



LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Advanced LIGO

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RF Signal Distribution (Cabling)

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1 Overview

The RF distribution system consists of a set of RF sources, a number of distribution amplifiers and the long haul cabling between electronics racks. This document describes the design of the cabling system. It consists of

- the rack-mounted patch panels,
- the long haul coaxial cables,
- the mounting and routing of the cables,
- the isolation transformers, and
- a cable plan.

The system is design with about 45% spare capacity.

2 Applicable Documents

The applicable documents can be located through the following wiki pages:

- [RF Design](#): Overview
- [RF Distribution Layout](#): List of long haul cable runs
- [RF Patch Panels](#): Panels, cables and isolation
- [RF Source](#): OCXO source stabilized to GPS
- [RF Distribution Amplifier](#): 8 output amplifier for RF signals

3 Rack Locations

The RF sources are located in the electronics room. The racks are ISC-C1 and ISC-C2 for the corner station and ISC-C1 in the end stations. The majority of the long haul RF signal distribution originates in one of these racks and terminates in one of the field racks. The field racks in the corner station are

- PSL-R2: Electronics for the PSL (reference cavity, premode cleaner, master oscillator),
- ISC-R1: Electronics to lock the mode cleaner and to operate the ALS,
- ISC-R2: Electronics for the reflection port,
- ISC-R3: Electronics for the anti-symmetric port,
- TCS-R1: TCS electronics,
- TCS-R2: TCS electronics.

The table below lists the nominal cable length between the rack following the cable trays.

Table 1: Nominal cable length between racks

Ifo	Location	Racks		Length (m)	Qty	Ext. (m)
H1/L1	LVEA	ISC-C1	ISC-R1	52	12	624
			ISC-R2	50	12	600
			ISC-R3	44	12	528
		ISC-C2	PSL-R2	55	12	660
			TCS-R1	44	2	88
			TCS-R2	48	2	96
	ISC-R1	PSL-R2	6	2	12	
	EX	ISC-C1	ISC-R1	26	12	312
	EY	ISC-C1	ISC-R1	26	12	312
	Total					
H2	LVEA	ISC-C1	ISC-R1	81	12	972
			ISC-R2	80	12	960
			ISC-R3	52	12	624
		ISC-C2	PSL-R2	84	12	1008
			TCS-R1	81	2	162
			TCS-R2	42	2	84
	ISC-R1	PSL-R2	6	2	12	
	EX	ISC-C1	ISC-R1	41	12	492
	EY	ISC-C1	ISC-R1	41	12	492
	Total					
Grand total (H1 & H2 & L1)						11270

4 Cable Selection

We require a loss no larger than 3 dB between the RF source and the amplifier. We allocated up to 1.2 dB to the isolation transformer and the local cabling. This leaves 1.8 dB of maximum loss for the long cable runs. The longest runs are part of the H2 system and are about 80 m. The highest frequency of interest in aLIGO is around 135 MHz. However, all our main signals are at 80 MHz or below. Therefore, the requirement for cable losses are 2.2 dB per 100 m at 80 MHz or lower.

Table 2: Cable Selection

Cable	Manufacturer	Ø (mm)	Bending radius (cm)	Loss (dB) 100 m 80 MHz
HELIAX LDF4-50A	Andrew	16	13	2.0
HELIAX LDF2-50A	Andrew	11	9.5	3.1
HELIAX LDF1-50A	Andrew	8.8	7.6	3.6
9310 (RG58)	Belden	4.9		11
RF400 (low loss RG8)	Belden	10.3	10	3.7
RF500 (7976A)	Belden	12.7	13	2.9
RF600 (7977A)	Belden	15.0	15	2.3
LMR-400	Times Microwave	10.3	10	3.7
LMR-500	Times Microwave	12.7	13	2.9
LMR-600	Times Microwave	15.0	15	2.3

From the above table the preferred cable is the LDF4-50A from Andrews. For a given diameter it has the lowest loss and the smallest bending radius. Alternate cables are the RF600 from Belden and the LMR-600 from Times Microwave Systems.

A table listing losses as function of frequency for advanced LIGO cable runs using the LDF4-50A cable is given below.

