NRL Report 5876

DEVELOPMENT OF A GATE SYSTEM FOR THE IMPROVEMENT OF THE MADRE RADAR

PART 1 - SYSTEM THEORY, CALCULATIONS, AND PLANNING

G. K. Jensen and J. E. McGeogh

Radar Techniques Branch
Radar Division

January 11, 1963

U. S. NAVAL RESEARCH LABORATORY
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ABSTRACT

The Madre radar signal processing technique provides a large signal-to-noise improvement over conventional radars for targets of essentially constant radial velocity, but this improvement is degraded whenever the radial velocity change within any 20-sec period produces a doppler change greater than 0.38 cps. At a carrier frequency of 26.6 Mc this is produced by a change in radial velocity of approximately 4 knots occurring in 20 seconds and represents an acceleration, if linear, of 0.2 knot per second. This limit is normally not exceeded when viewing targets of manned aircraft, but it may be expected to be exceeded in the viewing of missile launches. To overcome this acceleration degradation of the signal-to-noise ratio in the Madre radar system, an acceleration gate system is being developed.

Radial velocities and accelerations via a one-hop ionosphere ray path have been calculated for a Jupiter missile launched from the Atlantic Missile Range with observation points at the Chesapeake Bay Annex of NRL and also at a point in the plane of the trajectory. Calculations showed a system degradation in excess of 10 db for most of the powered portion of the launch for each point of observation.

A block diagram of the Acceleration Gate System is shown, and a brief description of the curve matching technique is given. Significant progress is reported on several key circuits of the new system.

PROBLEM STATUS

This is the first of a series of technical summary reports on the problem, covering system theory, calculations, and planning. The work reported was conducted during the period July 1, 1960 to December 31, 1960. Work on the problem is continuing.

AUTHORIZATION

NRL Problem R02-17
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of June 23, 1960

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DEVELOPMENT OF AN ACCELERATION GATE SYSTEM FOR THE IMPROVEMENT OF THE MADRE RADAR

PART 1 – SYSTEM THEORY, CALCULATIONS, AND PLANNING

INTRODUCTION

The purpose of adding an acceleration gate system to the Madre radar is (a) to permit the detection of targets having appreciable acceleration that would otherwise be undetectable because of signal-to-noise losses in the present system attributable to accelerating targets, and (b) to retain the signal-to-noise enhancement capabilities that the existing system now has for nonaccelerating targets. This detection will effectively be accomplished by a curve matching or fitting process. A large number of built-in functions will be compared simultaneously for the best match with the accelerating target signal. Originally, a 360-gate acceleration gate system was proposed; however, for purposes of economy, a system is being developed having only twelve acceleration gates tailored to the missile trajectories out of the Atlantic Missile Range (AMR) as viewed from NRL's Chesapeake Bay Annex.

BACKGROUND

The present Madre radar system processes the target doppler signal and displays it in two dimensions, with range rate as the ordinate and range as the abscissa. The coordinates of each target are identified by intensity modulating the grid of the cathode-ray-tube display with the target signal pulse. Doppler signals from 5 to 90 cps from the receiver are sampled and stored on the magnetic drum. Here a time compression of 82,800 to 1 occurs, causing the doppler signals read out of storage to cover the frequency range of 0.4 to 7.5 Mc. These signals are processed in the analysis channel and then drive the crt display.

Figure 1 is a block diagram of the analysis channel. It consists of a mixer which accepts signals from the drum and a reference oscillator that is swept in frequency. The difference frequency is selected by the narrow bandpass crystal filter centered on 13.0 Mc. Its bandwidth is 30 kc, hence only signals confined to this band will pass on to the detector. Further filtering takes place in the low-pass filter where the signal bandwidth is now limited to 0 to 2 kc. In all, the signal bandwidth is effectively narrowed by a ratio of 41,400 to 1, thus improving the signal-to-noise power ratio by a similar factor.

