

PFC/JA-88-9

Suppression of Feedback Oscillations in Free
Electron Lasers

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March 1988

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This work was supported by the National Science Foundation and the Office of
Naval Research.

Submitted for publication in: IEEE Journal of Quantum Electronics

March 28, 1988

Suppression of Feedback Oscillations in Free Electron Lasers

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The suppression of feedback oscillations in a free electron laser (FEL) oscillator has been investigated. It is found, through numerical simulation, that a narrow attenuating strip inserted in a waveguide will not reduce FEL performance at the desired frequency and will attenuate feedback oscillations. Simulations are presented for a 5mm wavelength FEL with a 40dB attenuator inserted in the interaction region.

PACS numbers:42.55Tb, 52.75Mb

The free electron laser (FEL) is a promising source of high power microwave and millimeter wave radiation. Unlike klystrons and travelling wave tubes (TWT), the FEL is a fast wave device and is consequently not limited, by size constraints, to low power levels at high frequencies, and, unlike gyrotrons, the FEL is readily operated as an amplifier. As with any high gain amplifier, the FEL is subject to feedback oscillations, i.e. a small fraction of the output power is inevitably reflected back to the input, where it is then reamplified.

At microwave and millimeter wavelengths it becomes difficult to design input and output couplers with VSWRs less than 1.05. Consequently, gains above 30dB are difficult to achieve, and, at substantially lower gains, phase control is imprecise.

Feedback oscillations in the FEL have often been observed. For example, in one experiment [1] feedback oscillations were always observed when the wiggler magnetic field strength exceeded a threshold value. and these oscillations precluded gain measurements above 20dB. Feedback oscillations have also been used to measure FEL gain [2].

Feedback oscillations are suppressed in a TWT by placing an attenuator in the TWT helix. In this letter we numerically study the performance of an FEL in which a similar technique is employed. A strong waveguide attenuator is placed in the middle of the FEL interaction region (Fig. 1). In front of the attenuator, the interaction proceeds normally, and the signal injected into the FEL grows to some intermediate value. The attenuator then sharply attenuates the microwave signal. The signal is, however, quickly regenerated by the bunched electron beam, which passes undisturbed through the attenuator. Well past the attenuator the interaction once more proceeds normally.

Feedback oscillations are strongly suppressed because the microwaves reflected by the output coupler are strongly attenuated during their reverse passage through the system, but, because they are propagating counter to the electron beam, they are not regenerated by the electron beam.

The interaction is studied with a numerical simulation described elsewhere [3]. The simulation allows for a collective space charge wave on a finite radius beam, the transverse structure of the waveguide mode, three-dimensional wiggler fields, the axial guide magnetic field and the mildly relativistic electron beam. Three-dimensional effects are included by using

appropriately calculated input parameters and analytic expressions for the transverse electron motion. The simulation is one-dimensional and assumes that the signal propagates in the TE_{11} waveguide mode.

We simulate 30A, 1MV electron beam, guided by a 1000G axial magnetic field through a 2.5m long, 3.3cm periodicity helical wiggler. A 4dB/cm, 10cm long (40dB total) attenuator begins at $z = 90$ cm. One watt of 60GHz microwave power is injected. In Fig. 2, curve A, the FEL is operated at a low wiggler field. The gain is low and the signal is attenuated by almost 40dB between $z = 90$ cm and $z = 100$ cm. The FEL performance at high wiggler field and high gain is shown in curves B and C, which differ only in that the attenuator has been removed in curve C. It is evident from these curves that the main effect of the attenuator is localized to its immediate vicinity. The FEL saturates at the same power level, and as expected, the attenuator delays the saturation point by about 15cm. The growth rate away from the attenuator is largely unchanged. However, just after the attenuator, the growth rate is substantially enhanced, and the signal is diminished by much less than 40dB in the attenuator itself. This increased growth rate and reduced attenuation is due to the unusually strong FEL interaction that results from the strongly bunched beam.

The behavior of the FEL past the attenuator region is related to that in a transverse optical klystron [4] (TOK). In the TOK the beam is pre-bunched before it enters the interaction region. The growth rate of the FEL (or the harmonic emission rate) is enhanced by the pre-bunching at the optical wavelength. In the device described here, the prebunching occurs before the attenuator, and an enhanced growth rate is observed after the beam leaves the attenuator. This study differs from the TOK in more than one respect. For these parameters, unlike in the TOK, the influence of longitudinal space charge is not negligible and, furthermore, the radiation propagates in a waveguide mode. The electron beam bunching is accomplished entirely by the FEL interaction, prior to the attenuator, without the utilization of any dispersive magnets. Finally, while the motivation for the TOK configuration is to increase the FEL power output, the motivation for our attenuator is to suppress undesirable feedback oscillations.

