IV-4. Generation of High-Power Nanosecond Pulses of Microwave Energy

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The subject of this paper is the generation and measurement of high-power nanosecond pulses of microwave energy. The technique involves the sudden release of energy stored in a standing wave in a linear resonator with a resultant gain in peak power over that used to charge the resonator. Alternative techniques using traveling-wave resonators[1] and other circuits[1,2] have not achieved equivalent power levels, and are inherently limited by greater losses, complex circuitry, and lack of power gain. The key to this technique is the ability to switch in less than a nanosecond by using a triggered high-pressure gas discharge gap. The apparatus was constructed for use at X-band frequencies to study breakdown of gases on a nanosecond time scale.

Pulse Generation Techniques. The resonant energy storage element consists of a straight length of waveguide, a coupling iris at the input and a normally open-circuit switch gap at the output as shown in Fig. 1(a). The operation consists of charging the resonator from a generator with a relatively long pulse and then releasing the energy by operating the switch from an auxiliary trigger discharge. The two components of the standing wave leave the resonator, forming a pulse whose length is twice that of the resonator and of time duration $2L/v_g$, where v_g is the group velocity. Pertinent characteristics of the generator, the relationship between the power gain,

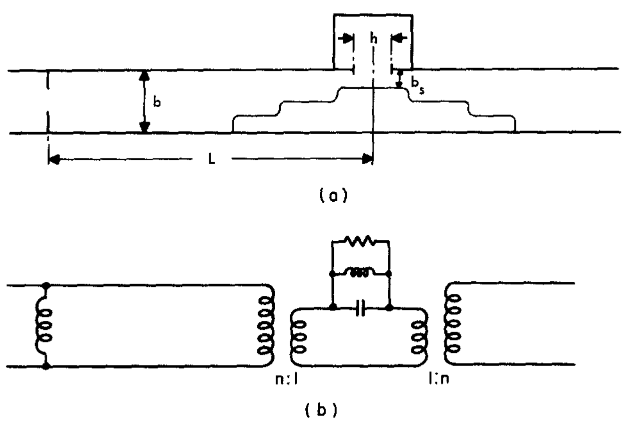

Fig. 1. Standing wave resonator. (a) Side view of waveguide. (b) Equivalent circuit.

the ratio of charging time to pulse length and coupling value of the iris, are shown in Fig. 2 for the case of critical coupling. (Higher values of coupling correspond to lower total losses and result in higher values of gain.) The efficiency can be deduced from the curves of constant efficiency.

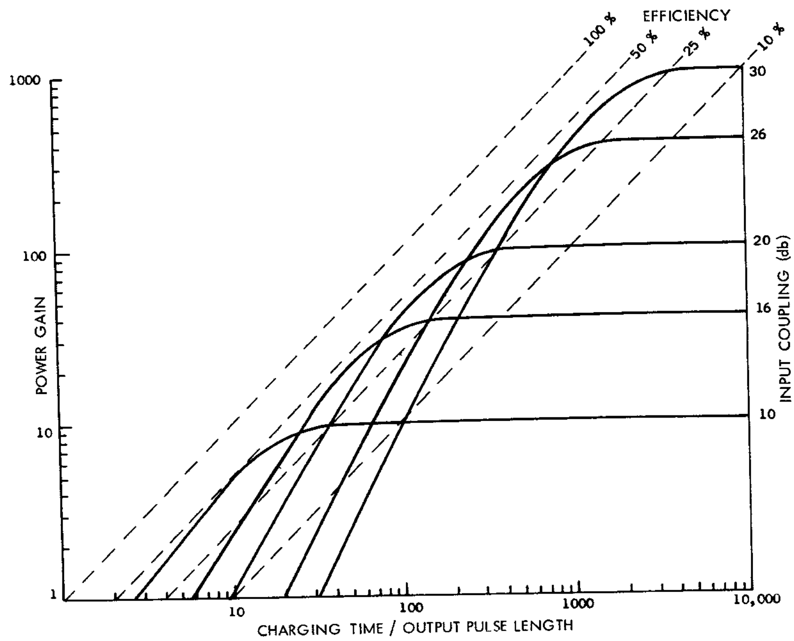

Fig. 2. Gain and efficiency characteristics of the nanosecond pulse generator.

Apparatus. The apparatus is constructed of WR 112 waveguide with the resonator nominally four feet long. At the operating frequency of 9 Gc, the optimum power gain is 10 db, which is consistent with the theoretical losses for the waveguide. The switch introduces negligible losses into the resonator circuit.

More details of the switch section are shown in Fig. 3. The normally open-circuit switch consists of a gap in the broad wall of the waveguide followed by a shorted tunable $\lambda/4$ length of TE_{11} circular waveguide. Although the details are not shown in Fig. 3, the structure is demountable so that the switching gap is removable. The trigger gap, which is essential, illuminates and initiates the main gap discharge. The reduced-height section of waveguide improves the effectiveness of the switch. One reason is that the greater currents result in a more intense discharge instead of less effective filamentary discharges. The switch is generally operated at pressures above an atmosphere. The reduced-height section also leads to an optimum condition for hold-off of the gap, because the gap field strength is related to the field strength of the forward wave in the main waveguide by:

$$E_g = \frac{\sqrt{bb_s}}{h} (2E),$$

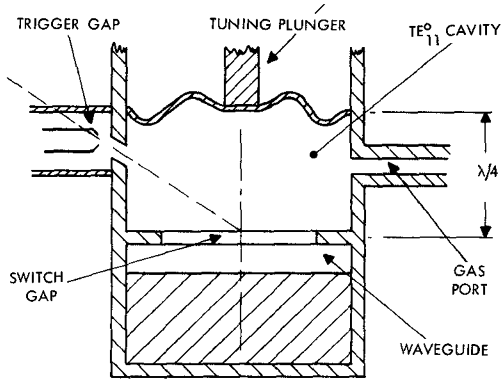

Fig. 3. Transverse section through switch and waveguide.

