LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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Document Type **LIGO-T050004-00-I** 2005/01/31

ANALYZING SYSTEM AND REFERENCE BEAM FOR INDIVIDUALLY MONITORING RECYCLING CAVITY SIDEBAND and CARRIER DYNAMICS

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Processed with LaTeX on 2005/01/31

1 Introduction

We propose to refine and regularize our H1 POY setup for monitoring and studying the individual carrier and sideband components (carrier, LSB, HSB) in the LIGO IFO recycling cavitys. A lashup of test gear and modules is to be converted to modules, in rack, and in DAQ standards. The extension to the AS/POB table is outlined, costed, as is the completion of a similar system for H2, and a complete LLO 4K system. This is an evolution of the SURF projects of Evan Goetz and Rick Garrelts.

Currently, diagnostics of recycling cavity buildup and stability in the LIGO IFO's are the SPOB signals (demodulated 2F) from the BS PO light signal, TV/Sphericon pictures, and deductions from the REFL and AS port photodiodes and resulting control signals. We here derive simple clean signals proportional to the RMS AMPLITUDE of the CARRIER, Lower Side Band (LSB), and Higher Side Band(HSB) in the RECYCLING CAVITY (or MODE CLEANER), and get them into the DAQ for monitor and study. A related 2F RMS signal is also provided.
A SHIFTED CARRIER REFERENCE beam is created and used for heterodyning; this also enables separated LSB, HSB, and CARRIER pictures with the PHASE CAMERA.

A robust lashup version exists and is operational on the LHO 4K for the "POY" beam.

The REFERENCE BEAM creation and launch gear has a 14" x 20" footprint on the rear of the PSL table. Fibers wend through the cable trays to ISCT3 (POY) and ISCT4 (AS, POB, POX). An optics module 12" x 14" on ISCT3 heterodynes the POY beam sample to derive RF versions of the CARRIER, LSB, and HSB. A lashup DEMOD electronics (of MINICIRCUIT modules and test gear, covering a fraction of a tabletop) derives DC rms amplitude versions of the signals. Four 2K DAQ channels are used, per analyzing station.

We propose to build and install a 4 channel DEMOD module, streamline the Heterodyne Optics, and build a second Optical and Demod System for the ISCT4 (AS, POB, POX ports). We herein review technichal aspects, and outline the costs associated, including creating systems for the LHO 2K and LLO 4K.

We envisage using the system to monitor and study especially the IFO Side Bands in the Recycling Cavity, the MODE CLEANER, and the problematic OUTPUT MODE CLEANER, as we struggle to reduce the lower frequency noise.

A talking point version (of this document), an overview and schematic diagrams, sample Data Viewer and DTT H1 POY results from the existing system, are appended.

2 Scheme

A light beam to be studied (eg POY port beam) is combined (optically heterodyned) on an RFPD with a reference beam, which is unmodulated PSL light shifted in freq + 75 MHz. The RF beat signals representing HSB, LSB, and Carrier are found in the RFPD products at 50 MHz, 100 MHz, and 75 MHz. Demodulation at these frequencies yields the independent side band and carrier signals. In current practice we convert to 1 KHz (use 75.001 MHz optic offset, 75.000 MHz demod) rather than DC, and do an RMS to DC conversion yielding DC DAQ signals of about 100 Hz bandwidth at ”DC”. Thus our signals are proportional to the CARRIER, LSB, and HSB AMPLITUDES RMS amplitudes. We further develop a related SPOY RMS (2F) signal.

3 REFERENCE BEAM GENERATION: OPTICAL SHIFT and FIBER LAUNCH/TRANSPORT

There is a test and monitor beam ($\sim$ 50 mW) internal to the PSL box. We bring this out, isolate with a Faraday, shift the light frequency with an AOM, and capture the up-shifted beam into fiber ($\sim$ 50% efficient) for transport (25 to 50 meters) to the POY, AS(POX, POB), and REFL tables.

Currently we have a reasonably elegant shift and launch system on the rear of the LHO 4K PSL table (see figure). This was set up with Rick Savage, refining the lashup of SURFers Rick Garrelts, and Evan Goetz. Two fibered shifted optical beams emerge and are sent to ISCT4 and ISCT3; fiber exists for a run to ISCT1. A lens, several mirrors, a Faraday Isolator, a LIGO standard ISOMET 1205 AOM, 50-50 Beam Splitter, and two NUFOCUS 9131 space to fiber capture modules comprise the shift-launch system. An IFR Freq synthesizer plus RF amp drives the AOM at 75.001 MHz (at $\sim$25 dBm); about 50%efficient..

4 ANALYZER OPTICS

We have on ISCT3 an optics module combining the reference beam, and the IFO POY beam sample ($\sim$5%) on a NUFOCUS 1811 RFPD. The reference beam is re-spatialized, rotated (1/2 wave plate), polarizaion analyzed (cube), and combined (Beam Splitter); beams are independently steered to the RFPD. The reference beam and POY beam are roughly matched in curvature on the RFPD; the beams are closely coaxial; the ref beam is large, thus constant to $\sim$ 10% over the 300u RFPD. The POY beam is imaged on the PD. The reference beam and POY beam DC levels are about 16 uW and 4 uW as seen by the RFPD.

5 ANALYZER ELECTRONICS

A lashup electronics setup derives LSB, HSB, CARRIER and 2F DC signals, suitable for DAQ and scope monitoring (see figure). The RFPD RF is amplified and fanned out passively. A system of Signal Generators [IFR 75 MHz, DS345 24.4995] plus the IFO 24.5 MHz, using mixers, doublers, filters, amplifiers, and splitters, creates LO signals for demod/mixers at 50, 100, 75, and 49 MHz HSB, LSB, Carrier, and 2F (SPOY RMS) signals. The LOs are combined with the RF signals in mixers employing LP and HP RF filters, mainly to reject the large carrier component. These IF output signals are actually at 1 KHz. The resulting signals are passed through SR560 amplifiers ”tuned” to 1 KHz with gains 20 carrier and 100 SB, 400 2F(SPOYrms). The 1 KHz is presented to a homebrew RMS to DC conversion unit (AD chip based). The 1 KHz scheme finesses the problem of phase drift in the fiber AND yields simply derived RMS (I + Q) signals. The outputs are presented to DAQ channels, for monitoring, eg with DATAVIEWER, DTT, and offline... and to a 4 channel scope.

The electronics lashup [rf amps, LO generators, DEMODs, SR560 ”signal conditioning”] is test equipment consuming (IFRs, SR560’s) and bulky (THOUGH FLEXIBLE); it begs a one or two module/board component based replacement.

6 PHASE CAMERA

Joe Betzwieser has PHASE CAMERA SYSTEMS on ISCT3 and ISCT4; using the heterodyning REFERENCE BEAMS enables making 2-D image analysis of the individual beam components, HSB, LSB, CARRIER.

7 REFERENCE BEAM SPLITTING

Presently the 4K beams are split optically before ”fibering”; thus two NUFOCUS Fiber Launchers are used; this uses the splitter intended for the 2K. We have aquired two (untested) 1 to 4 fiber splitters. These would reduce the number of optical splitting stations needed, and drive fibers to 3 tables [PO, AS, REFL] plus a monitor. This frees up the 2nd FIBER CAPTURE MODULE for the 2K, and enable the transport of reference beam to three or four tables.

8 2K SYSTEM: REFERENCE BEAM

We have the fiber for a similar setup on the 2K [PSL to ISCT9 and ISCT10]; an AOM and Faraday are needed; we will use the above 2nd FIBER CAPTURE MODULE. This setup was first used 15 months ago to transport a beam in the first capture trial, and the first version of analyzing electronics.[Evan Goetz SURF project].

