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ABSTRACT

Design details and operating characteristics of a Model VI Linear Amplifier System and a Model VI Preamplifier are described. The Model VI Linear Amplifier is a stable, low noise, moderate bandwidth, feedback amplifier which has extreme flexibility and good overload immunity. It is designed to handle pulses and waves with a wide variety of shapes, durations, and repetition rates. The Model VI Preamplifier was developed as a low noise, high stability, multipurpose preamplifier with either charge-sensitive or voltage-sensitive operation. It is compatible with solid-state, ionization-proportional, geiger, or scintillation detectors.

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PART I: MODEL VI LINEAR AMPLIFIER SYSTEM

Introduction

The Model VI Amplifier is a stable, low noise, moderate bandwidth, feedback amplifier which has extreme flexibility and good overload immunity. Unlike most amplifiers now in use, it is not limited to amplifying pulses or wave shapes within a narrow range.

This amplifier is designed to handle pulses and waves with a wide variety of shapes, durations, and repetition rates. Sine waves, square waves, or complex waves up to the frequency limitation of the amplifier may be handled as readily as short pulses.

For the wide variety of preamplifiers and particle detectors currently used by experimenters, the Model VI Amplifier provides a high degree of flexibility by employing front panel controls to select: input-pulse polarity; gain control over a 1000 to 1 range; differentiating modes of either standard RC clipping, single line clipping, or double line clipping; output pulse threshold cut of from 0 to 100 v; high and low frequency response; and adjustment of solid state detector bias from 0 to 270 v.

The amplifier occupies only 5-1/4 in. of panel space with a chassis depth of 13 in., and incorporates all amplifier circuits exclusive of preamplifier, all power supplies, and a forced-air ventilating system.

Receptacles are provided for pulse input, pulse outputs, 115 v power in, and preamplifier power.

Access to tubes and circuit has been made convenient and rapid by the unusual chassis construction, even though the amplifier occupies a small amount of rack space.

Applications

When the amplifier is used to drive a multichannel pulse height analyzer analyzing gamma spectra, the double line clipping mode can be used to keep base line shift and overload interference to a minimum.

For uses in which pulse height resolution must be exceptionally good and the primary limitations are amplifier noise and stability, as in analysis of alpha spectra, the amplifier can be used with single line or RC differentiation. The use of either one of these differentiating modes eliminates the extra noise placed on the amplified base line by the second differentiation of the noise. Also, since the pulse rates and overload problem encountered with alpha analysis are not nearly as severe as with gamma analysis, the need for double differentiation is normally not required.

For amplifying other wave shapes with minimum distortion, the amplifier can be used as a straight RC coupled amplifier. In this mode of operation, as well as in the line-differentiated modes, the upper and lower frequency response of the amplifier can be altered by means of the time-constant—rise-time control to meet the particular amplifying needs.

Sometimes it is also desirable to attach high impedance devices directly to an amplifier input without, relying upon a preamplifier for input coupling. One position of the Model VI Amplifier's coarse-gain control allows for this type of operation by providing a 55,000-ohm input impedance. Gain in this input position is then controlled by the fine-gain control knob.

Amplifier Stability

In order to realize a high degree of accuracy in any pulse analysis system it is necessary to maintain maximum amplifier gain stability. To ensure this, inverse feedback amplifier circuits have been used throughout this amplifier to minimize gain variations caused by temperature variation, power line variations, and by tube aging. Unlike many existing linear amplifiers, inverse feedback has also been used for stabilization of all pulse inverting stages and impedance coupling stages. Failure to feed back cathode followers or to tie inverter stages to feedback stabilization, as well as the use of such partially fed-back amplifier circuits as long-tailed pairs, will lead to reduced amplifier stability.

To further reduce gain variations, a fully regulated anode and filament power supply has been used to ensure gain stability in all amplifier circuits in the event of varying power line voltage, and low-temperature—coefficient precision resistors have been used where ever necessary—together with forced ventilation cooling—to ensure a minimum shift in amplifier gain because of temperature fluctuations.

Low-Noise Performance

Since noise generated at the input of the amplifier, appears along with the usable signal, or modulates the usable signal when a discriminator and postamplifier are used, it is desirable to maintain the amplitude of this noise signal at an absolute minimum. To accomplish this in the input of this amplifier it was necessary to use low impedance input circuits together with a cascode triode input stage. A 6922 tube was chosen for our use because tests indicated it to be superior, from a noise standpoint, to other single envelope double triode or single pentode stages.

