Report on the requirement of BS RoC error

Kentaro Somiya

July 17, 2012

1 Overview

We are about to order a beamsplitter (BS) for bKAGRA. This report gives the requirement of the surface error of the BS according to the simulation results of higher order spatial modes at the dark port before the OMC.

2 Calculation result

As is shown in JGW-G1200928, the OMC can suppress the second order mode, the largest of the higher order modes (HOM), by up to $\sim 1/8000$ and other higher order modes by at least $\sim 1/200$. Here we compare the TEM00 DC light without the offset for DC readout; namely it is mainly the light due to the reflectivity imbalance that comes down to the dark port. With the offset, the TEM00 light will increase by a factor of 2.3 at most. The HOM should be less than 0.5 % of the TEM00 light with the offset in order not to increase shot noise. Therefore, the requirement of the ratio from the second order modes to TEM00 light without the offset at the dark port will be $40 \sim 90$ in power and that from the other HOM to TEM00 will be $1 \sim 2$.

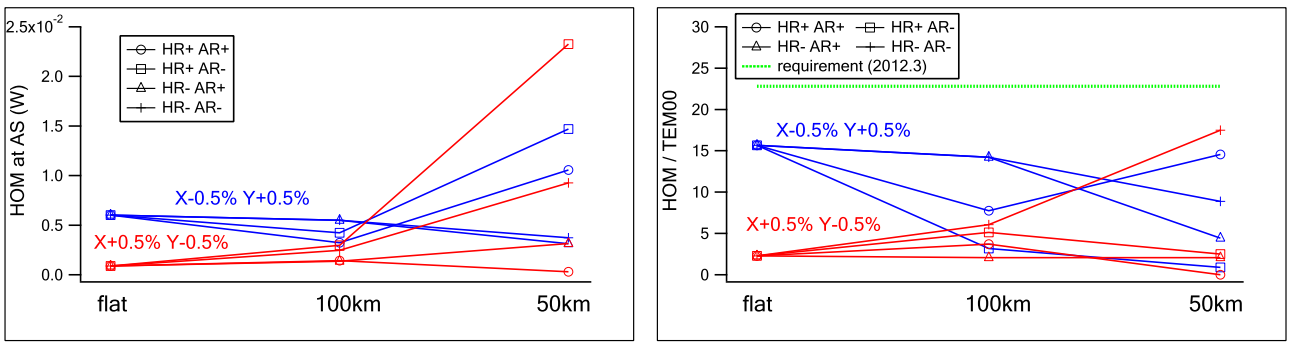

Figure 1: *Left:* Higher order modes at the dark port in power. *Right:* Ratio from the HOM to the TEM00 carrier light in power. The ITM and ETM RoC errors are set 0.5 %.

Figure 1 shows the higher order modes at the dark port of KAGRA. The left panel shows the light in power and the right panel shows the ratio to the TEM00 carrier light without the offset. The BS radius-of-curvature (RoC) errors can be both positive (convex HR and concave AR), both negative (concave

HR and convex AR), or one positive and one negative. Each curve with a different marker indicates each combination of the RoC errors. There is an imbalance between the result for positive error in ITMx (ETMx) and negative error in ITMy (ETMy) and the result for the errors vice versa, which would be due to various reasons including Schnupp asymmetry, finesse imbalance, loss imbalance, etc. The worst case appears to be that with positive ITMx (ETMx) and negative ITMy (ETMy) together with the BS error of concave HR and convex AR. This, however, still satisfies the requirement. The dashed line in the right panel shows the requirement set in JGW-G1200928 for the second order mode. The OMC can do a little better but let us keep this line as the requirement in this report.