A new optical analyzer module and electronics is needed, as the first system migrated to the 4K.

9 DAQ REQUIREMENTS

We currently use 4 GDS TEST channels; 2K channels seem adequate. We need 4 channels per analyzing station.

10 OPERATIONAL OBSERVATIONS

Present experience has shown the system to be stable [no frequent tweaking required] and yielded useful stable signals after some saturation problems were sorted out. The relative RMS response of the LSB and HSB are made equal at the few % level, could perhaps be established at the 1 % level. Bandwidth is 100 Hz; could be more. The transport fibers are NOT polarization preserving, but polarization is observed at $\sim$% 80% emerging from the fibers. Fiber motions of about 1 ft induces a polarization rotation $\sim$% 10's of degrees: not a problem here.

Bill Kells, Joe B, and Dave Ottaway have used one or another aspect of this system.

11 STUDIES, USES ENVISIONED, Anecdotal Observations

The present NPSPOB signal is the only recycling cavity signal that is commonly monitored at present; it is highly filtered, BW $\sim$ 1 Hz.

We imagine using the system to monitor the Sideband, Carrier buildup as the laser power is increased, and as the TCS system is "tuned". One presently observes the Sidebands non equal at lock, but becoming "more equal" as the system progresses towards common mode and the evolved TCS comes into action.

Sideband time structure has been observed to be remarkably interesting, if not downright ugly, in conditions where the 4K was thought to be working fairly well. We speculate that this challenges use of a small non sideband resonant OMC as has been recent experience.

We have seen interesting Recycling Cavity dynamics, wherein as the RM was driven at 13 Hz, one sideband increased in amplitude, the other decreased (at 13 Hz), $\sim$ 15% fractional amplitude, while the 2F wiggled with smaller fractional amplitude.

We observe at times $\sim$ 10-12 Hz large amplitude wiggles on the SB amplitudes.

We commonly observe at small ($\sim$10%) fractional amplitude these same 10-12 Hz wiggles come and go with a longer time period, like 30 sec. A guess is these represent a beating of two nearly equal freq bounce mode effects.

We suggest it will be revealing to study SB and Carrier dynamics of beams from the MODE CLEANER and an OUTPUT MODE CLEANER, as the input and length paramters are varied.

We hope to have a graduate student doing such studies this summer, perhaps also a SURF student. Dick Gustafson will pursue the issues, observations noted above.

A sample set of DATAVIEWER and DTT records are appended.

12 NEW ELECTRONICS

Paul S, Dick G, and Josh M will design a prototype DEMOD/ANAL module.

A designed component version of the present working system, with allowance for additions, extensions, and modification is practical.

Josh M will lay it out and get a number fabricated;

Dick G and Josh will do shake down.

13 COSTS

The expensive parts are the FARADAY $3K, Fiber Capture Units plus lens $2K, AOM $1.4K, RFPD 1811AC $1.1K, and terminated Fibers and Splitters at $1k per IFO. Some of these may be found in LIGO inventory, substantially reducing the component parts cost.

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COMPONENT COSTS

     DEMOD ANALYZER Boards: 8        $700,
       2 H1, 2 H2, 2 LLO, 2 Spare,
       PARTS RF, etc  per unit wag        $800
     ANALYZER OPTICS MODULE               $2600
     with 1811AC RFPD $1100,

     LAUNCH SYSTEMS: H2, LLO
      OPTICS  ( H2, LLO )
      LENS, Mount                    $300
      FARADAY ISOL, MOUNT            $3500
      AOM, Mount                     $1400

     LLO
      FIBER LAUNCH MODULE, Lens            $2K
       (nufocus 9131)
      FIBER: PSL to ISCT3, ISCT4           $800
      FIBER: SPLITTER                      $500
```

14 PROJECT OPTION SCALES and TOTAL PART COSTS

MINIMAL H1 REFINEMENT
2 Crystal Oscillators $500
[free up 2 IFRs]
Incorporate Amps into RMS/DC Converters $100
[free up four SR560's]
TOTAL H1 POY SYSTEM MINIMAL $600

H1 CLEANED UP SYSTEM [POY]
Electronics: Modulized [1st unit] $1000
$1k

H1 WITH 2nd ISCT4/AS/POB ANAL SYSTEM [AS/POB]
OPTICS MODULE [incl 1811AC rfpd $1.1] $2600
DEMOD/ANAL Electronics SYSTEM $800
TOTAL H1; 2 stations: POY and AS ANALYZERS $4.4k

H2 [POY, POB/AS] $5800
Finish Ref Beam Shift/Capture SETUP
[Faraday $3k, AOM $1.4K
miscl optics $1.2, RF amp .2K]
OPTICS MODULE ISCT9/POY SYSTEM
OPTICS MODULE [w 1811AC rfpd] $2600
DEMOD/ANAL Electronics SYSTEM $800
TOTAL 1 STATION: OPTICS AND ANAL SYSTEMS $9.2K

2nd OPTICS MODULE ISCT10/AS/POB SYSTEM
OPTICS MODULE [w 1811AC rfpd] $2600
DEMOD/ANAL Electronics SYSTEM $800
TOTAL H2 2 STATIONS $12.6

H1 and H2 2 STATIONS EA: OPTICS,
ANAL SYSTEMS $17K

LLO [POY, AS/POB],
Ref Beam Shift/Capture SETUP $7700
(Faraday $3k, AOM $1.4K, FIBER Capt $1.9K
miscl optics $1200, rf amp $140)
Fiber to ISCT3, ISCT4, ISCT1 $800
OPTICS MODULE ISCT3/POY SYSTEM:
OPTICS MODULE [w 1811AC rfpd] $2600
DEMOD/ANAL Electronics SYSTEM $800

```
LLO SMALL SYSTEM  1 ANAL STATION   TOTAL           $11.9K

 2nd OPTICS MODULE  ISCT4/AS/POB SYSTEM:
   OPTICS MODULE [ w 1811AC rfpd  ]           $2600
   DEMOD/ANAL Electronics SYSTEM              $800
   FIBER SPLITTER                             $300

