COMPARATIVE ANALYSIS OF DIFFERENT ELECTRO-OPTICAL INTENSITY MODULATOR CANDIDATES FOR THE NEW 40 GHz BUNCH ARRIVAL TIME MONITOR SYSTEM FOR FLASH AND EUROPEAN XFEL#

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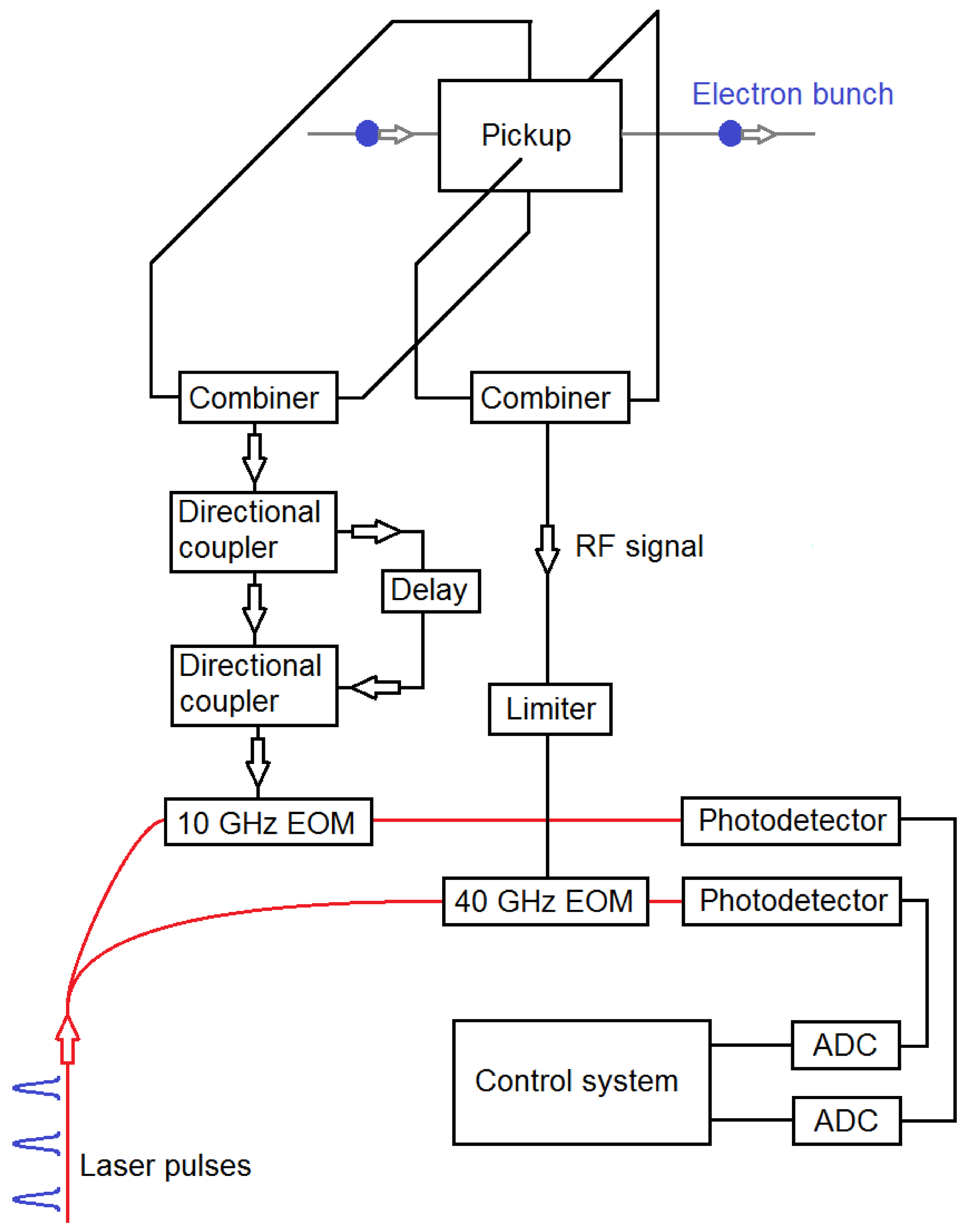
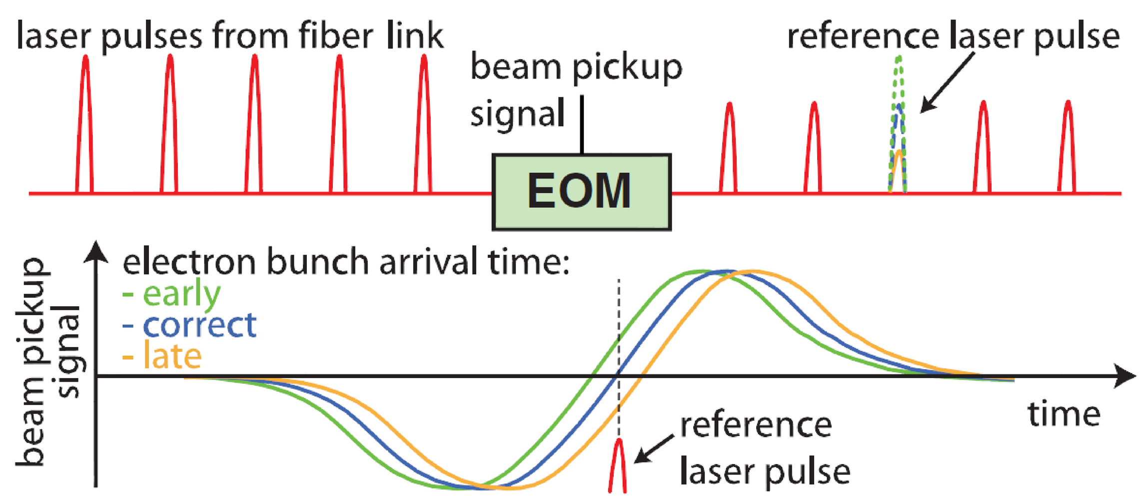
Introduction

