LIGO Meeting: December 2, 1997

Doubly Resonant Sideband Control for LIGO

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Acknowledgments: Jim Mason, David Tanner, Daniel Sigg, Peter Fritschel.

Agenda

1. Brief Outline of current scheme - Singly Resonant SideBand (SRSB) - and potential problems
2. The Doubly Resonant SideBand (DRSB) method
3. Summary of advantages/disadvantages cf the SRSB
4. Issues surrounding the DRSB method
5. Risk Assessment
6. Schedule Impact
7. A.O.B.

It will be assumed that the document "Doubly Resonant Sideband Control for LIGO" has been widely distributed.

1. SRSB

- Carrier resonant in arm cavities and Power recycling cavity (PRC)

  RF sidebands resonant in PRC only

  non-resonant sideband used for alignment

- *Length Control*

  In-phase demodulation at ports 1 and 2
  -> common mode length control
  -> requires reasonable sb gain

  Quad. demodulation at ports 2 and 3
  -> differential mode length control

  Table 2

- *Temporal stability* Table 3

  -> dominated by audio noise on the rf sidebands as carrier is highly filtered in coupled arm cavity/PRC system

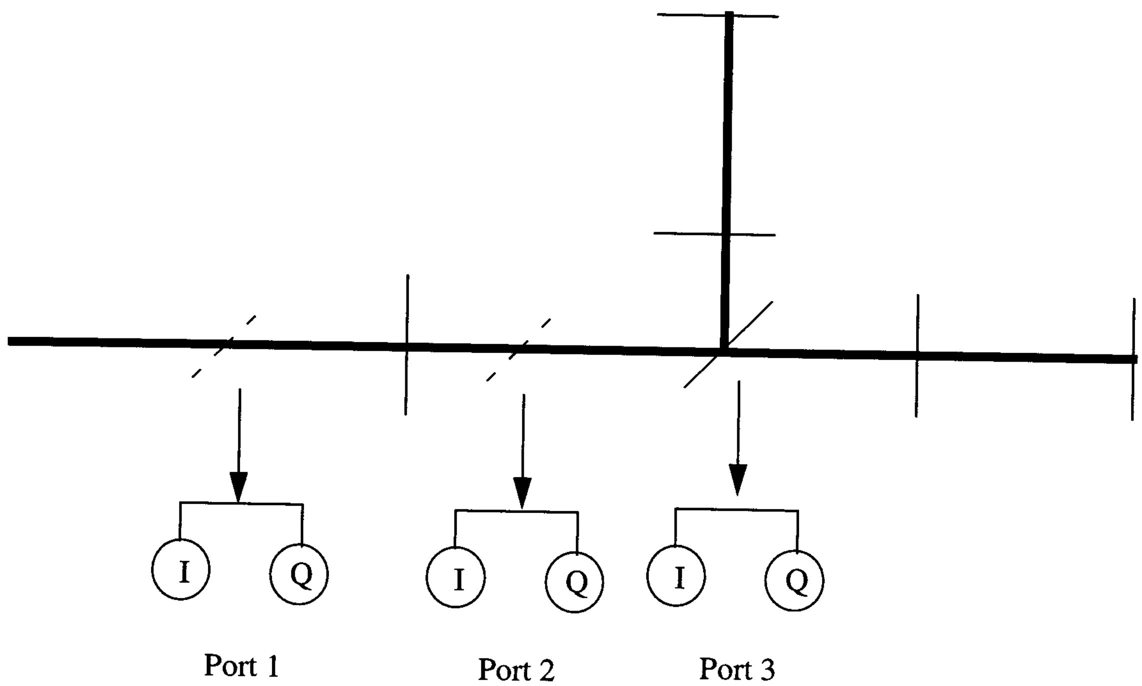

Figure 1: Schematic layout of LIGO interferometer

Table 2: SRSB Matrix of Discriminants (f = 24 MHz)

	$d\Phi_+$	$d\phi_+$
dV_1	-1	-0.001
dV_2	-1	+0.0007
	$d\Phi_-$	$d\phi_-$
dV_2	0.0076	1
dV_3	-1	-0.0076

Table 3: Stability Requirements (/radish) on SRSB at 100 Hz[a] (f = 24 MHz)