  LLO TWO ANAL SYSTEM POY,POB TOTAL                     $15.3K
```

Costs are estimated PARTS costs.
Assumes no replacement of parts in existant system.
Optics estimates are likely low; electronics high.

15 SUMMARY

I strongly request we maintain, better expand, the present system, and go for a second station (AS, POB) analyzer for H1.

The 4K SYSTEM "AS IS" with POY ANALYSER can be freed up of the 2 IFR's and 4 SR560's, and the lashup of amps, demods consolidated, for perhaps $600 in parts.

The H1 4K SYSTEM with POY ANALYSER can have a modulized electronics system, for about $1000 in parts.

The H1 4K SYSTEM with a POY and a POX, POB, or AS analyser on table ISCT4 could be had for about $4.4K in parts (2 stations).

The H2 IFO could have a one analyser (eg POY) system, for about $ 9.2K and two ANALYZER systems for $12.6K.

The H1 and H2 IFO's can have two analyzer systems for about $17K.

The LLO 4K could have a one analyzer system for about $11.9K, and two analyzer system for about $15.3K

A spare analyzer system for eg MODE CLEANER studies, would be very useful; about $3.4K.

SIDEBAND and CARRIER ANALYZER SYSTEM

INDEPENDENTLY MEASURES THE RECYCLING CAVITY POY BEAM COMPONENTS OF THE LHO 4K

ALSO CAN STUDY MODECLEANER, OUTPUT MODECLEANER, REFL BEAMS; CONTROL, DYNAMICS

HETERODYNES POY SAMPLE WITH 75 MHZ OFFSET OPTICAL CARRIER

F0UR SIGNALS PRODUCED FOR DAQ: LSB, CARRIER, HSB, 2F (SPOY) RMS

OFFSET CARRIER (REFERENCE BEAM) GENERATED ON PSL TABLE;
REF BEAM IS CAPTURED AND
FIBER TRANSPORTED TO ISCT3 AND ISCT4

OPTICS MODULE ON ISCT3: COMBINES REF BEAM AND POY SAMPLE;
PRODUCES RF SIGNALS @100, 75, 50, 49 MHz
LSB, CARRIER, HSB, 2f(SPOY) RMS

RF DEMOD SYSTEM MINICIRCUITS BASED PLUS AC RMS DC CONVERTER
PRODUCES RMS AMPLITUDE OUTPUTS FOR DAQ 0 – 5V; 100 HZ BW

USES FOUR 2K DAQ CHANNELS: GDS TEST

STATUS: OPERATIONAL; ELECTRONICS IS A LASHUP

NEEDS : APPROVAL FOR CONTINUED EXISTANCE

ELECTRONICS TEST GEAR REDUCTION, STREAMLINING