The currently installed Bunch Arrival time Monitors (BAMs) at the Free electron LASer in Hamburg (FLASH) achieved a time resolution of less than 10 fs for bunch charges higher than 500 pC. In order to achieve single spike FEL pulses at FLASH, electron bunch charges down to 20 pC are of interest. With these BAMs the required time resolution is not reachable for bunch charges below 500 pC. Therefore, new pickups with a bandwidth from DC up to 40 GHz are designed and manufactured. The signal evaluation takes place with a time-stabilized reference laser pulse train which is modulated by an Electro-Optical intensity Modulator (EOM) in dependency on the pickup signal. The new high bandwidth BAM system also requires new high bandwidth EOMs for the electro-optical frontend. The available selection of commercial EOM candidates for the new frontend is very limited. Furthermore, the EOMs are designed for cw laser, however the BAM system use a pulsed laser with a peak power in the order of 100 W.

Arrival time measurement at FLASH



Short bipolar RF signals from the pickup are directed to the EOMs. The EOMs additionally receives laser pulses from the synchronization system.

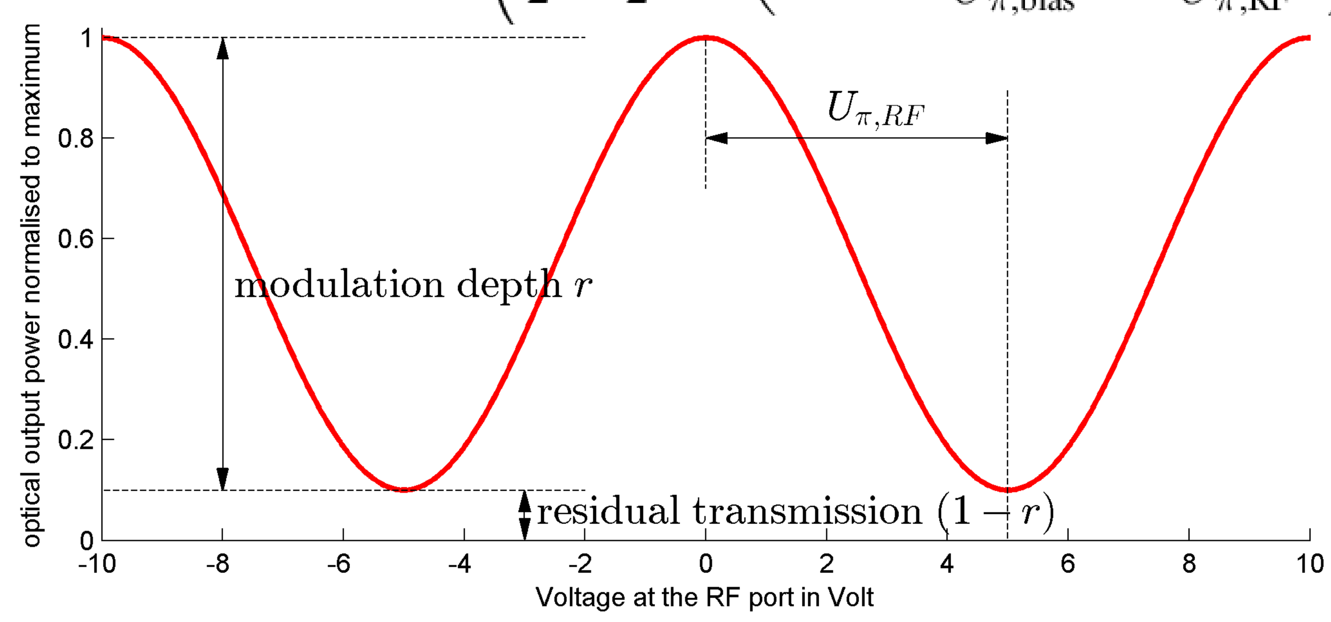


The EOM modulates the laser pulses in dependency of the timing between laser pulses and RF signal.

Mathematical description

The optical modulation of the EOM can be described with:

$$M_{\text{signal}} = (1-r) + r\left(\frac{1}{2} + \frac{1}{2}\cos\left(-\delta_0 + \frac{\pi U_{\text{bias}}}{U_{\pi,\text{bias}}} + \frac{\pi U_{\text{RF}}(t)}{U_{\pi,\text{RF}}}\right)\right)$$



The time shift between the reference laser pulse and the arrival time of the electron bunch can be calculated with:

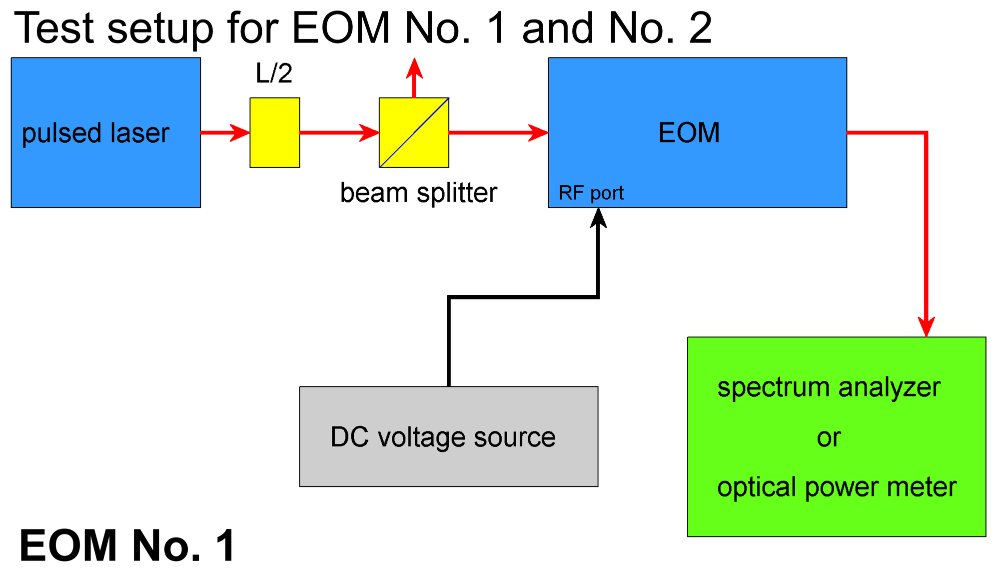
$$U_{\text{RF}}(t) \approx S t_{\text{shift to reference}} \quad \text{with} \quad t_{\text{shift to reference}} \ll \text{RF pulse duration}$$

$$t_{\text{shift to reference}} = \frac{\arcsin(\frac{2M}{r})}{2K} \underset{\text{Taylor}}{\approx} \frac{M}{Kr} + \frac{2M^3}{3Kr^3} + \cdots \quad \text{with} \quad K = \frac{\pi S}{2U_{\pi,\text{RF}}}$$