Laser		Oscillator		LO
Freq	Amp	Phase	Amp	Phase
2×10^{-7}	2×10^{-8}	-90 dBc	2×10^{-8}	-80 dBc[b] -120 dBc[c]

a. assumes $dL_- = 10^{-13}$ m

b. assumes sideband exact resonance in mode cleaner

c. assumes sideband detune from mode cleaner of 100 Hz

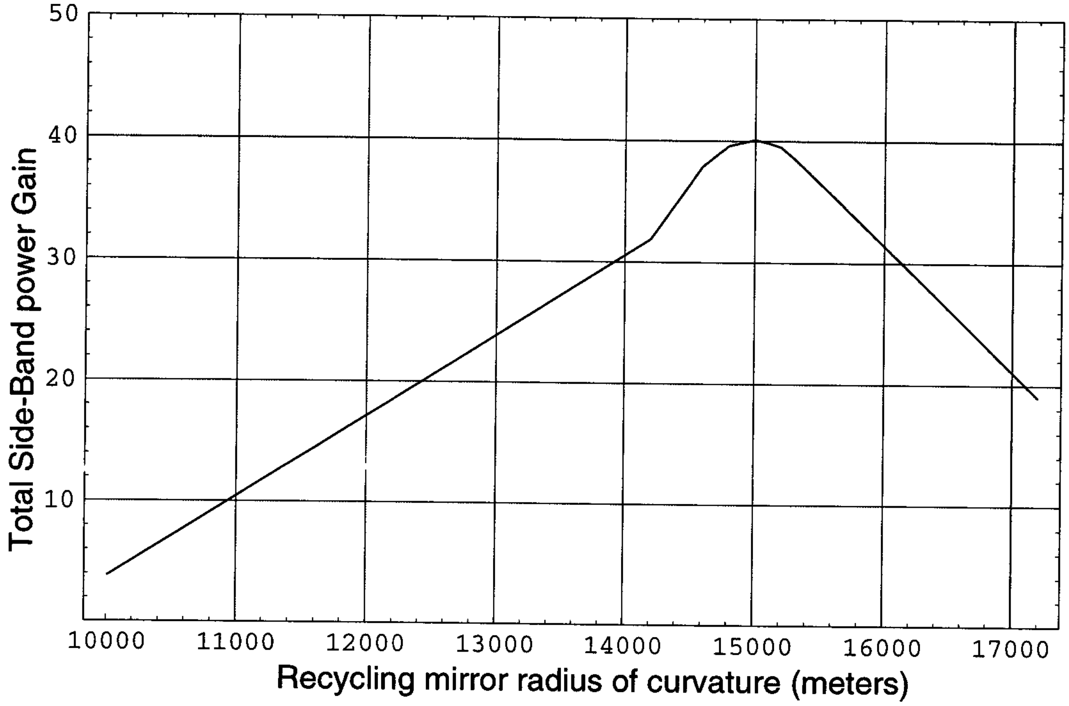

Figure 2: SB gain for optimal Recycling Mirror ROC of 15 km

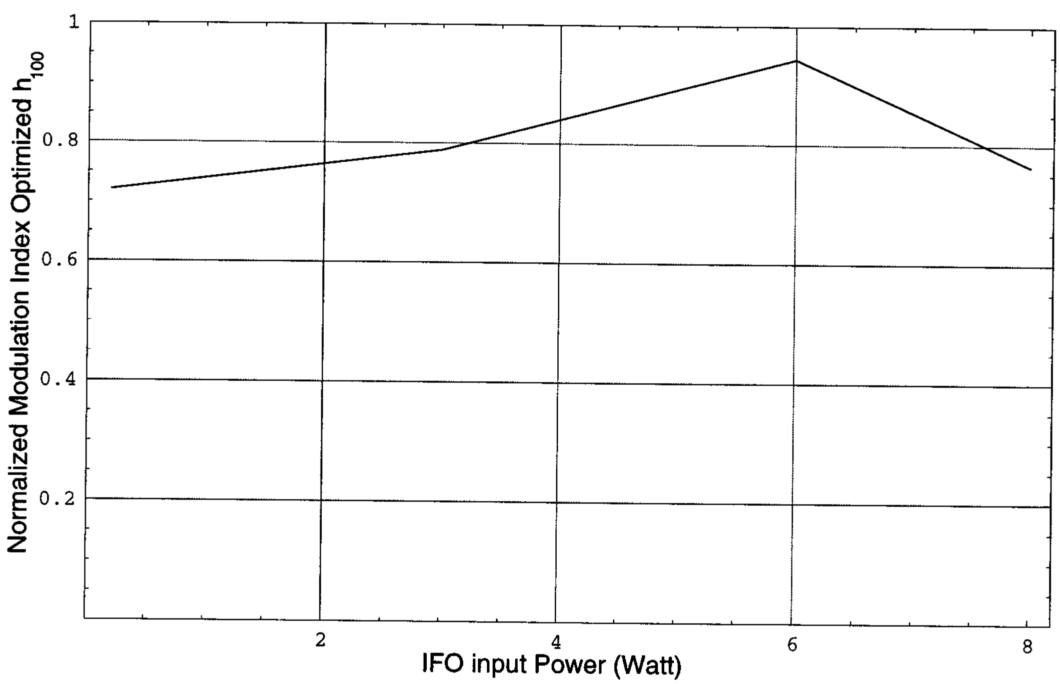

Figure 3: IFO sensitivity

Summary of Control Issues with SRSB

Power, W	δ/2,	Γ	Panti, 00	Gsb, 00	l- sig strength	Matrix, cm
8	0.21,	0.36	0.26	4.6	0.2	1 0.008 -1 -0.005
6	0.11,	0.3	0.72	34	1	-1 -0.003 -1 0.005
3	0.22,		0.22	5	0.2	1 0.008 -1 -0.005
0	0.33,	0.44	0.11	.94	0.1	1 0.008 -1 -0.006

Nb: for NRSB cm signal change at Port 1 is 1 0.008,

For DRSB Meetings

TODAY

LIGO.

- *Spatial stability*

  Carrier propagates in a stable geometry
  -> resilient to spatial errors

  Sidebands propagate only in an essentially degenerate plane mirror cavity
  -> highly sensitive to spatial errors
  -> sets tolerance on ROC s. (6%)

- *Thermal Lensing*

  Carrier is again resilient for the same reason as above <u>and</u> phase distortions tend to cancel

  Sidebands are strongly lensed
  -> without correction of the ROC of the power recycling mirror, sb gain falls from 40 to less than 2 compromising length control system and sensitivity
  -> recovered if ROC adjusted

  Figs 2 and 3.

- *Issues:*

  prediction of the correct ROC

  interferometer restricted to operate properly at only one input power

  other PRC effects

2. *The DRSB Method*

- RF sidebands are set to resonate in the arm cavities and the PRC along with the carrier

- signal still extracted as it is the difference between the carrier fields reflected off each arm which is measured, not a comparison between the rf sidebands and the carrier
  -> sensitivity achievable is similar to standard technique

- *Thermal lensing*

  RF sidebands now propagate in coupled cavity geometry -> resilient to lensing

- *Spatial Stability*

