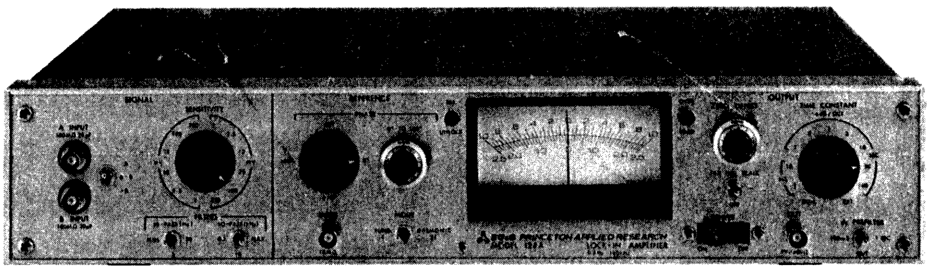
MODEL 128A LOCK-IN AMPLIFIER

SEE SAFETY NOTICE
PRECEDNG SECTION I
BEFORE OPERATING INSTRUMENT



OPERATING AND SERVICE MANUAL

EG&G BROOKDEAL ELECTRONICS
PRINCETON APPLIED RESEARCH

MODEL 128A
LOCK-IN AMPLIFIER

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EG&G BROOKDEAL ELECTRONICS
PRINCETON APPLIED RESEARCH

M128A; 9/83-500-MIC

Printed in U.S.A.

SHOULD YOUR EQUIPMENT REQUIRE SERVICE

A. Contact the factory (609/452-2111) or your local factory representative to discuss the problem. In many cases it will be possible to expedite servicing by localizing the problem to a particular plug-in circuit board.

B. If it is necessary to send any equipment back to the factory, we need the following information.

(1) Model number and serial number.

(2) Your name (instrument user).

(3) Your address.

(4) Address to which instrument should be returned.

(5) Your telephone number and extension.

(6) Symptoms (in detail, including control settings).

(7) Your purchase order number for repair charges (does not apply to repairs in warranty).

(8) Shipping instructions (if you wish to authorize shipment by any method other than normal surface transportation).

C. U.S. CUSTOMERS—Ship the equipment being returned to:

EG&G PRINCETON APPLIED RESEARCH
7 Roszel Road
(Off Alexander Road, East of Route 1)
Princeton, New Jersey

D. CUSTOMERS OUTSIDE OF U.S.A.—To avoid delay in customs clearance of equipment being returned, please contact the factory or the nearest factory distributor for complete shipping information.

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P. O. Box 2565
Princeton, NJ 08540

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This Warranty shall not apply to any instrument which our inspection shall disclose to our satisfaction, has become defective or unworkable due to abuse, mishandling, misuse, accident, alteration, negligence, improper installation or other causes beyond our control. Instruments manufactured by others, and included in or supplied with our equipment, are not covered by this Warranty but carry the original manufacturer's warranty which is extended to our customers and may be more restrictive. Certain subassemblies, accessories or components may be specifically excluded from this Warranty, in which case such exclusions are listed in the Instruction Manual supplied with each instrument.

We reserve the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

THERE ARE NO WARRANTIES WHICH EXTEND BEYOND THE DESCRIPTION HEREIN. THIS WARRANTY IS IN LIEU OF, AND EXCLUDES ANY AND ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESSED, IMPLIED OR STATUTORY, INCLUDING MERCHANTABILITY AND FITNESS, AS WELL AS ANY AND ALL OTHER OBLIGATIONS OR LIABILITIES OF EG&G PRINCETON APPLIED RESEARCH, INCLUDING, BUT NOT LIMITED TO, SPECIAL OR CONSEQUENTIAL DAMAGES. NO PERSON, FIRM OR CORPORATION IS AUTHORIZED TO ASSUME FOR EG&G PRINCETON APPLIED RESEARCH ANY ADDITIONAL OBLIGATION OR LIABILITY NOT EXPRESSLY PROVIDED FOR HEREIN EXCEPT IN WRITING DULY EXECUTED BY AN OFFICER OF EG&G PRINCETON APPLIED RESEARCH.

TABLE OF CONTENTS

FIGURES

TABLES

SAFETY CONSIDERATIONS

A. INTRODUCTION

The apparatus to which this instruction manual applies has been supplied in a safe condition. This manual contains some information and warnings that have to be followed by the user to ensure safe operation and to retain the apparatus in a safe condition. The described apparatus has been designed for indoor use.

B. INSPECTION

Newly received apparatus should be inspected for shipping damage. If any is noted, immediately notify EG&G PARC and file a claim with the carrier. The shipping container should be saved for possible inspection by the carrier.

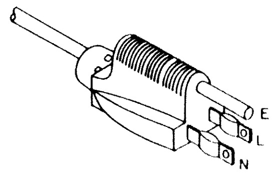
> **WARNING!**
> THE PROTECTIVE GROUNDING COULD BE RENDERED INEFFECTIVE IN DAMAGED APPARATUS. DAMAGED APPARATUS SHOULD NOT BE OPERATED UNTIL ITS SAFETY HAS BEEN VERIFIED BY QUALIFIED SERVICE PERSONNEL. DAMAGED APPARATUS WAITING FOR SAFETY VERIFICATION SHOULD BE TAGGED TO INDICATED TO A POTENTIAL USER THAT IT MAY BE UNSAFE AND THAT IT SHOULD NOT BE OPERATED.

C. SAFETY MECHANISM

As defined in IEC Publication 348 (*Safety Requirements for Electronic Measuring Apparatus*), the Model 128A is Class I apparatus, that is, apparatus that depends on connection to a protective conductor to earth ground for equipment and operator safety. Before any other connection is made to the apparatus, the protective earth terminal shall be connected to a protective conductor. The protective connection is made via the earth ground prong of the M128A's power cord plug. This plug shall only be inserted into a socket outlet provided with the required earth ground contact. The protective action must not be negated by the use of an extension cord without a protective conductor, or by use of an "adapter" that doesn't maintain earth ground continuity, or by any other means.

The power cord plug provided is of the type illustrated in Figure 1. If this plug is not compatible with the available power sockets, the plug or power cord should be replaced with an approved type of compatible design.

> **WARNING!**
> IF IT IS NECESSARY TO REPLACE THE POWER CORD OR THE POWER CORD PLUG, THE REPLACEMENT CORD OR PLUG MUST HAVE THE SAME POLARITY AS THE ORIGINAL. OTHERWISE A SAFETY HAZARD FROM ELECTRICAL SHOCK, WHICH COULD RESULT IN PERSONAL INJURY OR DEATH, MIGHT RESULT.



