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FAST PULSE BEAM GENERATION SYSTEMS FOR ELECTRON ACCELERATORS*

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INTRODUCTION

Electron accelerators making use of synchronous guided microwaves have by their nature a fine time structure on the resulting accelerated electron beam. In the case of the SLAC structure which operates at a microwave accelerating frequency of 2856 MHz, the electron bunch periodicity is 350 picoseconds and the width of the electron bunches is less than 3 picoseconds. With appropriate electron gun pulsing in combination with resonant transverse beam chopping a wide variety of short, or single bunch electron beams can be injected into the accelerator. Physics experiments making use of time-of-flight for neutral particle momentum analysis need very short, or single bunch electron beam pulses. The SLAC storage ring, SPEAR, requires two, one nanosecond injection pulses per accelerator RF pulse, and the new PEP storage ring will use a single one nanosecond pulse per accelerator RF pulse for filling. In both storage ring cases, the beam pulse generation must be synchronized to the ring operating frequencies. Generation of these pulses is accomplished with a combination of a fast pulsed grided gun and a synchronized transverse beam chopper. The SLAC injector system is shown in Fig. 1 below.

SLAC INJECTOR

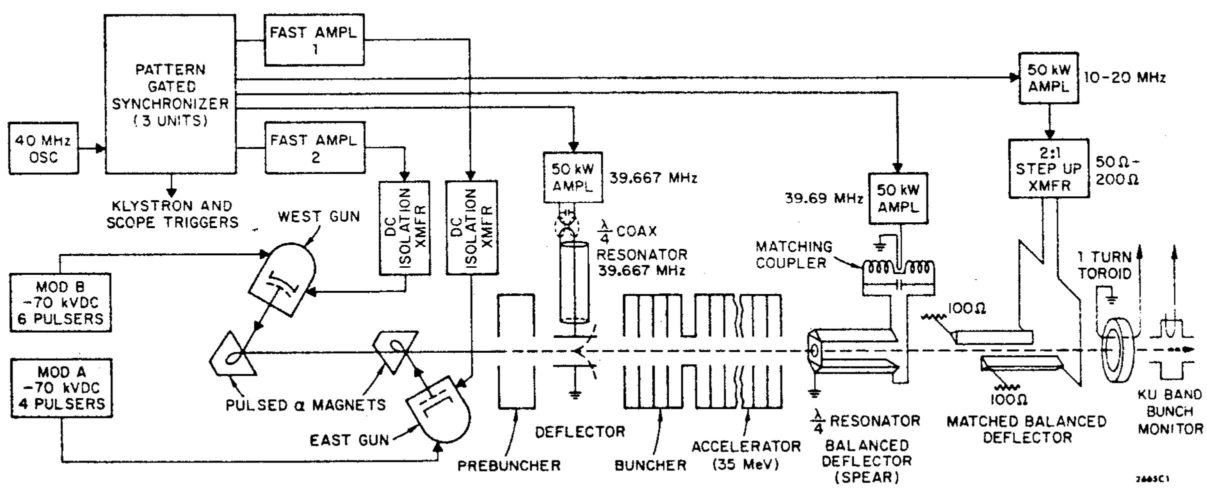

Fig. 1. Injector system block diagram.

GUN DESIGN.

We are fortunate at SLAC to have an electron trajectory computer program[1] which allows us to model various electron gun configurations predicting beam shapes, perveance, and optics. With the aid of this program we have designed several gun structures and tested them on the accelerator. Our design effort falls into two categories. The original SLAC gun series was fabricated entirely at SLAC and included a carefully made spherical cathode-grid assembly. Guns based on this design have output currents of up to 2 amps

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when driven with grid pulses of 1000 volts. Our latest gun design makes use of a prefabricated cathode-grid assembly normally used in small UHF planar triodes. The cathode and grid in this assembly are flat, and the grid-cathode spacing is less than one millimeter. The transconductance of this structure is in the range of 30,000 micromhos. When the oxide cathode has been properly converted, a 200 volt pulse on the grid will drive almost 5 amps from the cathode. The cathode-grid capacity is only 12 picofarads including the socket, so with a 50 ohm drive source the cathode can be turned on in a time of 600 picoseconds. A cross section of this gun type is shown in Fig. 2. This whole gun, isolation transformer, pulser system currently has the capability of delivering electron beam pulses with full width at half maximum of 3 nanoseconds. We are currently working on a pulser system to be mounted directly in the gun structure which will deliver full width at half maximum pulses of less than one nanosecond.