  tolerance to ROC error ~ 50%

- *Temporal Stability*

  RF sidebands are now highly filtered

  see Table 5

  - rf oscillator phase noise
  - cavity length matching

- *Length Control*

  linearly dependent length control
  -> cannot extract Michelson d.o.f.

  see Table 4

3. Summary Comparison

Table 1.

Table 5: Stability Requirements (/radish) on DRSB at 100 Hz[a] (f = 19.7 MHz)

Laser		Oscillator		LO
Freq	Amp	Phase	Amp	Phase
1×10^{-5}	1×10^{-6}	-84 dBc	1×10^{-6}	-120 dBc[b]

a. assumes $dL_- = 10^{-13}$ m

b. assumes sideband exact resonance in mode cleaner; not greatly changed by 100 Hz MC detuning.

Table 4: DRSB Matrix of Discriminants

	$d\Phi_+$	$d\phi_+$
dV_1	-1	-0.0076
dV_2	1	+0.0076
	$d\Phi_-$	$d\phi_-$
dV_2	1	0.0076
dV_3	-1	-0.0076

Because of the linear dependence of the mixer signals we cannot extract Michelson d.o.f.

2 SUMMARY OF ADVANTAGES / DISADVANTAGES OF DRSB

Table 1: Modulation Scheme Comparison

	DRSB	SRSB
DRSB Advantages		
Spatial Filtering - Tolerance to Input Power, ROC, at 10% loss in sens		
Maximum power input (6 W nominal) Maximum ROC error in RM	> 60 W > 50 %	7 W 6 %
Length Sensing and Control		
Change in sideband gain for above power and ROC tolerances Change in sideband gain for lock acquisition (cold) mode	1 % 1 %	40 % factor 25
Temporal Filtering - Coupling of Laser Fluctuations to GW signal		
Frequency Noise Intensity Noise Beam Jitter Noise RF Intensity Noise	1 1 1 1	50 50 50 50
DRSB Disadvantages		
DC Arm length control	0.3 mm	-
Required sidebands	19.7 MHz, 502.35MHz	25 MHz
Schedule impact on ISC	~ 3 months (?)	-

The most serious technical problem in the implementation of DRSB is control of the arm cavity DC length at the level of 0.3 mm. We have no experience in DC control of a 4 km cavity at this level; however we find an adequate error signal for the DC length control is available. We also have no experience with sideband generation and detection at 500 MHz, but the technology for this is available. These problems are discussed in later sections.

