LIGO Laboratory / LIGO Scientific Collaboration

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Arm Cavity Geometry for H1 ALS Test With X And Y Arm

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1 References

1. aLIGO optics inventory, https://nebula.ligo.caltech.edu/optics/
2. “E080511 ITM Polish”, https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=116
3. “Advanced LIGO Input Test Mass Coating Specification”, https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=690
4. “E080512_ETM_Polishing_Specification”, https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=166
5. “Advanced LIGO End Test Mass (ETM) Coating Specification”, https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=994
6. a la mode matlab package by Nic Smith, https://github.com/nicolassmith/alm

2 Summary

Mode matching, arm finesse and transmissivity of all possible combinations of ETMs and ITMs for full ALS test phase (HIFO-X) was studied.

One Arm Test configuration for Y arm is somewhat less attractive due to the fact that we need to maintain different X and Y arm common mode servo even though this is not a serious technical issue.

All configurations will provide reasonable mode matching. Though some configurations are somewhat better than the others, there seems to be no serious argument for favoring a pilot optic over a real one when/if the latter is available.

3 Optics

Due to production and installation schedule, we cannot install production optics for all TMs at the time of fully implemented ALS test (HIFO-X) where both of the arms are available to provide both common and differential ALS signal. Table 1 shows all optics that are potentially used. For serial numbers (ETM01 etc.) in the table, see Reference 1.

Nominal numbers are based on the polishing and coating specifications[2-5]. For radius of curvature of pilot optics (ETM02, ETM04 and ETM05) measured numbers were used. For the transmission of the HR surface of the pilot optics, first the number in the optics inventory table[1] was referred to (ETM02 and 04 red). When that's unavailable, vendor report was used (ETM02 and 04 green). Only when neither of these were available was the nominal number used (ETM05).

	ITM	ETM
X Arm	Nominal, ROC=1934m T(red)=1.4%, T(green)=1%	Nominal, ROC= 2245m T(red)=5ppm, T(green)=5%
	Pilot ETM05, ROC=2250.02m ITMHR (no report in dcc, used nominal params) No AR	
Y Arm	Pilot ETM02, ROC=2307m ITMHR T(red)=1.38%, T(green)=0.95% No AR	Nominal, ROC= 2245m T(red)=5ppm, T(green)=5%
		Pilot ETM04, ROC=2312m ITMHR T(red)=1.5%, T(green)=1.03%

Table 1: List of optics that might be used for HIFO X test.

Even though the cavity parameter mismatch is not a serious problem for the purpose of ALS testing, arm cavity transmission and finesse were calculated (Table 2).

The only coating configuration drastically different from nominal is One Arm Test configuration (pilot-pilot) for Y arm where both of the mirrors have the ITM coating. This increases the green finesse by a factor of 3 and decreases the red finesse by a factor of 2, while drastically increasing the arm transmissivity, only for Y arm. The imbalance doesn't seem to be a serious flaw as the green light from each end station is tightly locked to each arm by separate servo, nor the increased transmission a serious benefit as far as HIFO-X is concerned. However, due to the fact that we need to maintain two common mode servo configuration for X and Y arm ALS because of different optical gain and arm pole, this is not the best configuration.

	T(green)	Finesse(green)	T(red)	Finesse(red)
Nominal IX and EX	54.8%	102	0.14%	446
Pilot IX nominal EX	52.9%	102	0.14%	445
Pilot IY nominal EY	51.1%	103	0.14%	452
Pilot IY pilot EY (OAT)	96.3%	316	96.5%	217

Table 2: Finesse and the transmissivity of the arms. Losses in the substrate and the coating are ignored. Reflectivity of non-AR surface is accounted for, reflectivity of AR surface is assumed to be 1.

