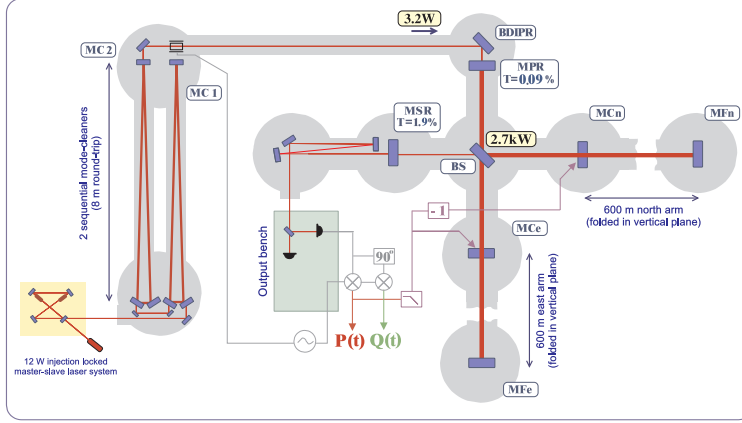Figure 1.1 Sensitivity of GEO 600 as of 2008

Figure 1.2 Schematic layout of GEO 600 with heterodyne read-out, as used until 2009. The light of the laser is sent through the two Mode Cleaners (MC1 and MC2) and enters the interferometer at the Power Recycling mirror (MPR) with a power of 3.2 W. The light power is enhanced in the Power Recycling resonator and reaches about 3 kW at the beam splitter (BS). Note that the arms are folded, i.e. the light path goes from the beam splitter via the far mirrors (MFn and MFe) to the inboard mirrors (MCn and MCe), which are suspended 25 cm above the outgoing beam and then back via the far ends of the arms to the beam splitter. The signal recycling mirror (MSR) is located to the left of BS in this figure.

these investigations GEO 600 reached an observation time of 86.0% of the overall time. During Astrowatch GEO 600 was partly joined by the 2 km LIGO detector, LIGO-H2, at the Hanford site. The average sensitivity of GEO 600 was roughly a factor of two lower than that of the LIGO-H2 detector for frequencies above 500Hz. Typical sensitivities of the GEO 600 and the LIGO-H2 detector during astrowatch are shown in figure 1.3.

Throughout the whole data taking period GEO 600 used Schnupp modulation for heterodyne read–out, Signal Recycling detuned to a frequency of 530 Hz, a light power at the input to the Power Recycling cavity of about 3 W with a Power Recycling factor of about 1000 as indi-
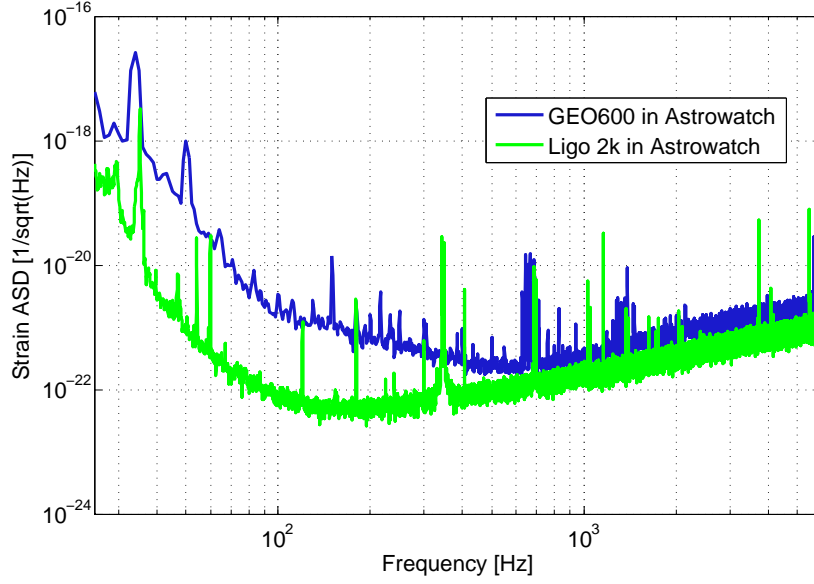
Figure 1.3 Noise performance of GEO 600 and LIGO-H2.