L = LINE OR ACTIVE CONDUCTOR (ALSO CALLED "LIVE" OR "HOT")
N = NEUTRAL OR IDENTIFIED CONDUCTOR
E = EARTH OR SAFETY GROUND

Figure 1. POWER CORD PLUG WITH POLARITY INDICATIONS

D. POWER VOLTAGE SELECTION AND LINE FUSES

Before plugging in the power cord, make sure that the equipment is set to the voltage of the ac power supply.

> **CAUTION!**
> THE APPARATUS DESCRIBED IN THIS MANUAL MAY BE DAMAGED IF IT IS SET FOR OPERATION FROM 110 V AC AND TURNED ON WITH 220 V AC APPLIED TO THE POWER INPUT CONNECTOR.

A detailed discussion of how to check and, if necessary, change the power-voltage setting follows.

The line voltage is selected by means of a rear-panel switch. FOR SAFETY, UNPLUG THE POWER CORD WHEN CHECKING THE LINE VOLTAGE SETTING OR WHEN CHECKING THE FUSES. FUSES SHOULD ONLY BE CHANGED BY QUALIFIED SERVICE PERSONNEL WHO ARE AWARE OF THE HAZARDS INVOLVED. Depending on the switch position, either "115" or "230" (both are printed on the switch) will be visible to the viewer. For operation from a line voltage from 100 V ac to 130 V ac, 50-60 Hz, "115" should show.

SECTION I
CONDENSED OPERATING INSTRUCTIONS

The following condensed operating instructions are provided as an assistance in placing the Model 128A Lock-In Amplifier into operation as quickly as possible. Generally speaking, these condensed instructions will allow good results to be obtained in most instances. However, because of the brevity of these instructions, many considerations having importance in particular applications have been foregone. For this reason, it is advisable to read Section IV, the complete Operating Instructions, to be assured of achieving optimum performance. **NOTE:** As written, these condensed instructions do not apply to units having either the Internal Oscillator or Tuned Amplifier modifications. If the unit in question has either or both of these modifications, the operator is referred to Subsections 4.7 and 4.8.

STEP ONE

PRELIMINARY STEPS: Check that the rear-panel 115/230 V switch is in the proper position. Remove the top cover and verify that the two Reference Lock-On Speed switches are properly set. For operation below 5 Hz, they should be set to SLOW. For operations above 5 Hz, they should be set to FAST. (Units are shipped with these switches set to FAST.) Replace the cover and plug in the line cord. Turn the power on.

STEP TWO

REFERENCE CHANNEL: Check that the Reference Mode switch is set to the proper position. With the switch set to "f", the detector is driven at the frequency of the applied reference signal. Set to "2f", the detector is driven at twice the frequency of the applied reference to facilitate second harmonic measurements. Next connect the reference signal (100 mV pk-pk or greater) to the Reference Input connector and wait for the REF. UNLOCK light to go out before proceeding. Usually this will be but a few seconds. However, at low frequencies, a longer time is required.

STEP THREE

SIGNAL CHANNEL: Set the Input Selector to "A" (single-ended), "A−B" (differential) or "−B" (single-ended), whichever is appropraite. Set the Sensitivity switch to "250 mV". If signal channel filtering is desired, set the HI-PASS and LO-PASS Filter switches as required. Connect the signal source to the Model 128A Input.

STEP FOUR

OUTPUT CONTROLS: Set the Zero Offset toggle switch to the center (OFF) position. Then set the DC Prefilter to 100 ms and the Time Constant switch to 0.3 SEC.

STEP FIVE

FINAL ADJUSTMENTS: Rotate the Sensitivity switch counterclockwise until the panel meter begins to deflect. Adjust the Phase Quadrant switch and Phase dial for maximum meter indication. When the Sensitivity and Phase adjustments are optimally set, the meter should indicate the maximum possible on-scale reading. If the Overload light comes on, increase the prefilter and time constant settings. Also try "bracketing" the signal frequency with the HI PASS and LO PASS filters. If these techniques don't help, rotate the Sensitivity switch as far clockwise as is required to eliminate the overload. Set the time constant as required to reduce the output noise to an acceptable level.

STEP SIX

READING: The input signal level is read from the panel meter. If the input signal is a sinewave, the meter directly indicates the rms amplitude of the input signal. However, if the signal frequency is near enough to a selected HI or LO PASS filter frequency to be influenced by the filter, the filter attenuation effects must be taken into account. If the input signal is not a sinewave, then the harmonic response of the instrument must be taken into account as well.

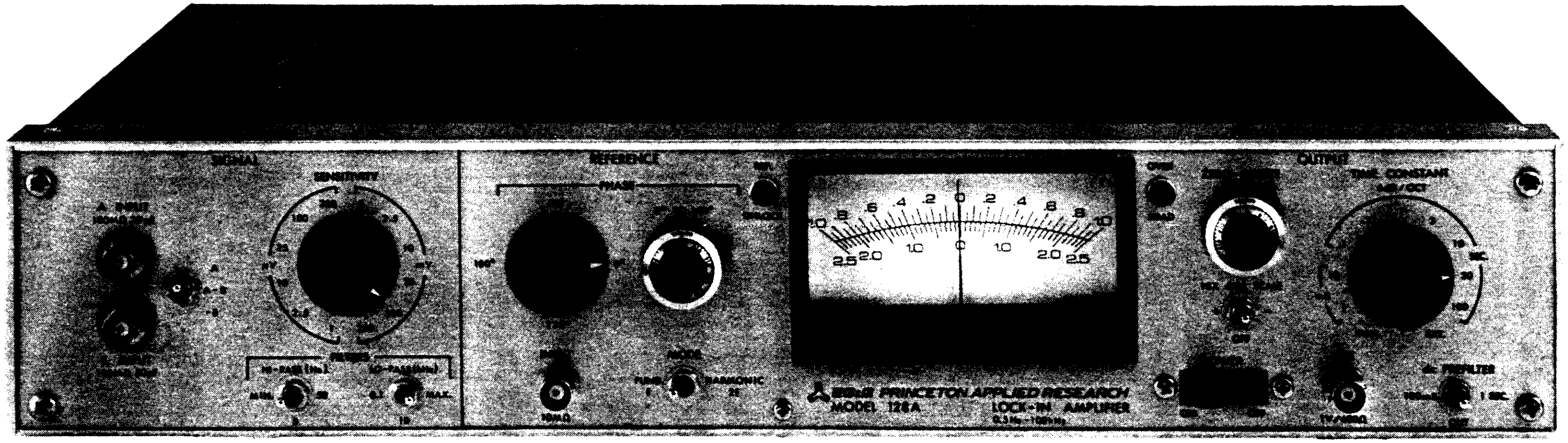


Figure I-1. MODEL 128A LOCK-IN AMPLIFIER

SECTION II
CHARACTERISTICS

2.1 INTRODUCTION

The Model 128A Lock-In Amplifier enables the accurate measurement of signals contaminated by broad-band noise, power line pickup, frequency drift, or other sources of interference. It does this by means of an extremely narrow band detector which has the center of its passband locked to the frequency of the signal to be measured. Because of the frequency lock and narrow bandwidth, large improvements in signal-to-noise ratio can be achieved, allowing the signal of interest to be accurately measured, even in situations where it is completely masked by noise.