The signal as read out of the drum storage consists of 23 range gates (0 to 450 naut mi) of information occupying a single track on the full circumference of the drum. Each range gate has 3600 samples of signal written in it, which took 20 seconds to complete. The readout of all 23 range gates takes place in one drum revolution, or 1/180 second. Due to the time compression that results, the signals can be analyzed for all range rates, as well as all ranges, in only two seconds, where otherwise a large multiplicity of fixed-frequency doppler filters would be required. Range rate is measured by moving the scanning oscillator about 22 kc for each drum revolution. This means that all 23 range gates are analyzed for signals having a particular doppler frequency, and thus range rate, in this period (5.5 msec). During the next drum revolution all range gates are examined

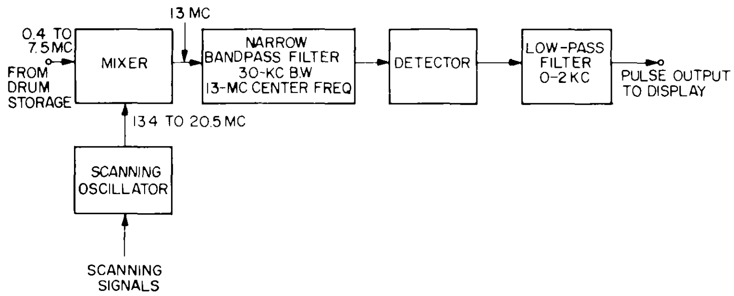

Fig. 1 - Signal analysis channel

for signals having the next higher range rate. This process continues for about 320 drum revolutions, or nearly 2.0 seconds, at which time all range and range rate gate combinations have been examined for signals. The total process is then repeated. The display sweeps are kept in step with the scanning oscillator and range cycles to insure an orderly presentation of information.

To summarize, the present system provides 23 range gates and 320 range rate gates (primary display) of information, which requires about 2.0 seconds to analyze. A large gain in signal-to-noise ratio accrues provided that the signal's doppler frequency does not deviate more than 30 kc at the drum output in the 20 seconds required to fill the storage. If it does it will be attenuated by the 30-kc bandwidth predetection filter. If the 30-kc limitation is converted to knots, it can be seen that at an operating frequency of 26.6 Mc the target must hold a radial range rate within 4 knots for 20 seconds, or 0.20 knot per second.

High-speed vehicles such as missiles can produce higher accelerations than 0.20 knot per second. The expected radial velocities and accelerations of an actual Jupiter missile launched from the AMR when viewed from the Chesapeake Bay Annex (CBA) were computed by an NRL mathematician.* This missile impacted 640 naut mi down range. Figure 2 shows both velocity and acceleration plotted as a function of time. Also included is a curve to indicate the number of range rate gates over which the doppler frequency in any one range gate will be spread by acceleration in the 20 seconds required to fill the storage. For example, if the signal energy was spread uniformly over ten range rate gates, then only one-tenth of the energy would be found in any one gate, and thus the signal-to-noise ratio would be degraded by 10 db.

In this case (Fig. 2) the radar is viewing the missile at nearly a right angle to the plane of its trajectory. In fact, at 103 seconds the radial acceleration passes through zero. The shaded portion of the curve indicates the period of time during which the loss will be less than 10 db on an average.

Another view of the same missile trajectory is shown in Fig. 3, where the radar is sited in the plane of the trajectory 750 naut mi from the launching area. Again acceleration and velocity, along with the number of gates traversed by the doppler signal frequency, are plotted versus time. Here it will be seen that at 10 seconds the doppler frequency is already changing at a rate which, if continued without change, would cause it to traverse ten range rate gates in 20 seconds. As time continues, the number of gates traversed increases rapidly.

*Burton N. Navid, Applied Mathematics Staff.