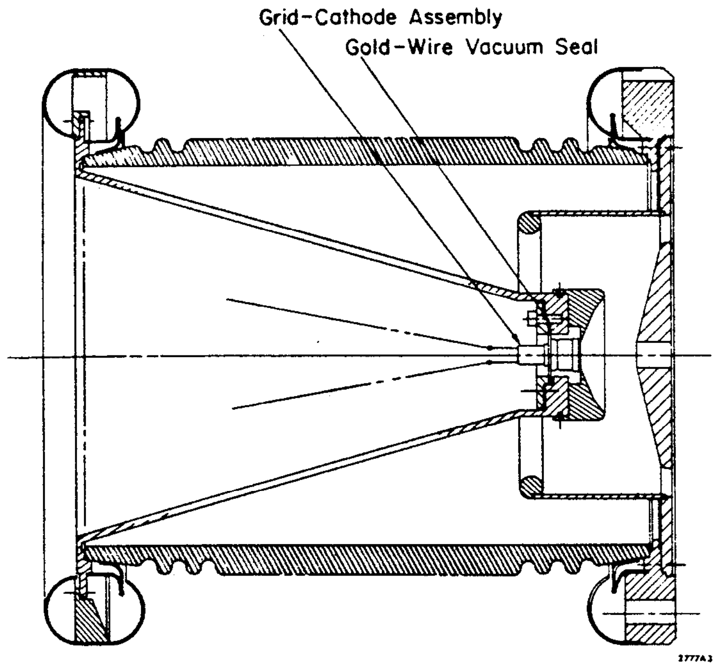

Fig. 2. High current, fast pulse gun.

PULSER SYSTEMS

We have developed a series of fast amplifier systems over the last six years making use of various UHF planar triodes and a variety of ballun-type isolation-inversion transformers. In general, there are two basic pulser systems, one based on line-type modulator principles, and the other based on linear and class C amplifier technology. The choice between the two technologies is determined by the need for multiple pulsing during a normal accelerator beam pulse. Where only a single, or possibly two short beam pulses are required during each accelerating pulse, line type pulser techniques can be used to make a pulser quite small and compact. For the more general cases where multiple pulses are required, or the pulses must vary in width, the full cascaded amplifier technique must be used.

In either system, pulses are generated in ECL logic circuits at a voltage level of one volt. This voltage level is amplified in a standard broad-band solid state amplifier to a level of ten volts. At this point the design of the pulser system begins. If a line-type pulser system is being used, the first stage is an avalanche transistor circuit which boosts the pulse amplitude to 150 volts delivered into a 50 ohm load. The rise time is about one nanosecond. The output of this circuit is used to drive a small ceramic UHF planar triode from cutoff to saturation. The plate of this tube can deliver 6 amps into a 50 ohm load giving an output voltage of 300 volts. With careful circuit layout, stray circuit capacity can be kept to a minimum and rise and fall times of the output pulse can be less than one nanosecond each. We are presently working on an additional stage for this pulser which will drive 20 amps into a 50 ohm load for an output of 1000 volts. All of these circuits are quite small and can be mounted directly on the back of the gun structure.