Signals applied to the input (single-ended or differential) are routed through a series of amplifiers which allow full-scale sensitivity ranges down to one microvolt. Switch selectable low-pass and high-pass filters allow considerable noise reduction ahead of the phase-sensitive detector. This pre-detector noise reduction can be further enhanced by making use of the optional plug-in (internal) selective amplifier. At the phase sensitive detector, the signal is compared with the reference signal derived from the experiment. Only those signal components which are synchronous with the reference yield a net dc detector output. Noise and other non-synchronous signals do not contribute a net dc output, but only ac fluctuations which can be reduced to any arbitrary value according to the amount of filtering selected with the Time Constant switch. This switch allows time constants as large as 100 seconds to be selected, with provision for achieving larger externally determined time constants if necessary. Post-detector dc amplifiers drive the panel meter and signal output connectors. Other features include provision for calibrated zero suppression of up to 10 x full scale, a two-position dc prefilter, and the capability of driving the reference input of the detector at double the frequency of the signal applied to the Reference Input connector to facilitate second harmonic measurements. An optional plug-in oscillator (internal) is available for use in applications where the experiment does not produce a reference signal itself, but is capable of being driven by a signal furnished by the Lock-In Amplifier.

With its wide range of capabilities and ease of operation, the Model 128A Lock-In Amplifier should find extensive application in situations where the accurate measurement of signals is complicated by the presence of noise and interference.

2.2 SPECIFICATIONS

SIGNAL CHANNEL

(1) INPUT TYPE

Single-ended or differential as selected by front-panel switch.

(2) INPUT IMPEDANCE

100 MΩ shunted by no more than 20 pF.

(3) SENSITIVITY

12 full-scale ranges in 1-2.5-10 sequence from 1 μV to 250 mV.

(4) FREQUENCY RANGE

0.5 Hz to 100 kHz.

(5) COMMON MODE REJECTION

At least 100 dB at 1 kHz.

(6) MAXIMUM COMMON MODE VOLTAGE

3 V pk-pk to 20 kHz; then −6 dB/octave above 20 kHz.

(7) DETECTOR BIAS

Internal network allows dc bias current of either polarity to be provided at the "A" Input to facilitate operation with diode detectors which require biasing. (See page VII-3 and Parts Location Diagram on page VII-2.)

(8) NOISE

At 1 kHz the signal channel noise will not exceed 10 $nV/Hz^{1/2}$.

(9) LOW PASS FILTER

Switch selectable 6 dB/octave low-pass filter which can be set to 3 dB down frequencies of 100 Hz, 10 kHz, or MAX (greater than 100 kHz).

(10) HIGH PASS FILTER

Switch selectable 6 dB/octave high-pass filter which can be set to 3 dB down frequencies of 50 Hz, 5 Hz, or MIN (below 0.5 Hz).

(11) OVERLOAD DETECT

Front-panel indicator lights if applied signal plus noise is large enough to cause overload at any of several critical overload monitor points.

(12) GAIN STABILITY

0.1%/°C.

(13) GAIN LINEARITY

0.05%.

(14) OVERALL GAIN ACCURACY

±2%.

REFERENCE CHANNEL

The Model 128A reference channel automatically locks onto and tracks an applied reference signal over the entire operating frequency range of the instrument. As a result, the instrument is immune to frequency and phase shifts as long as the reference and signal to be recovered change together.

(1) TRACKING RANGE

5 Hz to 100 kHz (FAST) or 0.5 Hz to 100 kHz (SLOW) as determined by the setting of two internal switches. Faster lock-on time and slewing rate obtained with switches set to FAST make this range preferable except when operating below 5 Hz.

(2) MODES

Either of two modes, f and 2f, can be selected by means of a front-panel switch. In the "f" position, the phase-sensitive detector is driven at the same frequency as the applied reference signal. In the "2f" position, the phase-sensitive detector is driven at twice the frequency of the applied reference signal to facilitate second harmonic measurements.

(3) INPUT IMPEDANCE

10 MΩ shunted by no more than 20 pF.

(4) MINIMUM REFERENCE SIGNAL REQUIREMENT

100 mV pk-pk, any waveshape crossing its mean only twice each cycle. Minimum time required on either side of the mean is 100 ns. Amplitude excursions must be at least 50 mV on each side of the mean. Maximum input signal is 5 V (pk-to-mean). Best phase accuracy is obtained with a 1 V rms sinewave.

(5) LOCK-ON TIME

A function of internal switch setting as follows.

Selected Range	Lock-On Time
SLOW (0.5 Hz to 100 kHz)	20 sec. per octave
FAST (5 Hz to 100 kHz)	2 sec. per octave

(6) PHASE

Calibrated Phase controls allow the phase of the reference drive to the Phase-Sensitive Detector to be set at any angle relative to the input signal. The controls consist of a Phase Dial with a range of 100° and a Phase Quadrant switch which provides incremental phase shifts of 90°. The phase shift accuracy of the dial is better than 0.2° over the entire frequency range. The resolution of the dial is better than 0.1°. The incremental phase shifts provided by the Quadrant switch are accurate to 0.2°. The overall phase accuracy of the instrument, including shifts in both the reference and signal channels, is typically better than 5°.

(7) DETECTOR BIAS

Internal network allows dc bias current of either polarity to be provided at the REF. IN connector to facilitate operation in situations where the reference signal is taken from diodes requiring biasing. (See page VII-6 and Parts Location Diagram on page VII-5.)

PHASE SENSITIVE DETECTOR, DC AMPLIFIER

(1) OUTPUT DRIFT

0.1%/ °C.

(2) OVERLOAD CAPABILITY

1000 times full scale up to a maximum at the input of 650 mV rms. Overload capability is defined as the ratio, at the input of the Model 128A, of the maximum pk-pk non-coherent signal which can be applied without overloading the Model 128A to the pk-pk coherent signal required to yield full scale Model 128A output. Note that, expressed as the ratio of the pk-pk non-coherent signal to the *rms value* of the coherent signal required for full-scale output, this number can be as great as 2800. Maximum acceptable signal is a 650 mV rms sinewave.

(3) NON-COHERENT REJECTION

50 ppm maximum. Non-coherent rejection is defined as that offset which results from applying a non-coherent signal having a pk-pk amplitude 1000 times the pk-pk amplitude of the coherent signal required to obtain full-scale output.