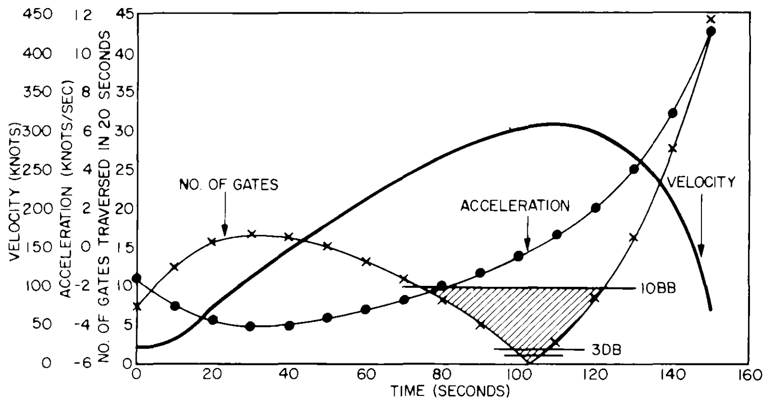

Fig. 2 - Predicted Jupiter missile characteristics viewed from CBA

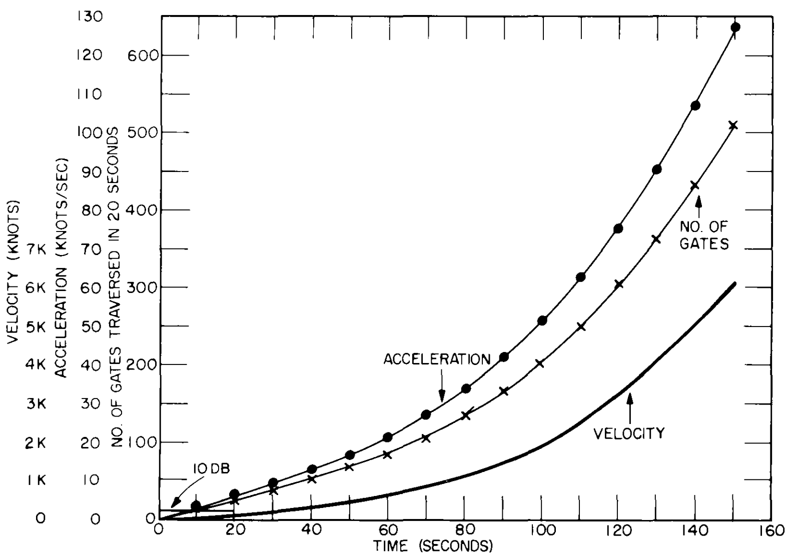

Fig. 3 - Predicted Jupiter missile characteristics viewed from a point 750 naut mi from the launch site and in the plane of trajectory

The two graphs are examples of a favorable and an unfavorable (for the Madre radar system) missile trajectory with respect to the radar site.

OPERATION OF THE ACCELERATION GATE SYSTEM

If it is desired to detect a rapidly accelerating target by means of a revision in the Madre radar such that the same sensitivity is achieved as that of the original radar for targets of limited acceleration, then a means must be provided for confining all doppler signals to the narrow output bandwidth (30 kc) of the original Madre system for the full integration period. The doppler signal is available at the drum output, but the problem is that it varies in frequency during the 20 seconds in which it was sampled and stored on the drum, and, of course, it is also buried in noise. The signal will appear in one of the 23 range gates, which are each read out in 240 μs.

A solution to the problem is to modulate the scanning oscillator (Fig. 1) during a range gate so that the deviation of the doppler frequency due to acceleration is canceled out at the mixer of the analysis channel and a constant i-f output is realized. The modulation must be repeated during each of the 23 range gates for a given range rate, and then it must be continued while the remaining range and range rate gates are examined for signals.

The above process converts an analysis channel into an acceleration gate where all range and range rate gates are examined for targets having a given acceleration. Other acceleration gates may be established by paralleling analysis channels and modulating the reference frequency of each with a different function. The original proposal for this system suggested a total of 360 acceleration gates for an operational radar. This number is flexible and may be increased. The analysis time necessary to examine all combinations of the 360 acceleration gates, 320 range rate gates, and 23 range gates is still only 2 seconds – the same time as required by the present system for analysis of only range rate and range. (An NRL report is available which gives a more complete description of the acceleration gate system than will be given here and which also discusses a number of other important considerations.*)

The basic design philosophy employed was not to store all possible missile trajectories that a radar might be called upon to view, which could be infinite in number, but to store only a selection of modulating functions, each with a time duration equal to the integration period after read out. This selection is to be tried simultaneously for a good match. Since one function should match some part of a number of trajectories, the number of function generators required in the system will be reduced. This design philosophy, of course, cannot be followed completely in the 12-gate system.

