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FUNCTIONAL DESCRIPTION OF THE TRIGGER SYSTEM
FOR THE STANFORD TWO-MILE ACCELERATOR

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by

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I. INTRODUCTION

Because the Stanford linear electron accelerator produces a pulsed electron beam, a trigger system for precisely timing the switching of the various subsystems is necessary. The following components and subsystems of the machine are controlled (turned on and off at the correct time) by the trigger system:

| <u>Component or Subsystem</u> | <u>Function of Component or Subsystem</u> |
|---|---|
| 1. High power klystron modulators | Provide cathode voltage pulses for the high power klystrons which in turn feed pulses of microwave energy into the accelerator waveguide at periodic intervals along the 10,000 foot length |
| 2. Sub-booster klystron modulators | With the associated sub-booster klystrons, provide rf input pulses for the high power klystrons |
| 3. Injector(s) | Source of electron beam to be accelerated |
| 4. Pulsed magnets | Deflect accelerated electron beam to any of three end stations on a pulse-to-pulse basis |
| 5. Physics experimental equipment in end stations (counters, bubble chamber, spark chamber, etc.) | To obtain data during experiments |
| 6. RF phasing system | Periodically (60 pps) corrects phase of microwave signal at each klystron |
| 7. Data handling system | Multiplexes and transmits accelerator operational data to Central Control |
| 8. Beam monitors | Measure intensity and position of electron beam |

The purpose of this report is to present an up-to-date* explanation of the operation of the SLAC trigger system with emphasis on the system functions and block diagrams.

II. FUNCTIONAL DESCRIPTION OF THE MAJOR COMPONENTS IN THE TRIGGER SYSTEM

The following drawings should be studied first to gain an overall understanding of the trigger system:

Fig. 1 - A simplified system block diagram showing how the different parts of the system relate to each other, with a single sentence description of their functions.

Fig. 2 - A tabular listing of the major components and their functions, including input and output information.

Fig. 3 - The location of the major parts of the trigger system.

Detailed explanations of the trigger system components follow.

A. SEQUENCE GENERATOR

The functions of the sequence generator are (a) to produce a 360-pps pulse train to drive the Master Trigger Generator (the source of "clock"**) pulses); and (b) to produce the six different phases of 60 pps pulses needed to form the rate pulses.

The sequence generator produces the pulses shown in Fig. 4, which, when combined, produce a symmetrical 360-pps pulse train. The six individual phases are brought out on separate lines and added in various combinations to form the rate pulses.

Figure 4 shows the time relationships of the input and output waveforms of the sequence generator. The six equally spaced phases of 60-pps output pulses are formed from the positive-going and negative-going zero crossings of the input. These sine waves of input current are changed to voltage pulses by the saturating transformers, whose

* This report does not include the beam switchyard and pulsed magnet subsystems, which are still in the embryonic stage.