cated in figure 1.2. The peak sensitivity of GEO 600, $2.2 \cdot 10^{-22} [1/\sqrt{Hz}]$, is reached around the detuning frequency of 530 Hz (see figure 1.1). At higher frequencies the sensitivity of GEO 600 is mostly shot noise limited. Below 100 Hz technical, alignment related noise sources dominate the spectrum.

1.4 Upgrade plans

With the beginning of the S6/VSR2 science run within the LIGO scientific collaboration and Virgo on July, 7th 2009, the upgrade program of the GEO 600 detector started. The new configuration will mainly concentrate on sensitivity improvements at frequencies above 500 Hz, where about an order of magnitude can be gained by lowering the shot noise. Besides technical noise sources, thermal noise (mainly coating Brownian noise and thermo-refractive noise at the beam splitter) will put a limit on the sensitivity of GEO 600 below 500 Hz The upgrades will include the following subsystem improvement steps:

- Tuned signal recycling and DC readout

- Implementation of an output mode-cleaner
- Injection of squeezed vacuum into the asymmetric port
- Reduction of the signal recycling mirror reflectivity
- Increase light power inside the interferometer

All of these upgrade steps are independent from each other, as far as implementation and control is concerned. Therefore, we plan to establish full locking and analysis of the performance after each upgrade step, including data taking to gain experience with the then actual new configurations.

Shot noise in an interferometric gravitational wave detector originates mainly from the vacuum fluctuations entering the output port. The contributions that come from the fluctuations on the input laser beam are small compared to those entering the output port because the input laser beam is well stabilized, filtered by the Power Recycling cavity, the interferometer is operated close to the dark fringe, and the Schnupp asymmetry and the imbalance in the losses of the arms of the interferometer are small. Reducing the vacuum fluctuations entering the output port in the 'phase quadrature' can therefore reduce the observed shot noise, see section 1.4.3.

1.4.1 From RF readout to DC readout

So far GEO 600 used a heterodyne read-out technique with Schnupp modulation to read out the gravitational wave signal and obtain error signals for the differential Michelson length control. In GEO 600 the Schnupp modulation frequency is about 14.9 MHz and therefore the readout technique is also called **R**(adio)-**F**(requency) readout or heterodyne readout, as mentioned in section 1.2. Unfortunately this method increases the observed shot noise by collecting additional (vacuum) noise from twice the modulation frequency. These noise sidebands beat with the modulation sidebands at the modulation frequency, producing noise at the modulation frequency which gets demodulated into the signal frequency band (Buonanno et al. (2003)). This RF-readout technique was chosen for all first generation GW detectors because the lasers used were shot noise limited only in the MHz frequency range. The improved amplitude stability of (stabilized) solid state ND:YAG lasers in the detection frequency band in addition to the filtering properties of the Power Recycling cavity now allows to switch to a self–homodyne readout technique, also called DC readout. Here the operation point is slightly (in the range

of about 5 pm to 50 pm) detuned from the dark fringe, which yields a dependence of the light power at the output port on the arm length difference. In the frequency space picture the laser carrier frequency serves as the Local Oscillator to beat with the sidebands induced by the gravitational waves. As no noise contributions are mixed into the GW frequency band from other parts of the spectrum that do not carry GW information the shot noise for DC readout is lower than for RF read-out. All large interferometric gravitational-wave detectors will switch to DC readout on their way to the 'advanced' generation. The first experiences with DC readout in the GEO 600 detector are reported in Hild et al. (2009), Grote (to be published) and Degallaix (to be published in JPCS). DC readout is also beneficial for the injection of squeezed states: the squeezing level and the correct phasing has to be taken into account only at the laser carrier frequency and the respective signal sideband frequencies, but not at the modulation frequencies; see also section 1.4.3.