If the full potentialities of the system are to be utilized to uncover the minimum detectable target signal from the noise, its doppler frequency must remain within the 30-kc passband of the predetection filter for the full integration period. Thus it is not possible to "look" at the doppler frequencies with a shorter sampling period at one or more points in a range gate.

TECHNICAL PROGRESS

General Comments

The design, construction, and engineering analysis of the design of the 12-gate acceleration gate system is well underway. Where more than one unit of a given electronic subsystem is required, only one will be constructed, and the remainder will be obtained on outside contract.

Figure 4 shows an overall block diagram of the system. Only a single input is required from one track on the drum. Output from the analysis system will be presented on three oscilloscopes, one displaying range rate versus range information, the second, acceleration versus range, and the third, acceleration versus range rate.

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* G. K. Jensen, "An Improved Gate System for the Madre Radar," NRL Report 5570 Dec. 1960.

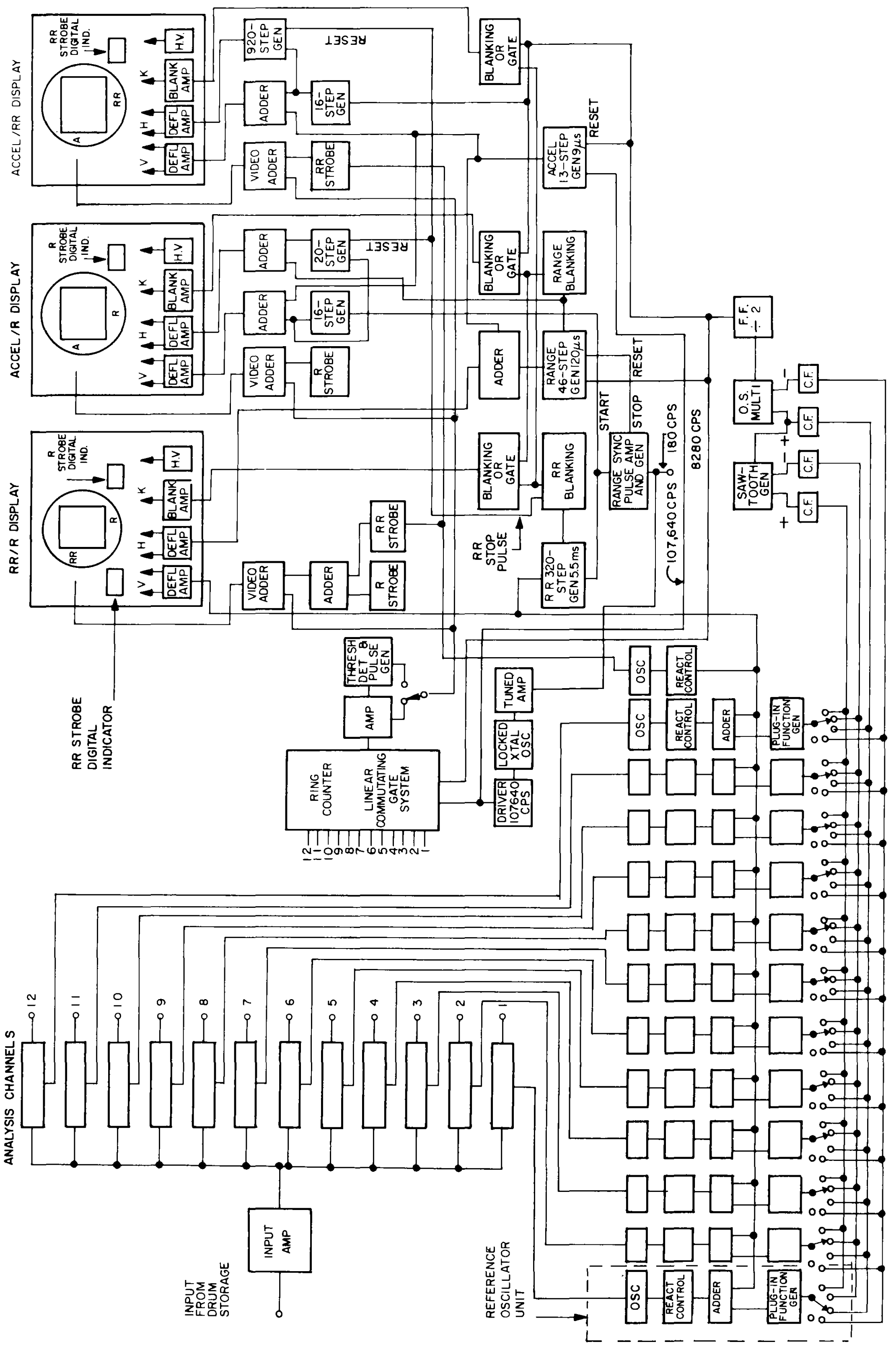


Fig. 4 - Acceleration gate system block diagram

The input signal feeds the 12 analysis channels in parallel. These channels will be similar to the one illustrated in Fig. 1. Each of these channels requires a special scanning or reference frequency which is modulated with the appropriate acceleration function. The modulated reference frequencies are provided by the circuits labeled reference oscillator unit. These units each consist of an oscillator, reactance modulators, adder, and a function generator. A choice of four waveforms is provided as parallel drive to the function generators. The purpose of the function generator network is to appropriately modify one of the input waveforms to generate the desired modulating function.

Signal output may occur simultaneously from all 12 analysis channels. This creates a display problem because cathode-ray tubes have only a single control grid and thus require information in sequential form rather than in simultaneous form. Display conversion of information in this system is accomplished with an electronic commutator consisting of a ring counter and 12 linear gates. The output of the commutator is fed either directly or through a threshold detector to the grids of the three displays. Since this is an experimental system, and for reasons of flexibility, it was thought desirable to modify or degrade the signal-to-noise ratio as little as possible between the final narrow banding in the analysis channels and the display. This will allow the noise threshold to be set at the display in accordance with the requirements of each particular experiment. However, an alternate automatic threshold detector is also being provided.