** The term "clock" pulses will be used in referring to main trigger pulses.

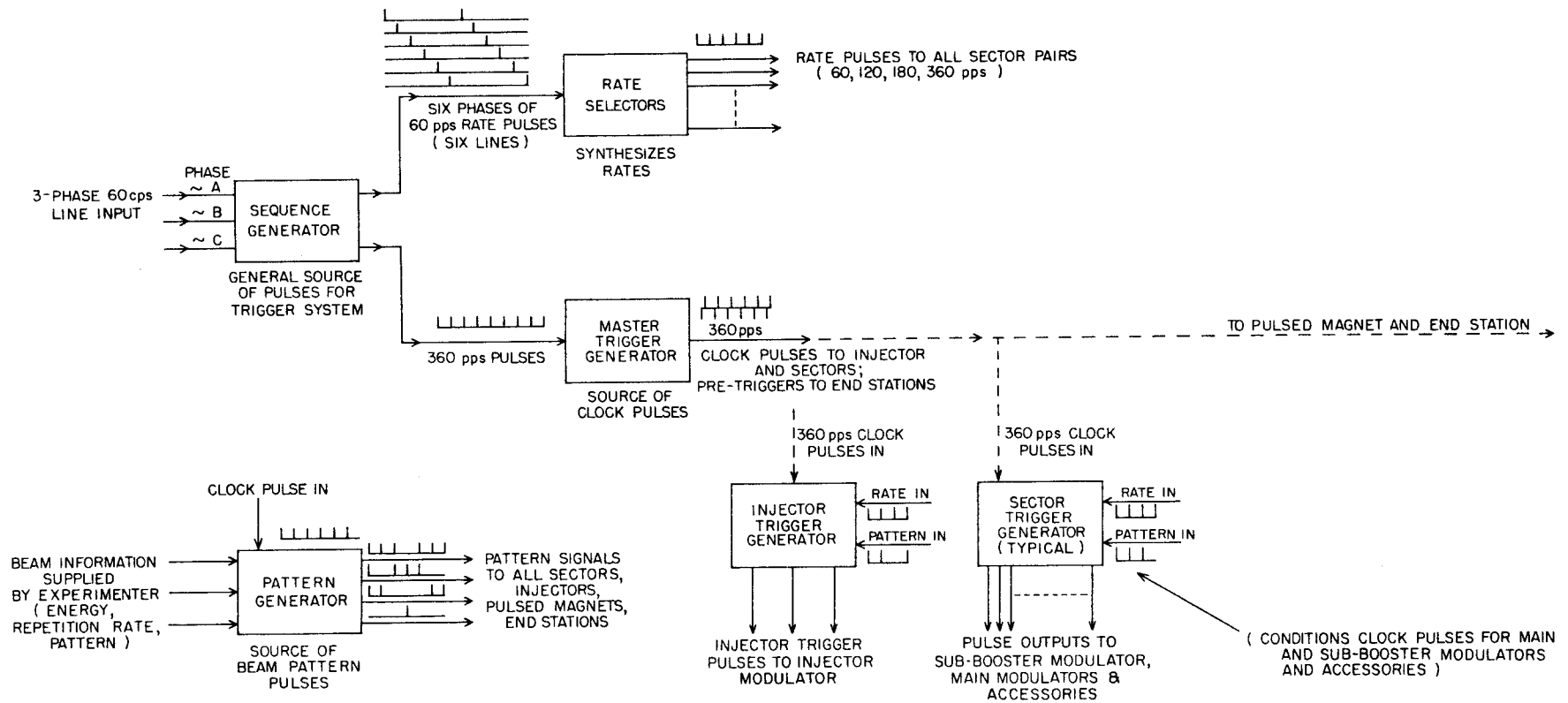


FIG.1 SIMPLIFIED TRIGGER SYSTEM BLOCK DIAGRAM

| Unit | Quantity Required | | Location | Function | Input | Output | | | | | |
|--------------------------|----------------------------|----------------|----------------------------|--|---|--|-----------------------|-------------------------------|----------------|------------------|---|
| | For Sectors 1 and 2 | For 30 Sectors | | | | Description | Voltage 0 to Peak | Repetition Rate | Rise Time | Pulse Width | Time Relative to Clock*** |
| Sequence generator | 1 | 3 | Central Control | Converts three-phase power line input to pulses for rate selectors and master trigger generator | Three-phase power line: 208 volt phase to phase, 120 volt phase to neutral, 60 cps sine waves | 1. Six different phases of 60 pps for rate selector 2. One 360 pps output for MTG 3. One 60 pps output for syncing sectors | +10 | 60 360 60 | 0.4 ms | 1.4 ms | -0.7 ms (adjustable) |
| Rate Selector | 1 | 15 | Central Control | Sets the basic* pulse repetition rate for the main modulators in each sector pair** | The six different phases of 60 pps from the sequence generators | Any of the four regular rate pulse signals, i.e., 60, 120, 180 & 360 | +10 | 60, 120, 180 or 360 | 0.4 ms | 1.4 ms | -0.7 ms |
| Master trigger generator | 1 | 3 | Sector 0 (Injector) | Generates pre-trigger and main "clock" pulses for distribution to sectors and end station | 360 pps pulse train from sequence generator | Positive and negative 360 pps pulses to main trigger line and sectors | -400 pre +400 main | 360 | 20 ns | 400 ns | -25 ns 0 |
| Sector trigger generator | 2 | 30 | At west end of each sector | To condition (delay, perform logic on, sharpen, amplify) and distribute clock pulses to the main and sub-booster modulators and accessories | Positive clock pulses from master trigger generator via main trigger line and takeoff tee | 1. Eight separate pulse trains for each of the main modulators - ten in Sector 1 2. One double 360 pps pulse output for sub-booster modulator 3. Separate 360 pps outputs for data transmission, beam monitoring and portable rate generator 4. "On-time" and delayed 60 pps outputs for phasing system | -10 +40 | See text Double 360 360 | 40 ns 40 ns | 400 ns 400 ns | 0 or +25 to +50 μ s 0 and +25 to +50 μ s 0 0 and +25 to 50 μ s |
| Pattern generator | <input type="checkbox"/> 1 | 3 | Central Control | Contains advance information as to whether next clock pulse will be used to accelerate the beam or not in any particular sector. Controls sector, injector, pulsed magnets accordingly | Internally programmed according to experimenter's requirements | A wide range of periodic and aperiodic pulse trains from 0 to 360 pps | +10 | Variable up to 360 pps | 0.4 ms | 1.4 ms | -0.7 ms (tentative) |
| Comparator | 0 | 1 | Sector 0 | Monitors the three master trigger generators. Switches to a new generator in case of fault | Output pulses from all MTG's | Output pulses from one of the MTG's | -400 pre +400 main | 360 | 20 ns | 400 ns | -25 μ s 0 |

NOTE: There will be an injector-trigger generator(s); requirements are not firm at this writing.

* Modified by pattern pulses

** Each rate selector supplies separate rate lines to each of a pair of sectors, but both sectors are supplied the same rate signals.

*** - means early (ahead of clock)
+ means late

☐ A rate selector will be used to simulate a pattern generator for Sectors 1 & 2 test.

FIG. 2--Trigger system components.

