

# TWO-WAY AMPLIFICATION FREE ELECTRON LASER OSCILLATOR

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## Abstract

A schemes which increase round trip gain of free-electron laser oscillators with keeping rather high saturation power is proposed. In this schemes, laser beam interact with electron beam both in forward passage and backward passage in a wiggler during its round trip in a optical cavity. The small signal gain of this scheme is square of usual free-electron laser system.

## Introduction

The most of the free-electron laser(referred to henceforward by FEL) projects operated or proposed employ linacs as sources of electron beams. But the start up time of FEL to the laser power of interest are estimated few to tens micro-seconds which is comparable to the duration of the macro-pulse of the usual pulse operated linacs. So, the high gain at the stage of start up, which is also the small signal gain regime, is necessary to get to the saturation power rapidly and to increase the average power of FEL.

The small signal gain of a usual free electron laser can be increased with the electron beam of the higher peak current and/or the longer wiggler. But the wiggler length is limited by several effects. The energy spread and emittance of a electron beam diffuses the bunching of electrons of the scale of the laser wave length caused by FEL interaction and the slippage between the electron micropulse and the light pulse, which is caused from the difference of the speeds of the electrons and the laser pulse, also limit the interaction time which is the duration of the overlapping. And the increase of the transverse size of light by its diffraction in a wiggler also limits the wiggler length to avoid the interruption of the light pulse by the wiggler magnet poleface. And moreover the

long wiggler has the lower saturation power. In such a situation, the alternate scheme to get higher gain should be adopted.

## Two-way amplification FEL oscillator

To get more gain than usual FEL oscillator system, we propose a two ways amplification FEL oscillator. In usual FEL systems, the light pulse is amplified once in its round trip motion in the optical cavity. In this scheme, using an constant wiggler, which is suited to get high gain at small signal region, the light pulse is amplified in both forward and backward passage in this wiggler during its back and forth motion in the optical cavity. It is expected that this scheme provides almost square of gain of usual one way FEL in the small signal gain regime and higher saturation power than the case with a long wiggler.

We examine two case of the possible realizations of this scheme. This scheme needs two electron beams running in opposite directions. To get these beam, case A uses two electron beams from two different accelerators and each beam drives FEL for the back and forth passages of the light respectively. In case A, tuning of energies and timing between these linacs is difficult and the cost for the accelerator is very expensive. Case B uses the isochronous beam transport system of 180° bending which recirculates the electron beam from the wiggler to re-inject to the same wiggler in the opposite direction. Case A and case B is in Fig. 1.

Isochronosity is required to keep the longitudinal length of the electron micro-pulse. Such isochronous 180° bending beam transport system was already exists for a kind of linac called 'Reflextron'[1,2] and its transport matrix is unit and its size is nearly half meter for 8 MeV electron. The transport system connecting the wiggler and this 180 deg

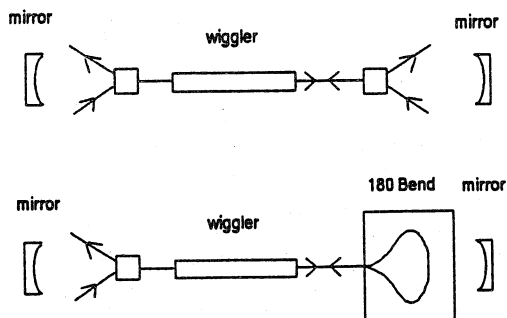


Figure 1: Schematic diagram for case A (upper) and case B(lower)

table 1

Parameter	Value1
Electron beam	
Energy	42.5
Energy Spread	1% (1/e full width)
Current	100 A
Emittance	$3 \times 10^{-6}$ m rad
Undulator	
aw(rms)	0.54
Wavelength	2.73 cm
Length	1.0 m
Optical	
Wavelength	$10 \mu\text{m}$
Mirror positon	-3.692, 3.226 m
Mirror curvature	-3.800, 3.350 m

bending system is easily designed such as two FODO cells with unit transport matrix. So if the focusing strengths of the wiggler for both transverse directions set to be equal and the electron beam size is matched to this focusing to keep its constant size in the wiggler in the forward passage, the electron beam size is also matched for the backward passage in the wiggler too.

### Numerical Experiment

The numerical experiment is done for a case of a infrared FEL similar to LANL with the parameter in table 1[3].

The calculation is made with the 3-dimensional code for a single longitudinal mode of the light, which is for the case with etalon, and a longitudinally uniform electron beam. It solve the paraxial equation for laser field using transverse Fourier expansion and is including betatron motions of electrons.