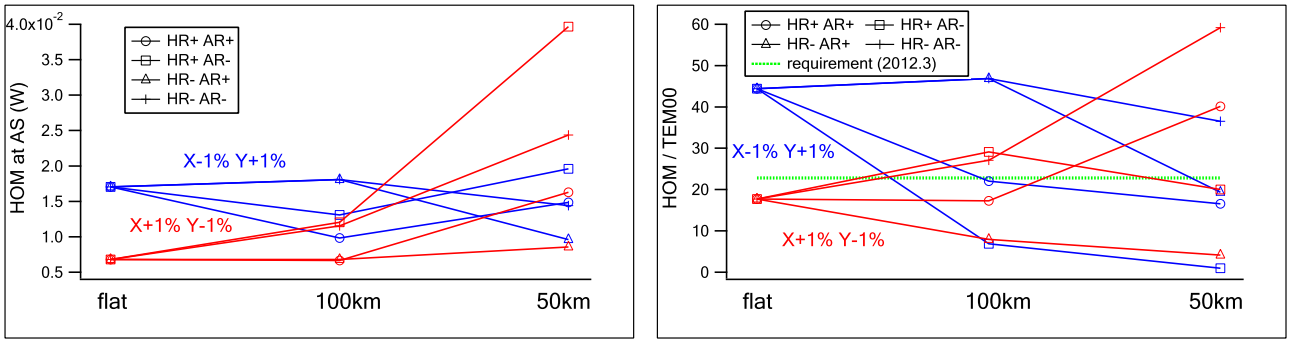

Figure 2: *Left:* Higher order modes at the dark port in power. *Right:* Ratio from the HOM to the TEM00 carrier light in power. The ITM and ETM RoC errors are set 1 %.

Figure 2 shows the higher order modes in the case the test mass RoC errors are ±1 % instead of ±0.5 %. The requirement set above cannot be satisfied even without any BS surface errors.

3 Conclusion

Provided that the ITM/ETM surface accuracy is set within ±0.5 %, the BS surface requirement will be ±100 km or better. Looking at the ratio to the TEM00, the requirement could be ±50 km, but the HOM power itself increases remarkably when the error goes from ±100 km to ±50 km and it may cause a problem. The result with the 100 km error does not seem different from the one without any error on the BS surface.

Appendix: FINESSE simulation

We use FINESSE to calculate the HOM. We do the calculation up to the 7th order (namely up to the 6th order). There are some technical remarks to be mentioned here.

First, the surface error causes phase shift in the TEM00 light. We manually fix the error for MICH, PRCL, and SRCL by tuning the microscopic phase of the length. During the calculation, ETMs are removed to avoid the confusion with the arm errors.

Second, since we take into account a limited number of the HOM it is important to set a proper reference that determines the cavity mode. While the arm reference is set with each arm cavity, the

recycling cavities should be set with mirrors without the ITM differential errors or Schnupp asymmetry. The reference for the output light is set with a proper dummy OMC.

Namely we do the following tuning for each point in the plots:

(i) add RoC errors

(ii) tune MICH phase to minimize the light at the dark port

(iii) tune PRCL phase to maximize the power in the arm cavity

(iv) tune SRCL phase to maximize the 3 kHz signal field at the dark port (the ad command is used).

The offset to each control signal for the phase tuning is shown in the table below:

X/Y	+0.5%/-0.5%	+1%/-1%	-0.5%/+0.5%	-1%/+1%
Flat BS	0.16 mdeg	0.18 mdeg	-0.12 mdeg	-0.2 mdeg
HR+100km/AR+100km	8.2 mdeg	-0.55mdeg	25 mdeg	33 mdeg
HR+100km/AR -100km	92 mdeg	50mdeg	170 mdeg	210 mdeg
HR -100km/AR+100km	120 mdeg	140mdeg	11 mdeg	4.2 mdeg
HR -100km/AR -100km	24 mdeg	30mdeg	11 mdeg	4.1 mdeg
HR+50km/AR+50km	63 mdeg	44mdeg	96 mdeg	110 mdeg
HR+50km/AR -50km	560 mdeg	490mdeg	700 mdeg	770 mdeg
HR -50km/AR+50km	280 mdeg	300mdeg	210 mdeg	180 mdeg
HR -50km/AR -50km	69 mdeg	77mdeg	48 mdeg	37 mdeg