Table 3: Cable Losses for H1 (LDF4-50)

Freq. (MHz)	ISC-C2 PSL-R2	ISC-C1 ISC-R2	ISC-C2 TCS-R1	ISC-C2 TCS-R2	EX/EY ISC
9	0.32	0.26	0.26	0.28	0.15
24	0.57	0.46	0.46	0.50	0.27
35	0.70	0.56	0.56	0.61	0.33
45	0.79	0.63	0.63	0.69	0.38
80	1.07	0.86	0.85	0.93	0.51
135	1.40	1.12	1.11	1.22	0.66

Table 4: Cable Losses for H2 (LDF4-50)

Freq. (MHz)	ISC-C2 PSL-R2	ISC-C1 ISC-R2	ISC-C2 TCS-R1	ISC-C2 TCS-R2	EX/EY ISC
9	0.49	0.30	0.47	0.24	0.24
24	0.88	0.54	0.84	0.43	0.42
35	1.07	0.66	1.02	0.53	0.51
45	1.21	0.74	1.16	0.60	0.58
80	1.63	1.00	1.56	0.81	0.78
135	2.14	1.31	2.05	1.06	1.03

The majority of RF inputs are designed for 10 dBm whereas the outputs are designed for 13 dB. For shorter runs the loss may not add up to 3 dB and the inputs have to be adjusted using attenuators. Type N attenuator are available from Mini-Circuits with part numbers UNAT-1, UNAT-2 and UNAT-3 for 1 dB, 2 dB and 3 dB, respectively.

5 Patch Panels

A standard patch panel is used. It is 2U high (3.5”) and contains 6 N feedthrough adapters across. The feedthrough adapters are type N and are isolated, i.e., Pasternack PE9382. The panel is about 5” recessed to accommodate an optional isolation transformer (balun). The patch panel is shown in D1100TBD-v1. The required patch panels are listed in the table below.

Table 5: Patch Panels

Panel	Location	Destination	Signals	Comment
1	ISC-C1	ISC-R1	6	Corner, rack position 39
2	ISC-C1	ISC-R1	6	Corner, rack position 37
3	ISC-C1	ISC-R2	6	Corner, rack position 35
4	ISC-C1	ISC-R2	6	Corner, rack position 33
5	ISC-C1	ISC-R3	6	Corner, rack position 31
6	ISC-C1	ISC-R3	6	Corner, rack position 29
7	ISC-C2	PSL-R2	6	Corner, rack position 39
8	ISC-C2	PSL-R2	6	Corner, rack position 37
9	ISC-C2	TCS-R1/R2	2/2	Corner, rack position 35
10	ISC-R1	ISC-C1	6	Corner, rack position 39

11	ISC-R1	ISC-C1	6	Corner, rack position 37
12	ISC-R1	PSL-R2	2	Corner, rack position 35
13	ISC-R2	ISC-C1	6	Corner, rack position 39
14	ISC-R2	ISC-C1	6	Corner, rack position 37
15	ISC-R3	ISC-C1	6	Corner, rack position 39
16	ISC-R3	ISC-C1	6	Corner, rack position 37
17	PSL-R2	ISC-C2	6	Corner, rack position 39
18	PSL-R2	ISC-C2	6	Corner, rack position 37
19	PSL-R2	ISC-R1	2	Corner, rack position 35
20	TCS-R1	ISC-C2	2	Corner, rack position 39
21	TCS-R2	ISC-C2	2	Corner, rack position 39
22	EX-ISC-C1	EX-ISC-R1	6	EX, rack position 39
23	EX-ISC-C1	EX-ISC-R1	6	EX, rack position 37
24	EX-ISC-R1	EX-ISC-C1	6	EX, rack position 39
25	EX-ISC-R1	EX-ISC-C1	6	EX, rack position 37
26	EY-ISC-C1	EY-ISC-R1	6	EY, rack position 39
27	EY-ISC-C1	EY-ISC-R1	6	EY, rack position 37
28	EY-ISC-R1	EY-ISC-C1	6	EY, rack position 39
29	EY-ISC-R1	EY-ISC-C1	6	EY, rack position 37

There are 29 patch panels per detector, or 87 in total. Only patch panel 9 fans into 2 destinations. All other patch panels are connected to exactly one other one and are connected 1:1. Each patch panel incorporates an attachable aluminum strip to label the individual signals. Labels can be manufactured through Frontpanel Express as required.