Noise susceptibility inherent in many existing double line differentiated amplifiers because of direct line pickup has been handled conveniently in the Model VI Amplifier by incorporating, as an integral part of the chassis, a shielded compartment to contain the clipping lines. This arrangement also increases tube and part accessability by eliminating the cumbersome copper cable shields often used.

Regulated dc filament power has been provided for all heaters of critical tubes in the preamplifier, the input amplifier, and the second amplifier loop, so as to further reduce noise induced by cathode temperature fluctuations and by cathode-to-heater leakage, and also to improve gain stability.

Microphonic isolation of the input amplifier loop has also been accomplished by shock mounting this entire amplifier subassembly from the main amplifier chassis.

The mechanical and electrical layouts of electronic circuits and their associated wiring required considerable planning in order to reduce ground loop coupling to an absolute minimum (so that noise interference originating from the power source, adjacent equipment, and power supply would not couple into the amplifier). This was particularly important because the amplifier has amplifying capabilities in the low-frequency spectrum near the power line frequency.

Frequency Response Control

Control of the upper and lower frequency response of this amplifier is provided for by means of a front panel control, since the user often wishes to reduce bandwidth in order to achieve a greater signal-to-noise ratio by attenuating undesirable high frequency noise or signals present. Also, the user may want to reduce low frequency response in order to attenuate undesirable low frequency disturbances such as power line interference and microphonics which may be present along with the incoming signal.

The frequency response control provides five positions of high-frequency roll off: approximately 2, 1, 0.5, 0.25, and 0.12 Mc, respectively. Four positions of low frequency roll off are provided: roughly 200, 1000, 10,000 and 100,000 cycles, respectively. Both low- and high-frequency roll off are accomplished in a single twelve-position switch which has a dial calibration listing clipping times and rise times rather than frequency, since this amplifier is primarily designed for pulse work.

Overload Performance

When an amplifier is used to amplify gamma-produced pulses for analysis in a multichannel pulse height analyzer, it is of utmost importance to have an amplifier that exhibits rapid recovery characteristics from high overload conditions. This ensures accurate measurement of the low-energy parts of the gamma spectrum, whose pulse height may be an extremely small fraction of the higher energy pulses present. The relative heights of pulses to be analyzed may be as great as several hundred to one, and the amplifier must be capable of handling this sort of overload with rapid recovery. The Model VI Amplifier incorporates the double line differentiating technique, which is almost universally employed to provide the needed extreme overload recovery characteristic by restricting the time taken by the pulse undershoot and by providing good pulse symmetry even on heavy overload conditions. Aside from the necessary shaping by the line differentiators, symmetry-restoring limiting diodes are also provided between all amplifier feedback loops to prevent overloading of the subsequent amplifier loops. The incorporation of a special amplitude-limiting circuit in the first feedback loop allows for the elimination of the clipping diode drive circuit usually needed to ensure overload protection for the input circuits. This was done to minimize the noise at the amplifier input without reducing its overload pulse handling capabilities.

To ensure stability and pulse symmetry at the amplifier output, the output amplifier feedback loop makes use of a White feedback follower as an integral part of the output loop feedback circuit.

Amplifier Description

The Model VI Amplifier consists of three cascaded inverse feedback loop amplifiers having gains of 20, 20, and 58, respectively (see Figs. 1, 2, and 3). The total gain of this composite amplifier is the product of these three gains, which is approximately 23,000. When both line clippers are inserted, the maximum gain is reduced to 1/4 of the above figure, and with one line clipper inserted the maximum gain is reduced to 1/2 of the above figure, giving maximum gains of 5750 for double clipping line operation and 11,500 for single clipping line operation. In addition to the three cascaded loop amplifiers there is an extra unfed-back output cathode follower providing means for driving long cables where pulse symmetry and linearity of the regular feedback follower are not absolutely needed. This output follower is coupled to the amplifier output through a threshold circuit having a 0 to 100 v range, allowing for further expansion of a part of the energy scale, where extremely fine resolution is desired.

