LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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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

Rack locations are described in D1003142. The RF sources are located in the electronics room. The racks are ISC-C4 and ISC-C3 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),
- PSL-DR: Diode room for the PSL (ALS fiber distribution),
- 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 racks following the cable trays. Due to high costs only 75% of the initial cable runs will be laid down. The savings are indicated in separate columns.

Table 1: Nominal cable length between racks

Ifo	Location	Racks		Length (m)	Qty	Save	Orig. (m)	Save (m)	Ext. (m)
H1 L1	LVEA	ISC-C4	ISC-R1	52	12	1	624	52	572
			ISC-R2	50	12	4	600	200	400
			ISC-R3	44	12	5	528	220	308
		ISC-C3	PSL-R2	55	12	3	660	165	495
			TCS-R1	44	2	0	88	0	88
			TCS-R2	48	2	0	96	0	96
		ISC-R1	PSL-R2	6	2	0	12	0	12
			PSL-DR	48	2	0	96	0	96
	EX	ISC-C1	ISC-R1	26	12	4	312	104	208
	EY	ISC-C1	ISC-R1	26	12	4	312	104	208
	Total						3328	845	2483
H2	LVEA	ISC-C4	ISC-R1	81	12	1	972	81	891
			ISC-R2	80	12	4	960	320	640
			ISC-R3	52	12	5	624	260	364
		ISC-C3	PSL-R2	84	12	3	1008	252	756
			TCS-R1	81	2	0	162	0	162
			TCS-R2	42	2	0	84	0	84
		ISC-R1	PSL-R2	6	2	0	12	0	12
			PSL-DR	15	2	0	30	0	30
	EX	ISC-C1	ISC-R1	41	12	4	492	164	328
	EY	ISC-C1	ISC-R1	41	12	4	492	164	328
	Total						4836	1241	3595
Grand total (H1 & H2 & L1)							11492	2931	8561

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-C3 PSL-R2	ISC-C4 ISC-R2	ISC-C3 TCS-R1	ISC-C3 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-C3 PSL-R2	ISC-C4 ISC-R2	ISC-C3 TCS-R1	ISC-C3 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-C4	ISC-R1	6	Corner, rack position 39
2	ISC-C4	ISC-R1	6	Corner, rack position 37
3	ISC-C4	ISC-R2	6	Corner, rack position 35
4	ISC-C4	ISC-R2	6	Corner, rack position 33
5	ISC-C4	ISC-R3	6	Corner, rack position 31
6	ISC-C4	ISC-R3	6	Corner, rack position 29
7	ISC-C3	PSL-R2	6	Corner, rack position 39
8	ISC-C3	PSL-R2	6	Corner, rack position 37
9	ISC-C3	TCS-R1/R2	2/2	Corner, rack position 35

10	ISC-R1	ISC-C4	6	Corner, rack position 39
11	ISC-R1	ISC-C4	6	Corner, rack position 37
12	ISC-R1	PSL-R2/DR	2	Corner, rack position 35
13	ISC-R2	ISC-C4	6	Corner, rack position 39
14	ISC-R2	ISC-C4	6	Corner, rack position 37
15	ISC-R3	ISC-C4	6	Corner, rack position 39
16	ISC-R3	ISC-C4	6	Corner, rack position 37
17	PSL-R2	ISC-C3	6	Corner, rack position 39
18	PSL-R2	ISC-C3	6	Corner, rack position 37
19	PSL-R2	ISC-R1	2	Corner, rack position 35
20	TCS-R1	ISC-C3	2	Corner, rack position 39
21	TCS-R2	ISC-C3	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
30	PSL-DR	ISC-R1	2	Corner, diode room

There are 30 patch panels per detector, or 90 in total. Patch panels 9 and 12 fan 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-C4	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	Distribution
		2	79.200	ALS Fiber
		3		Spare
		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	5	39.7	Return PLL Beat Note
		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
EY ISC-C1	26	5	39.7	Return PLL Beat Note
		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
PSL-DR	30	1	79.4	ALS fiber AOM

7 Cable Routing and Mounting

Cables are run inside the existing advanced LIGO cable trays. The cables are bundled into 10 runs consisting of up to 12 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-C4	1/2	ISC-R1	10/11	11	52	81	ALS/MC
ISC-C4	3/4	ISC-R2	13/14	8	50	80	Reflection port
ISC-C4	5/6	ISC-R3	15/16	7	44	52	Anti-symmetric port
ISC-C3	7/8	PSL-R2	17/18	9	55	84	PSL
ISC-C3	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
		PSL-DR	30	2	48	15	ALS
EX-ISC-C1	22/23	EX-ISC-R1	24/25	8	26	41	EX
EY-ISC-C1	26/27	EY-ISC-R1	28/29	8	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 59 cable runs per detector, or 177 in total. The number of currently used signal lines is 41 per detector, or 123 in total. Gray highlighted runs will not be installed initially.

Table 8: Cabling for long haul RF signals

From			To			Frequency (MHz)	Comment
Location	Panel	Signal	Location	Panel	Signal		
ISC-C4	1	1	ISC-R1	10	1	71.000	Distribution
		2			2	79.200	ALS Fiber
		3			3		Spare
		4			4	24.078	MC Distribution
		5			5	9.099/8.684	Main modulation
		6			6	5th harm.	Auxiliary modulation
ISC-C4	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-C4	3	1	ISC-R2	13	1	9.099/8.684	Distribution
		2			2	5th harm.	Distribution
		3			3	2nd harm.	Demodulation
		4			4	3rd harm.	Demodulation
		5			5	10th harm.	Demodulation
		6			6	15th harm.	Demodulation
ISC-C4	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-C4	5	1	ISC-R3	15	1	9.099/8.684	Distribution
		2			2	4th harm.	Distribution
		3			3	5th harm.	Distribution
		4			4	2nd harm.	Demodulation
		5			5	10th harm.	Demodulation
		6			6		Spare
ISC-C4	6	1	ISC-R3	16	1		Spare
		2			2		Spare
		3			3		Spare
		4			4		Spare
		5			5		Spare
		6			6		Spare
ISC-C3	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-C3	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-C3	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
		3	PSL-DR	30	1	158.4	ALS AOM
		4			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		Spare
		5			5	39.7	Return PLL Beat Note
		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		Spare
		5			5	39.7	Return PLL Beat Note
		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	D1101479-v1	LIGO	Patch panel
360	PE9382	Pasternack	Isolated N feedthrough adapter
8500 m	LDF4-50A	Andrew	Heliax cable
360	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 attentuator (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