Fractional Gain at Low Power

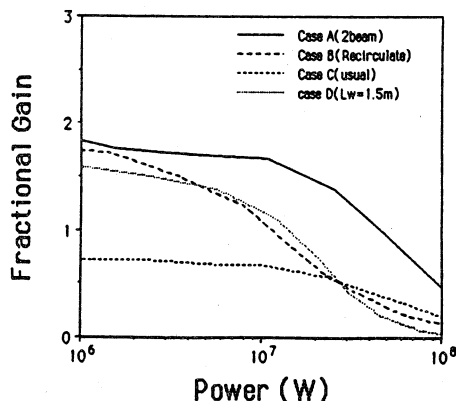


Figure 2: Fractional gain at small signal regime

In the calculations, the isochronous  $180^\circ$  bending system is treated as that the bunching of the electron beam caused from the FEL interaction is diffused out in it by the residual non-isochronosity and the path length difference due to its finite emittance. So the electron longitudinal distribution at the exit of the  $180^\circ$  bending system set to be uniform in this calculation.

The calculations are performed for case A, case B and case C which is the case of an usual FEL and for the comparison, case D which is the case of the usual FEL with 1.5m long wiggler which has the almost the same round trip gain at small signal regime as the case A and B.

The saturation power is defined as the power that the gain at that power is equal to the round trip loss of the cavity. In this case we set this loss few percent.

Fig. 2 shows the fractional gain, which is gain - 1, of those 4 cases in the small signal regime and Fig.3 shows the fractional gain at high power regime where the gain are small to be almost the same as usual cavity losses, which is the saturation power. Case A, which is with two different electron beams, has the higher gain and saturation power than case C, the usual system. Case B has also the larger small signal gain but less saturation power than case C but higher than case D, with the longer wiggler.

The small signal gain of case A and case B are almost square of the usual gain. About the fact that the saturation of case B is not

### Fractional Gain at High Power

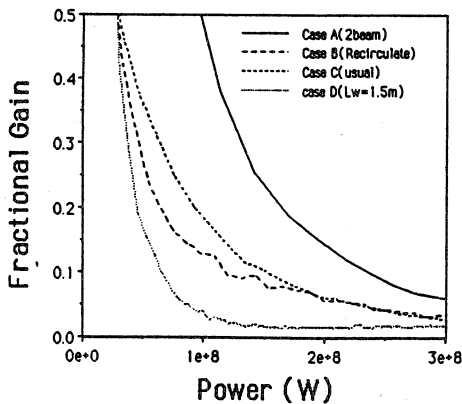


Figure 3: Fractional gain at high power regime

### Fractional Gain and Energy Spread

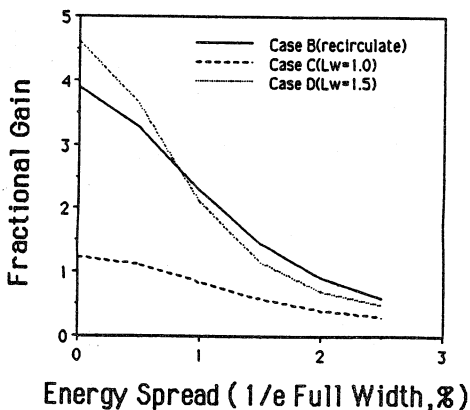


Figure 4: Fractional gain degradation with the increase of electron energy spread

the same as case A, the calculated data shows that the light power is absorbed in the backward passage so that the higher gain is necessary in the forward passage. This causes lower saturation power. This reduction is just like the saturation of the longer wigglers but the diffusion of the bunching in the  $180^\circ$  bend improve the absorption of the light energy compared with the case of a longer wiggler.

Fig. 4 shows the relation of the gain and the energy spread of the electron beam for the wiggler length 1m(case C), 1.5m(case D), 2m and case A. Case C, with the longer wiggler, shrink down rapidly than case B. So the two-way amplification.

### FEL in High Mirror Loss Region

This scheme have a good advantage compared with usual long wiggler systems, in the range of the light wave length where the mirror losses are so high that the high small signal gain device is necessary to get above the FEL oscillation threshold. The round trip gain in an usual system which has the FEL gain  $G_1$  and the mirror reflectance  $R$  is  $RG_1R$ , on the other hand in this scheme with the FEL gain  $G_2$  and the same reflectance of mirror, the round trip gain is  $G_2RG_2R$ . If  $R = 0.2$ , then  $G_1$  must be greater than 25 and  $G_2$  must be greater than 5, which is 5 times smaller value than the usual system to get to the threshold of the oscillation where the the round trip gain greater than 1.

### Conclusion

This scheme is shown to be effective to get higher small signal gain than the usual system and has the larger saturatoin power than the case to use longer wiggler to get the same high gain as this scheme.

### References

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