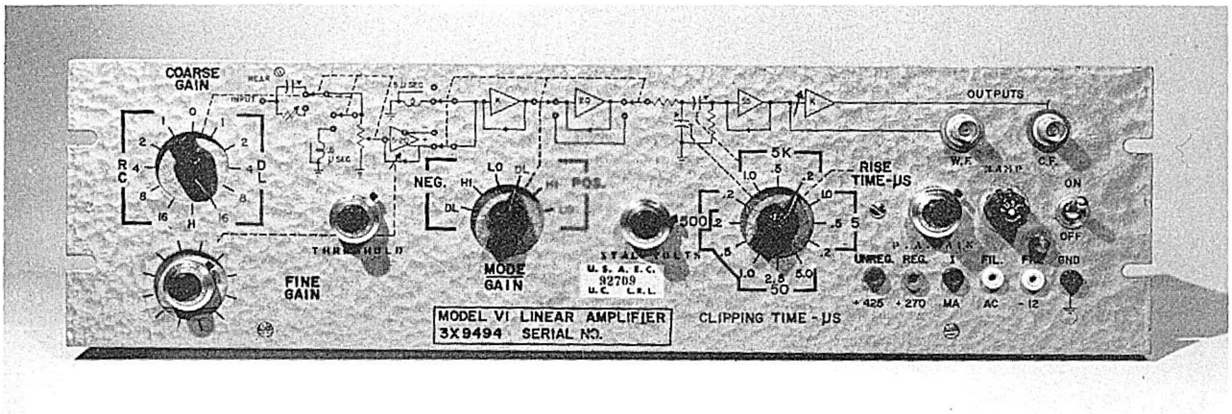

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Fig. 1. Control panel of Model VI Linear Amplifier.

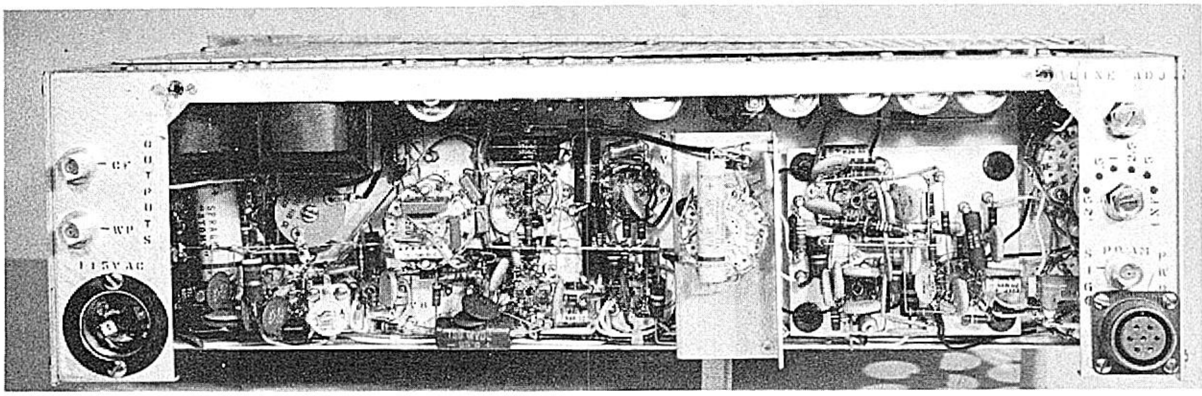

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Fig. 2. Rear view of Model VI Linear Amplifier.