The more general amplifier system, and that which is used extensively at SLAC, is a two chassis, six stage class B and class C UHF amplifier chain which is shown in Fig. 3. The concept for this amplifier system was originally developed at EGG in Santa Barbara a number of years ago. UHF planar triodes with transconductance in the 20,000 to 50,000

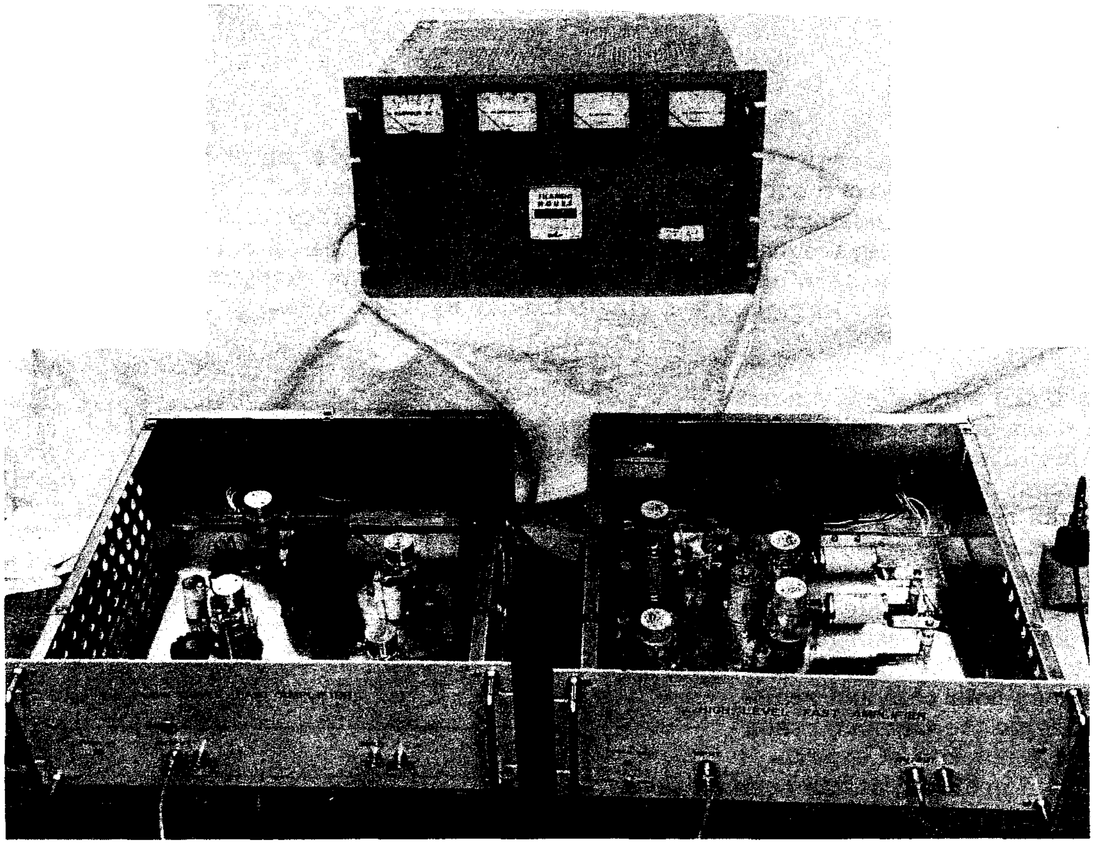

Fig. 3. Fast pulse amplifier system.

micromho range are cascaded using broad-band ballun-type interstage inverting-isolation transformers. Individual stage gains are in the range of 1.6 to 4 depending on design. The whole amplification process extends beyond the linear region of the tubes, so non-linear time domain analysis must be used to analyze each stage. A computer program was developed to perform this analysis and is described in Ref. 2. The peak current capabilities and the transconductance of the tubes are a function of operating hours. When an amplifier system as shown in Fig. 3 contains new tubes, it has a peak output voltage of more than 1500 volts delivered into a 50 ohm load. Rise and fall times are in the order of 1.5 nanoseconds. After 4000 hours of operation, the peak output has dropped to 400 volts and the rise and fall times have deteriorated to about 2.5 nanoseconds each. At this point the tubes are changed. These amplifiers can handle trains of short pulses with repetition rates up to 40 MHz during the normal 1.6 microsecond accelerating time. Various time-of-flight experiments make use of short or single bunch pulse trains with repetition rates in the 5 to 40 MHz range. By multiplexing inputs, one amplifier system can serve several experiments at a time.

