Gain Saturation Measurements in CO_2, TEA Amplifiers[*]

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Measurements of gain in CO_2, TEA pulsed amplifiers operating at a pressure of 330 Torr are described. The energy gain in traversing a small amplifying section decreases to one-half the small-signal value at an energy flux density of 1.2 Jcm^{-2}.

The level of energy density in a single-pulse necessary to saturate the gain of CO_2, TEA pulsed discharges is of practical importance. Many devices for exciting large volumes of gas have been reported.[1,2] These devices will find use as amplifiers in order to achieve high output powers while maintaining acceptable mode control.

In defining the gain of TEA amplifiers, the energy gain per pulse is a useful concept. Experimentally, the energy per pulse as opposed to the power is the easier beam parameter to measure for CO_2, TEA discharges. Moreover, in theoretical analysis it is useful to consider a pulsed amplifier as storing a fixed amount of energy per pulse in the population inversion.

Helical-wound resistive-pin discharges were used for the gain investigations of this work. Both the oscillator and amplifier, shown in Fig. 1, were identically constructed using 1000-Ω resistive pins. Except for a closer spacing of the helices, the oscillator and amplifier are similar to helical configurations described by Beaulieu.[3] In addition to identical physical construction, the oscillator and amplifier were operated at the same pressure and electrically in parallel to assure identical, simultaneous discharges.

The helical configuration used with an internal aperture resulted in a reproducible well-defined beam of low divergence for the 370-cm-long oscillator. A typical output at 330-Torr pressure is shown in Fig. 2, which is the result of 10 consecutive pulses observed with a 77 °K Au-doped Ge detector. Oscillations in the tail of the pulse are electrical pickup and not part of the signal. The pulse consisted of a main peak of 0.2–0.3-μsec duration followed by a tail 2–3 μsec long. Measurements with a pyroelectric detector designed to measure pulse energy indicated the energy per pulse was nearly constant with a variation of less than 5% for over 80% of the pulses. Because of the reproducibility of the energy per pulse, differential techniques were not used in measuring the gain of the amplifier.

The energy density of the oscillator beam was increased by focusing with a long focal length mirror. A 6-m radius-of-curvature mirror provided a spot size of 3.8 mm diameter which varied by less than 10% along the amplifier length. The spot size was defined by placing an adjustable iris in front of the pyroelectric detector and measuring the aperture opening which caused the detected energy to fall to one-half the peak value. Finally, the input energy density to the amplifier was determined by dividing the input energy per pulse by the area of the spot size i.e., the input beam profile is assumed to be constant over the area of the spot size and zero elsewhere. To provide various energy densities, previously calibrated dielectrically coated germanium flats were used as attenuators for the oscillator.

Since the gain of the amplifier is a function of rotational transition, the spectral distribution of the oscillator was investigated. Data obtained with a spectrometer indicated the oscillator operated most of the time on a single rotational line, the $P(18)$. At other times smaller amounts of energy could be detected at the $P(16)$ and $P(22)$ lines. Because the maximum of the gain distribution occurs near the $P(18)$ line, the gain is nearly constant for lines adjacent to the $P(18)$. Consequently, the gain measured in this work is indicative of the P transitions with the highest gain and would not be significantly influenced by smaller amounts of energy at adjacent transitions.

The results of the gain measurements are given in Fig. 3 where the gain is defined as the ratio of the energy per pulse detected after the amplifier to before the amplifier with a slight correction for reflection losses in the NaCl amplifier windows. Data indicated by solid dots was taken with a pyroelectric detector and represents two measurements in which the optics, voltages, pressures, etc., were reset to the same experimental conditions. Data indicated by circles was obtained with a thermocouple power meter responding to average power at a repetition of 2 pps. The accuracy of the energy measurements and the beam-profile assumption are sufficient to enable the data of Fig. 3 to be of practical use in determining gain-saturation thresholds in TEA discharges. For the data of Fig. 3 the experimental conditions were the following: (a) a pressure of 330 Torr in both the amplifier and oscillator, (b) a discharge capacitor of 0.1 μF charged to 23 kV, and (c) a premixed gas mixture of 12% CO_2, 10% N_2, and 78% He by volume.

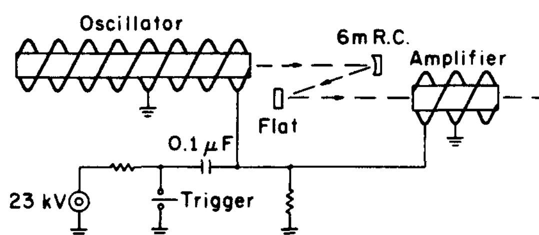

FIG. 1. Experimental apparatus for measuring gain, consisting of a 370-cm active length oscillator of 780 resistive pins and a 135-cm active length amplifier of 310 resistive pins.