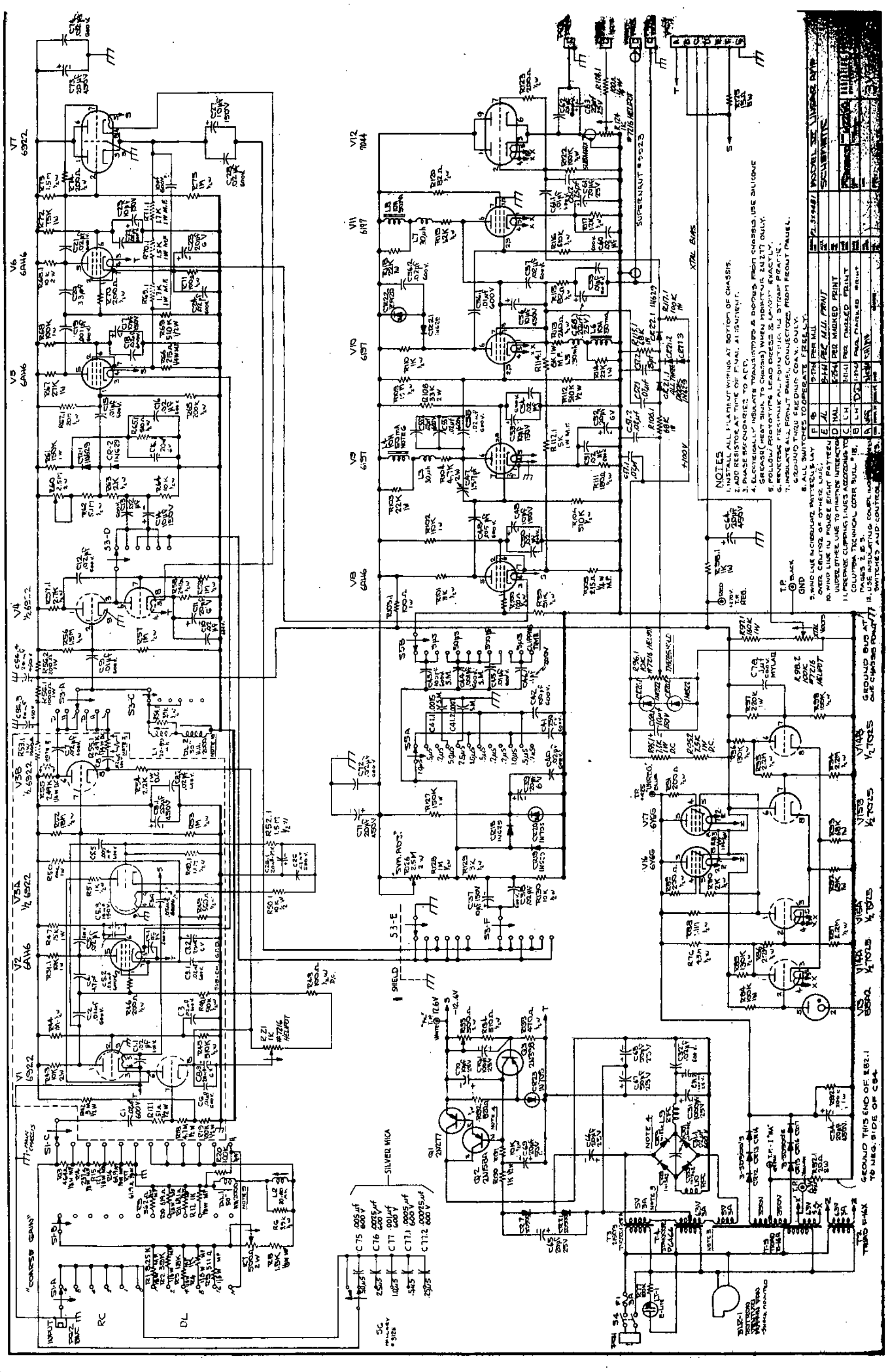

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Fig. 3. Circuit diagram of Model VI Linear Amplifier.

Detailed Circuit Description

The input signal passes from the input receptacle of the amplifier into the input coarse-gain—mode switch. It is the function of this switch to provide for: coarse gain control of the amplifier, insertion of the first line clipper for pulse shaping, and insertion of a high impedance input attenuator for use of the amplifier when no preamplifier is available and high impedance input operation is desired. This gain-mode switch provides five positions of gain with input line clipping, five positions of gain without input clipping, one position of high-impedance input with R. C. clipping, and a zero gain position. From the output of this gain-mode switch the signal passes to the input of the first inverse feedback amplifier. The first two tubes in this amplifier (VI and V2) provide the voltage gain whereas tube V3B serves three functions: matching into the low-impedance second clipping line, pulse inversion when negative input pulses are present, and providing drive to the low impedance feedback network.

Tube V3A of this input amplifier is used to prevent grid current from flowing at the grid of V2 on high-overload conditions. This is accomplished when pulses large enough to overload the grid of V2 overcome the grid bias applied to V3A, allowing V3A to conduct and act as an inverse feedback limiter.

Fine gain adjustment is provided for in this amplifier by varying the feedback in this first feedback loop amplifier. This is accomplished by means of a ten turn Helipot which provides an accurately resettable gain variation of ten to one.

In order to prevent clipping line reflections, pot R7 serves as the adjustment for matching the input clipping line and must be adjusted correctly to prevent pulse reflection from the grid end of this line.

The output follower of the first loop feedback amplifier provides a resistor in its anode equal to its cathode load, so that inversion can take place in this section of the over-all amplifier circuit without loss in amplifier stability, which would arise from using an inverter not clamped to a feedback circuit.