BEAM CHOPPERS

Where gun pulser systems leave off, beam choppers begin. By transversely sweeping the gun generated beam across an aperture, the transmitted portion of the beam can be shortened in time. In some accelerators, this technique is used in place of longitudinal bunching to generate a bunched electron beam suitable for acceleration. Where electron beams are well below relativistic potentials, simple electrostatic deflector plates serve well to sweep the beam across the defining aperture. In the SLAC injector the first set of chopping plates is such a deflector system. The deflector resonator is a quarter wave resonant coaxial line with the deflecting plates mounted on the open circuit end of the resonator. The resonator frequency is 39.667 MHz, the 72nd subharmonic of the microwave accelerating frequency. Since the chopper is mounted downstream of the first longitudinal buncher, the beam already has a 350 picosecond structure compressed into

120 degrees of the accelerating RF. To generate periodic single bunches in the accelerator the chopper must sweep out of the aperture bunches adjacent to the bunches transmitted on the chopper zero crossings. These zero crossings occur every 12.5 nanoseconds at the 39.667 MHz chopping frequency. If the gun pulse is less than 10 nanoseconds and well centered on the chopper zero crossings, the combination of this chopper system and the fast pulsing gun system will generate a single bunch, or train of single bunch beam pulses in the accelerator.

There are some disadvantages to beam choppers operating at low beam potentials. The deflection process must be large angle because of the restricted beam drift space inherent in transporting low energy, high current beams. This means relatively large deflection voltages, and much beam interception on the deflecting plates which causes both real and reactive loading on the chopper resonator. For a number of experimental beam profiles, it has been found advantageous to do beam chopping downstream of the first accelerator section where the beam energy is 35 MeV. At this point the chopping aperture can be well downstream of the deflector system so very little beam loading occurs in the deflector resonator.

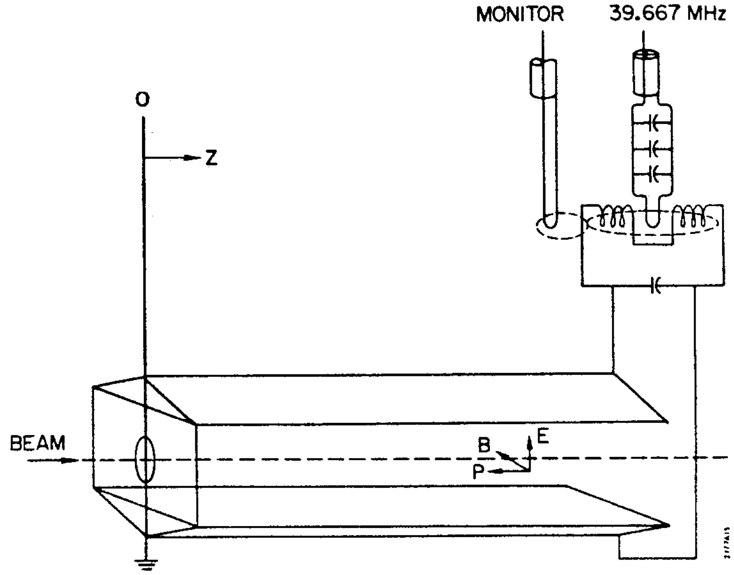

Fig. 4. Downstream deflector schematic.