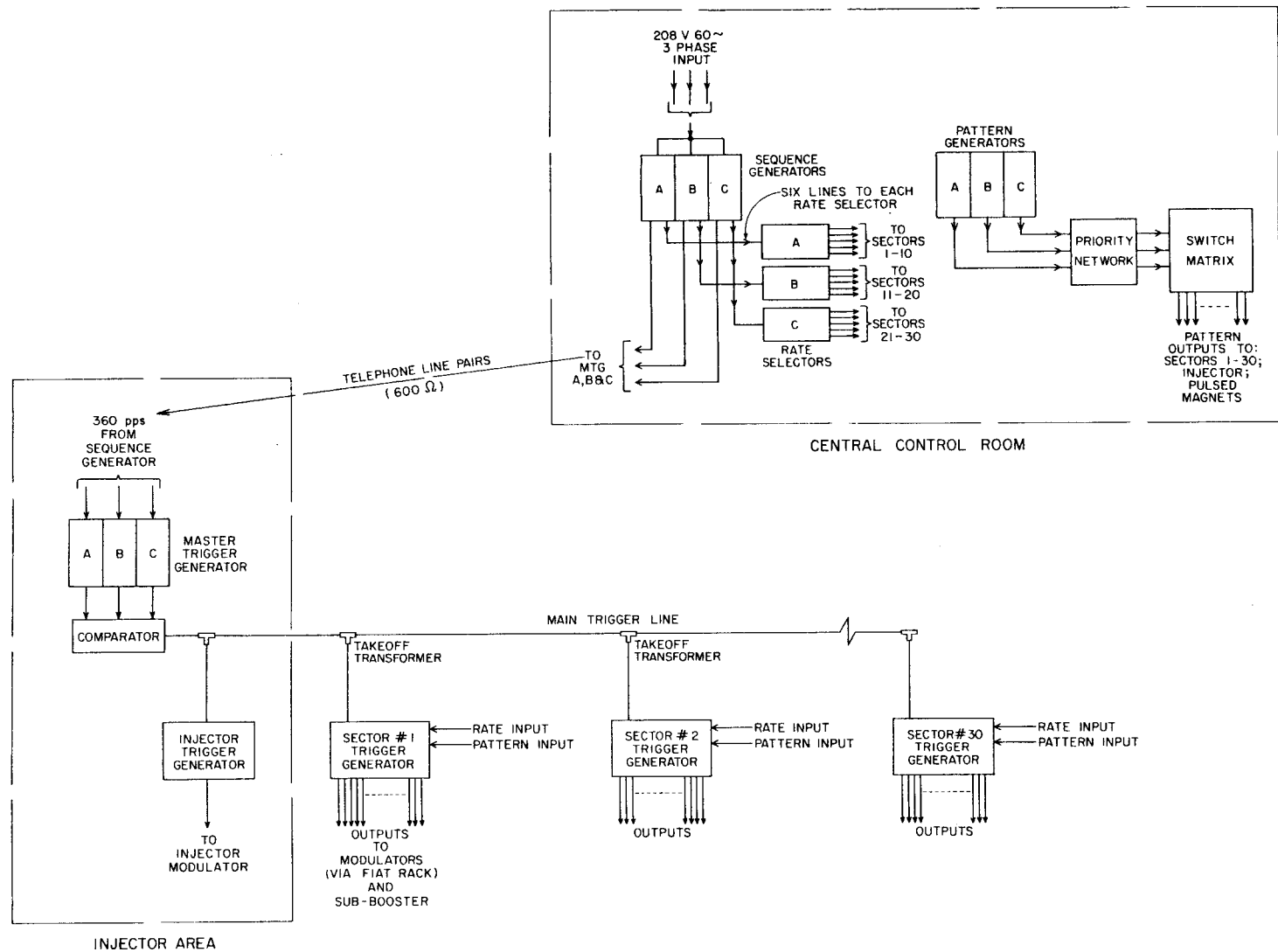
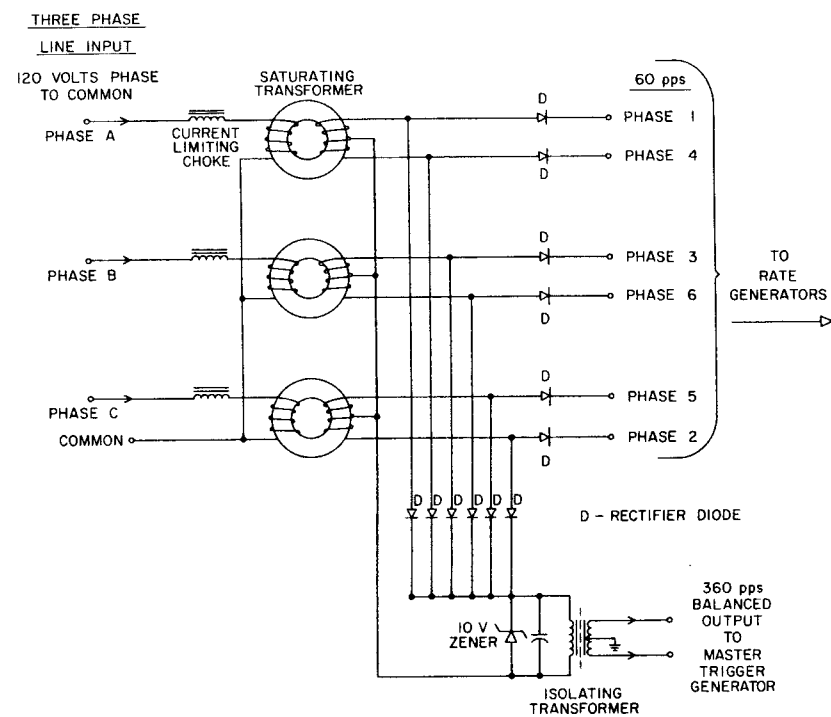
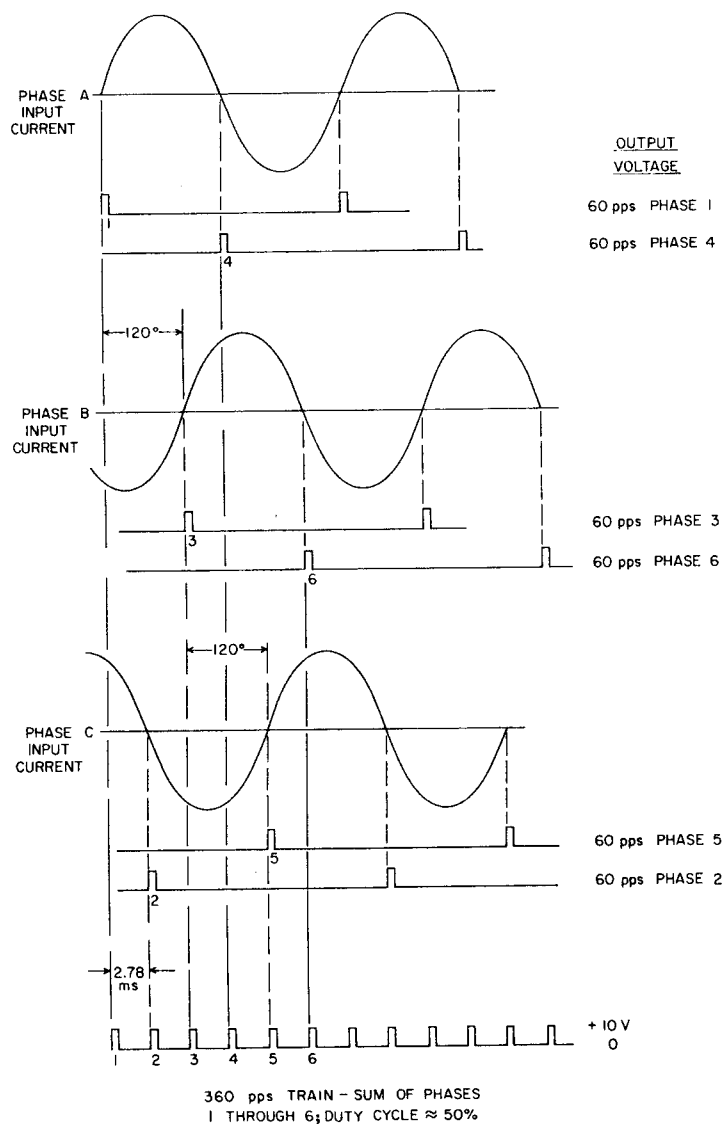