From the output of the first amplifier loop the signal is fed to the mode-polarity-gain switch. This switch provides for; pulse polarity reversal, by selecting the appropriate polarity from the dual polarity output of the first amplifier loop; Hi-Lo gain operation, by elimination of the second loop amplifier from the circuit in the low gain positions; and the insertion of the second clipping line by means of switching. In order to prevent overloading of the second amplifier loop when high overloads are encountered, it is necessary to limit symmetrically the positive- and negative-going pulses developed in the process of double delay line clipping. This is accomplished by a pair of silicon limiting diodes operating into a relatively low-impedance circuit. A White cathode follower (V4) is employed to drive this low impedance limiting circuit, and serves to isolate the varying load of the diode limiter from the clipping line. Since the White follower is a feedback amplifier with unity gain, stability is not sacrificed by employing this necessary coupling stage.

The output from the limiter is now fed either to the input of V5, which is the input tube of the second amplifier loop when the "Hi or DL" settings of the mode-polarity-gain switch are used, or to the input of V8 of the output amplifier loop by way of the rise-time-clipping T. C. switch when the "Lo" position of this switch is used.

When the Hi and DL positions of the mode-polarity-gain switch are selected, the second amplifier loop is used to amplify all pulses. This second amplifier loop consists of three tubes. The first two are amplifiers, and the third tube acts as a low-impedance driver for the feedback circuit and the second symmetry restoring limiter. The gain of this second loop amplifier is accurately maintained by inverse feedback at approximately 20 by precision feedback-determining resistors R66 and R75-1.

After the level of pulses has been symmetrically limited (referring to overload conditions in which limiting takes place) to a sufficiently low level so as not to overdrive the output loop amplifier, the signal passes back through the mode-polarity-switch and is routed through the rise-time—clipping-time control. This rise-time—clipping-time control regulates the lower and upper frequency cutoff of the amplifier or, expressing it in pulse terminology, regulates the desired rise and RC clipping for the pulses being amplified.

When the Lo positions of the mode-polarity-gain switch are used, the second amplifier loop is bypassed, and the signal passes from the output of V4 to the input grid of V8 through the time-constant—clipping-time control.

The third amplifier loop, which is an inverse feedback loop amplifier having a stabilized gain of approximately 60, is designed to drive a 125-v maximum positive and negative signal from its symmetrical output in to a moderate length of cable, or to drive a 125-v maximum positive signal into a long cable from its nonsymmetrical output. The first two tubes of this feedback loop amplifier, V8 and V9, serve as voltage amplifiers, and tubes V10 and V11 serve as a high-level symmetrical output feedback follower. All four of these tubes are contained in the inverse feedback circuit of the last loop, and RF and audio chokes are used in the appropriate places to allow series ac operation of V10 and V11, and to allow the plate of V9 to have sufficient swing to drive to high signal-putput levels desired. Audio chokes, as well as the normally used RF chokes, are employed to extend the available low-frequency response of the output stage, thereby reducing the tendency for lockup of the output amplifier loop on extremely long-tailed overloads; and also allowing for the amplifier to be employed for amplifying many types of lower frequency wave shapes not readily handled by other amplifiers not using these low-frequency chokes in this type of circuit.

Because of the current-handling limitations, as well as the capacity loading limitations, of a White follower when it is used as part of an inverse feedback amplifier, an additional unfed-back cathode follower is employed which is capable of driving long lengths of cable with up to 125-v maximum positive pulse output. This additional follower provides a means of introducing a threshold cut, with a minimum cut of about 1 v and a maximum cut of 100 v. A diode discriminator circuit provides the cut and the cathode follower acts only as the output coupling device.

Operating Performance

The approach described herein of combining the man functions of standard and specialized amplifiers into a single, compact, fairly inexpensive, easy to operate and service package, should appeal to those looking for a flexible, accurate, and, stable linear amplifier to handle the many varied applications dictated by todays increasing amplifier requirements.

The use of these amplifiers at Lawrence Radiation Laboratory has proved them to be extremely stable, very noise free, and compatible with almost any pulse-amplifying need. For gamma-amplifying use and for use where burst conditions and high repetition rates are prevalent, performance has proved superior to that obtained in the A8 or DD2 amplifiers. In use with solid state detectors, stability has been high enough and noise low enough to obtain electronic resolution of the order of 7 kv out of 6 Mev, using stock Model VI Preamplifiers.