Output information is in effect three-dimensional in character and would be most advantageously presented in three dimensions. As a practical matter, cathode-ray tubes are capable of displaying information in only two dimensions; hence, for display purposes it is necessary to break the three-dimensional information down into pairs of dimensions. This, however, introduces a number of problems. For example, consider the acceleration versus range display. Here, the raster of sweep lines will repeat many times (every drum revolution) one on top of the other before the 2.0-sec analysis period is completed. Noise which is written in each time will add and build up the intensity of the long persistence phosphorous screen, thus reducing the signal-to-noise ratio of a signal which occurs only once per period. In the case of the other two displays the lines in the direction of the range rate or range coordinate will have a very large number of elements written on them, which will exceed the resolution capability of the cathode-ray tube (for the 360-gate acceleration gate system). Here again a loss of signal-to-noise ratio will result.

An examination of the number of lines required in each coordinate of the displays reveals that only 12 lines are required for the acceleration coordinate, 46 for the range coordinate, and 320 for the range rate coordinate. Since so few elements are needed in the acceleration and range coordinates, the large surplus of elements between the minimum number required and the maximum number allowable under the resolution limit of the cathode-ray tube may be used to eliminate the loss of signal-to-noise ratio due to the two previously mentioned problems. This can be done by adding low-level auxiliary step sweeps to the main horizontal and vertical sweeps for each of the displays so that, by using a small offset, no sweep line falls exactly on a previous sweep until the complete 2.0-sec analysis cycle is completed, and the sweep lines having a large number of elements are folded so that the number of elements on any given line is not excessive. In order not to smear out the elements on the display, it is planned to use stepped sweep signals instead of sawtooth signals.