4 Mode Matching

	Pilot IX, nominal EX			Nominal IX and EX		
Pilot IY, nominal EY	XY	Green	0.9996	XY	Green	0.954
		Red	0.9996		Red	0.953
	X-nominal	Green	0.962	X-nominal	Green	1
		Red	0.961		Red	1
	Y-nominal	Green	0.954	Y-nominal	Green	0.954
		Red	0.953		Red	0.953
Pilot IY, pilot EY	XY	Green	0.998	XY	Green	0.945
		Red	0.998		Red	0.944
	X-nominal	Green	0.962	X-nominal	Green	1
		Red	0.961		Red	1
	Y-nominal	Green	0.945	Y-nominal	Green	0.945
		Red	0.944		Red	0.944

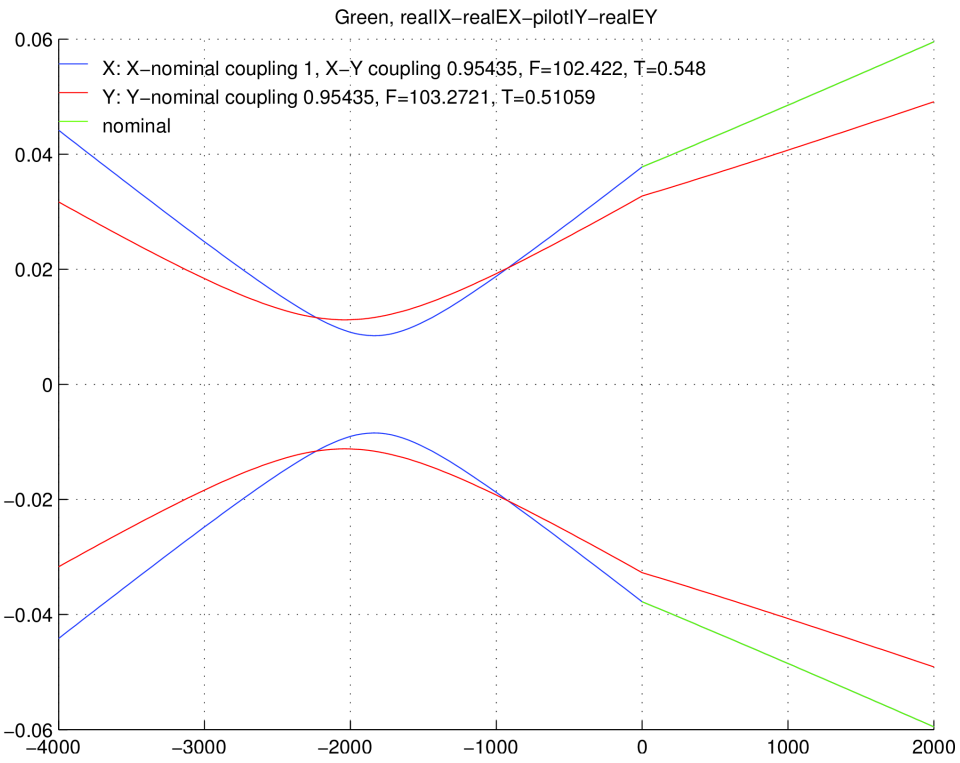
Table 3: Mode overlap of X-Y, X-nominal and Y-nominal OUTSIDE of the ITM side of the arm cavity.

A matlab script (included in the same DCC number, which depends on ALM matlab package[6]) was used to calculate the mode overlap of X-Y, X-nominal and Y-nominal outside of the ITM side of the arm cavity. The nominal mode is defined as the mean of the X and Y arm mode when all optics have nominal ROC. The coupling was calculated outside of the ITM side of the arm cavity to correctly account for the ITM lensing.

In all cases, the mode overlap between X arm and Y arm as well as the mode overlap between the ideal mode and the arm mode is larger than 94%, both for green and red light. Since the mode overlap is conserved by any ABCD matrix system, this means that, for example, the mode overlap of X and Y ALS beam on ISCT1 is larger than 94%.

In this respect all configurations are acceptable. If anything, using pilot IX makes the XY matching almost perfect, but this is not a strong argument for using a pilot IX when the real one is available.