General Amplifier Characteristics

Operating modes:

1. RC coupled
2. Single line clipped
3. Double line clipped
4. RC clipped
5. Combinations of above modes

Gain stability:

Better than 1% gain for 105 to 125 v line variation

Maximum gain:

RC clipped - 23,000
Single line clipped - 11,500
Double line clipped - 5,750

Overload recovery:

10xoverload - 4 μsec
100xoverload - 6 μsec
1000xoverload - 10μsec

Input attenuator range:

1, 2, 4, 8, 16; plus a high-low gain range of 22

Fine-gain range:

10 - 1

Rise time:

0.2, 0.5, 1.0, 2.5, 5.0 μsec

RC clipping time:

0.2, 0.5, 1.0, 2.5, 5, 50, 500, 5000 μsec

Input noise for peak-to-peak value of:

	0.2 μsec	0.5 μsec	1.0 μsec
Double line clipped	100 μv	80 μv	60 μv
RC clipped	50 μv	40 μv	30 μv

Input impedances:

RC mode - 1000 ohms
DD mode - 2100 ohms
Hi Z input mode - 55000 ohms

Operational model:

1. RC clipped
2. Double line clipped
3. Single line clipped

Outputs:

	Maximum	Peak-to-peak	Location
Symmetrical	±125 v	250 v	front and rear
Non symmetrical	+125 v	125 v	front and rear

Dimensions:

Panel height - 5-1/4 in.; standard 19-in. panel
Depth - 13 in.
Width - 17 in.

Features:

1. Polarity reversal from front panel
2. Additional standard output follower for driving long cables
3. Panel switching of all operating modes
4. Self-contained regulated power supplies for amplifiers and preamplifiers
5. Control of low- and high-frequency response from front panel
6. DC for filaments of most amplifier tubes as well as preamplifier tubes
7. Ability to amplify wave shapes other than pulses over a wide range of frequencies
8. Helipot control of fine-gain adjustment to give positive accurate resettable gain settings, and to act as gain control for high input impedance operation
9. Forced-air cooling for long component and tube life
10. Twelve positions for coarse-gain, providing five coarse-gain settings with input line clipping, five coarse-gain settings without line clipping, one zero-gain setting, and one high-input impedance setting

11. Incorporation of additional amplifier attenuation, accomplished by removing the second feedback loop amplifier — thereby giving greater stability for the low-gain positions
12. Application of inverse feedback to stabilize not only the amplifier loops but also the coupling and output followers
13. Excellent overload recovery
14. Use of symmetrical pulse limiters between all feedback loops to prevent the driving of following amplifier loops beyond their dynamic range, either in the negative or positive direction
15. Use of a feedback-type limiter circuit in the first loop amplifier which prevents first loop overload, without the use of an input follower drive circuit with its inherently noisier performance
16. Preamplifier plug compatible with DD2 preamplifier
17. Extremely low-noise operation ensured by the selection of an excellent input tube and by the use of dc on most amplifier filaments
18. Threshold output control providing cut from 0 to 100 v
19. Control providing voltage for solid state counter bias

PART II: MODEL VI PREAMPLIFIER

Introduction

The Model VI Preamplifier is a low noise, high stability, multipurpose preamplifier designed primarily to operate in conjunction with the Model VI Linear Amplifier (described in Part I). This unit features either charge-sensitive or voltage-sensitive operation, and is compatible with solid state, ionization, proportional, geiger, or scintillation detectors. When connected to a Model VI Amplifier this preamplifier derives its plate power, filament power, and solid state detector bias voltages from this amplifier.

For solid state detector operation the preamplifier will handle either the standard or guard-ring type detectors. A wide range of preamplifier gains can be chosen for solid state counting, and either charge-sensitive or voltage-sensitive operation may be used. Input stages have been designed to have extremely low noise and microphonics. Stock Model VI Preamplifiers will produce electronic resolution approaching 0.1% for a 6 Mev equivalent alpha.

Ionization, geiger, proportional, or scintillation detectors may also be used, since there are provisions for bringing in high voltage and for connecting to these types of detectors. As in the case with solid state detectors a wide gain range is available.

Circuitry

The preamplifier consists of three individually fed-back amplifier stages which can be used in a number of combinations (see Figs 4 and 5). The last stage may be used alone, it may be used with either the first or second stage driving it, or it may be used so that a cascaded connection of the first and second stages drives it.

Stage one is a charge-sensitive feedback amplifier, stage two is a voltage-sensitive feedback amplifier, and stage three is a White cathode follower.