Example: With a non-coherent signal applied having a pk-pk amplitude 1000 times the pk-pk coherent signal required to obtain full-scale output, there will occur an offset at the output caused by the non-coherent input signal. The amplitude of this offset will be no greater than:

$50 \times 10^{-6} \times 1000$

$= 50 \times 10^{-3}$ of f.s. output

= 50 mV (f.s. = 1 V)

(4) TIME CONSTANT

Front-panel switch allows selection of 6 dB/octave filter time constants of 1 ms, 10 ms, and .1 s through 100 s in 1-3-10 sequence. Also MIN (time constant ≅0.7 ms) and EXT, which allows time constants longer than 100 s to be achieved by means of external capacitors. A separate front-panel toggle switch allows another 6 dB/octave filter to be inserted, if desired. This filter has a time constant of either 100 ms or 1 s, whichever is selected.

(5) ZERO OFFSET

A calibrated, ten-turn, Zero Offset dial, with up to ten times full-scale capability is provided.

(6) FULL-SCALE OUTPUT

±1 V.

(7) OUTPUTS

(a) Panel meter, ± full scale.

(b) Front-panel BNC connector. One volt out corresponds to full-scale panel meter deflection. Output resistance is 600 ohms.

(c) Rear-panel Recorder Out binding posts, spaced to accept standard double-banana connector. Output resistance is 600 ohms.

GENERAL

(1) AMBIENT OPERATING TEMPERATURE RANGE

15°C to 45°C.

(2) AUXILIARY POWER OUTPUT

±15.5 V regulated dc at 20 mA is provided at rear-panel connector.

(3) POWER REQUIREMENTS

100-130 V ac or 200-260 V ac, 50-60 Hz. May also be powered from ±24 V dc source (such as batteries). Power consumption: 15 watts.

(4) SIZE

17-3/4" W x 3-1/2" H x 14" D (45 cm W x 9 cm H x 36 cm D).

(5) WEIGHT

14 lbs (6.4 kg).

(6) MODIFICATIONS

(a) Model 128A/97 Monitor Modification

Three rear-panel BNC connectors are installed which permit monitoring of: (1) Output of Signal Channel before demodulation (please note that the Signal Channel monitor is provided as part of the Tuned Amplifier modification as well), (2) Squarewave output of Reference Channel, and (3) Full-wave demodulated Mixer output before Time Constant filter.

(b) Model 128A/98 Tuned Amplifier Modification

Internal plug-in board is available which provides a tuned bandpass or notch characteristic at a Q-of-5. The frequency can be adjusted over a 3:1 range by means of a rear-panel adjustment, and can be set to any frequency from 1 Hz to 100 kHz by changing capacitors mounted on component clips located on the plug-in circuit board.

(c) Model 128A/99 Internal Oscillator Modification

An internal low distortion oscillator is available which provides a sinewave output adjustable from 0-to-10 V pk-pk at 600 ohms. The frequency is adjustable over about a 3:1 range by means of a rear-panel adjustment, with the actual frequency range spanned by the adjustment being determined by a pair of internal capacitors mounted on the oscillator circuit board. Operation from about 1 Hz to 100 kHz is possible. This option, in conjunction with the 2f mode of operation, is particularly useful for harmonic detection where the modulation frequency must be at one half the detected frequency.

SECTION III
INITIAL CHECKS

3.1 INTRODUCTION

The following procedure is provided to facilitate initial performance checking of the Model 128A. In general, this procedure should be performed after inspecting the instrument for shipping damage (any noted to be reported to the carrier and to Princeton Applied Research Corporation), but before using the instrument for experimental measurements. Should any difficulty be encountered in carrying out these checks, contact the factory or one of its representatives. It might be noted that it is not the purpose of these checks to demonstrate that the instrument meets all specifications, but rather simply to show that it is functioning normally. If normal indications are obtained for the functions checked, one may reasonably assume that those functions which are not checked are working properly as well.

3.2 EQUIPMENT NEEDED

(1) Sinewave Oscillator to provide a 100 mV rms sinewave at 1 kHz. **NOTE:** If the instrument to be checked is equipped with the Tuned Amplifier modification, then the oscillator will have to provide a 100 mV rms sinewave at the tuned frequency. If the instrument in question is equipped with the Internal Oscillator modification, no external oscillator will be required. This applies whether or not the unit is equipped with the Tuned Amplifier modification.

(2) General purpose oscilloscope. This item is required only in the case of units having the Tuned Amplifier modification.

(3) Suitable cables for interconnecting the above instruments.

3.3 PROCEDURE

(1) Check the position of the rear-panel 115/230 switch. Be sure the number showing in the window corresponds to the line voltage to be used.

(2) With the Power switch set to OFF, plug in the line cord.

(3) Set the Model 128A controls as follows.

Input Selector: A
Sensitivity: 100 mV
Filters
  HI-PASS: MIN.
  LO-PASS: MAX.
Phase
  Quadrant switch: 270°
  Phase dial: 90°
Mode: f
Zero Offset
  switch: OFF (center position)
  dial: 1.00 (one turn from fully counterclockwise position)
Time Constant: .3 SEC.
DC Prefilter: OUT
Reference Tracking-Rate switches (two internal switches): FAST (unless unit is equipped with Tuned Amplifier or Internal Oscillator set for frequency below 5 Hz, in which case switches should be set to SLOW). **NOTE:** Instruments are normally shipped with these switches set to FAST.
Power. ON

(4) Applies only to units *not* equipped with the Internal Oscillator modification. If the Model 128A has this modification, go to step 5.

Connect the output of the external oscillator (set for 100 mV rms sinewave out at 1 kHz) to both the "A" and Reference Inputs. If the unit in question has the Tuned Amplifier modification, set the oscillator to the tuned frequency specified when the unit was ordered.

(5) Applies only to units having the Internal Oscillator modification.

Connect a cable from the rear-panel REF. OSC. OUT connector to the front-panel "A" Input. There is no need to connect this signal to the Reference Input connector (labeled MONITOR in units equipped with the Oscillator modification). The connection to the Reference Channel of the Model 128A is made internally at the factory. The rear-panel REF. AMPLITUDE adjustment should be set so that the amplitude of the signal at the REF. OSC. OUT connector is 100 mV rms. An accurate ac voltmeter may be useful for setting this level (units leave the factory set for a nominal 100 mV rms out).

(6) Applies only to units having the Tuned Amplifier modification. In the case of units not having this modification, go directly to step 7.

(a) Connect the oscilloscope to the rear-panel SIG. MON. connector.

(b) Vary the frequency of the signal applied to the "A" Input (use the rear-panel REF. OSC. FREQ. ADJ. control in units equipped with an Internal Oscillator) for peak signal amplitude as observed with the oscilloscope.

(7) Set the Phase Quadrant switch to 0°. Then adjust the Phase dial for "0" panel meter indication.