Chopping relativistic beams requires fairly high power deflectors. There are two of these deflectors in the SLAC injector. One is a traveling wave resonant system tuned to 39.667 MHz, and the second is a nonresonant set of deflector plates that can be powered by any frequency from 5 to 20 MHz. A schematic diagram of the resonant system is shown in Fig. 4. The upper and lower plates form a velocity-of-light strip transmission line with transverse E and B fields. The forward wave on the line does not interact with the relativistic electron beam because the effects of the E and B fields cancel. For the backward traveling wave the effects of the E and B fields add, and if the line is one quarter wavelength long, maximum deflection occurs. The transverse momentum (p_x) imparted to an electron beam by this deflector system is given by

$$p_x = \frac{2eE_0}{\omega_c} \left[\cos\left(\omega_c\left(t_0 + \frac{L}{c}\right)\right) \sin\left(\frac{\omega_c L}{c}\right)\right] \qquad (1)$$

where (e) is the charge on an electron, (E_0) is the peak transverse electric field, (ω_c) is the deflector drive frequency, (t_0) is the entrance time of the electron bunch, and (L) is the length of the deflector. [2] Given the transport geometry and the location of the chopping aperture, the necessary transverse momentum can be derived to deflect the beam out of the accelerator. By using Eq. (1), the deflector line geometry, and the resonator Q, the deflector RF power to chop a beam to an arbitrary pulse width can be obtained. In the SLAC structure, one kilowatt of RF drive chops the beam into one nanosecond pulses, and a drive of 12 kilowatts is sufficient to chop the beam into single bunches. The vacuum feedthrough insulators on the existing structure are marginal at this power level, so this deflector system is not used for single bunch chopping. It is used to generate the one nanosecond SPEAR injection pulses, and it may be used for PEP injection as well.

SYNCHRONIZERS

At SLAC, the accelerator repetition rate is tied to the power line frequency, the microwave drive for the klystrons is multiplied up from a crystal oscillator, the SPEAR storage ring frequency is separately determined, and the new PEP ring will have a separate drive frequency as well. To get a fast beam generation system operating, all of these frequencies have to be tied together in some manner. A pattern-gated synchronizer is used to do this. The crystal oscillator used to generate accelerator microwave drive is used as the primary standard. When single bunch chopping is desired, the 39.667 MHz chopper frequency is derived from this source. The rough timing for the gun triggers is still derived from power line zero crossings, but the fine timing is synchronized to the crystal oscillator. Since SPEAR and PEP are on the other end of the accelerator three kilometers away, a high quality coaxial transmission line also used to distribute the klystron RF drive is used to transmit bursts of RF from SPEAR or PEP for chopper synchronization. PEP and SPEAR do not require single bunch beams, so no attempt is made to tie the accelerator RF to their operating frequencies. Operation of the synchronizer system is discussed in detail in Ref. 2.

FAST BEAM PICKUPS

To view single bunch beams, a pickup with at least a 3 gigahertz bandwidth is required. At SLAC this is accomplished by inserting a small ceramic gap in the beam vacuum pipe, and then loading the downstream side of the pipe with magnetic material consisting of ferrite cores, and some iron. All of the frequency components contained in the beam appear across the gap. The low frequency limit of the gap pickup is determined by the inductance of the downstream section of the beam pipe to ground. The ferrite loading here keeps this inductance high. The high frequency limit of the pickup is determined by the RC time constant of the gap loading resistance and the gap capacity. For the highest sensitivity, a high quality air dialectric coaxial cable is connected directly across the gap to pick up the signal and transport it out of the radiation area. Since the cable impedance is 50 ohms, this determines the R in the RC time constant. The pickup is a one-to-one current transformer, and when working with beam pulses in the 50 to 200 milliamp range, the resulting output signals can be quite high with respect to normal sampling scope input levels. By loading the gap with additional parallel resistance, the R in the RC time constant can be reduced giving the gap a higher frequency response and reducing the sensitivity. The SLAC gaps are resistance loaded to 10 ohms. The best of the SLAC pickup systems is located at the one kilometer point of the accelerator, and with the aid of a sampling scope the microwave bunch structure can be viewed. The system has a one hundred picosecond rise time overall. The sampled data making up this display is distributed to interested experimental areas.

CONCLUSIONS

Fast beam generation and chopper systems presently in existence at SLAC allow us to generate almost any short or single bunch beam profile needed by experimenters. Research into new and easier methods of beam generation and chopping continue, and we expect to have subnanosecond gun pulser systems operational in the near future.

REFERENCES

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