Recent experimental studies of FEL performance with a prebunched electron beam have been performed [5] in the linear and nonlinear regimes. In these experimental studies, enhanced FEL growth is observed in the region

directly past a tungsten mesh which is stretched across the waveguide, near the middle of the interaction region.

Several surveys (not shown) demonstrate that the device behavior is not significantly changed by varying the attenuator position so long as the attenuator remains well within the linear gain region. As expected, if the attenuator is placed near the saturation zone, the output power is reduced. The device bandwidth is not substantially changed by the attenuator. The observed growth and loss rates near the attenuator are quite large in relation to the microwave wavelength (1/2 cm), consequently actual device behavior may be somewhat different than the performance predicted by the computer simulation.

In conclusion, the proposed attenuator should significantly reduce feedback oscillations without degrading the FEL performance.

This work was supported by the National Science Foundation and the Office of Naval Research.

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Figures

FIG. 1. Schematic of the FEL with an attenuator inserted in the interaction.

FIG. 2. Signal power is shown as a function of FEL interaction length. In curve A, the wiggler field is low and the electron beam is not strongly bunched before entering the attenuator region. There is almost 40dB of attenuation between $z = 90\text{cm}$ and $z = 100\text{cm}$. In curve B, the wiggler field is increased and the electron beam is strongly bunched before it enters the attenuation region. The total attenuation is reduced from 40dB and the growth rate is enhanced after the attenuator. Curve C is identical to Curve B except that the attenuator has been removed. Comparing Curves B and C shows that the attenuation in B delays saturation by about 15cm, but does not substantially reduce the saturated power level. The growth rate well past the attenuator in B is largely unchanged from that in C.