6 Ground Isolation

In order to avoid ground loops between the different rack locations an isolation transformer is installed on the destination end of each RF signal line. The balun is described in E1100596-v1 and [D1101077-v1](#).

Table 6: Location of Balun Isolation Transformers.

Location			Frequency (MHz)	Comment
Location	Panel	Signal		
ISC-C1	2	1	79.400	Return ALS DIFF VCO
		2	79.400	Return ALS COMM VCO
		3	79.400	Return PSL VCO
ISC-R1	10	1	71.000	ALS DIFF VCO
		2	71.000	ALS COMM VCO
		3	71.000	PSL VCO
		4	24.078	MC Distribution
		5	9.099/8.684	Main modulation
		6	5 th harm.	Auxiliary modulation
ISC-R2	13	1	9.099/8.684	Distribution
		2	5 th harm.	Distribution
		3	2 nd harm.	Demodulation
		4	3 rd harm.	Demodulation
		5	10 th harm.	Demodulation
		6	15 th harm.	Demodulation
ISC-R3	15	1	9.099/8.684	Distribution
		2	4 th harm.	Distribution
		3	5 th harm.	Distribution
		4	2 nd harm.	Demodulation
		5	10 th harm.	Demodulation
PSL-R2	17	1	21.500	Modulation
		2	21.500	FSS
		4	35.500	Modulation
		5	35.500	PMC
		6	35.500	Injection Locking

Location			Frequency (MHz)	Comment
Location	Panel	Signal		
PSL-R2	18	2	80.000	ISS AOM
PSL-R2	19	1	79.4	PSL VCO
TCS-R1	20	1	40.000	TCS AOM
TCS-R2	21	1	40.000	TCS AOM
EX ISC-C1	22	6	79.4	Return ALS laser VCO
EX ISC-R1	24	1	71.000	ALS laser VCO
		2	24.4	ALS Modulation
		3	24.4	ALS Demodulation
		4	24.4	ALS WFS 1
		5	24.4	ALS WFS 2
EY ISC-C1	26	6	79.4	Return ALS laser VCO
EY ISC-R1	28	1	71.000	ALS laser VCO
		2	24.4	ALS Modulation
		3	24.4	ALS Demodulation
		4	24.4	ALS WFS 1
		5	24.4	ALS WFS 2

7 Cable Routing and Mounting

Cables are run inside the existing advanced LIGO cable trays. The cables are bundled into 9 runs consisting of either 12 or 2 individual coaxial cables. Stainless steel cable ties are used to keep the bundle together and to mount it to the cable tray. Cable ties are MLTFC4S-CP316 or MLTFC4H-LP316 from Panduit for the larger bundles and MLTFC2S-CP316 or MLTFC2H-LP316 for the smaller bundles. The corresponding tool is Panduit GS4MT. There should be a cable tie roughly every 60 cm. If a mounting clip is required, one can use Panduit MTM2H-Q, Panduit MTM1H-C or Panduit MPWM-H56-Q depending on the circumstances.

Table 7: List of cable runs and bundles.

From		To		Bundle	Length (m)		Comment
Location	Panel	Location	Panel		H1/L1	H2	
ISC-C1	1/2	ISC-R1	10/11	12	52	81	ALS/MC
ISC-C1	3/4	ISC-R2	13/14	12	50	80	Reflection port
ISC-C1	5/6	ISC-R3	15/16	12	44	52	Anti-symmetric port
ISC-C2	7/8	PSL-R2	17/18	12	55	84	PSL
ISC-C2	9	TCS-R1	20	2	44	84	TCS X
		TCS-R2	21	2	48	42	TCS Y
ISC-R1	12	PSL-R2	19	2	6	6	MC
EX-ISC-C1	22/23	EX-ISC-R1	24/25	12	26	41	EX
EY-ISC-C1	26/27	EY-ISC-R1	28/29	12	26	41	EY

The total run of large cable bundles is 885 m which requires an estimated 1500 cable ties. The total run of small cable bundles is 328 m which requires an estimated 550 cable ties.

8 Cable Plan

There are a total of 78 cable runs per detector, or 234 in total. The number of currently used signal lines is 41 per detector, or 123 in total.