FIG. 3 LOCATION OF MAJOR COMPONENTS OF TRIGGER SYSTEM



NOTE: THERE IS A FOURTH SATURATING TRANSFORMER CHANNEL TO PRODUCE 60 pps SYNC PULSES; THESE PULSES SENT TO ALL SECTORS.

OUTPUT PULSES: AMPLITUDE: +10 VOLTS
RISE TIME 10-90%: 0.4 MILLISECONDS
PULSE WIDTH AT 50% POINT: 1.4 MILLISECONDS

FIG.4 SEQUENCE GENERATOR WAVEFORMS AND SCHEMATIC

cores have the property of becoming quickly saturated with flux as the magnetizing current increases. Inductors in series with each transformer limit the surge current during the time when the core is saturated and the transformer impedance is negligibly low. The output pulses are properly channeled by diodes.

An important function that the sequence generator fills is the locking of the output pulses to the incoming 60-cycle line frequency. (These pulses define the timing of the "clock" pulses for the machine.) This technique is useful in eliminating noise caused by beat frequencies that would be present with a system not locked to line frequency.

There is a high degree of reliability obtained by using the three-phase line as an input. In the event of the failure of any phase, a filter in the master trigger generator has a sufficiently long time constant to maintain a train of output clock pulses from the master trigger generator. This guards against a sudden dumping of the entire 240-modulator power load.

The use of three sequence generators is a further aid to reliability. Each generator supplies rate signals for one-third of the machine, another safeguard against a sudden loss of the entire modulator power load. Each sequence generator also supplies pulses to one of the three master trigger generators; thus, the system for generating clock pulses is triply-redundant from power line input to clock pulse output.

B. RATE SELECTOR

Each rate selector is a bank of six single-throw switches with a common output. One rate selector is required for each pair of 333-foot-long accelerator sectors and can produce any of the four standard repetition rates (60, 120, 180, and 360 pps). The rate pulses determine the highest regular repetition rate of any sector pair; i.e., if the sector rate is set at 120 pps, the sector can produce "prompt"* pulses at a maximum rate of 120 pps. The rate selector is used to conserve power

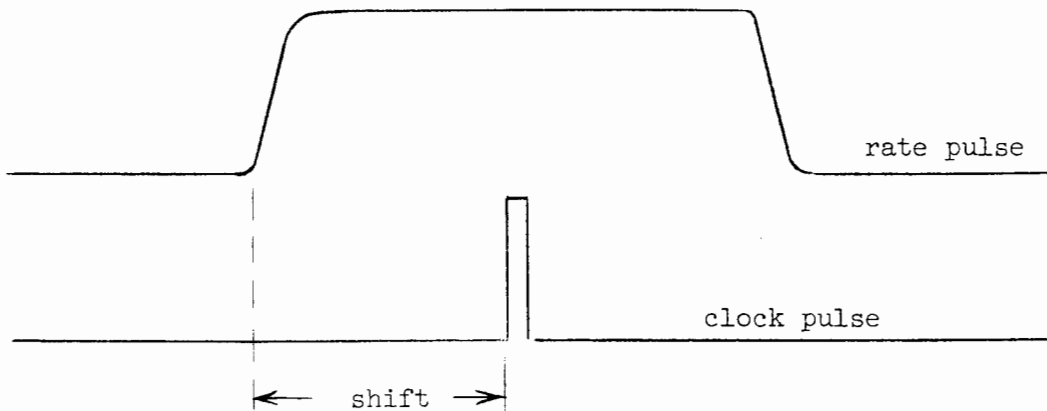
* There are two basic types of pulses: (1) those that are timed to accelerate the electron beam, or "prompt" pulses; and (2) those that are delayed and do not accelerate the electron beam, or "delayed" pulses.

and klystron life by running the sector at the lowest repetition rate consistent with beam requirements. The various rate pulse trains are produced by summing the appropriate phases of 60-pps pulse trains, as shown in Fig. 5, using combinations of closed switches. There is also an "OFF-ON" switch in the rate line to each sector to permit shutting down any sector.

C. MASTER TRIGGER GENERATOR

The master trigger generator is the source of precisely timed pre-trigger and main "clock" pulses for the trigger system. The block diagram, Fig. 6, shows how the master trigger generator converts the slow-rising, 360-pps pulses from the sequence generator into fast, low-jitter, positive and negative output pulse pairs.