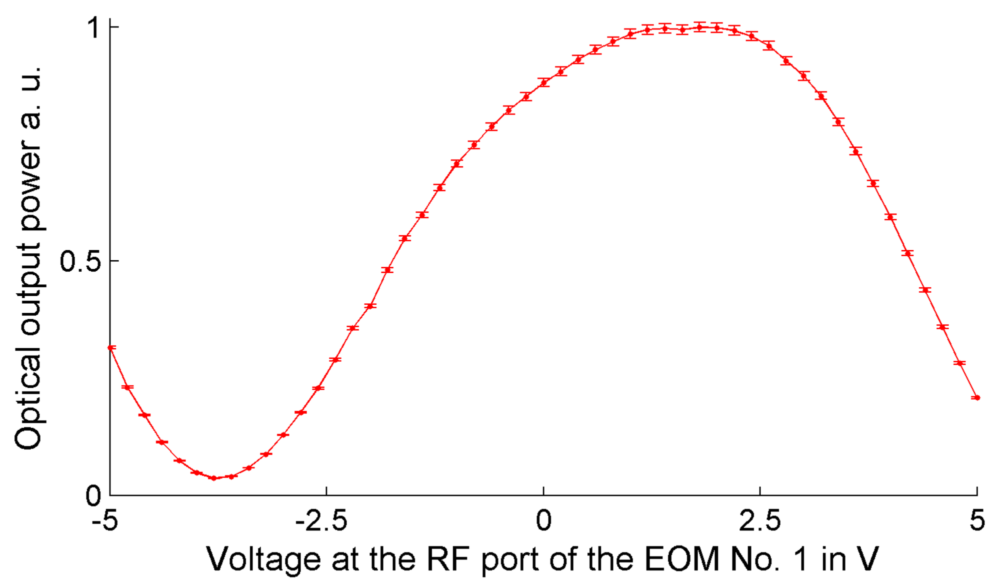
The accuracy of the time measurement is estimated to: $\Delta t \approx \frac{\Delta M}{Kr} = \frac{2U_{\pi,\text{RF}}}{\pi S r}\Delta M$

Measurement

Test setup for EOM No. 1 and No. 2



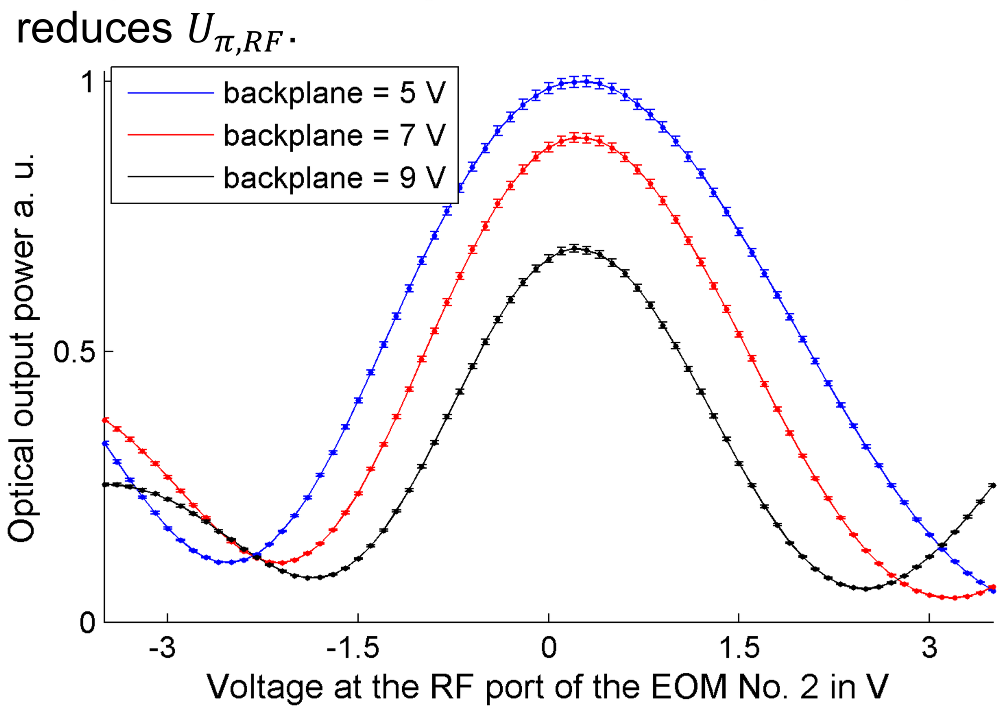
EOM No. 1



$U_{\pi,RF}$ from EOM No. 1 is calculated to 5.4 V. The modulation depth is 96.4 %