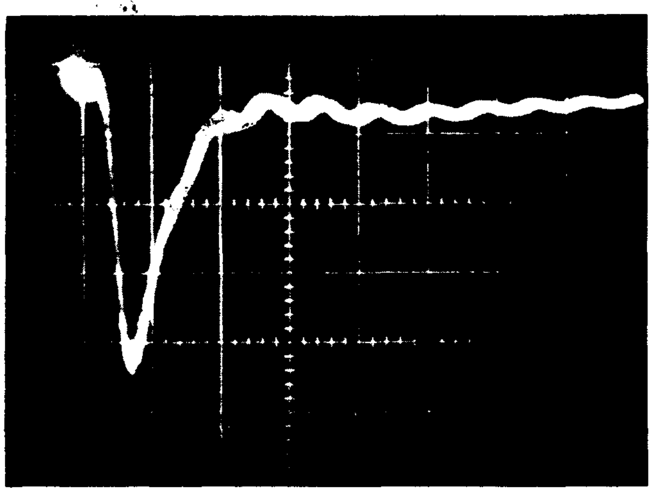

FIG. 2. Typical oscillator output consisting of 10 consecutive superimposed pulses. Horizontal scale is 0.2 μsec/div (negative signal).

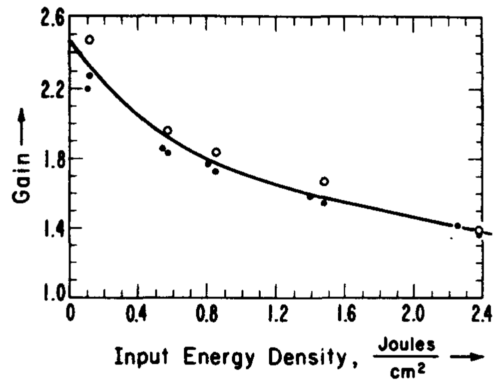

FIG. 3. Amplifier gain versus input pulse energy density for a mixture of 12% CO_2, 10% N_2, 78% He, at a pressure of 330 Torr.

Since the amount of amplification was relatively small, the saturation of the gain, is indicative of the saturation for a differential length of amplifier. The information on the actual population inversion or α, the gain coefficient which can be defined by

$$\text{gain} = e^{\alpha L}, \tag{1}$$

L is the length of the amplifier, can be obtained by plotting the logarithm of the gain in Fig. 3. In this manner, α is found to decrease by 10% from the small-signal value at a flux density of 0.21 J cm^{-2} while dropping to one-half the small signal value at 1.2 J cm^{-2}. These results are in agreement with a statement by Beaulieu that saturation was evident in the gain of 20-dB gain amplifier at 200 mJ cm^{-2}.[3]

Errors in the measurements due to diverging-lens effects in the amplifier discharge are negligible. Lens effects have been observed in helical-wound discharges.[3] By studying cavity geometries which resulted in stable oscillators using the entire oscillator-amplifier length as an oscillator, it was concluded the amount of divergence of the oscillator probe beam in transversing the 135-cm-long amplifier used in the measurements was negligible.

Calculations indicate the level of gain saturation measured in this work is greatly influenced by V-V energy transfer and rotational cross relaxation during the pulse. Using rate equations to calculate the energy density for saturation of a single rotational transition and assuming damping of the inversion only by the radiation field with no pumping occurring during the pulse yields a value of 4 mJ cm^{-2}, much lower than the measured value. Additional pumping by V-V collisions and rotational cross relaxation is occurring to help maintain the population of the levels involved in a single rotational transition. Fortin has shown the tail behavior of pulses like Fig. 2 can be attributed to the nitrogen content of the gas mixture.[4] Moreover, measurements by Moore *et al*. indicate the collision time for N_2–CO_2, V-V exchange is fast enough at the pressures involved to allow energy transfer during the tail of the pulse.[5]

Because of the cross relaxation effects, the level of saturation will depend on the pulse width. If the pulse width is very short, for example, a single mode-locked TEA pulse, the gain saturation would occur at a lower energy density than the 1.2 J cm^{-2} measured in this work. The results of this work are applicable to TEA amplifiers driven by pulses like Fig. 2 which are typical of TEA oscillators. Pulses of significantly different temporal shape would have different saturation characteristics.

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