Schnupp modulation with a reduced modulation index will still be used in GEO 600 for generating the error signals of the differential wave–front sensing for the Auto–Alignment system. As these reduced modulation sidebands will be removed with an output mode cleaner (see next section), RF oscillator phase noise, which was close to limiting the noise in RF-readout, will no longer be a problem.

1.4.2 Output Mode Cleaner

The light at the output port of GEO 600 is not a pure Gaussian TEM00 mode but due to the imperfections of mirror surfaces and thermal effects in the optics also contains higher order modes. Due to different Guoy phases the higher order modes, i.e. the non-TEM00 light, do not fulfil the same dark fringe interference conditions and hence do not respond to a differential length change with the same sign and amplitude as the main part of the beam, i.e. the TEM00 mode. Therefore the relative signal content in the higher order modes is much lower than in the fundamental mode. The higher order light on the other hand fully contributes to the shot noise, which reduces the maximally possible detector sensitivity. There are different solutions to this problem: One solution is to make the local oscillator beam stronger, such that the shot noise from higher order mode light gets lower in proportion to the signal output and to the shot noise from the local oscillator light. This works for RF readout as well as for DC readout, as long as the local oscillator beam does not have too much higher order mode content itself. LIGO and GEO have

used this solution while operating with RF readout. Increasing the local oscillator level has technical constraints however, as more light power has to be detected, and the interferometer can become less stable in case of DC readout with a large dark fringe offset. If higher order modes cannot be sufficiently reduced by thermal compensation systems (see section 1.4.5 below), another solution is the implementation of an Output Mode Cleaner (OMC), which can remove most of the higher order mode light before detection. This is planned for GEO 600. The GEO 600 OMC (Degallaix (to be published in JPCS)) is a four mirror cavity with a round trip length of roughly 66 cm as shown in figure 1.4. The mirrors are mounted on a fused silica base plate with UV light curing epoxy glue. The Finesse of about 150, giving a FWHM line width of about 3 MHz assures that the modulation sidebands (14.9 MHz) are reflected by the OMC when it is tuned to carrier resonance. With proper mode matching, the light in the TEM00 mode will get transmitted and the unwanted light in higher TEM modes will be reflected. The target transmission for the OMC is 98%. One of the mirrors is mounted on a piezo-electric actuator. Dithering of the OMC length with this Piezo-actuator allows the generation of error signals for the length control and for the Auto–alignment system aligning the beam onto the OMC. More details are described in (Prijatel (to be published in JPCS)). The Output Mode Cleaner will be put into an additional vacuum vessel attached to (but seperated by a viewport from) the GEO vacuum system. This vessel will contain some mode matching optics for the Output Mode Cleaner, the Output Mode Cleaner itself, a Faraday isolator for the injection of squeezed light and one or more photo diodes. The vacuum level foreseen for operation is about 10^{-2} mbar. All the optical elements will be placed on a platform seismically isolated with a Minus-K$^{®}$ (http://www.minusk.com/) isolation system.