4. Issues with DRSB

(a) DC arm cavity length control required to ~ 0.3 mm
-> should be possible

(b) RF oscillator phase noise

(c) Controlling the Michelson

- propose to use SRSB for these d.o.f.
- $f_{SRSB} > 4.5 \times f_{DRSB}$ to avoid intermod. products (unless MZ used?)
- given this must choose frequency close to 1 FSR of Michelson asymmetry to recover sb gain
- permits the choice of SRSB such that transmission to antisymmetric port is small ==> $f_{SRSB} = 25.5 \times f_{DRSB}$

- Control matrix given in Table 6.

Table 6: DRSB Matrix of Discriminants with f_D= 19.7 MHz, f_S = 502.35 MHz

	$d\Phi_+$	$d\phi_+$
dV_1^S	-1	-0.004
dV_2^S	-1	+0.006
dV_1^D	1	0.0076
dV_2^D	-1	-0.0076
	$d\Phi_-$	$d\phi_-$
dV_2^S	0.0076	1
dV_3^S	-1	-0.0076
dV_2^D	1	0.0076
dV_3^D	-1	-0.0076

This matrix yields linear independence of the arm and Michelson d.o.f.

Two Obvious Issues:

(i) This SRSB will still suffer strong thermal lensing

-> still need to carefully determine appropriate ROC;

But: - SRSB is only used for auxiliary length control, where requirements are lower, not GW signal extraction

- SRSB is overcoupled, so can suffer some loss

In addition:

- extra noise filtering can be used to allow greater tolerance to differential length change and hence impact of distortions such as thermal lensing is much less significant.

The bottom line: if the SRSB control used here with the DRSB is compromised, it would have catastrophically failed as the primary control system.

(ii) detection at 500 MHz
alternatives

5. Risk Assessment

S. Whitcomb

6. Design and Schedule Impact

Electronics

Mechanics

The 2 km Interferometer

7. A.O.B.

SRSB Risk Assessment

What might go wrong	Probability / Impact
• Thermal lensing off by 25%	High / h_{SN} ↑ 10%
• " " " " 100%	Low / h_{SN} ↑ 50%
• RM radius off by 6%	Moderate / h_{SN} ↑ 5%
• Contamination causes absorption	Low-Mod / h_{SN} ↑ 10% in 6 months
• Laser intensity stabilization not adequate	Low / h_{SN} ↑ ×2
• RF oscillator AM feedthroug	Low(?) / h_{SN} ↑ ×2
• Pointing noise (beam jitter)	Low(?) / h_{SN} ↑ ×2
• Start-up problem for lock-acquisition	Low / several month delay in commissioning
• Complete breakdown of control system	V. Low / major delay/rework

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\+ SRSB scheme will ~~probably~~ almost certainly work for initial LIGO

\- Will probably suffer ~10% in shot noise

\- System does not have much robustness or room for growth

DRSB Risk Assessment

What might go wrong	Probability/Impact
• RF oscillator can't meet ϕ noise spec	? Low / h_{SN} ↑ ×2
• High f photodiode problems	Low / Commissioning delay ?
• Delay in commissioning (due to extra LSC work)	Low-Mod / Delays in finding "real" problem
• Difficulties matching arms	Low / Minor delays
• Unknown noise coupling	?? / ??

+ DRSB will (almost) certainly work if SRSB works, and in some cases when it won't.
+ Significant margin for many noise sources (laser intensity noise, ...)

+− Possible delays now vs. possible later ones

− Will need significant development

+ Gives some room for growth (though not as much as I would like)

(SW's) Estimate of Schedule Impact

What Changes	How Much Delay
• Optical/Mechanical Layout	
M/C, RC Lengths	1 Month
Pick-offs, Relocations, Etc	3 Mon
• Suspension Height Adaptors	1 Month (+ 1 Month)
• RM Coating	—
• RF Source New Frequencies Tighter Phase Spec	} 4-6 Mon(?)
• High Frequency Modulators	Negligible?
• High Frequency Photodiodes	6 Mon(?)
• Servo Design Modeling Tuning	} 6 Mon(?)
• New WFS Photodiode	4 Mon

Core Optics: Substrate Absorption