(USES 2HP, 1 SR SIG GENS; 4 SR560'S)
BEST DONE WITH NEW DEMOD MODULE: DG, PS, JM

DESIRABLE: OPTICS AND DEMOD MODULE FOR ISCT4
(POB, POX, AS BEAMS) 2nd H1 STATION

DESIRABLE: SPARE STATION (OPTICS MODULE, DEMOD MODULE) FOR MC, OMC, REFL MONITOR/STUDYS

SUGGEST: SIMILAR SYSTEM FOR LHO 2K

SUGGEST: SIMILAR SYSTEM FOR LLO 4K

DICK
GUSTAFSON
1/20/05

PART, COMPONENT COSTS

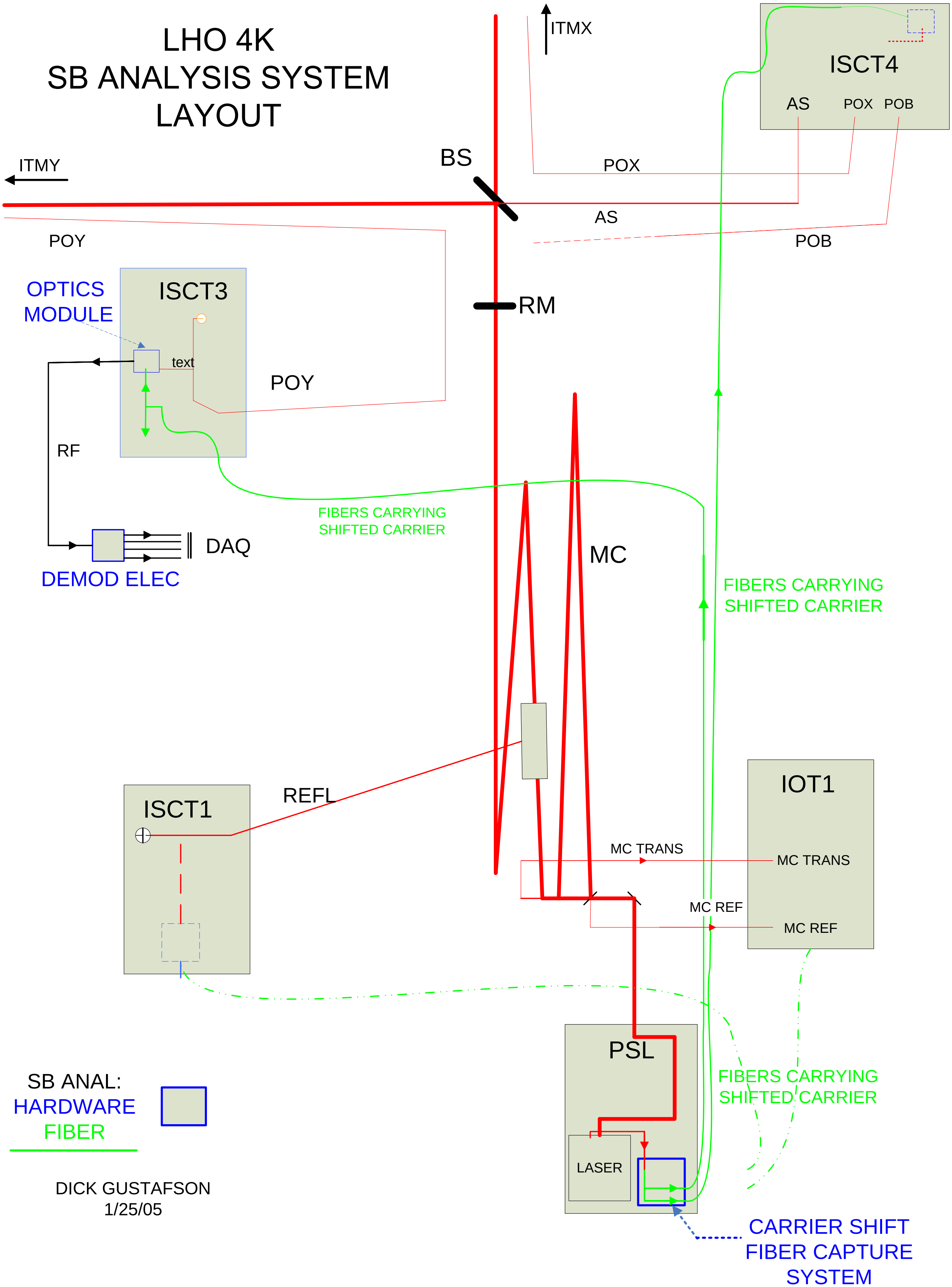
THE EXPENSIVE PARTS ARE:

FARADAY ISOLATOR	$3K	THESE ARE COMPONENT, PART, BOARD COSTS
FIBER CAPTURE UNITS	$2K,	
AOM	$1.4K,	
RFPD 1811	$1.1K,	
FIBER AND FIBER SPLITTERS	$1K / IFO	

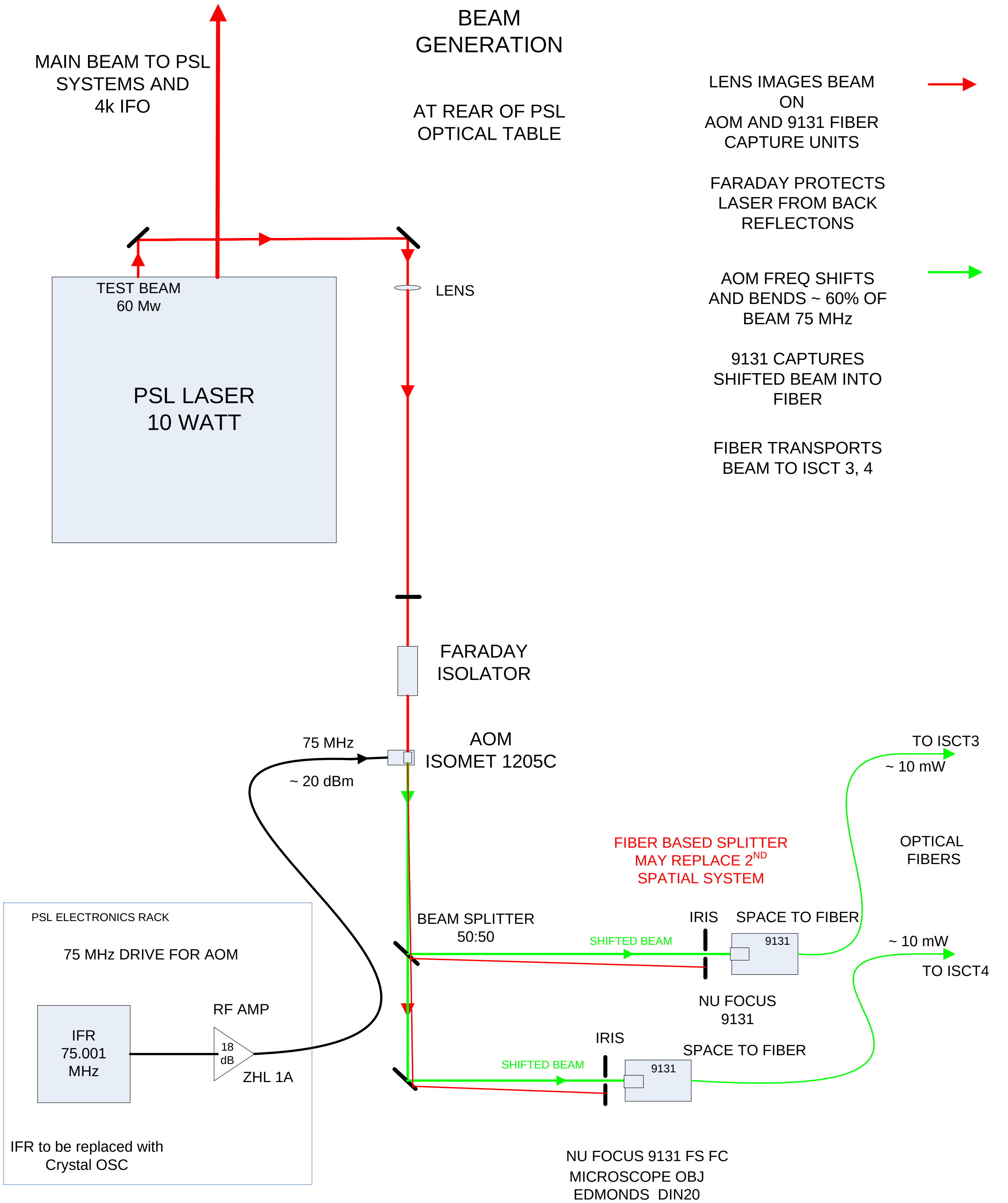
OPTIONS

H1	MINIMAL REFINEMENT: CRYSTAL OSCILLATORS	$600
H1	DEMOD ELECTRONICS MODULE	$1000
H1	WITH 2ND STATION @ $3.4K ISCT4: OPTICS, DEMOD MODULES	$4.4 K
H1, H2	SPARE STATION: MC, OMC, REFL; STUDYS, MONITOR	$3.4K
H2	1 STATION POY (ISCT9)	$9.2 K
	2 STATION POY, AS (ISCT 9, 10)	$12.6 K
	SOME H2 PARTS EXIST	
LLO	1 STATION POY (ISCT 3)	$11.9 K