(see Fig. 1(a)). The limiting condition is that the height of the low impedance section be somewhat greater than the gap width.

A block diagram of the circuitry is shown in Fig. 4. The timing of the trigger discharge is set to occur near the end of the one microsecond charging pulse. The high-power pulse is viewed on a traveling-wave deflection oscilloscope by means of a broadband detector, a modified standard X-band detector. The two to three volts of signal required for the traveling-wave oscilloscope is obtained by using a high-voltage diode (MA 462) operating at a power level of about 10 milliwatts. The peak power

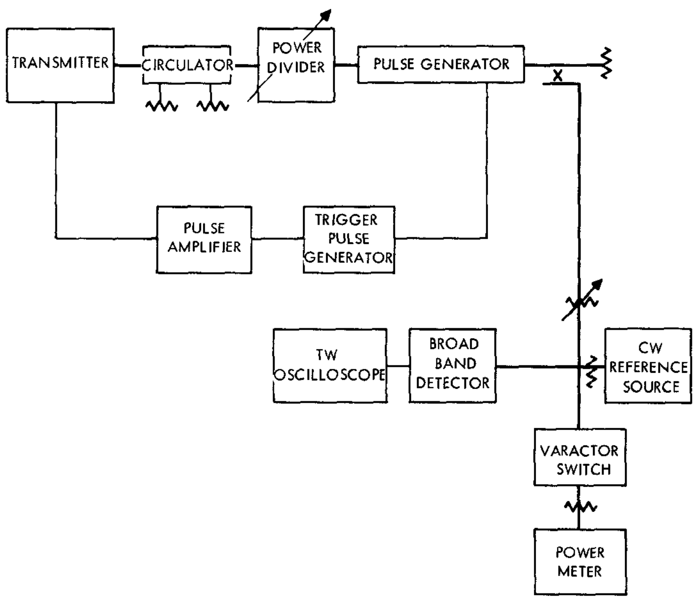

Fig. 4. Block diagram of nanosecond pulse generator.

measurement technique uses a varactor switch which operates rapidly enough to generate a 10 nanosecond reference pulse from an accurately determined CW source. The unknown pulse is compared to the calibrated pulse in the detector by using the magic tee shown in Fig. 4. A broadband precision calibrated attenuator is used in setting the level of the unknown pulse.

Results. A typical waveform of the high power pulse is shown in Fig. 5 on two different time scales. The pulse rises to its peak value in approximately 1 nanosecond; however, it is believed that this is due to the detection circuitry rather than to the switching action. At the end of the pulse,

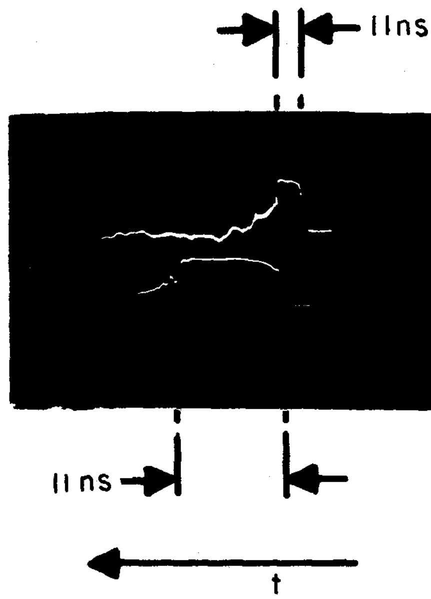

Fig. 5. Waveform of a nanosecond output pulse.

there is an initial rapid fall and then evidence of the switch recovering. The trailing edge of the pulse could be improved by adding a second switch across the output waveguide. Because of the rapid switching action, there is no difficulty in generating pulses as short as two nanoseconds by this technique. The maximum value of peak power generated is approximately one megawatt when using pressures of 40 pounds per square-inch gauge.

A very important factor for proper switching is the intensity of the trigger discharge. While the energy is being stored, the gap must hold off the full field strength and then, in less than a nanosecond, the intense trigger discharge must lower the breakdown threshold of a gap by more than a factor of two. The effectiveness of the trigger is indicated by the fact that it is possible to operate at a given pressure while varying the input power level by a factor as great as 10: 1. Air was the most successful gas for switching, and the switching gaps could be used for weeks without deterioration.

Conclusions. The technique described is a practical one for generating nanosecond pulses of microwave energy with large values of peak power and very short pulse duration. Pulses of this nature have not been obtained previously. Since the switching times are so unusually fast, it would be important to study the switching phenomena in more detail in order to more fully understand it.

ACKNOWLEDGMENT

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