signal is 8 times that of the input signal, but the frequency is unchanged. A reiteration of this process produces the phase multipliers 64 and 512.

DISCUSSION

The phase multiplier is intended to be used with phase meters for which the input signal amplitudes are unimportant.[3] Hence variations in gain of the multiplier are of no consequence except insofar as they may affect the phase shift within the multiplier. All gain stages are highly degenerative, so that this should not be a serious problem.

The chief limitations on the phase gain which may be effectively used are (1) the frequency and amplitude stability of the sources; and (2) the phase stability and rate of change of phase with frequency of the multiplier.

Clearly, nothing which may be done to the multiplier can improve the frequency stability of the sources. The source amplitude stabilities may be improved by interposing limiting amplifiers between the sources and the multiplier inputs.

The phase drift and "noise" were measured as follows: The inputs were paralleled and connected to a Hewlett-Packard model 200 CD oscillator set to 10 kc and 3 V rms. After an initial warmup of 1h, the phase angle of the multiplier output was monitored by means of a recording phase meter.[3] The short-term (1 min) phase "noise" was approximately 0.01° peak-to-peak, and the long term drift (1 h) was 0.03° peak-to-peak, both referred to the multiplier input.

[3] Type 405 Phasemeter, Ad-Yu Electronics Laboratory, Inc., 249 Terhune Avenue, Passaic, New Jersey.

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Silicon-Controlled-Rectifier Long-Pulse Driver for Injection Lasers*

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A pulser capable of driving injection lasers with long pulses (>30 μsec), high duty cycle, and currents of up to 20 A has been designed and operated. Higher currents may be obtained by increasing the power capabilities of the circuit components. Special features of the pulser are its low cost, simplicity of construction, and laser overload protection.

IN the experiments performed at this laboratory, a laser pulser supplying relatively long pulses of high current at a high duty cycle was required. Since most of the pulsers available for driving semiconductor lasers provide rather short pulses (<1 μsec), an inexpensive pulser based on a silicon-controlled-rectifier (SCR) multivibrator circuit[1] was designed to meet these requirements. The laser pulser has been used to drive both MIT Lincoln Laboratory and General Electric GaAs injection lasers.[2] The supply will provide pulse lengths from about 30 μsec to 1 sec (Ref. 3) with duty cycles as high as 100%. Although similar to the standard commutation circuit pulse shape (which is asymmetrical rather than square), the precise shape of the laser current pulse will depend upon the particular values assigned to circuit compontents L1 and C2 (see Fig. 1). Increasing the values of these components provides a rounder but more symmetrical pulse shape. Since these components affect only the beginning and end of the pulse, however, pulses greater than about 100 μsec appear essentially square. Currents of about 20 A have been obtained with the particular unit shown in Fig. 1, but it is an easy matter to increase this current by increasing the power capabilities of the curcuit components. A protection circuit was incorporated in the pulser to prevent damage to the laser in the event of a circuit failure. A small unit pulser, such as the General Radio 1217B, is required to drive the SCR pulser. Laser current pulse length and repetition rate are regulated directly by the controls on the unit pulser, while laser current amplitude is controlled by the Variac (T1). The three constituent blocks of the pulser (dc power supply, commutation circuit, and protection circuit) are indicated in Fig. 1. The cost of the pulser is approximately $100.

The pulse length setting on the unit pulser must be

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[1] For the standard SCR multivibrator circuit and its operation, see F. W. Gutzwiller, *Silicon Controlled Rectifier Manual* (General Electric Company, Auburn, New York, 1964), 3rd ed., pp. 78, 111.
[2] In an experiment to detect the double-quantum photoelectric effect in sodium metal [M. C. Teich, J. M. Schroeer, and G. J. Wolga, Phys. Rev. Letters **13**, 611 (1964)], pulses of 35 μsec duration at a repetition rate of 2 kc were used to drive an MIT Lincoln Laboratory GaAs laser (at 77°K). A General Radio 1217B unit pulser was used to drive the SCR pulser.
[3] The upper limit depends only on the maximum pulse length capability of the unit pulser used to drive the SCR pulser. The General Radio 1217C provides pulses of up to 1 sec in duration.