1.4.3   Squeezing

At frequencies above 500 Hz shot noise is the dominant noise source in GEO 600. The upgrade plans are therefore aiming at reducing the shot noise level. The interferometer is operated close to the 'dark fringe'. Almost all light entering either the input or the output port is hence reflected back to the same port. The vacuum fluctuations entering and being reflected back to the output port, are interfering with the carrier light, which is present due to the slight offset from the 'dark fringe' for DC-readout, and give rise to the shot noise on the photo detector. Only
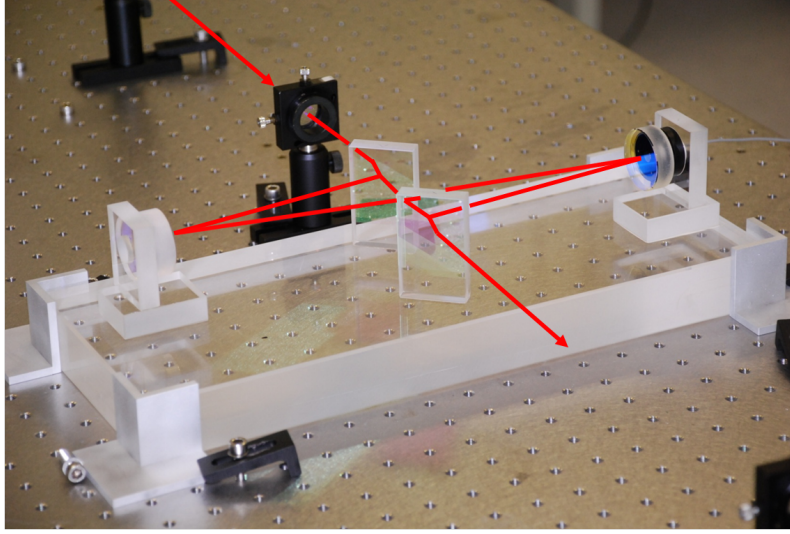
Figure 1.4 The output mode cleaner for GEO 600

the fluctuations in the same quadrature as the carrier light at the output port causes differential phase noise in the interferometer arms, hence we will call it the phase quadrature. As these fluctuations are causing the shot noise, the injection of squeezed light, where the noise in the phase quadrature is decreased, lowers the shot noise detected by the photo detector. The squeezed vacuum injected into the output port of GEO 600 will have a squeezing level of about 10dB and with tolerable losses of about 15% reach a shot noise reduction of about 6dB, i.e. a factor of two in strain amplitude spectral densitiy. The injection will be done via the Faraday isolator mentioned above. To make optimal use of the squeezing over the full detection frequency range, the squeezing ellipse, i.e. the phase of the injected squeezed light, must be optimally oriented with respect to the light leaving the output port for all frequencies within the detection bandwidth. In case of a detuned (with respect to the carrier) Signal Recycling cavity this can be achieved by sending the squeezed light through additional filter cavities (Harms et al. (2003); Kimble et al. (2001)) or using Twin Signal Recycling (Thüring et al. (2009, 2007)). For tuned (zero frequency detuning) Signal Recycling the orientation of the squeezing ellipse is frequency independent and no filtering of the squeezed light is required. The expected improvement in the GEO 600

sensitivity by using squeezing (together with the series of other changes) is shown in figure 1.5.

1.4.4 Signal Recycling Modifications

In the past GEO 600 used Signal Recycling mostly **detuned** to a signal frequency of 530 Hz. To improve the sensitivity over the full frequency range of interest, GEO 600 will use squeezing together with **tuned** Signal Recycling (Hild et al. (2007)). The achievable sensitivity is shown in figure 1.5. The phase modulation caused by a gravitational wave creates two signal sidebands around the carrier light. Only one of these sidebands is resonantly enhanced in a detuned Signal Recycling cavity. The other sideband is far away from the resonance of the detuned Signal Recycling cavity. Tuned Signal Recycling on the other hand resonantly enhances both signal sidebands, providing higher optical gain on resonance, which results in lower shot noise at the resonance frequency than detuned Signal Recycling. In the case of GEO 600 this does not influence the total sensitivity as at low frequencies the total noise is dominated by thermal noise and technical noises anyway.

Widening the bandwidth of GEO 600 by increasing the transmission of the Signal Recycling mirror from 2% to 10% improves the high frequency shot noise at the expense of the low frequency one. Being limited by thermal noises at frequencies below 700 Hz anyway this influences the overall noise for low frquencies only marginally. The crossover point between coating thermal noise and shot noise only moves from 700 Hz (curve ④ in figure 1.5) to 800 Hz (curve ⑤ in figure 1.5), while the high frequency total noise drops by a factor of about two. Further increasing bandwidth would raise the low frequency shot noise to an undesirable level while giving marginal improvement at high frequencies.