5 Plots


Green, realIX−realEX−pilotIY−realEY
X: X−nominal coupling 1, X−Y coupling 0.95435, F=102.422, T=0.548
Y: Y−nominal coupling 0.95435, F=103.2721, T=0.51059
nominal
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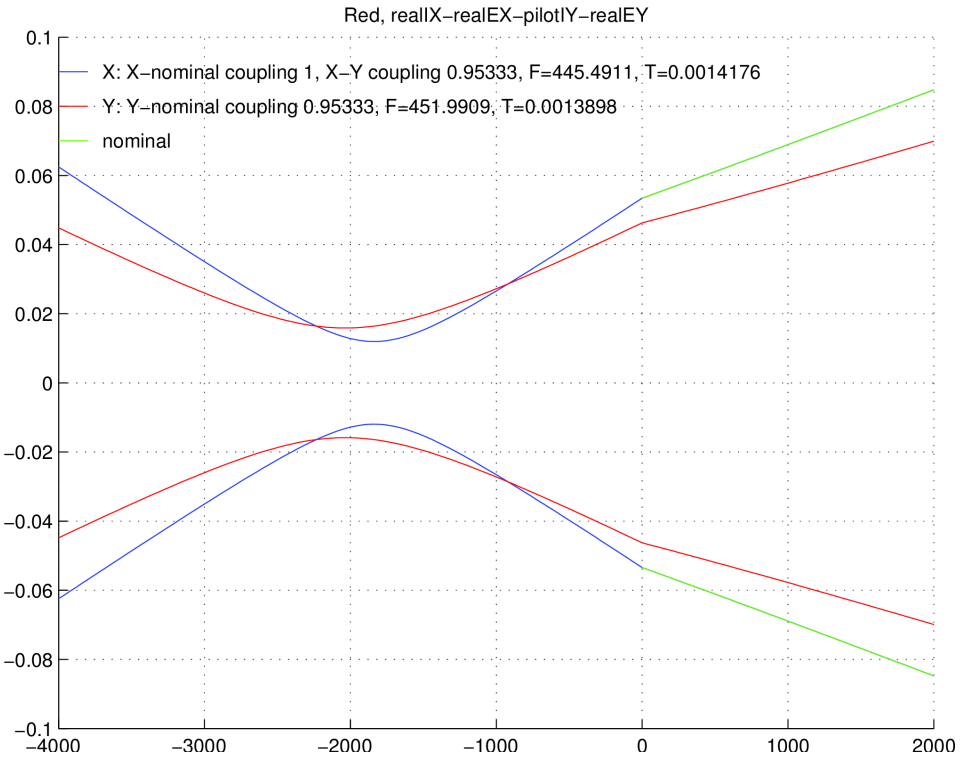
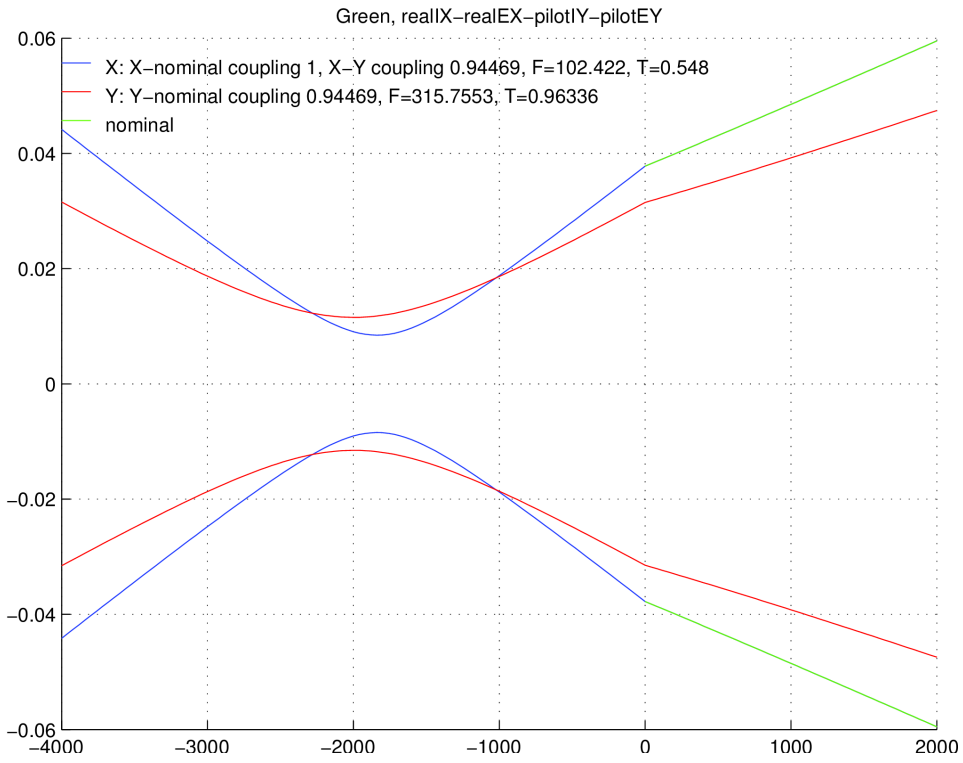