	2 STATION POY, AS (ISCT 3, 4)	$15.3 K

DICK GUSTAFSON
1/20/05

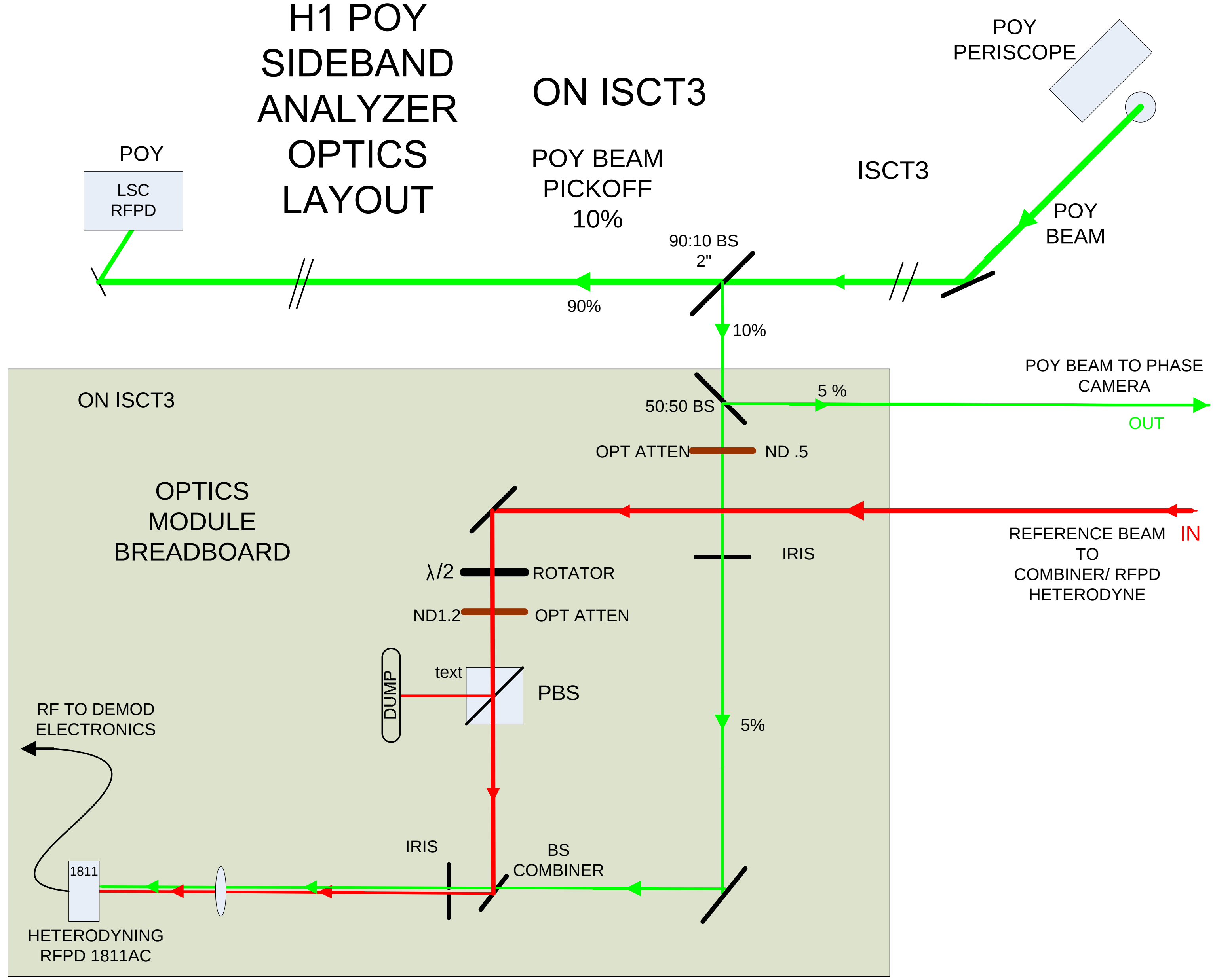

LHO 4K
SB ANALYSIS SYSTEM
LAYOUT
ITMX
ISCT4
AS
POX
POB
ITMY
BS
POX
AS
POY
POB
OPTICS
MODULE
ISCT3
RM
text
POY
RF
FIBERS CARRYING
SHIFTED CARRIER
DAQ
DEMOD ELEC
MC
FIBERS CARRYING
SHIFTED CARRIER
IOT1
ISCT1
REFL
MC TRANS
MC TRANS
MC REF
MC REF
PSL
FIBERS CARRYING
SHIFTED CARRIER
SB ANAL:
HARDWARE
FIBER
LASER
DICK GUSTAFSON
1/25/05
CARRIER SHIFT
FIBER CAPTURE
SYSTEM

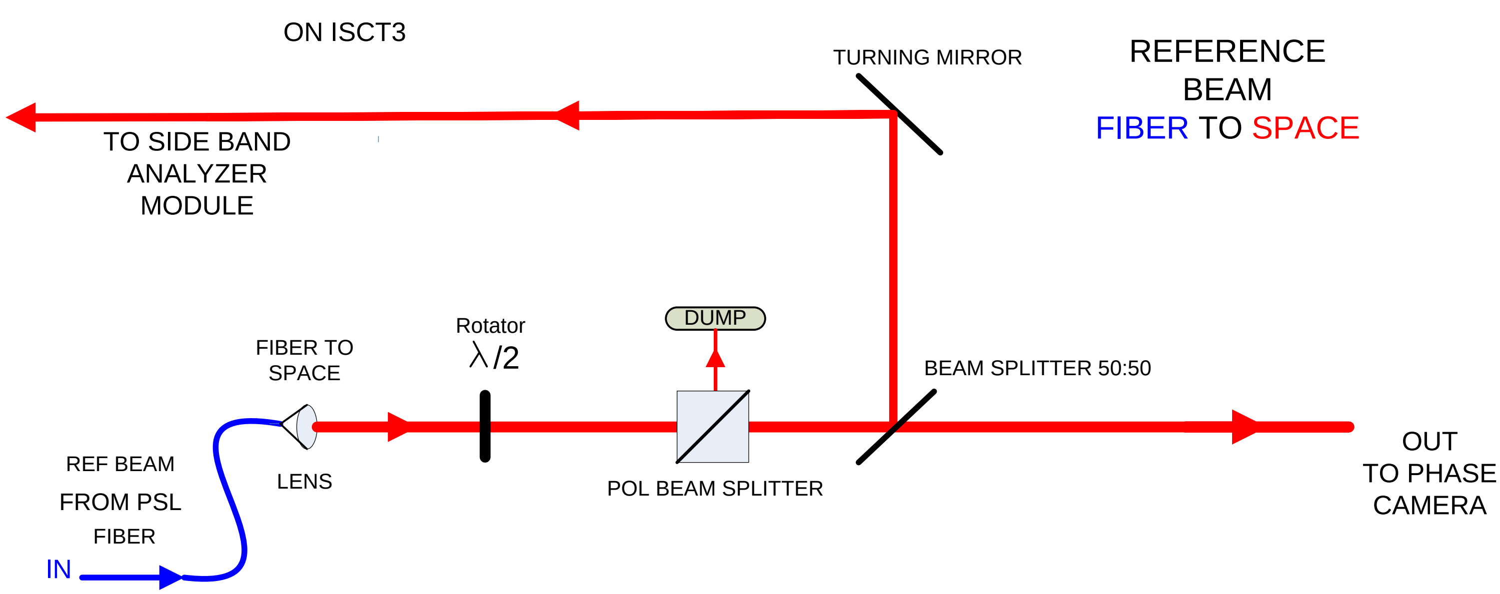
REFERENCE BEAM GENERATION



Dick Gustafson
1/10/05

H1 POY SIDEBAND ANALYZER OPTICS LAYOUT





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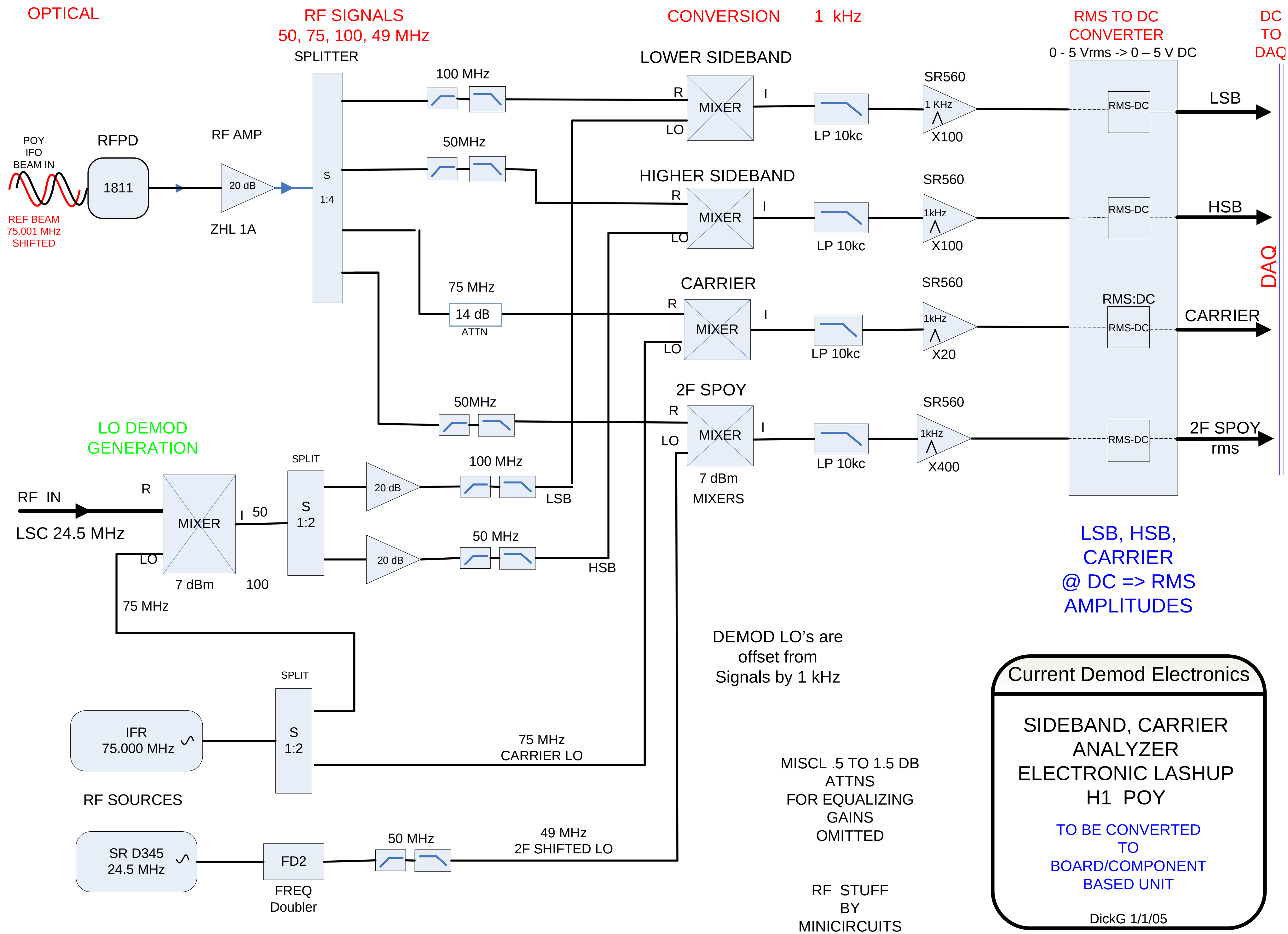
1/10/05

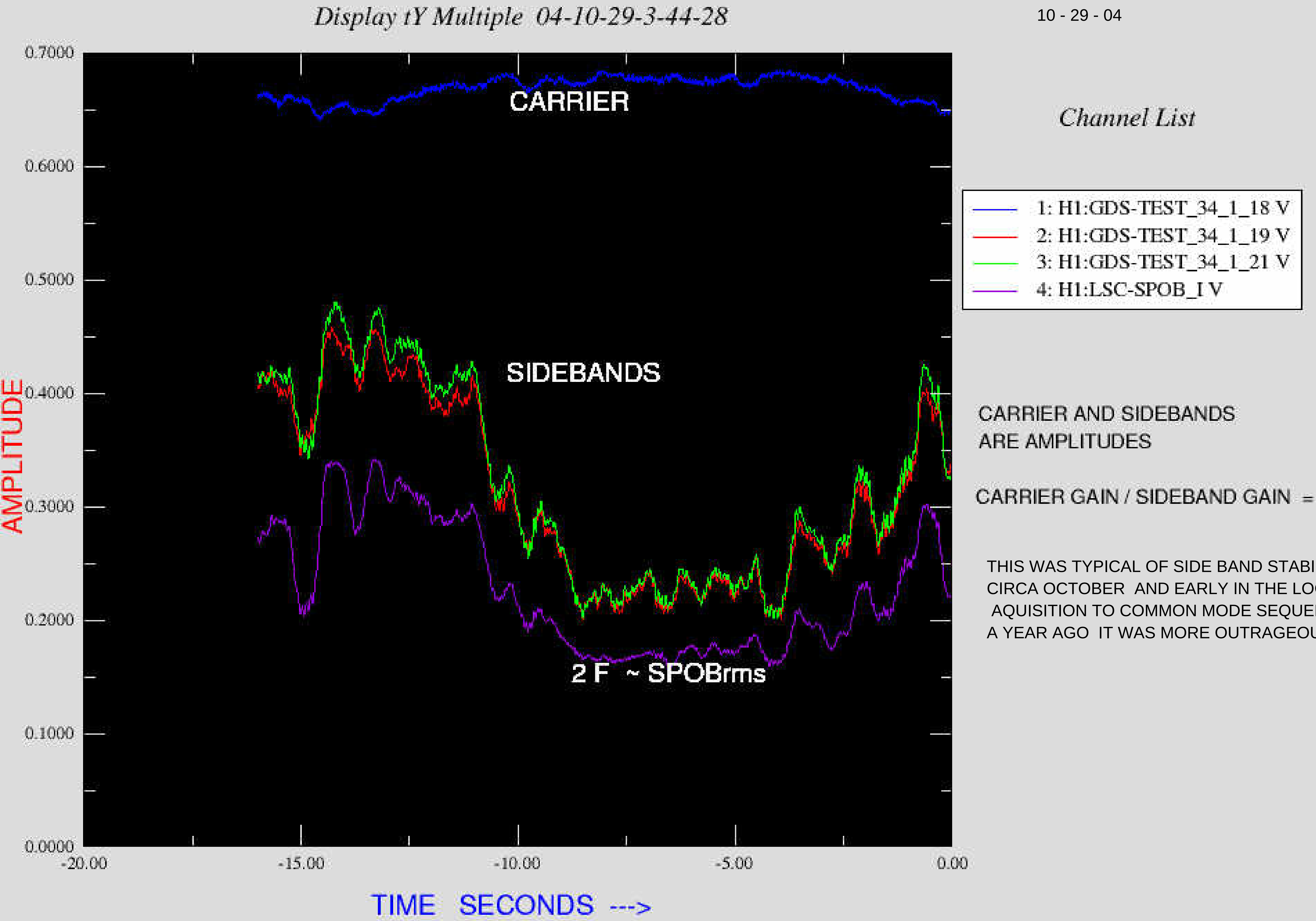


OPTICAL
RF SIGNALS
50, 75, 100, 49 MHz
SPLITTER
CONVERSION
1 kHz
RMS TO DC
CONVERTER
0 - 5 Vrms -> 0 – 5 V DC
DC
TO
DAQ
POY
IFO
BEAM IN
RFPD
1811
REF BEAM
75.001 MHz
SHIFTED
RF AMP
20 dB
ZHL 1A
S
1:4
100 MHz
50MHz
75 MHz
14 dB
ATTN
50MHz
LOWER SIDEBAND