The input pulses are first carefully filtered with a 360-cps band pass filter into a relatively pure and jitter-free sine wave. A phase shifter retards the phase of the wave to ensure that the clock pulses



derived from this wave will be centered relative to the rate pulses. A pulse shaper then converts the 360-cps sine wave to a negative 360-pps pulse train. This output splits into an undelayed and a delayed channel and is regenerated and amplified to form the pre-trigger and main pulses. These pulses are combined in the output pulse transformer and sent down

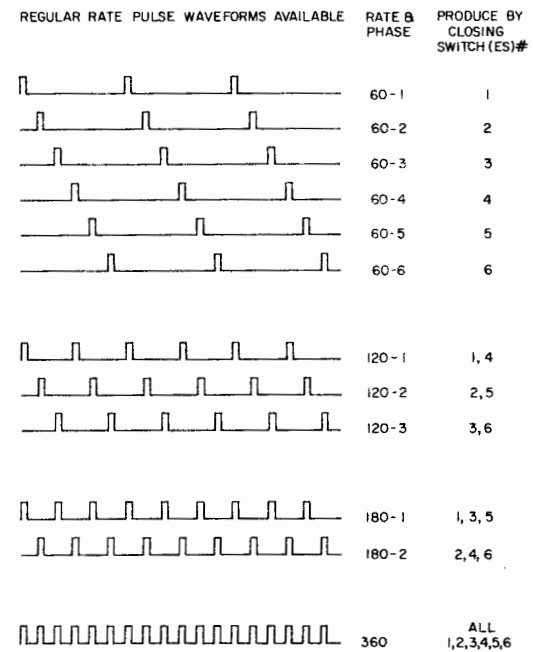
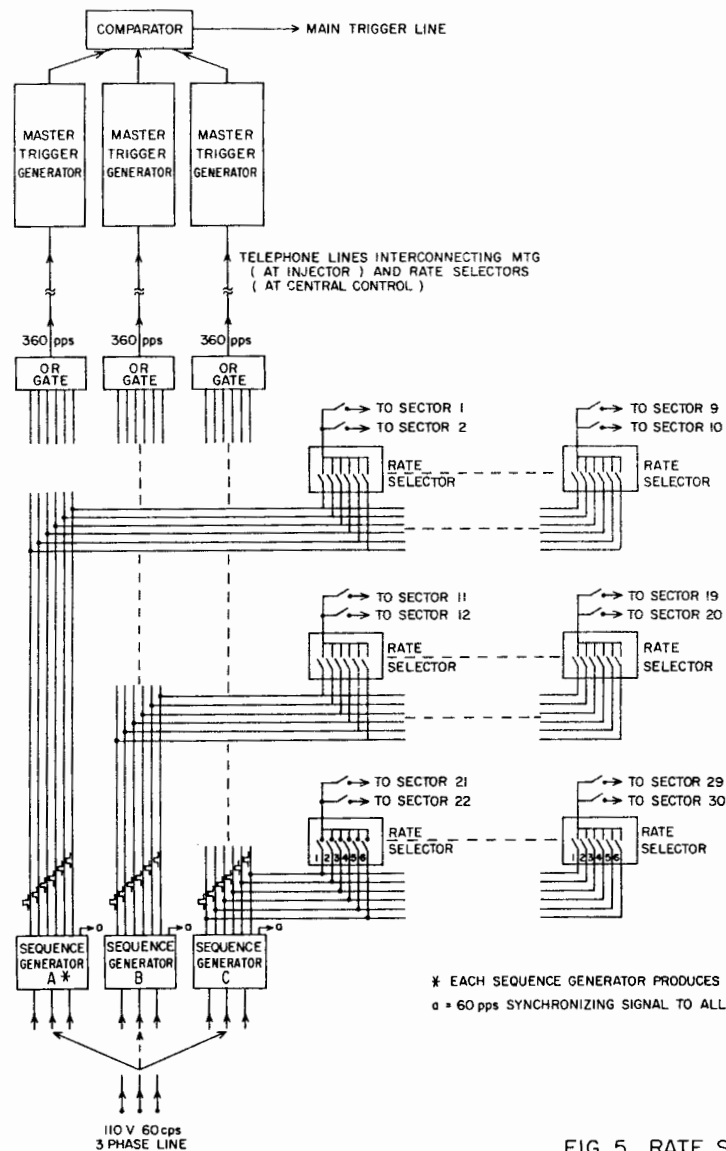
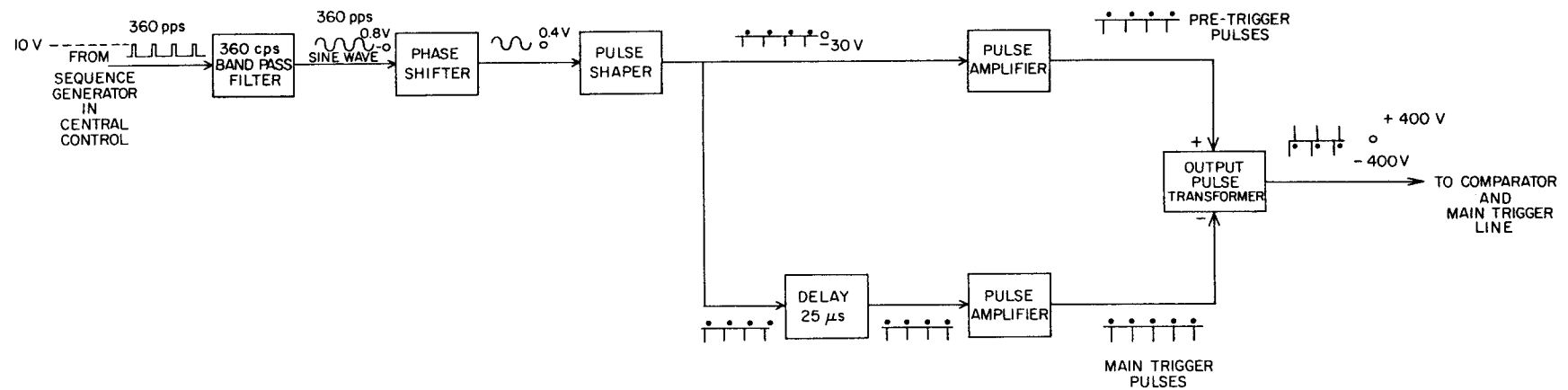


FIG. 5 RATE SELECTORS



OUTPUT PULSES FROM MTG : (SEE FIG. 2)

| PULSE NAME | FUNCTION | TIME RELATIVE TO MAIN PULSE | POLARITY | REP RATE | AMPLITUDE | RISETIME | WIDTH |
|-------------|--|-----------------------------|----------|----------|-----------|----------|--------|
| PRE-TRIGGER | TRIGGER INSTRUMENTS IN TARGET AREA | - 25 μ s | - | 360 pps | - 400 V | 20 ns | 400 ns |
| MAIN | TRIGGER INJECTOR, MODULATORS & SUB-BOOSTER VIA SECTOR GENERATORS | 0 | + | 360 pps | + 400 V | 20 ns | 400 ns |

• DOT DENOTES MAIN PULSE TIME (CLOCK TIME)

FIG. 6 MASTER TRIGGER GENERATOR BLOCK DIAGRAM

the main trigger line.

