Transit Time Isolation of a High Power Microwave Amplifier

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We report experimental results from a high power X-band traveling wave tube amplifier designed to eliminate sidebands due to reflections from its output. The amplifier has a very low energy velocity, such that the time it takes a wave to be reflected from the output to the input is of the order of, or greater than, the electron beam pulse duration. The bandwidth of the output spectrum is limited by the very narrow passband of the periodic structure. The amplifier has been operated at power levels of up to 160 MW at 9 GHz for pulse durations of 50 ns.

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The high power microwave requirements of the next linear collider (NLC) are very demanding, typically of order 200 MW per meter of acceleration structure. This is expected to correspond to a gradient of 100 MV/m for a pulse duration of more than 100 ns. The general trend in this area of research [1] is to expand beyond the S-band klystron to frequencies in the range 10–35 GHz. The main reason for this trend is that for a given accelerating gradient the necessary microwave power varies qualitatively as the inverse of the operating frequency squared ($P \propto f^{-2}$). Thus an increase by a factor of 3 in the frequency can lower the necessary power by 1 order of magnitude. This increase in the frequency is accompanied by a corresponding reduction in the physical dimensions of the klystron's cavities and drift region. This becomes a significant drawback when rf breakdown is considered. The smaller the volume of the cavity, for a given stored energy, the larger the electric fields and thus the probability of rf breakdown increases. This problem becomes acute in the extraction cavity.

In order to overcome this problem it is possible to replace the extraction cavity by a traveling wave structure, i.e., a disk loaded waveguide. Unlike the klystron where the cavities are electromagnetically isolated (by the drift region which is below cutoff) the traveling wave structure is a set of coupled cavities. In this case the beam-wave interaction is distributed along the entire interaction length whereas in a klystron it is limited to the close vicinity of the cavity.

The use of traveling wave amplifiers for the production of high power microwave radiation in the X band has been reported previously [2–5]. In a single stage amplifier, which consists of a section of corrugated waveguide, driven by a 0.85 MV, 0.8–1.6 kA, 100 ns electron beam, total power levels of up to 150 MW were measured. Beyond these power levels the system was noisy and prone to oscillation. In addition, for output powers above 80 MW the output spectrum showed the development of sidebands.

The coupling between the cavities also permits a backward electromagnetic wave to propagate. At very high gain this wave may cause the system to oscillate. To avoid the single stage oscillations, which are caused by the reflection of an electromagnetic wave from the output end of the amplifier to its input, a two-stage sever amplifier was developed. This device consists of two rippled wall waveguides isolated from each other by a sever, consisting of a lossy section of waveguide operated below cutoff. The space charge waves, which develop along the beam in the first stage, propagate through the sever whereas the electromagnetic mode is strongly (~25 dB) attenuated. In addition, the sever attenuates the reflected wave from the output end of the second stage, and prevents system oscillation due to feedback. With this device total power levels of up to 400 MW were achieved for beam currents of 0.8–1.2 kA and with an efficiency of more than 40%. Sidebands were observed at all output power levels in the two-stage amplifier, with the output spectrum extending over 300 MHz. The sidebands were asymmetrically located with respect to the input frequency and at the highest output levels carried up to 50% of the power.

In parallel with these experiments, theoretical analysis [6–9] has shown several interesting results: (i) As a result of the interaction process the energy spread of individual electrons can be as high as 60% of the initial beam energy, while the average energy of the beam is reduced by less than 10% [6]. (ii) When edge effects are included the pure electromagnetic transmission characteristics of a slow wave structure are dominated by reflections which cause a frequency dependent standing wave pattern. This results in waves of certain frequencies being preferentially transmitted, whereas others are partially reflected. The separation of the transmission peaks, $\Delta f$, is determined by the total length of the structure $d$ and the group velocity ($V_{gr}$) by the relation $\Delta f = V_{gr}/2d$. In the presence of an electron beam the peak value of the transmission coefficient increases due to the gain but the separation of discrete peaks remains unchanged. Consequently, the effective bandwidth of the interaction becomes narrower