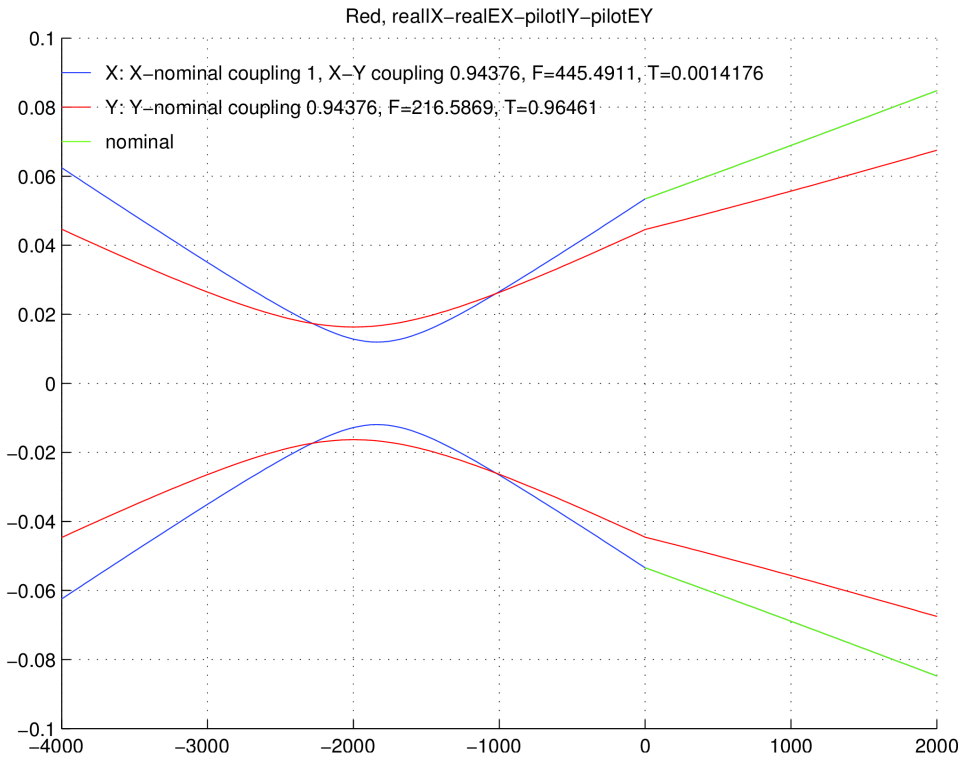
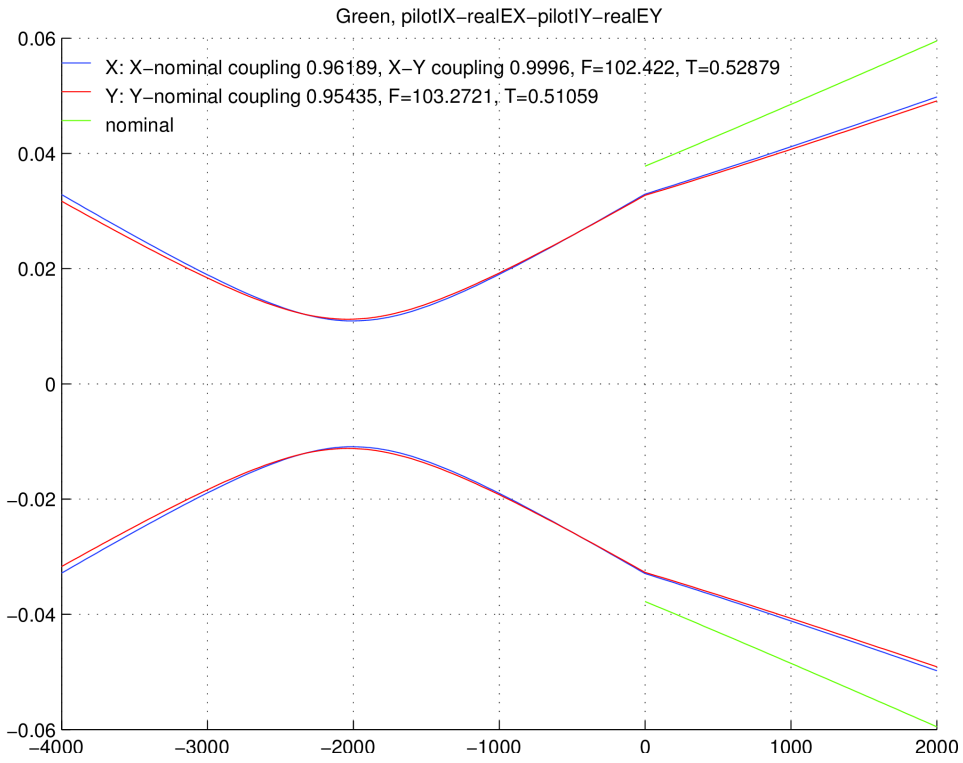
0.04
0.02
0
−0.02
−0.04
−0.06
−4000
−3000
−2000
−1000
0
1000
2000