EOM No. 2

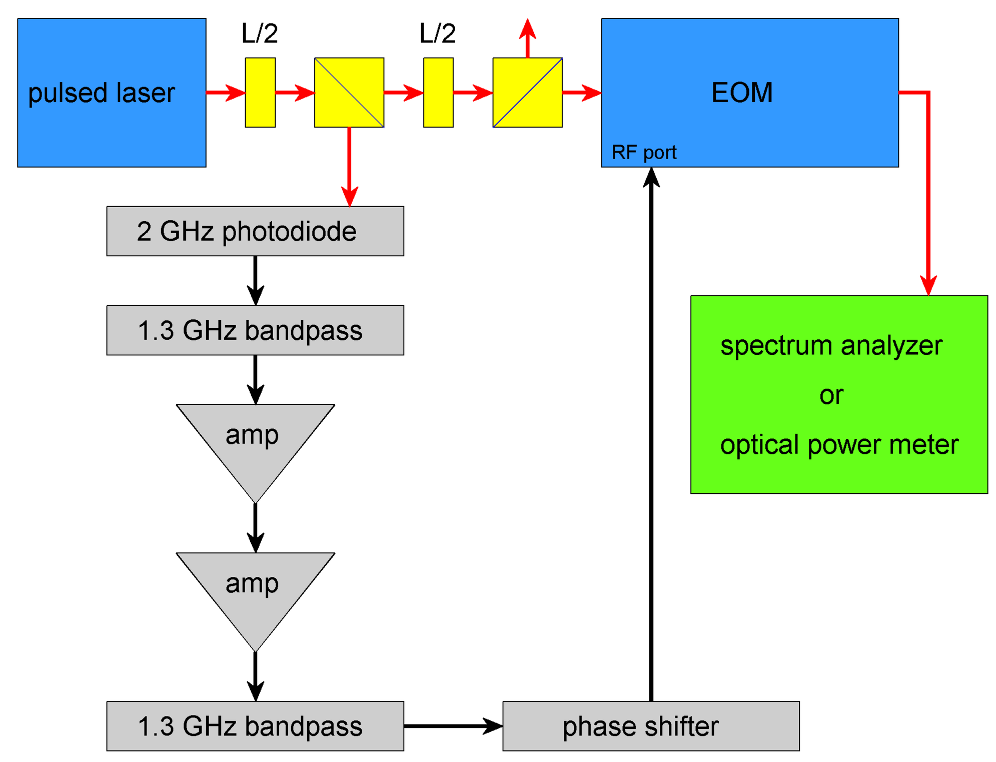
The control of EOM No.2 is more complex. Also this EOM has an additional port for the backplane. A voltage at the backplane port reduces $U_{\pi,RF}$.