The main and auxiliary step sweep generators are shown on the right-hand side of Fig. 4. Also included are the start and stop signals, blanking, adders, deflection drivers, and strobe generators necessary to actuate the displays.

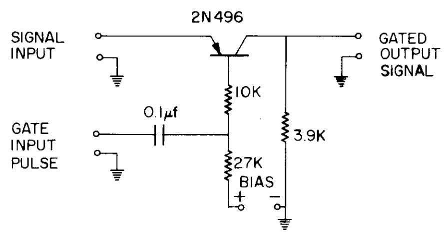
The following paragraphs will deal with the design and development of specific portions of the system.

Linear Gate System and Ring Counter

Sequential sampling of the analysis chassis outputs is accomplished by 12 linear gates, each placed in series with one analysis chassis to a common overall output. The electronic commutating action is performed by a ring counter consisting of 13 binary stages in which each binary supplies the switching pulse for one of the gates. The last or 13th binary provides the time necessary for retrace in the displays.

A number of gate circuits have been investigated for possible application in the full system, as well as in the 12-gate system. A series-type gate was required so that the outputs could be connected in parallel. This cannot be done conveniently with the shunt type without the addition of an isolation network or stage. Other requirements were: (a) a fast pulse rise and fall time to accommodate a 9-μsec pulse width, (b) linear response over a wide dynamic range of at least 40 db, (c) high attenuation during the off period and low attenuation during the on period, and (d) simplicity of circuit design. The circuit that appeared most suited to the requirements was a single-transistor gate circuit, shown in Fig. 5, which was developed as a final result of the study.

Fig. 5 - Transistor gate



This transistor gate provides an attenuation of about 52 db at the beginning of the off period and increases to 60 db for the remainder of that period. The rise and fall times are approximately 50 nanoseconds, and the series resistance during the on period is about 20 ohms. A gating pulse of 50 volts peak-to-peak is sufficient for passing a signal of 18 volts peak-to-peak amplitude.

Many transistors were measured for potential use in this gate. In order to obtain fast rise and fall times, transistors with good high-frequency response were desirable. Those with high collector-to-base voltage ratings allowed operation at higher signal levels. The 2N496, a pnp silicon alloy type, was the most suitable of the available types for rise times and signal amplitude capabilities.

The transistor gate circuit does not balance out the entire gating pulse. Since all gate outputs are connected in parallel and the switching times are short, the signal output will not appear to be added to the offset voltage. This is not expected to be objectionable, but will be fully examined when the ring counter is completed.

The ring counter which supplies the switching pulses to the gate circuits is designed to use standard plug-in binary units manufactured by Engineered Electronics. This chassis, which includes the transistor gates, has been constructed. The design includes reset circuits for the ring counter that will make it self-starting and prevent more than one pulse from stepping around the ring.

The output of the ring counter is 8280 cps. This is used as a reference frequency in addition to gate switching. It supplies the blanking signal for the acceleration sweeps, the reset for the acceleration step generator, the input for the range step generator, and the input for the acceleration sweep modulation of the reference oscillator. Originally it was intended to supply the input of the ring counter with a 107.640-kc signal that was to be obtained by a multiplication of a 4140-cps signal of the Madre timer. This precise frequency was not made available. Therefore, the input had to be obtained from the 180-cps drum synchronizing pulse. This has been accomplished by a simple circuit consisting of a 107-kc tuned amplifier driving a locked crystal oscillator. The tuned amplifier provides gain to increase the amplitude of the locking signal, and the crystal oscillator has adequate stability and Q value to lock on the desired multiple of 180 cps and reject the other multiples of 180 cps.

This circuit with output drivers has been designed, constructed, and made operational.

Reference Oscillator Unit

A single reference oscillator unit has been designed and constructed (see Fig. 6). It is to be used as an experimental chassis for setting up a variety of modulation wave shapes for frequency modulating the scan oscillator that supplies the analysis chassis. The frequency modulation is to be accomplished by the use of a Vari-L current controlled inductor in combination with voltage-variable diode capacitors. The sawtooth and rectangular waveform generator, from which the acceleration modulation waveforms are produced, has been designed and constructed. A monitor chassis also has been designed and constructed to indicate the actual modulation waveform on the oscillator output signal.