Red, realIX−realEX−pilotIY−realEY
X: X−nominal coupling 1, X−Y coupling 0.95333, F=445.4911, T=0.0014176
Y: Y−nominal coupling 0.95333, F=451.9909, T=0.0013898
nominal
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
−4000
−3000
−2000
−1000
0
1000
2000


Green, realIX−realEX−pilotIY−pilotEY
X: X−nominal coupling 1, X−Y coupling 0.94469, F=102.422, T=0.548
Y: Y−nominal coupling 0.94469, F=315.7553, T=0.96336
nominal
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−4000
−3000
−2000
−1000
0
1000
2000


Red, realIX−realEX−pilotIY−pilotEY
X: X−nominal coupling 1, X−Y coupling 0.94376, F=445.4911, T=0.0014176
Y: Y−nominal coupling 0.94376, F=216.5869, T=0.96461
nominal
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
−4000
−3000
−2000
−1000
0
1000
2000


Green, pilotIX−realEX−pilotIY−realEY
X: X−nominal coupling 0.96189, X−Y coupling 0.9996, F=102.422, T=0.52879
Y: Y−nominal coupling 0.95435, F=103.2721, T=0.51059
nominal
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0.02
0
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−4000
−3000
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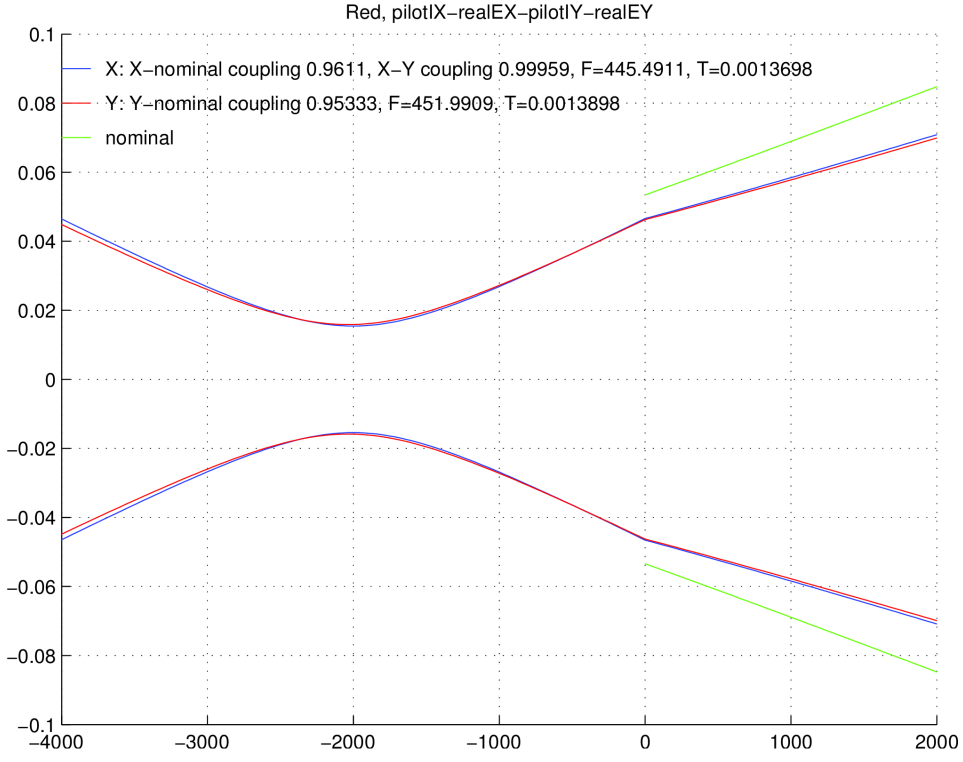
−1000
0
1000
2000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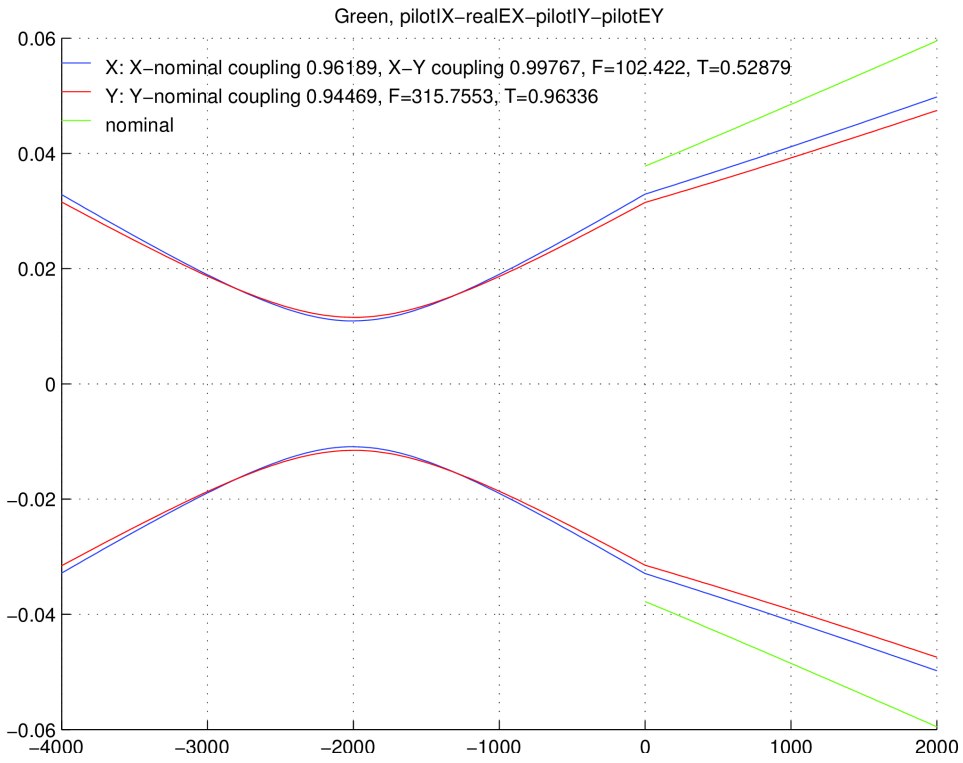
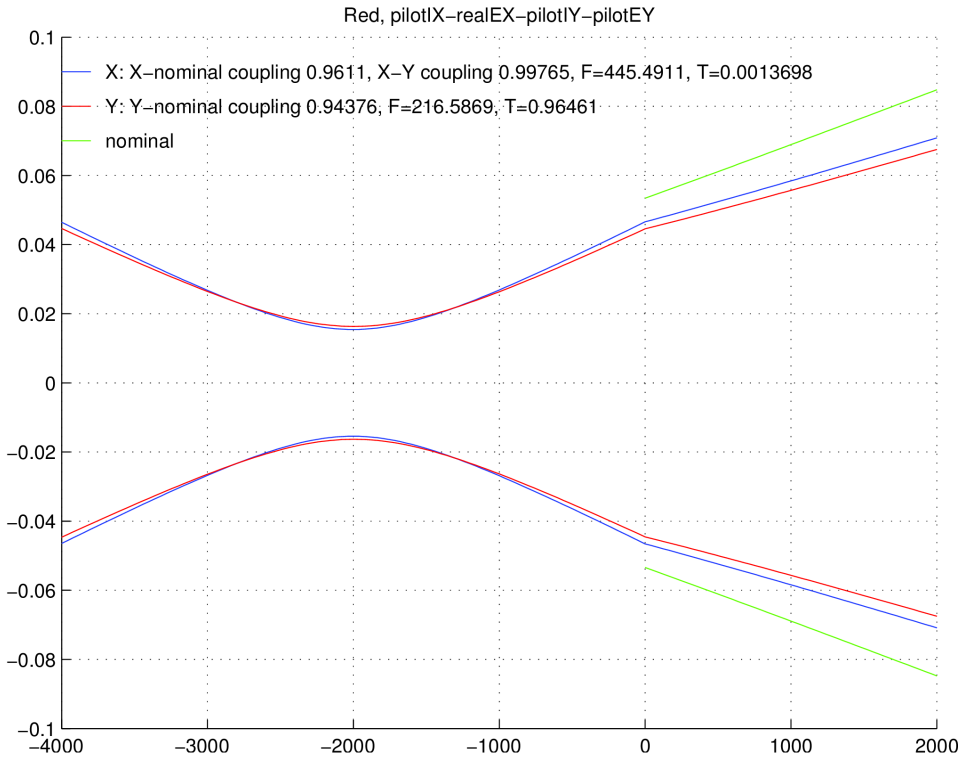
X: X−nominal coupling 0.9611, X−Y coupling 0.99959, F=445.4911, T=0.0013698
Y: Y−nominal coupling 0.95333, F=451.9909, T=0.0013898
nominal
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
−4000
−3000
−2000
−1000
0
1000
2000


Green, pilotIX−realEX−pilotIY−pilotEY
X: X−nominal coupling 0.96189, X−Y coupling 0.99767, F=102.422, T=0.52879
Y: Y−nominal coupling 0.94469, F=315.7553, T=0.96336
nominal
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−4000
−3000
−2000
−1000
0
1000
2000


Red, pilotIX−realEX−pilotIY−pilotEY
X: X−nominal coupling 0.9611, X−Y coupling 0.99765, F=445.4911, T=0.0013698
Y: Y−nominal coupling 0.94376, F=216.5869, T=0.96461
nominal
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
−4000
−3000
−2000
−1000
0
1000
2000