R
MIXER
LO
I
LP 10kc
SR560
1 KHz
X100
HIGHER SIDEBAND
R
MIXER
LO
I
LP 10kc
SR560
1kHz
X100
CARRIER
R
MIXER
LO
I
LP 10kc
SR560
1kHz
X20
2F SPOY
R
MIXER
LO
I
LP 10kc
SR560
1kHz
X400
7 dBm
MIXERS
RMS-DC
RMS-DC
RMS:DC
RMS-DC
RMS-DC
LSB
HSB
CARRIER
2F SPOY
rms
DAQ
LO DEMOD
GENERATION
RF IN
LSC 24.5 MHz
R
MIXER
LO
I
50
7 dBm
100
75 MHz
SPLIT
S
1:2
20 dB
20 dB
100 MHz
LSB
50 MHz
HSB
LSB, HSB,
CARRIER
@ DC => RMS
AMPLITUDES
DEMOD LO's are
offset from
Signals by 1 kHz
SPLIT
S
1:2
IFR
75.000 MHz
75 MHz
CARRIER LO
RF SOURCES
SR D345
24.5 MHz
FD2
FREQ
Doubler
50 MHz
49 MHz
2F SHIFTED LO
MISCL .5 TO 1.5 DB
ATTNS
FOR EQUALIZING
GAINS
OMITTED
RF STUFF
BY
MINICIRCUITS
Current Demod Electronics
SIDEBAND, CARRIER
ANALYZER
ELECTRONIC LASHUP
H1 POY
TO BE CONVERTED
TO
BOARD/COMPONENT
BASED UNIT
DickG 1/1/05

10 - 29 - 04

RECYCLING CAVITY SIDEBAND AND CARRIER   POY BEAM VIEW

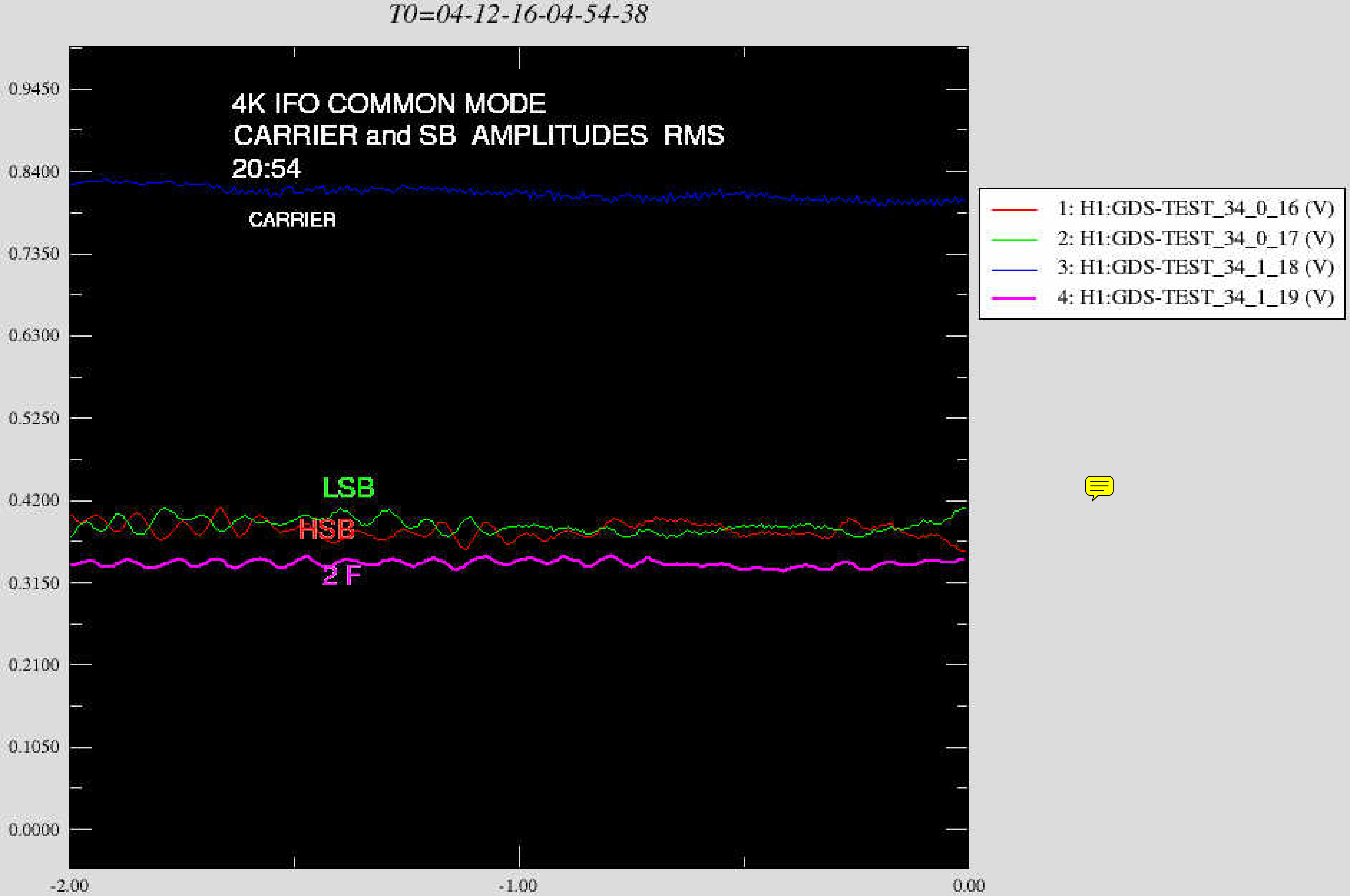
10 - 29 - 04



CARRIER AND SIDEBANDS
ARE AMPLITUDES