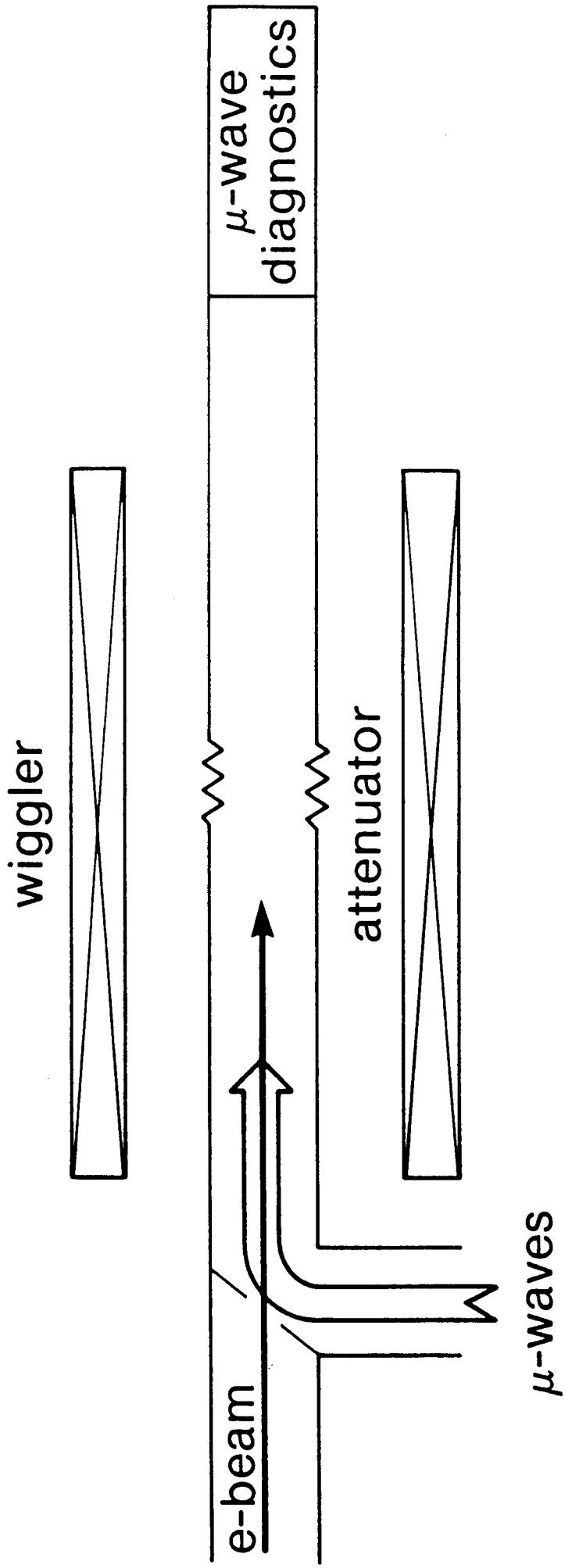


Fig. 1
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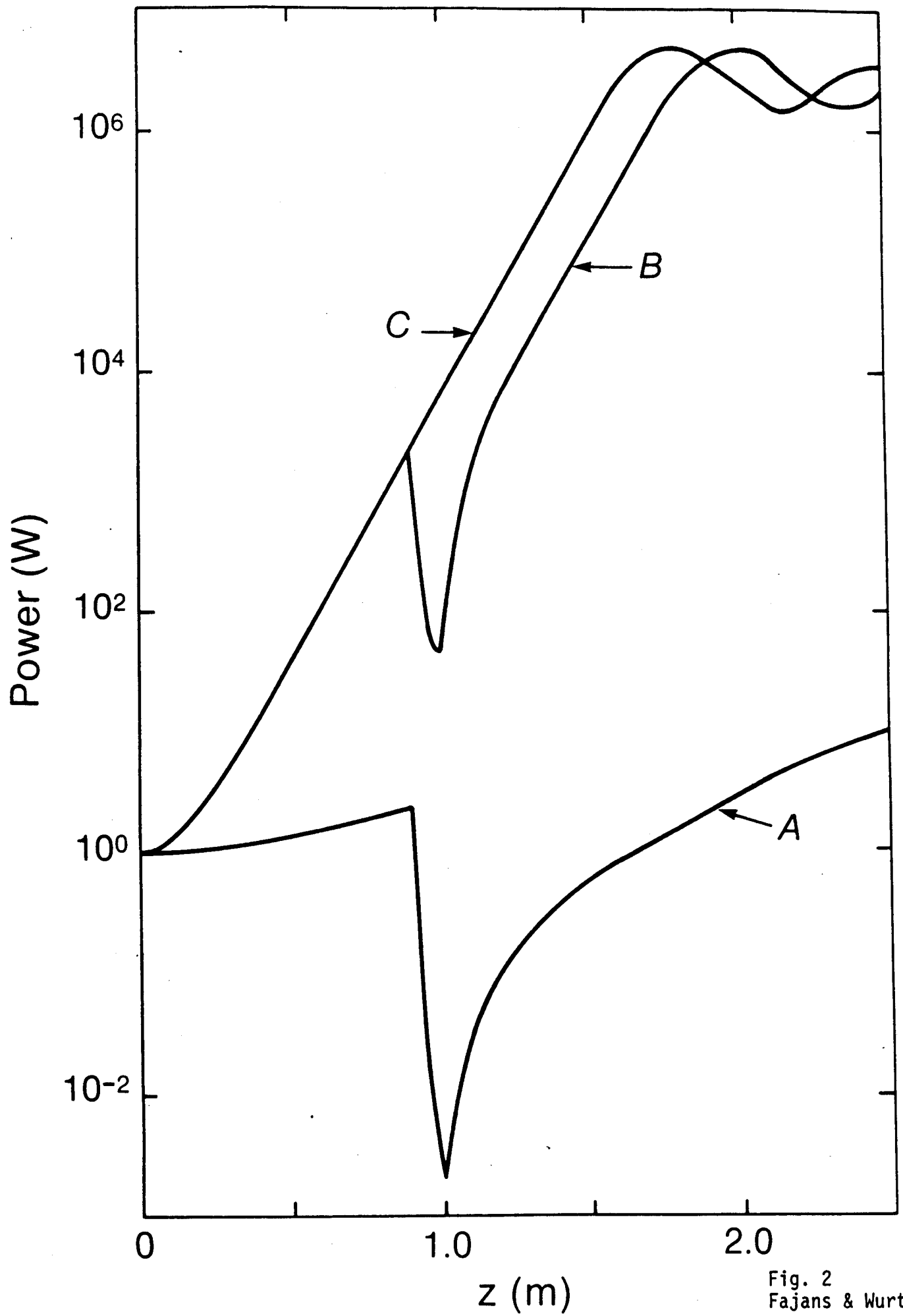


Fig. 2
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