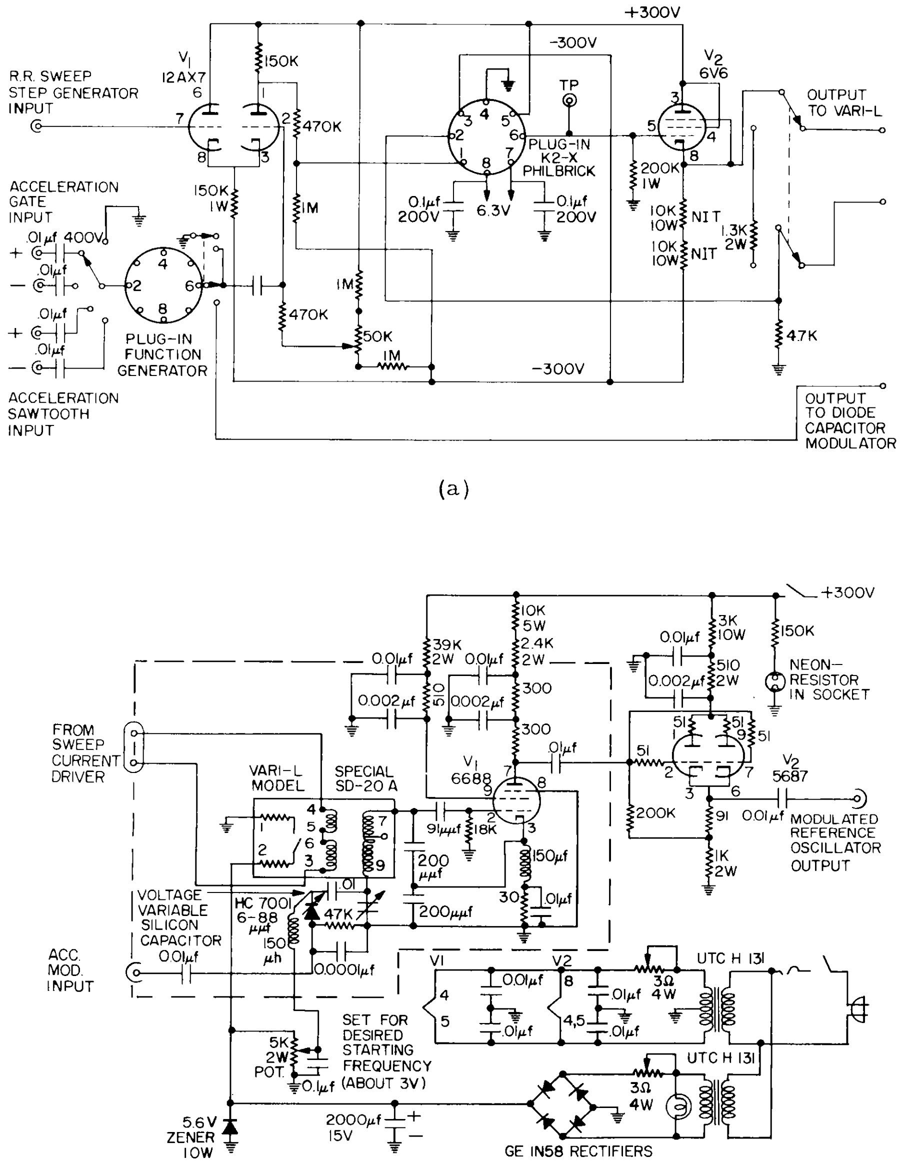
Analysis Channel

The design of the analysis channel is similar to that shown on Fig. 1 which is presently being used in Madre. A unit has been constructed and is ready for evaluation.