Solid stage detectors are normally fed into the input of the charge-sensitive stage, as this will generally produce the best resolution because of the charge-sensitive amplifiers ability to automatically compensate for temperature- and voltage-induced pulse height changes prevalent in most solid state detectors. The input stage, which is exceedingly noise free, uses three RCA 7586 nuvistors. Two of these nuvistors are employed in a cascode circuit to obtain high gain with minimum noise, and the third is used as an output follower which drives not only the output but also the top of the cascode stages plate load resistor to further increase the unfed-back loop gain of the input amplifier. When using proportional or ion collection detectors such detectors are best fed into the input of the second stage, which is a voltage-sensitive feedback amplifier having low noise characteristics and a voltage gain of approximately 25. As in the first amplifier stage, this stage also employs a cascode-connected input stage for minimum noise.

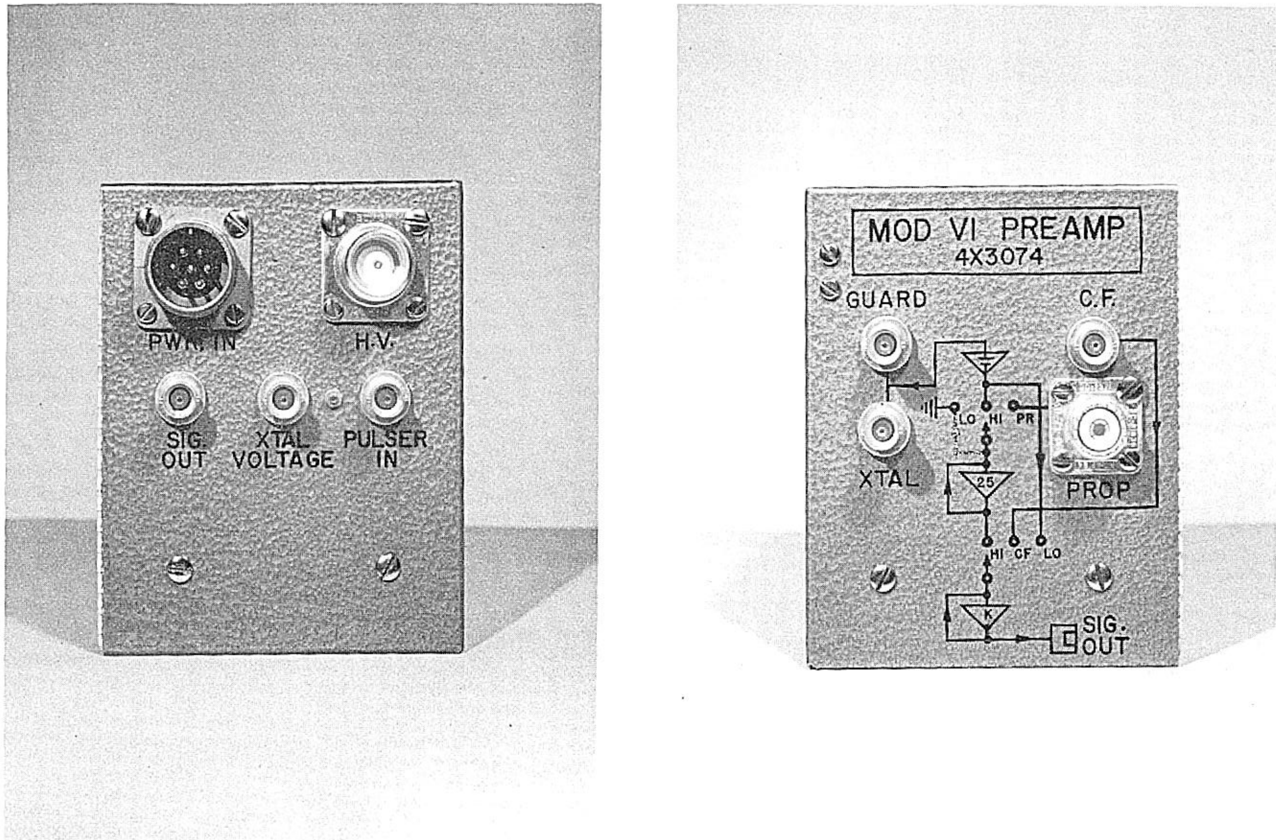

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Fig. 4. Model VI Preamplifier input and output connectors.