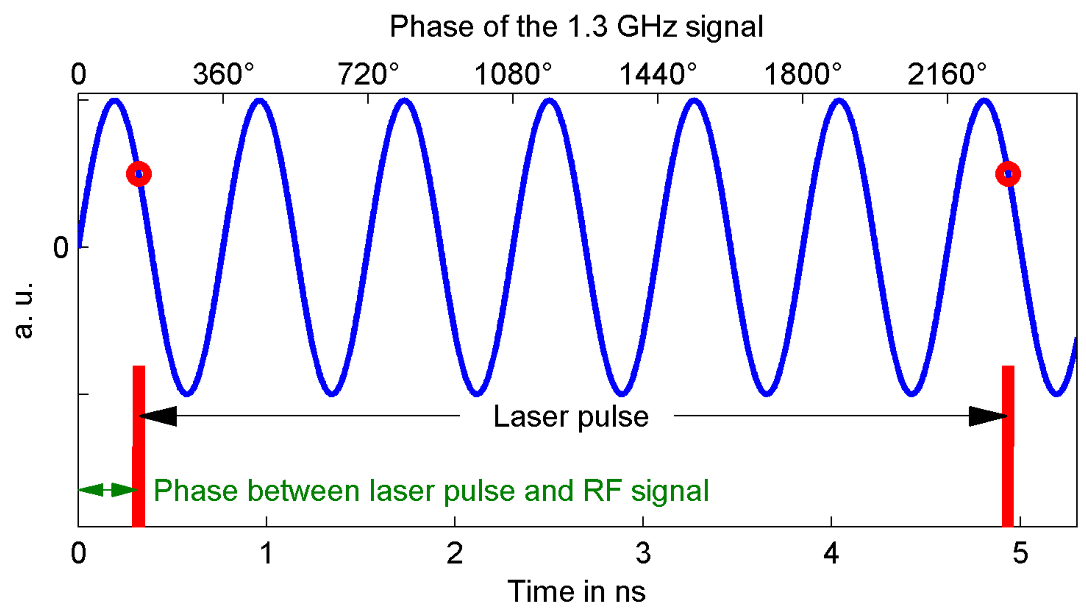


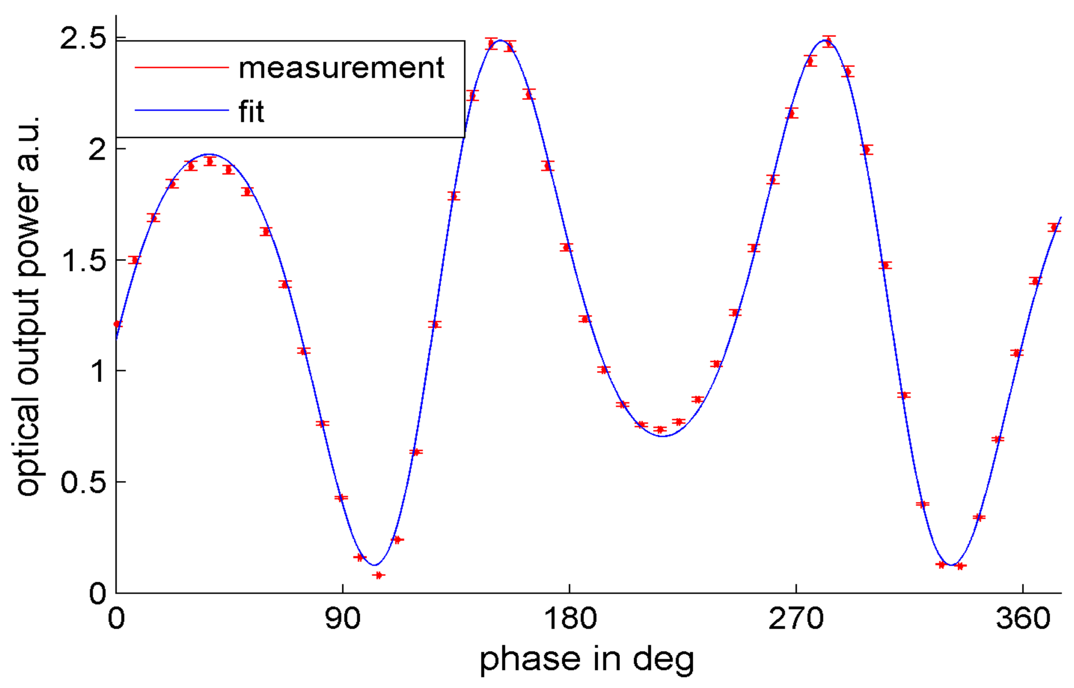
The modulation is not symmetrical. The smallest $U_{\pi,RF}$ is 2.1 V (on the neg. side). The best measured modulation depth is 94.9 % (on the pos. side)

EOM No. 3

This EOM indicates a high-pass characteristic at the RF port. The DC voltage source has changed to a 1.3 GHz source.







The fit result indicates a $U_{\pi,RF}$ with 2.96 V and a modulation depth of 95 % (on the pos. side)

Results & Outlook

	EOM No. 1	EOM No. 2	EOM No. 3
active optical material	$LiNbO_3$	InP	polymer
$U_{\pi,RF}$	5.4 V	2.1 V – 3.2 V	2.96 V
insertion loss @ 5mW	4.8 dB	19.2 dB	8.7 dB
bandwidth (3 dB point)	20 GHz	> 33 GHz	> 30 GHz

The EOM No. 3 is the most suitable candidate for the BAM system. The next steps are to install this type of EOM in the new electro-optical front end of the BAM system and testing the performance with low bunch charges at FLASH.

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