(8) Set the Phase Quadrant switch back to 270°. The panel meter should indicate full scale to the right ± a few percent of full scale. The accuracy of this reading

will depend on the amplitude accuracy of the signal applied to the "A" Input.

(9) Adjust the amplitude of the signal applied to the "A" Input as required to obtain exactly full-scale panel meter indication.

(10) Set the Phase Quadrant switch to 180°. The panel meter should indicate "0" ±5% of full scale.

(11) Set the Phase Quadrant switch to 90°. The panel meter should indicate negative full scale ±5% of full scale.

(12) Set the Phase Quadrant switch to 270° to restore the positive full-scale panel meter indication.

(13) Set the Zero Offset toggle switch to "+". The panel meter indication should go to "0" ±5% of full scale.

(14) Begin rotating the Offset dial counterclockwise. The panel meter indication should increase linearly, tracking the dial setting. When the dial is fully counterclockwise, the panel meter should indicate full scale ±5%. Reset the Zero Offset toggle switch to the center (OFF) position.

This completes the initial checks. If the indicated results were obtained, one can be reasonably sure that the Model 128A is functioning normally.

SECTION IV
OPERATING INSTRUCTIONS

4.1 INTRODUCTION

Even though operation of the Model 128A is straightforward, there are a number of factors of which the operator should be aware to be assured of achieving optimum performance in all situations. This section of the manual treats these considerations in some detail. Topics covered include grounding, noise performance, harmonic sensitivity, operation in conjunction with the plug-in accessories, and others. For an overall "quick look" at how the instrument is operated, the operator is referred to Section I, the condensed operating instructions.

4.2 PRELIMINARY CONSIDERATIONS

4.2A POWER REQUIREMENTS

The Model 128A requires 100-130 V ac or 200-260 V ac, 50-60 Hz. The power consumption is 15 watts. The unit may also be powered by batteries by applying ±24 V to the appropriate pins of the rear-panel octal connector (see BATTERY OPERATION, page IV-10). A rear-panel slide switch determines whether the ac power circuits are connected for operation from 100-130 V or from 200-260 V. For operation from 100-130 V, "115" should show in the window. For operation from 200-260 V, "230" should show.

4.2B FUSING

The Model 128A is protected by a single fuse mounted on its rear panel. A slow-blow 1/4 A fuse is used for operation from 115 V. A slow-blow 1/10 A fuse is used for operation from 230 V. It occasionally happens that a slow-blow fuse fails in shipment as a result of shock and vibration. Hence, if the fuse is found to be bad when the instrument is operated for the first time it is advisable to try and change the fuse. If normal operation follows, chances are there are no other problems. However, if the replacement fuse fails, there is something wrong which will have to be corrected before proceeding.

4.2C WARM-UP PERIOD

For most applications, five minutes. Where it is desired to achieve the best possible gain and output stability, allow an hour.

4.2D OPERATING FREQUENCY

Although one can, in principle, make equally accurate measurements at any frequency within the operating range of the instrument, operation is simplest and least subject to error over a range having as its lower limit, perhaps a few hundred Hz, and as its upper, perhaps 10 kHz. At very low frequencies, phase offsets occur which could matter if one is interested in the absolute phase of the input signal. Another problem of low frequency operation is that of 1/f noise, including both that which develops in the Model 128A and that which originates in the experiment itself to degrade the signal-to-noise ratio ahead of the lock-in amplifier. Increased response and settling time could be a significant problem if one were operating in conjunction with the optional plug-in tuned amplifier. At high frequencies, radiation and associated pick-up tend to be bothersome. Another high frequency problem is that of signal attenuation as a result of the input cable capacitance. This is especially a problem when working from a high source resistance. Other frequencies to avoid are 60 Hz and its lower order harmonics. By avoiding these frequencies, the operator assures that he will be measuring the signal of interest only, uninfluenced by power frequency pick-up, either internal or external.

4.2E GROUNDING

In any system processing low-level signals, proper grounding to minimize the effects of ground loop currents, usually at the power frequency, is an important consideration. In the case of the Model 128A, special design techniques have been employed to give a high degree of ground-loop signal rejection in single-ended applications. Even so, it will often prove advisable to operate differentially, even when examining a single-ended signal source, to achieve the greatest possible rejection. Figures IV-1 and IV-2 illustrate this point. Note from Figure IV-1 that the signal source is located inside a grounded enclosure (shield), to which signal source common is attached at one point. The braid of the

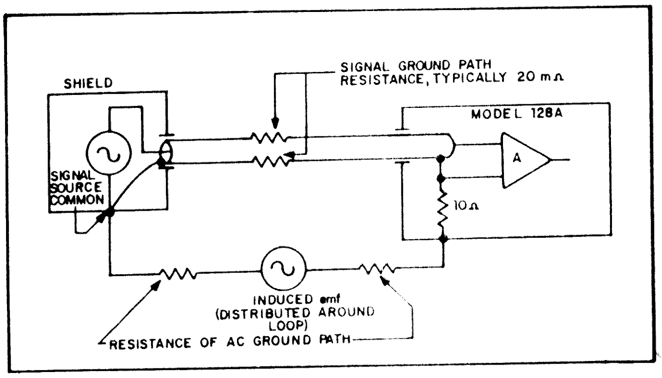


Figure IV-1. GROUND-LOOP SUPPRESSION BY TEN-OHM INPUT GROUND

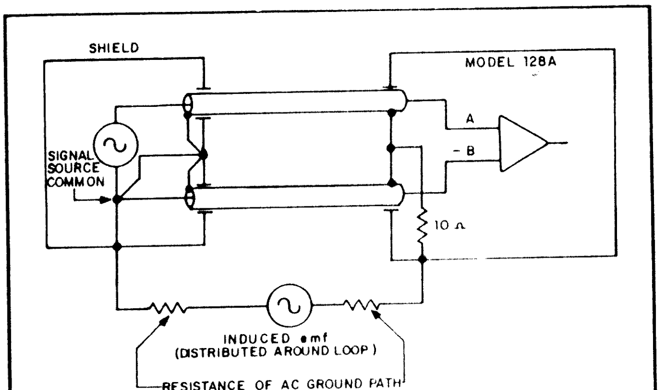


Figure IV-2. DIFFERENTIAL MEASUREMENT OF "SINGLE-ENDED" SIGNAL

signal cable is grounded directly to signal source common as well, thereby assuring that no signal currents or ground-loop currents will flow through the shield, a desirable condition for the best possible shielding. The Model 128A is operated single-ended, using the "A" input. Note that the "low" side of the amplifier input is not grounded to the chassis directly but by way of a ten ohm resistor. Further note that the braid of the signal cable is returned to this resistor, and not to the chassis. A ground loop generator is indicated as being connected between the chassis of the Model 128A and signal source common. This path would ordinarily consist of the ac ground "third wire", paralleled by the braids of other cables connecting the system components. The ground loop generator will cause currents at the power frequency to flow through the braid of the signal cable, through the ten ohm resistor, and back through the ac ground path to complete the loop. Because of the ten ohm ground employed in the Model 128A, these currents are attenuated over what they would be if the Model 128A input were returned directly to the chassis. More importantly, most of the ground loop signal is dropped across the ten ohm resistor and little across the braid of the signal cable, the ratio being the ten ohms of the resistor to the 10 to 20 milliohms (typical) of the braid resistance. As far as the input of the Model 128A is concerned, the ground loop signal is reduced by this ratio, and the ground loop interference is thus perhaps a factor of five hundred or one thousand less than would be the case without the ten ohm ground.