For high reliability, three identical master trigger generators are run continuously, one supplying pulses to the trigger system through a comparator, the other two standing by. The comparator monitors the clock pulses and switches a redundant generator into service (during an interpulse period) in case of failure or deterioration of the output of the active trigger generator.

The pulses leaving the comparator are fed into the main trigger line, a low-loss, two-mile-long coaxial cable that delivers clock pulses to the accelerator sectors and experimental areas. A low-loss cable is necessary to preserve fast rise times and good timing accuracy throughout the length of the machine.

D. SECTOR TRIGGER GENERATOR

1. Functions

The sector trigger generator must satisfy the following requirements:

- a. Trigger the sub-booster modulator at a constant double 360-pps repetition rate, i.e., a pair of 360-pps pulses spaced 25 to 50 μ sec.
- b. Trigger the main modulators at a regular rate; specifically, 60, 120, 180, or 360 pps.
- c. Deliver a regular or irregular train of "prompt" pulses to the main modulators on demand. (These pulses are timed so that the modulator output will accelerate the beam.)
- d. Deliver a regular or irregular train of "delayed" or standby pulses to the main modulators on demand. (These pulses are timed late, so that the modulator output will not accelerate the beam.)
- e. Change from "delayed" to "prompt" pulse on demand (from the pattern generator) during an interpulse period, i.e., $1/360$ sec.

- f. Deliver pulses to components or subsystems as follows:
- (1) 60-pps "prompt" and "delayed" pulses to phasing system
 - (2) 360-pps pulses to beam monitor equipment
 - (3) 360-pps pulses to data handling system
 - (4) 360-pps pulses to portable rate generator

In addition to the above requirements, the sector trigger generator has the vital function of delaying modulator pulses for the following purposes:

- a. To compensate for the difference in speed of propagation of the electron beam (c) and the clock pulses down the main trigger line (0.92 c). A fixed passive delay T_c is used. See Sector Block Diagram, Fig. 7.
- b. To compensate for the effect of beam loading. A 0 to 1 μ sec passive delay T_L , which is remotely adjustable in 50-nsec steps from Central Control, is used.
- c. To position the sub-booster modulator pulse correctly relative to the main modulator pulse. The passive delay T_S is manually set at the sector for a range of 1.3 to 2.075 μ sec in steps of 25 nsec.
- d. To compensate for the difference in thyatron switch tube (in the main modulator) ionization time as a function of average power (repetition rate, voltage). Two ganged passive delays T_A , which are adjustable from Central Control, are used over a range of 0 to 150 nsec in 50-nsec steps.
- e. To produce a delayed or standby pulse. This pulse occurs too late (by 25 to 50 μ sec) to accelerate the beam, but is not late compared to the interpulse period, so that the modulators "think" they are working at a regular rate (position modulation 1 to 1-1/2%). An active delay T_D is used. It is initially set for the prescribed delay, which varies from sector to sector in order to avoid coherent acceleration of stray electrons.