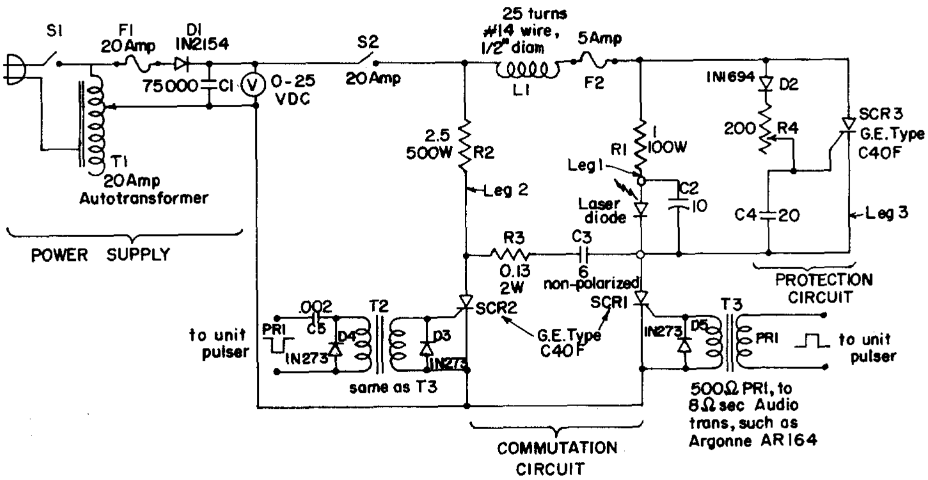

FIG. 1. Schematic diagram of the SCR laser pulser. The three constituent blocks (dc power supply, commutation circuit, and protection circuit) are indicated. All resistors are wire-wound, and values are given in ohms. Capacitors have a minimum working voltage of 25 V dc, and values are given in μF.

above a certain minimum value in order for the SCR pulser to operate. The lower limit on pulse length is governed by the value of commutation capacitor C3 (in conjunction with R1 and R2). However, if the capacitance is below a critical value (which depends on the individual circuit), the circuit will not commutate at all. We have found 6 μF a suitable commutation capacitance for our pulser, providing a minimum pulse length of 30 μsec. For best operation, the dc resistances of legs 1 and 2 of the commutation circuit (see Fig. 1) should not differ too greatly. Circuit elements L1 and C2 were inserted to reduce the current spike which typically occurs at the end of each pulse in a multivibrator circuit. Resistance R3 was inserted to minimize transients. Small transformers were used to couple power from the unit pulser to the SCR gates. Capacitor C5 combined with the transformed secondary impedance of transformer T2 (about 2500 Ω) form a pulse differentiator, which when combined with diode D4 insures that SCR2 is properly triggered at the end of the unit pulser input pulse.

The protection circuit operates by integrating the signal appearing across the laser. After a specified time delay (determined by the capacitance C4 and the protection potentiometer R4), SCR3 will be triggered thereby shunting the laser. Because the resistance of this leg (leg 3) is low, a very heavy current will be drawn, causing fuse F2 to blow quite rapidly. Thus, if for any reason, current flows through the laser for a time longer than that prescribed by the setting of R4, current to the laser will be cut off. The value of F2 should be just above the *average* laser current. Protection resistance R4 should be adjusted such that the time to trigger SCR3 be longer than the pulse length but shorter than the damage time to the laser. For the operation at pulse lengths longer than several hundred microseconds, it might be necessary to increase R4, C4, or both.

The components employed in our pulser were used because of their ready availability. The particular values used in our supply are those specified in Fig. 1; some of these (especially the small diodes) are not critical. The capacitors used for filtering (C1) were as large as could conveniently be obtained. Even with these large capacitors, a small amount of ripple remained giving rise to a 60 cycle modulation of a few percent on the light output from the laser. This may be eliminated, if desired, by the insertion of a very low resistance choke (we used a 20 mH iron core inductor having a dc resistance of 1 Ω) in a standard π-configuration filter following the rectifier diode D1. This will reduce the ripple by a factor of 50, but necessitates a higher working voltage for the input capacitor. Capacitors of the large size used in the filter section invariably have low working voltages, and care must be taken not to exceed the stated value. In fact, the maximum current available to the laser in our unit was limited to about 21 A by the capacitor (C1) working voltage of 25 V. The maximum deliverable current may be increased by increasing the ratings of the various components in the pulser. A small viewing resistor (of approximately 0.05 Ω) may be inserted in series with the laser to monitor the current, but the oscilloscope used to measure this current should be isolated from ground. Initial adjustments and test should be made with a $\frac{1}{4}$ or $\frac{1}{2}$ Ω resistor or a test diode replacing the laser. The pulser is operated by first turning on the unit pulser, and then advancing the Variac to provide more than 10 V dc. Switch S2 is then closed to start laser operation. If this order is not followed, the circuit will not commutate properly and fuse F2 may blow.

A gate-turn-off device (GTO) would seem to provide an even simpler method for designing a laser pulser: A single GTO could be used, eliminating the commutation circuit and raising the efficiency of the unit to nearly 100%. Unfortunately, however, the present state of the art of these devices does not now allow them to handle currents of this magnitude.