However, in some applications, this would not be enough. Figure IV-2 shows how this same signal could be measured operating the Model 128A differentially. In this instance, the Model 128A Input Selector is set to "A–B" and two input cables are used, one connected to the signal source and the other to signal source common. At the source end, the braid of both cables is returned to signal source common. At the lock-in amplifier end, the ten ohm ground serves to attenuate the ground loop currents and maintain a small ground loop signal drop across the braids the same as in Figure IV-1. However, in the first instance, the amplifier "looked" at the potential difference between the center conductor of the cable and the braid. In the second, it sees the potential difference between the "A" Input and "B" Input. The ground loop signal current flowing in the signal cable braid is of no consequence. The very high common mode rejection of the amplifier assures that common mode power frequency pickup will not be a problem either.

However, when operating differentially, it is important to take a little trouble to assure that common mode interference arising in ground loops is just that, that is, without a significant differential component. This should not prove a problem as long as both signal cables follow the same path.

Figure IV-3 shows the Model 128A operated differentially to measure an "off ground" signal. The most important consideration in an application of this type is to be sure that the common mode signal component is not so large as to exceed the common mode input limit of the Model 128A. (See Specs.)

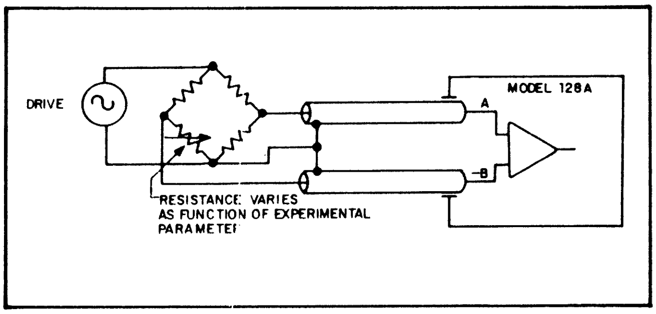


Figure IV-3. DIFFERENTIAL MEASUREMENT OF "OFF-GROUND" SIGNAL

The reduction of power frequency interference is not the only benefit to be derived from proper grounding and differential operation. A much more serious source of interference is coherent interference at the signal frequency which results when drive signal current is allowed to flow through the braid of the signal cable. Figures IV-4 and IV-5 are provided to illustrate this problem and the steps which can be taken to prevent it. To begin with, Figure IV-4 shows the experiment with just about everything possible "done wrong". The lock-in amplifier is operated single-ended. The ground connections at the experiment are made to the enclosure, allowing currents to flow through it, and, in particular, the drive signal currents have the opportunity to flow through the braid of the signal cable. The drive signal, in addition to providing the reference input signal to the Model 128A, can be presumed to be driving other components of the system as well. Depending on the nature of the experiment, these currents could range from very small to quite large, perhaps even amperes if the experiment involves driving a low impedance coil. Note that the various loads for the drive are represented by a single resistor returned to ground somewhere on the enclosure. Most of this drive signal current can be presumed to flow through the shield back to the drive signal source. However, a small but significant part of it will flow through the parallel path consisting of the braid of the signal cable, the ten ohm resistor, and the braid of the reference signal cable. The voltage drop of this current across the resistance of the signal cable braid, even though attenuated by the ratio of the ten ohm resistor to the braid resistance, can constitute a serious source of interference at low signal levels, particularly in that this interference is coherent, in phase, and directly adds to the signal of interest. It is not hard to envision situations where this interference signal could well be larger at the input of the lock-in amplifier than the signal of interest itself.

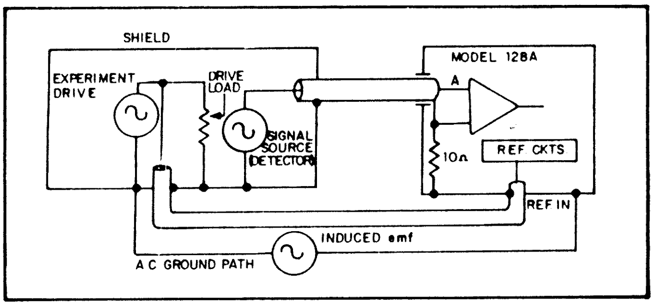


Figure IV-4. EXAMPLE OF EVERYTHING "DONE WRONG"

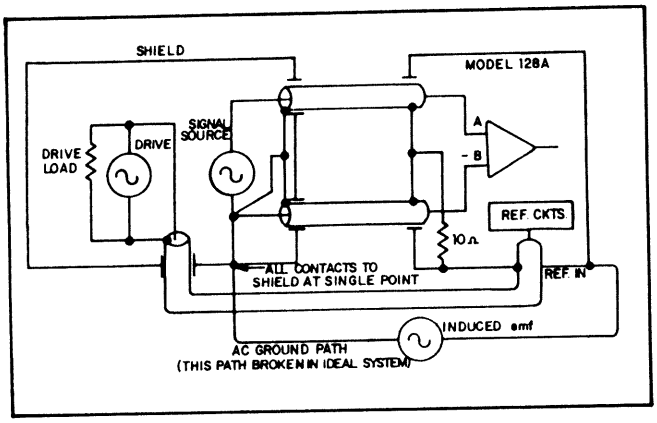


Figure IV-5. ERRORS DEPICTED IN FIGURE IV-4 CORRECTED

Figure IV-5 shows the steps which can be taken to circumvent this problem. All of the drive signal current is returned directly to the drive signal source except for the very small component (reference input resistance of Model 128A is 10 MΩ) which is applied to the Model 128A by way of the Reference Input. Second, no current, whether drive current, reference current, or signal current, is allowed to flow through the experiment shield; the shield contacts ground at one point only. The only coherent signal which can flow through the parallel path of the signal cable braid is a small portion of that allowed by the ten megohm Reference Input resistance. Furthermore, the use of differential operation assures that even this small amount can have no effect. By using the arrangements indicated, one could operate with very large drive currents without concern that they might contaminate the signal of interest. If electrostatic coupling of the drive signal to the detector is a problem, mounting a conducting material around the signal source detector should prove helpful. The electrostatic shield should be connected to the system at but one point, signal source common.