Table 8: Cabling for long haul RF signals

From			To			Frequency (MHz)	Comment
Location	Panel	Signal	Location	Panel	Signal		
ISC-C1	1	1	ISC-R1	10	1	71.000	ALS DIFF VCO
		2			2	71.000	ALS COMM VCO
		3			3	71.000	PSL VCO
		4			4	24.078	MC Distribution
		5			5	9.099/8.684	Main modulation
		6			6	5 th harm.	Auxiliary modulation
ISC-C1	2	1	ISC-R1	11	1	79.400	Return ALS DIFF VCO
		2			2	79.400	Return ALS COMM VCO
		3			3	79.400	Return PSL VCO
		4			4		Spare
		5			5		Spare
		6			6		Spare
ISC-C1	3	1	ISC-R2	13	1	9.099/8.684	Distribution
		2			2	5 th harm.	Distribution
		3			3	2 nd harm.	Demodulation
		4			4	3 rd harm.	Demodulation
		5			5	10 th harm.	Demodulation
		6			6	15 th harm.	Demodulation
ISC-C1	4	1	ISC-R2	14	1		Spare
		2			2		Spare
		3			3		Spare
		4			4		Spare
		5			5		Spare
		6			6		Spare

From			To			Frequency (MHz)	Comment
Location	Panel	Signal	Location	Panel	Signal		
ISC-C1	5	1	ISC-R3	15	1	9.099/8.684	Distribution
		2			2	4 th harm.	Distribution
		3			3	5 th harm.	Distribution
		4			4	2 nd harm.	Demodulation
		5			5	10 th harm.	Demodulation
		6			6		Spare
ISC-C1	6	1	ISC-R3	16	1		Spare
		2			2		Spare
		3			3		Spare
		4			4		Spare
		5			5		Spare
		6			6		Spare
ISC-C2	7	1	PSL-R2	17	1	21.500	Modulation
		2			2	21.500	FSS
		3			3	21.500	Spare
		4			4	35.500	Modulation
		5			5	35.500	PMC
		6			6	35.500	Injection Locking
ISC-C2	8	1	PSL-R2	18	1	35.500	Spare
		2			2	80.000	ISS AOM
		3			3		Spare
		4			4		Spare
		5			5		Spare
		6			6		Spare
ISC-C2	9	1	TCS-R1	20	1	40.000	TCS AOM
		2			2		Spare
		3	TCS-R2	21	1	40.000	TCS AOM
		4			2		Spare

From			To			Frequency (MHz)	Comment
Location	Panel	Signal	Location	Panel	Signal		
ISC-R1	12	1	PSL-R2	19	1	79.4	PSL VCO
		2			2		Spare
EX ISC-C1	22	1	EX ISC-R1	24	1	71.000	ALS laser VCO
		2			2	24.4	ALS Modulation
		3			3	24.4	ALS Demodulation
		4			4	24.4	ALS WFS 1
		5			5	24.4	ALS WFS 2
		6			6	79.4	Return ALS laser VCO
EX ISC-C1	23	1	EX ISC-R1	25	1		Spare
		2			2		Spare
		3			3		Spare
		4			4		Spare
		5			5		Spare
		6			6		Spare
EY ISC-C1	26	1	EY ISC-R1	28	1	71.000	ALS laser VCO
		2			2	24.4	ALS Modulation
		3			3	24.4	ALS Demodulation
		4			4	24.4	ALS WFS 1
		5			5	24.4	ALS WFS 2
		6			6	79.4	Return ALS laser VCO
EY ISC-C1	27	1	EY ISC-R1	29	1		Spare
		2			2		Spare
		3			3		Spare
		4			4		Spare
		5			5		Spare
		6			6		Spare

9 Bill of Material

Qty.	Part Number	Distributor	Comment
90	D1100TBD-v1	LIGO	Patch panel
500	PE9382	Pasternack	Isolated N feedthrough adapter
12000 m	LDF4-50A	Andrew	Heliac cable
500	12EZNM	Andrew	Connector N male
2	12-HPT	Andrew	Manual hand prep tool
150	D1101077-v1	LIGO	Balun
TBD	UNAT-n	Mini-Circuits	Type N attenuator (n dB)
1500	MLTFC4H-LP316	Panduit	Stainless steel cable ties, 200 mm
550	MLTFC2H-LP316	Panduit	Stainless steel cable ties, 360 mm
2	GS4MT	Panduit	Installation tool