1.4.5 Light Power Increase

The final step in the series of foreseen GEO 600 upgrades is an increase in light power inside the interferometer by a factor of about ten. Several changes are needed to achieve this goal:

Mode Cleaner Modifications

GEO 600 uses two consecutive optical resonators for removing light that is not in the fundamental Gaussian TEM00 mode and for reducing spatial beam fluctuations. Scattering inside these Mode Cleaners due to
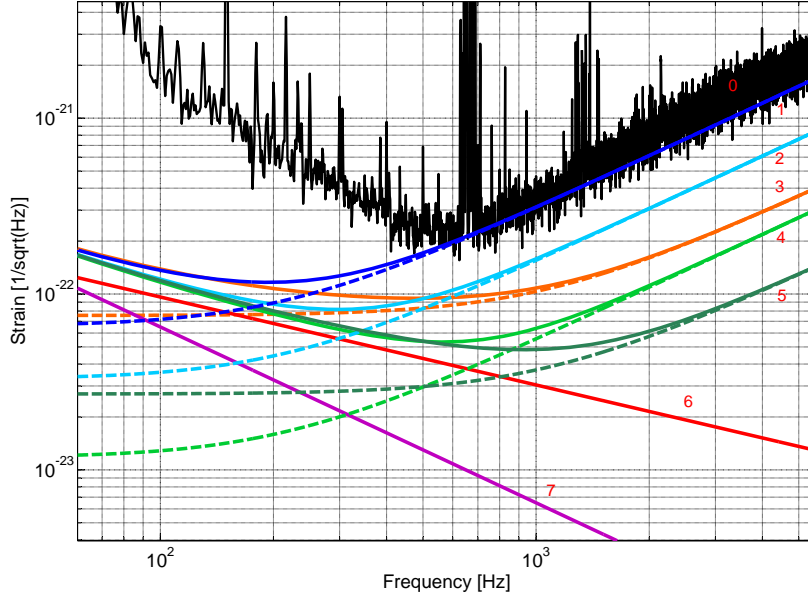
Figure 1.5 Sensitivity of GEO 600 for different configurations.
Solid lines indicate total noise, dashed lines represent shot noise only.
Technical noise sources are neglected here.
⓪GEO 600 sensitivity 2009
①DC, tuned SR, T_{SR}=2%, P=3.2 W
②DC, tuned SR, T_{SR}=2%, P=3.2 W, 6 dB Squeezing
③DC, tuned SR, T_{SR}=10%, P=3.2 W, 6 dB Squeezing
④DC, tuned SR, T_{SR}=2%, P=20 W, 6 dB Squeezing
⑤DC, tuned SR, T_{SR}=10%, P=20 W, 6 dB Squeezing
⑥Coating thermal noise
⑦Thermo-refractive noise of the beam splitter

imperfections of the mirror surfaces results in a loss of light power between the laser and the interferometer of about 50%. If these losses are reduced the throughput of the Mode Cleaners and hence the power available at the Power Recycling mirror can be increased. When bringing the Mode Cleaners into resonance the light power inside the resonators and with it the radiation pressure on the mirrors suddenly changes. This sudden change of force acting on the mirrors exceeds the dynamical range of the longitudinal feedback system and needs to be compensated by an additional feed-forward control. Increasing the light power inside the Mode Cleaners, both by reducing the optical losses and by increasing the laser power (see below) would lead to undesirable problems with

radiation pressure in the Mode Cleaners when keeping the same cavity finesse. Reducing the reflectivity of the coupling mirrors and with it the power build-up inside the Mode Cleaners, improves the throughput and reduces radiation pressure problems at the same time. The filtering properties of the initital Mode Cleaners were designed very conservative (Winkler et al. (2007)) and will still yield a sufficiently high suppression level after the decrease in finesse. Exchanging the Mode Cleaner mirrors will increase the throughput by a little less than a factor of two. The high power compatibility of the subsequent auxiliary optics (electro-optic-modulator, Faraday isolators) still needs to be tested and confirmed.