CARRIER GAIN / SIDEBAND GAIN = 1/5

THIS WAS TYPICAL OF SIDE BAND STABILITY
CIRCA OCTOBER AND EARLY IN THE LOCK
AQUISITION TO COMMON MODE SEQUENCE.
A YEAR AGO IT WAS MORE OUTRAGEOUS.

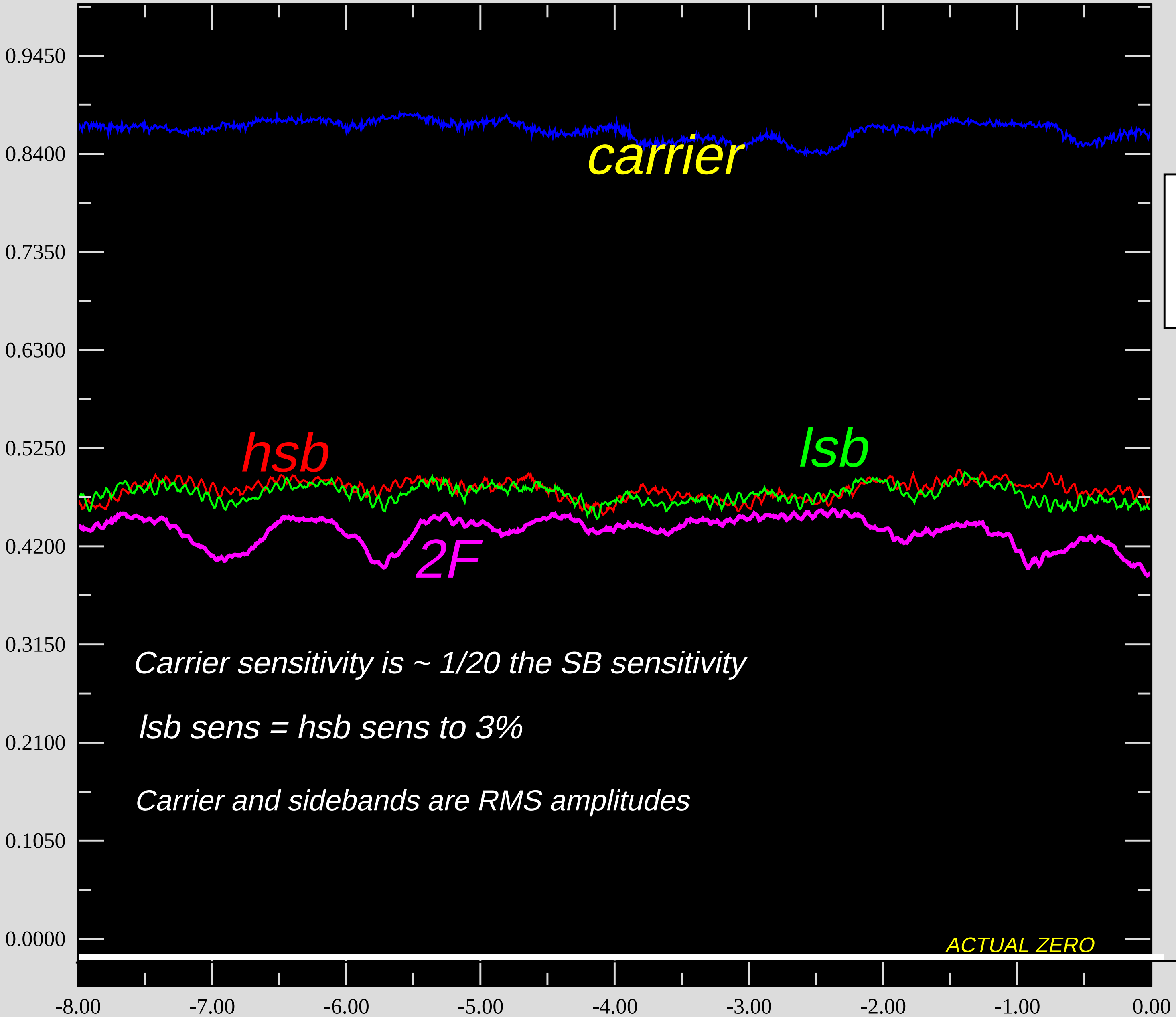

T0=04-12-16-04-54-38
4K IFO COMMON MODE
CARRIER and SB AMPLITUDES RMS
20:54
CARRIER
LSB
HSB
2 F
0.9450
0.8400
0.7350
0.6300
0.5250
0.4200
0.3150
0.2100
0.1050
0.0000
-2.00
-1.00
0.00
1: H1:GDS-TEST_34_0_16 (V)
2: H1:GDS-TEST_34_0_17 (V)
3: H1:GDS-TEST_34_1_18 (V)
4: H1:GDS-TEST_34_1_19 (V)

RECYCLING CAVITY AMPLITUDES 1/20/05 ~ 9PM

T0=05-01-21-05-11-00

ISCT3 SPOY BEAM ANALYSIS
DATA VIEWER RECORD

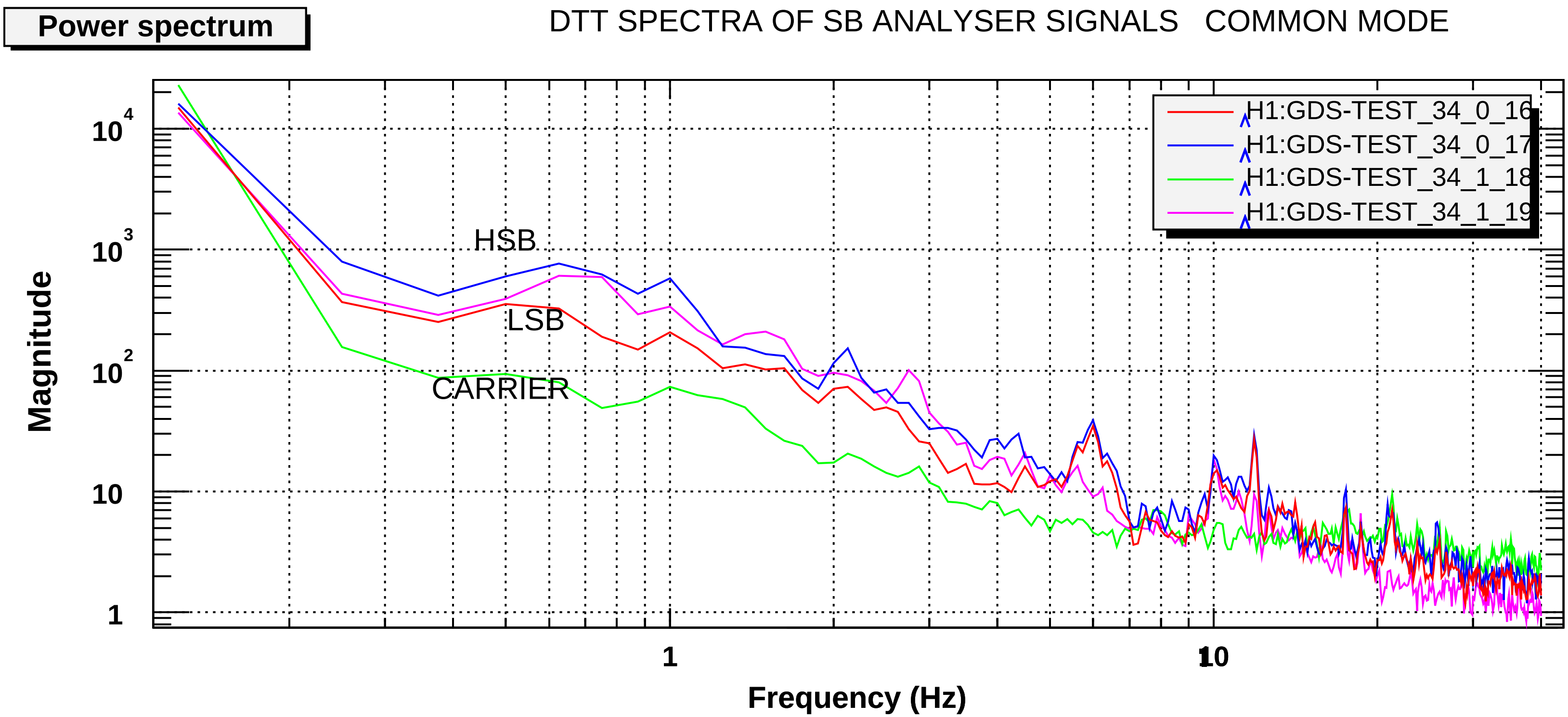
H1 COMMON MODE
1.9 WATTS

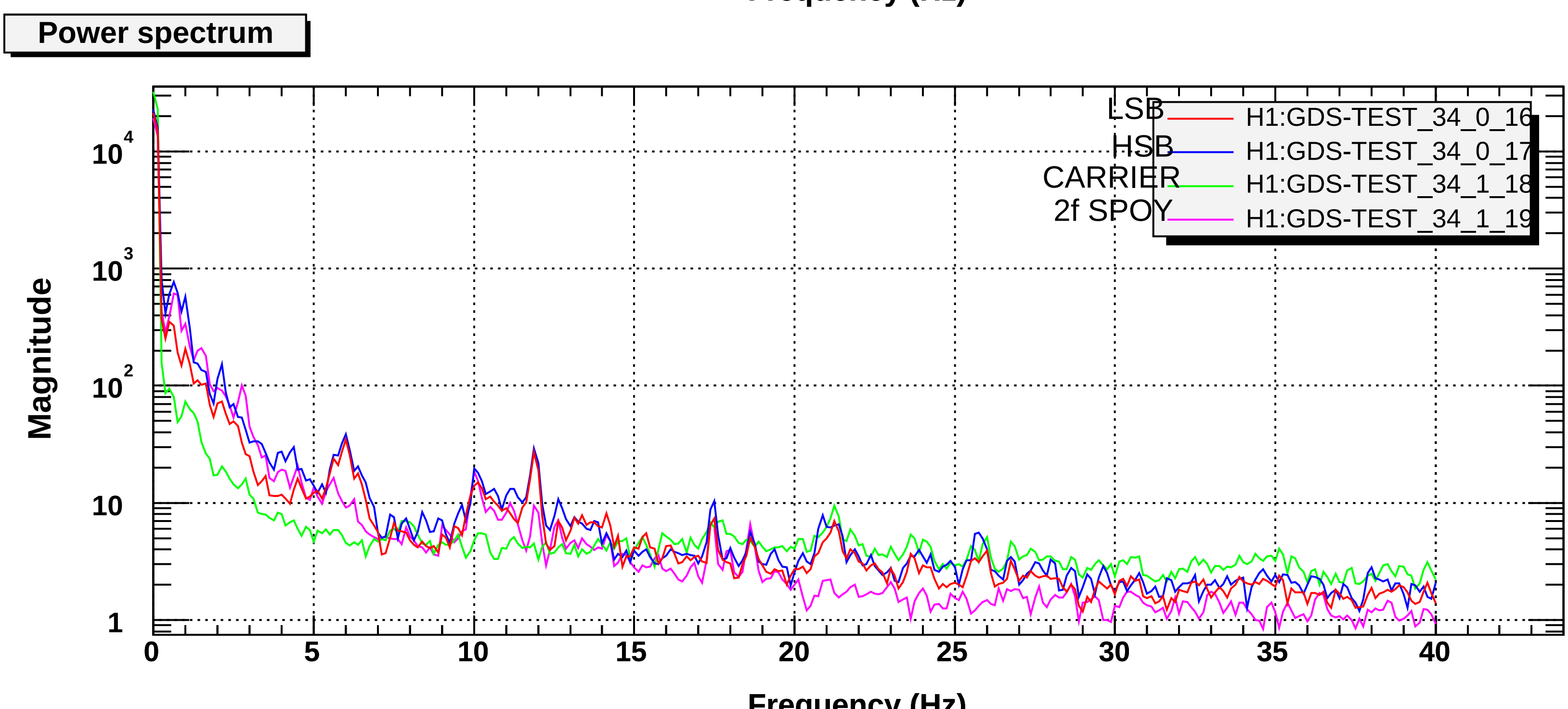


hsb	1: H1:GDS-TEST_34_0_16 (V)
lsb	2: H1:GDS-TEST_34_0_17 (V)
carrier	3: H1:GDS-TEST_34_1_18 (V)
2F	4: H1:GDS-TEST_34_1_19 (V)

NOTICE lsb ~= hsb
lsb and hsb have opposite
~ 10 Hz wiggles

2F ~ hsb x lsb





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