4.2F NOISE

Any electronic signal processing system adds noise to that already accompanying the signal to be measured, and a Lock-In Amplifier is no exception. Even though the method of signal processing used in a Lock-In Amplifier allows very large improvements in signal-to-noise ratio to be achieved, the amount of noise contributed by the Lock-In Amplifier itself affects its performance and limits the achievable improvement.

One convenient way of specifying the noise performance of an amplifier is to speak of its noise figure, which indicates the amount of noise the amplifier adds to the source thermal noise. Source thermal noise is used as the basis for comparison because it is completely predictable, always present, and is the least amount of noise which can possibly accompany any signal. Its value, in volts rms, is given by the following formula.

$$E_n = \sqrt{4kTBR_s} \qquad \text{IV-1}$$

where:

E_n = rms noise voltage within the bandwidth of the measurement

k = Boltzmann's constant = 1.38×10^{-23} joules/kelvin

T = absolute temperature in kelvins

R_s = Resistance in ohms of the resistive component of the impedance across which the voltage is measured

B = Bandwidth over which the measurement is made

Mathematically expressed, noise figure can be stated as:

$$NF(dB) = 20 \log_{10} \frac{\text{Noise Voltage at Output of Amplifier}}{\text{That Portion of Numerator Attributable to Source Thermal Noise}} \qquad \text{IV-2}$$

Noise figure is not constant but varies as a function of the source resistance, frequency, and temperature. When the loci of all points having the same noise figure are plotted as a function of frequency and source resistance (temperature fixed), the result is a noise figure contour. A full set of contours completely specifies the noise characteristics of the amplifier over its working range. Figure IV-6 contains a full set of contours for a typical Model 128A. The utility of these contours are, first of all, that they clearly indicate the best noise performance region in terms of operating frequency and source resistance, and secondly, that they allow one to directly compute the total noise accompanying the signal (amplifier noise and source thermal noise considered, other noise sources neglected). The relating formula is:

$$E_t = \sqrt{4kTBR} \times 10^{NF/20} \qquad \text{IV-3}$$

where E_t is the total noise referred to the input in volts rms and all other terms are as defined previously. Note that

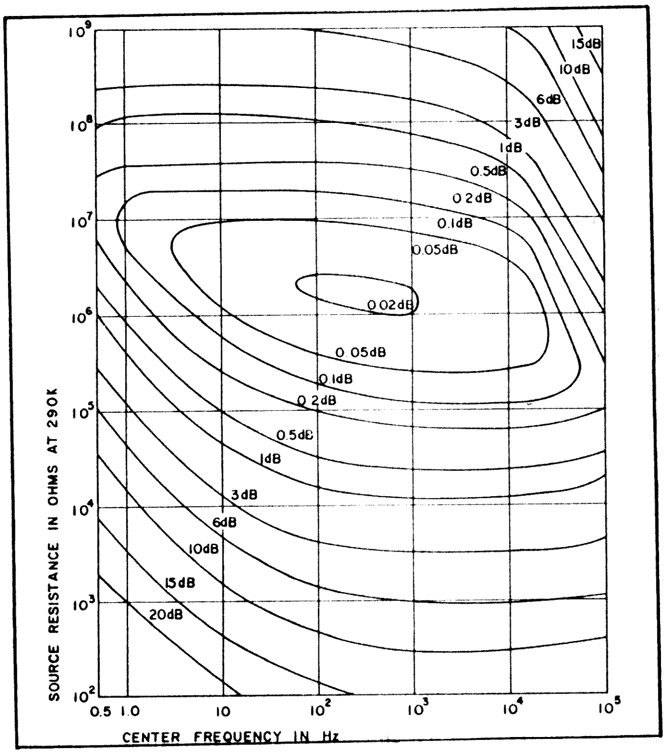


Figure IV-6. TYPICAL MODEL 128A NOISE FIGURE CONTOURS

with a noise figure of 3 dB, the amount of noise contributed by the amplifier is 1.4 times the source thermal noise. At 1.4 times the thermal noise, the amplifier noise just begins to be noticeable. At lower noise figures, the amplifier for all practical purposes may be regarded as noiseless. Generally speaking, if one can operate anywhere inside the 3 dB contour, amplifier noise considerations may be neglected.

As critical as amplifier noise is in certain applications, it is nevertheless possible to overemphasize its general importance. For example, if the signal amplitude is significantly higher than the amplifier noise, the subject becomes purely academic. Similarly, if preamplification is provided ahead of the Model 128A, with the result that the amplified source noise at the input to the Model 128A is far greater than the amplifier noise, there is little point in striving to operate inside the 3 dB contour of the Model 128A. However, where a preamplifier is used, it is important that these same considerations be carefully evaluated *for the preamplifier*. In other words, when using a preamplifier, try to operate inside the 3 dB contour of the preamplifier. A quick check of Figure IV-6 followed by a computation of the total noise (Equation IV-3) should give one a realistic idea of the importance of amplifier noise considerations to the measurement at hand.

Where amplifier noise is a consideration, one should try to operate inside the 3 dB contour by appropriately adjusting the operating frequency or source resistance. The choice of operating frequency is usually determined by the type of sensor used and by the capabilities of the chopper, where one is used. Often, the experimenter has some control over his choice of frequency and so can adjust things so that he is operating at the low noise end of the frequency range available to him.

The situation with regard to source resistance may be less flexible because the source resistance is usually determined solely by the type of sensor used. Once the commitment to a particular sensor has been made, it can be difficult to adapt the system to another one. Hence, in applications where noise is a potential problem, the choice of sensor should be made carefully and with full regard for the noise characteristics of the amplifier.

Two situations deserve special attention, the first being operation from a source resistance very much lower than optimum, and the second being operation from a source resistance very much higher than optimum. In either case, there may be a temptation to "improve" the source resistance situation by the use of resistors. In the case of the low source resistance, one may be tempted to connect a resistor in series with the source. In the case of the high source resistance, one may be tempted to connect a resistor in parallel with the source. Unfortunately, neither approach to the problem does any good and, in fact, both will result in further degradation of the signal-to-noise ratio ahead of the lock-in amplifier. The series resistor adds its thermal noise to that already accompanying the signal. Although the amplifier shows a "better" noise figure than before, it is only because the amplifier noise is now less relative to the thermal noise of the combined resistances (source plus series resistor). The signal is no larger (in fact, it may well be attenuated), the noise is greater, and the improved noise performance is illusory. Recall that noise figure only relates amplifier noise to thermal noise, and does not denote the absolute value of amplifier noise.