Laser Power increase

GEO 600 uses a 12 W master/slave Nd:YAG laser with a wavelength of 1064 nm at a power of about 6 W. With the optical losses in the Mode Cleaners of about 50% a laser power of about 3.2 W is available at the Power Recycling mirror (see figure 1.2). The laser will be exchanged for a master-slave-amplifier system delivering about 30 W, which has been developed by the Laser Zentrum Hannover. It is the same kind of laser that is being used in Enhanced LIGO (Smith for the LIGO Scientific Collaboration (2009)). The increase in laser power will yield a factor of about 5, which, together with the increase in the throughput of the Mode Cleaners, will give a power increase of a factor of 10 in the Power Recycling cavity.

Local Control Changes

The mechanical resonances of the triple pendula for seismic isolation of the main interferometer mirrors are actively damped by a local control system using shadow sensors to monitor the upper mass movement (Willke et al. (2002) and Plissi et al. (2000)). These shadow sensors are operated with a DC light source (an infra-red LED) and unfortunately detect some of the light scattered by the interferometer mirrors. This way slight fluctuations in the circulating light power, which can originate from a slight misalignment of one of the interferometer mirrors, result in a signal at the shadow sensor which is treated as a movement of the upper mass and a 'compensation' signal is fed back to the actuator. This in turn misaligns the mirror controlled by this sensor and can finally lead to an instability. The coupling increases with the light power inside the interferometer. In GEO 600 this effect has already been observed at the current circulating light power level and could make the

foreseen increase in laser power impossible. Operating the light source of the shadow sensor with current modulated in the kHz range and accordingly demodulating the signal of the photo-detector can make the system insensitive to low frequency fluctuations of the light power in the interferometer. If the system fulfils the expectations, all local control systems of the main GEO optics will be converted to AC operation. First experiments have already shown an encouraging performance.

Thermal Compensation System

As a consequence of the missing arm cavities and the high Power Recycling factor of GEO 600, as described in section 1.2.1, the full light power in the interferometer arms passes through the beam splitter. Although GEO uses fused silica glass (Suprasil® 311SV) with very low absorption of 0.5 ppm/cm, about 15 mW will be absorbed inside the beam splitter with the upgraded light power of 30 kW at the Power Recycling mirror. The local temperature increase causes a thermal lens which limits the maximum light power inside the interferometer that can be used. A system shining infra-red light onto the beam splitter, which is absorbed at the beam splitter surface, will be used to reduce the thermal lensing. Instead of using a CO_2 laser like in the other gravitational wave detectors (Waldman for the LIGO Science Collaboration (2006) and Acernese et al. (2008)) an incandescent light source will be used in GEO 600 minimizing the fluctuations in heating power to the required level which is beyond the current possibilities of a CO_2 laser. Due to the lack of arm cavities GEO 600 is as sensitive to beam splitter displacement as to a displacement of the mirrors in the interferometer arms. Due to the arm cavities LIGO and Virgo are mostly sensitive to displacement of the cavity mirrors but not the beam splitter. On the other hand in these interferometers, due to the high light power in the interferometer arms and not at the beam splitter, the thermal effects mostly arise at the inboard cavity mirrors and are corrected using a correction plate outside of the cavity. The absorbed power in the GEO 600 beam splitter of 15 mW is much less than the 0.4 W of heating anticipated for the coating of the input mirrors of the arm cavities of advanced LIGO and advanced Virgo, so less heating power will be required for the GEO thermal compensation system.

1.5 In the Future

As far as it can be foreseen now, in the period from 2011 to 2015 GEO 600 will be the only interferometer in the world that can be on-line for astrophysical observations for a substantial amount of time. The LIGO interferometers as well as Virgo will be upgrading to the advanced versions of their instruments. Therefore, according to current planning GEO 600 will spend more and more time in observation mode, as all the upgrades foreseen for GEO 600 at this time are implemented, and the sensitivity would approach the planned goal.

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