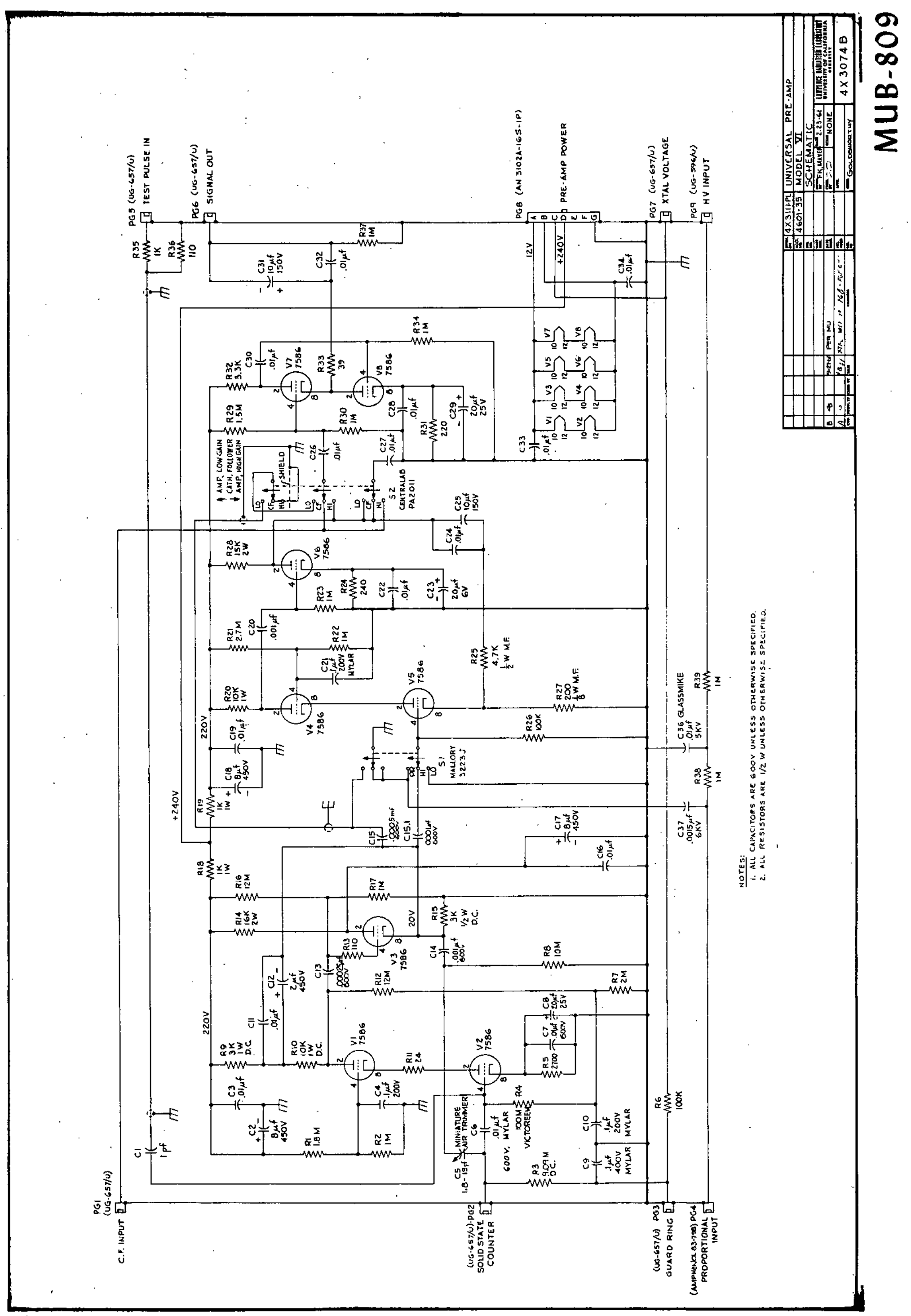

Fig. 5. Circuit diagram of Model VI Preamplifier.

If photomultiplier detectors are used, their output is sufficiently high so that no preamplification is necessary. Normally their output should be fed to the input of the third stage only, which is a White cathode follower having a stable gain of approximately one. This White cathode follower's main function is to drive the low impedance input of the Model VI Amplifier and its interconnecting cable with a high degree of stability and linearity.

Switches have been provided for selecting the proper operational mode for the preamplifier, and the symbol diagram drawn on the box should be used as a guide to their settings.

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