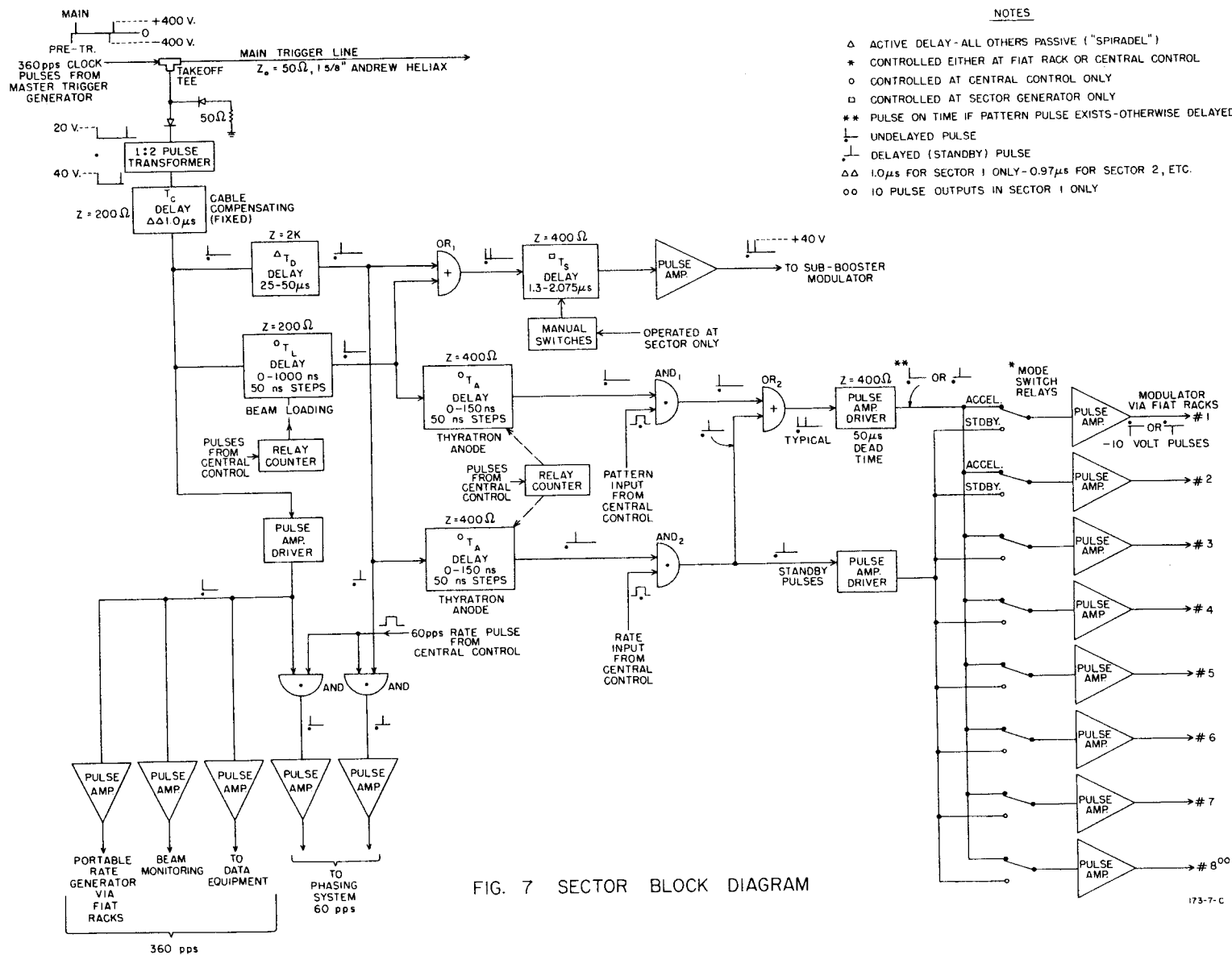


FIG. 7 SECTOR BLOCK DIAGRAM

2. Detailed Explanation of Sector Block Diagram

Refer to the Sector Block Diagram, Fig. 7.

The input to the sector generator is a train of positive 360-pps "clock" pulses supplied by the master trigger generator via the main trigger line and the sector takeoff tee. The sector takeoff tee is a device for tapping trigger pulses off the main line.

The pulses coming off the tee are exact replicas of the clock pulses on the main trigger line except that they are reduced in amplitude from 400 to 20 volts. The negative pre-trigger pulse is shunted to ground by a diode. The remaining +20-volt, 360-pps pulses (clock pulses) are passed through a pulse transformer that matches the 200-ohm impedance of delay T_c to the 50-ohm line. Delay T_c compensates for the slowness of the main trigger line relative to the electron beam by delaying the trigger to the gun and the triggers to all sectors, varying the amounts of delay in order to achieve synchronism.

The pulses leaving T_c are fanned out into three paths: (1) through delay T_D to produce standby pulses; (2) through delay T_L to produce prompt pulses that are corrected for beam loading effects; or (3) to synchronize most of the accessories, i.e., the phasing pulses, the data equipment pulses, the beam monitoring pulses, and the portable rate generator pulses.

The sub-booster modulator trigger pulses are formed by combining prompt and delayed pulses in the OR_1 gate. These pulses are delayed by T_s , amplified to 40-volt pulses, and sent out.

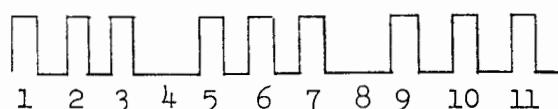
The main modulator trigger pulses are formed by combining prompt and delayed pulses in the OR_2 gate, but the process is a bit more complex. Prompt and delayed pulses are passed through T_A delays (this provides the proper thyatron firing time delay for a given repetition rate). The prompt pulses are then ANDed with pattern pulses in AND_1 ; there can be no transmission of "prompt" pulses through AND_1 without the simultaneous appearance of a pattern pulse. Therefore, the output of AND_1 is, in general, an irregular train of prompt pulses identical to the pattern pulse train. The AND_2 gate combines delayed pulses and rate pulses such that its output is a train of delayed pulses identical to the rate pulse train. The two outputs from AND_1 and AND_2 are then summed in the gate OR_2 .

The output is an irregular pulse train that will, in general, have prompt and delayed pulses in various combinations.

Consider an example: Suppose an experimenter wants a 180-pps beam. He sets a 180-pps rate for the sectors and the pattern generator, but because of priority limitations (see the following section) he can get only three out of every four pulses. Let us assume he resigns himself to these conditions and goes ahead with the experiment at this reduced average power; the diagram below illustrates the results.



180-pps rate pulses, the beam pattern desired



180-pps pattern pulses (one out of four missing), the beam pattern obtained

The OR_2 gate output for these circumstances is as follows: At time 1 both prompt and delayed pulses appear because both rate and pattern signals are present at the two AND gates. In this case the delayed pulse is deleted by the pulse amplifier driver, because it is designed to have sufficient "dead time" (50 μ sec) to reject the second pulse. Times 2 and 3 are the same conditions as time 1. At time 4 there is no pattern pulse; therefore, AND_1 does not transmit a prompt pulse. However, there is a rate pulse, so that a delayed pulse comes out of AND_2 and out of OR_1 . This delayed pulse gets through the pulse amp driver because it is now the "first" pulse. Thus, the line coming out of pulse amp driver 1 can have prompt or delayed pulses depending on whether a pattern pulse appears at the time in question. These pulses pass through the mode switch, are amplified to 10-volt pulses, and are sent to the modulators via the respective FIAT racks. The other mode switch position is standby. The standby line delivers delayed pulses at the rate determined by the rate signals. This switch position is used to test klystrons not in active service.