Step Generators

Figure 7 shows the schematic diagram of the range-rate step generator, which has been designed and constructed. It provides a step waveform to scan the reference oscillator, step signals for the range rate sweeps, and blanking signals; it times the 2.0-sec analysis cycle and provides reset signals for several other step generators.

Tubes V_1 and V_2, a keyer and one-shot, provide a constant pulse amplitude and width for the step generator, consisting of a constant current generator and thyratron reset, tubes V_3 and V_4. The phase of the step waveform is split by V_{5a}, and two low-impedance outputs are provided by V_{5b} and V_6. The number of steps in the waveform is determined by Schmitt trigger circuit V_7, and the blanking interval is determined by V_8. A low-impedance output for the blanking signal is obtained with the cathode follower V_9. The design of the remaining step generators will be similar to that of Fig. 7.



(a)

(b)

Fig. 6 - Reference oscillator unit comprising (a) sweep current mixer and driver, and (b) scanning oscillator

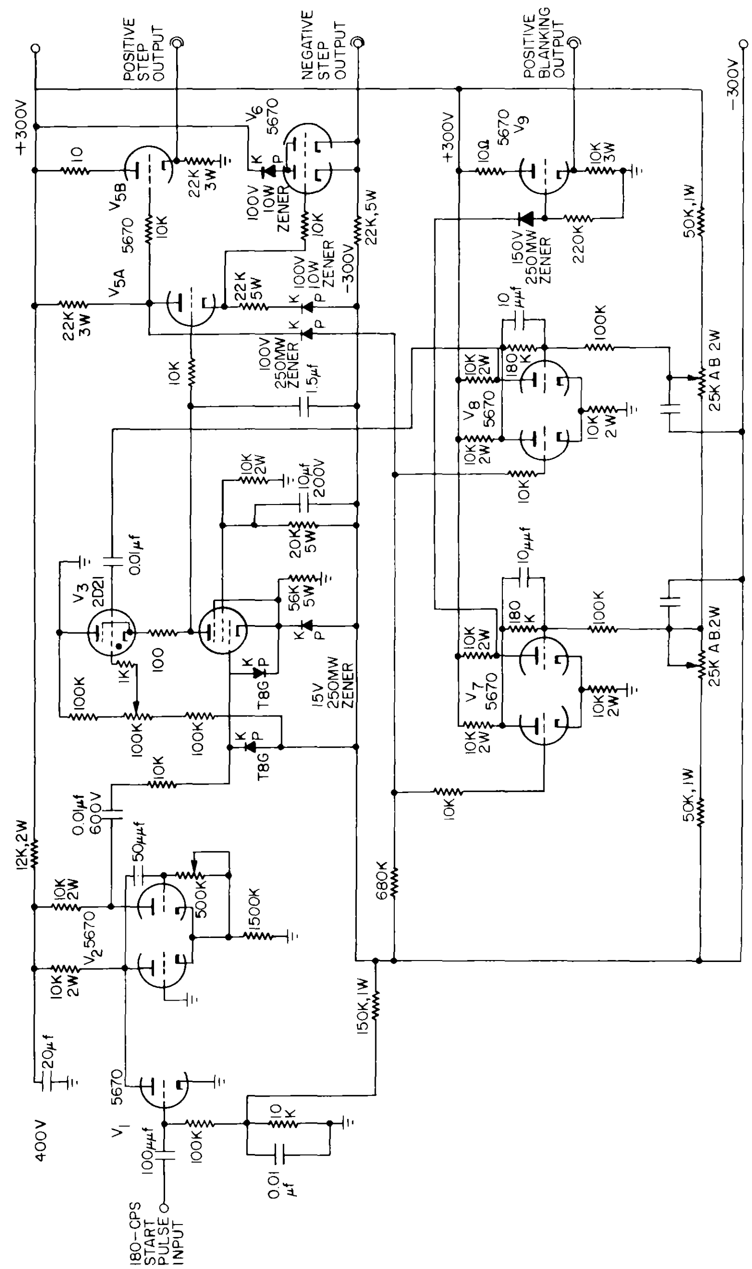


Fig. 7 - Range-rate step generator

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