E. PATTERN GENERATOR

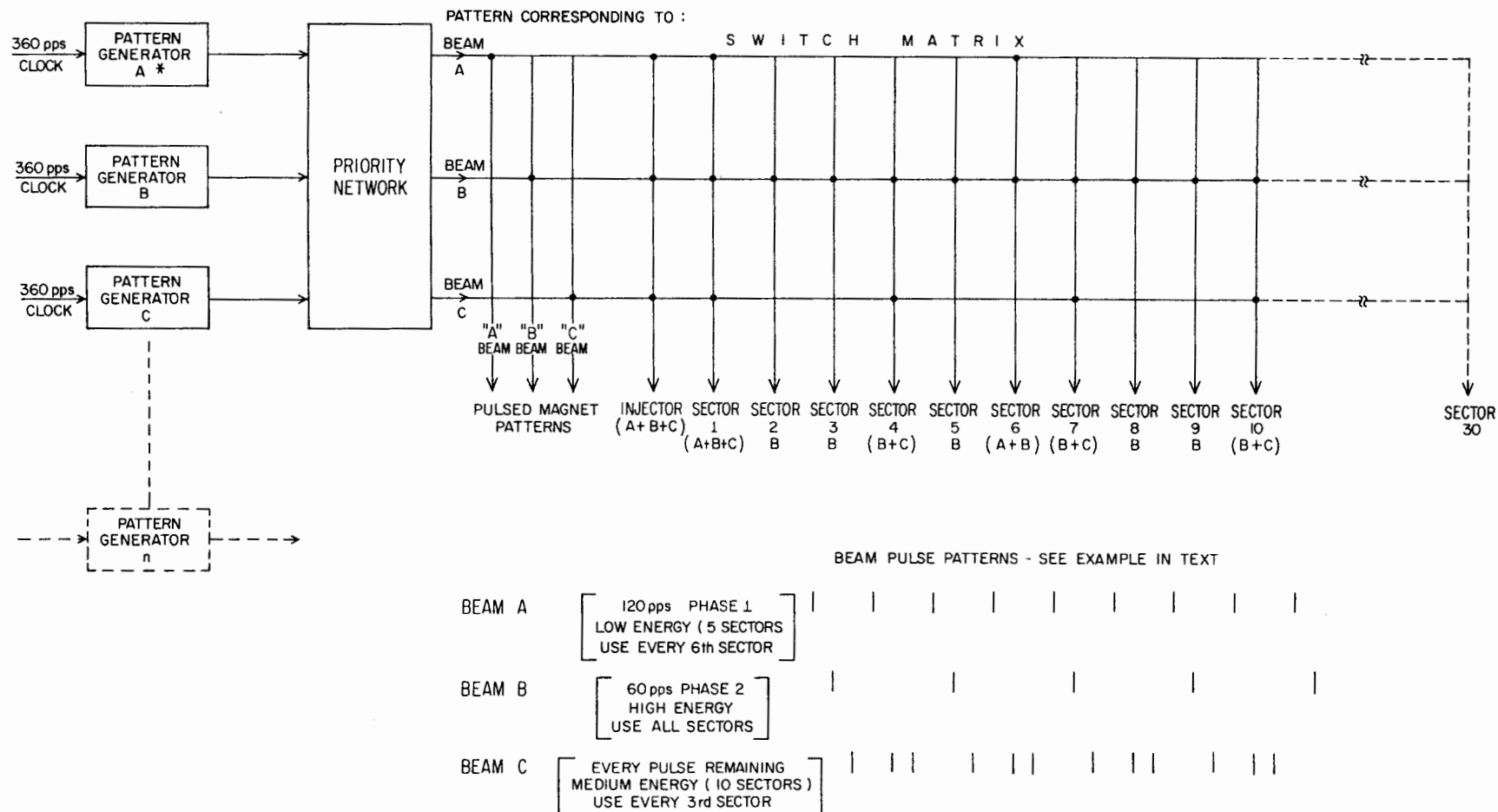
A pattern generator is required for each beam, and the output of each pattern generator has a regular or irregular pulse pattern exactly like that desired in the electron beam.* The pattern generator provides the flexibility required for multiple beam operation where each beam has independent energy and repetition rate requirements. It also conveniently solves the problem of triggering a bubble chamber with a quiet zone before and after the pulse. The strict phasing requirements of the machine require the modulators to run at a regular repetition rate. The regular repetition rate requirement is violated slightly, but not seriously, by pulsing the klystrons with a pulse delayed about 1% of the pulse period. The sector generator is designed to deliver an accelerating pulse if, and only if, a pattern pulse is present. If no pattern pulses are supplied, the sector merely delivers delayed pulses at the rate set by the rate generator. This logic is performed in the two AND gates in each sector.

Consider an example where three different beams are required, as follows (see Fig. 8, Pattern Generator Block Diagram).

| | |
|--------|--|
| Beam A | 120-pps repetition rate; low energy (5 sector's worth) |
| Beam B | 60-pps repetition rate; maximum energy (all sectors) |
| Beam C | All pulses remaining; medium energy (10 sectors) |

Because a maximum of 360 pulses are available in any second, the above requirements can be satisfied by setting pattern generator A to produce phase 1 of 120 pps, pattern generator B to produce phase 2 of 60 pps, and by letting pattern generator C produce 360 pps so that beam C will have the pulses left from A and B. This is done automatically by the priority network whose function it is to maintain a hierarchy in which beam A outranks B, and B outranks C, and therefore C receives any pulses left over from A and B. The required beam patterns are programmed into the three pattern generators. The different energy requirements are satisfied by using the switch matrix to select the proper number of sectors

* Subject to "priority" limitations.



*Each pattern generator output has a pulse train identical with the beam it represents, unless modified by priority network.

⊕ = Closed switch

⊖ = Open switch

FIG. 8 PATTERN GENERATOR BLOCK DIAGRAM

for each beam, as shown in Fig. 8. Thus, beam A, having low energy, uses only five sectors (any five), while pattern generator B sends pulses to every sector for maximum beam energy. Beam C uses every third sector. The pattern pulses arrive at the sectors sufficiently in advance of the beam to switch the sector from a standby pulse to a prompt pulse. In this mode, the pulses sent to all eight modulators are timed to accelerate the beam. After this, the sector will revert to standby for the next pulse unless another pattern pulse appears. In the standby mode, a delayed pulse is sent to the modulators and the beam is not accelerated.

ACKNOWLEDGMENT

The conceptual design of the trigger system is primarily due to Dr. K. B. Mallory.

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