Connecting a parallel resistor to lower a high source resistance has a similar effect. Even though the thermal noise does go down, the signal amplitude goes down even more. For example, if a source of resistance R were paralleled by another resistor of the same value, the signal amplitude would go down by a factor of two. However, the thermal noise would only be reduced to .707 of its initial value (thermal noise varies directly with the square root of the resistance), with a net degradation in signal-to-noise ratio.

In operating from low source resistances, however, one can usually improve the situation dramatically by using a transformer to raise the source resistance seen by the amplifier. The improvement one obtains with a transformer is real because the amplitude of both the signal and the noise is increased by the turns ratio. The source resistance is increased by the square of the turns ratio. For example, if one had a ten ohm source, one could use a 1:100 step-up transformer, in which case the amplifier would see a source resistance of 100 kΩ. At 100 kΩ the amplifier adds little additional noise. Even though the thermal noise of the transformer adds to that of the source, a very considerable improvement is usually achieved. P.A.R.C. manufactures a line of suitable signal transformers, each designed for optimum operation over a given frequency range. Performance information can be obtained from the factory or one of its representatives.

In using an external transformer in conjunction with the Model 128A, single-ended operation of the lock-in amplifier is advised. The extremely high inherent common mode rejection of the transformer makes differential operation of the lock-in amplifier unnecessary.

When working from a high source resistance, one could, in principle, use a transformer in the same manner to improve noise performance. Unfortunately, practical transformer design considerations usually prevent one from doing so. As a result, the options available to an experimenter working with a high source resistance device, such as a photomultiplier, are limited. Practically speaking, the best one can do is to make the load resistor as large as possible. The larger the source resistor, the less the shunting effect it will have, and the better the signal-to-noise ratio at the input of the amplifier will be. That this is so becomes clear when one recalls that the signal amplitude varies directly with the load resistance, while the thermal noise varies with the square root of the resistance.

Note that the entire preceding discussion of noise is based on comparing the noise generated by the amplifier with the source thermal noise. In many situations, other types of noise of interference may accompany the signal as well and could even dominate it. Where this is the case, the amplifier can only perform "better" than the noise figure contours indicate because the noise figures are based on a comparison of amplifier noise with the *minimum possible* noise which can accompany any signal, namely, the source thermal noise.

4.3 OPERATING THE MODEL 128A

4.3A INTRODUCTION

Operation of the Model 128A is straightforward. In most instances, the operator simply connects the reference signal, waits for the REF UNLOCK light to go out, and then connects the signal to be measured. The Sensitivity and Phase controls are then adjusted for maximum output without overload. Should overload occur, the dc filtering (Prefilter and Time Constant) is increased and/or the sensitivity is reduced as required to eliminate the overload. The reading can then be taken.

In many situations, achieving a successful measurement will depend not so much on critically adjusting the Model 128A controls as on taking the proper steps indicated by the preliminary considerations discussed in Subsection 4.2. Factors such as proper grounding and operating inside the 3 dB contour are most important in making low level measurements of noisy signals.

4.3B REFERENCE CHANNEL (see Subsection 4.9 for additional information)

Reference Signal Requirements

An outstanding feature of the Model 128A is its unique reference channel circuitry which allows it to lock onto and track a wide range of possible reference input waveforms. Once locked on, the reference remains locked on, even if the reference input signal changes in frequency. There are no Reference Channel controls of any kind which must be adjusted for proper reference channel operation. Once the light goes out, all that remains is to adjust the Phase controls so that the Reference signal applied to the mixer is at the proper phase relative to the signal to be measured. As stated in the specifications, the only requirements on the reference signal are that it swing at least plus and minus 50 mV with respect to its mean, that it cross its mean twice each cycle, and that it remain on each side of the mean for at least 100 ns. Sinewaves, square waves, triangle waves, and many others are all suitable. However, for best phase accuracy, a 1 V rms sinewave is recommended. One waveshape which at first glance may seem to suffice, but which does not, is the very narrow low duty factor pulse. For example, suppose one intended to use as a reference signal the pulse train depicted in Figure IV-7, that is, pulses having an amplitude of 1 V, a duration of 1 μs, and a period of 1 ms. The mean of this signal would be about 1 mV, and the excursions relative to the mean would be +999 mV and −1 mV. Thus, the individual pulses, even though they exceed the minimum excursion requirement on one side by some 950 mV, lack meeting the excursion requirement on the other side of the mean by a full 49 mV (50 mV required), with the result that the Reference Channel will not function properly. Thus, when using pulses as the reference input, take care that the duration of the pulses, relative to the pulse period, is great enough to give a mean of at least 50 mV. In the example just cited, if the pulse duration were increased to 100 μs as shown in Figure

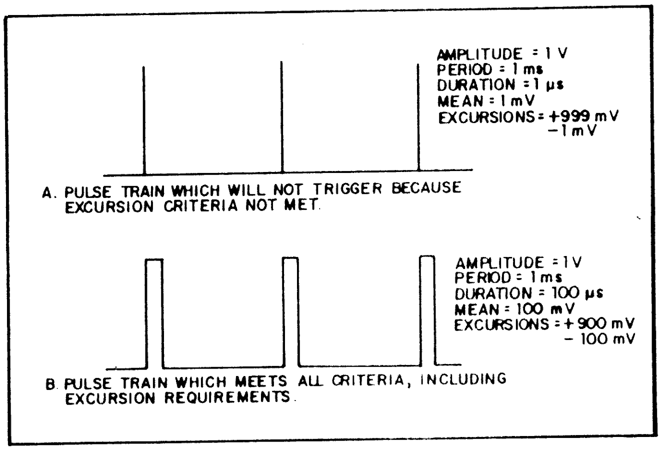


Figure IV-7. PULSE TRAIN AS REFERENCE DRIVE

IV-7B, the mean would increase to 100 mV, and the excursions (900 mV one side, 100 mV the other) would be more than adequate for proper triggering.

Even though the Model 128A can accept and track a wide range of possible reference signals, it is nevertheless important that the reference signal used be relatively noise free. Any superimposed noise can cause small zero crossings to occur in the region of the main waveform zero crossings, with the result that the Reference Channel momentarily "sees" a much higher reference frequency than what is really there. When this happens, the reference "lock" can be lost. Frequently, moderately noisy signals can be cleaned up sufficiently for satisfactory operation by interposing a single-section low-pass filter between the reference signal source and the Reference Input connector of the Model 128A.

On later instruments, space is provided for mounting the filter components on the Reference printed circuit board. Location of the mounting holes is indicated on page VII-5. To install the filter, transfer the wire which normally goes to quick-disconnect J419 over to quick-disconnect J429. Then install the filter components, a resistor for RX4 and a capacitor for CX1 (RX4 and CX1 are designations given on the schematic and parts-location diagram for these components). In most instances, optimum performance is obtained by setting the filter corner frequency ($f = 1/4\pi RC$) to the intended reference frequency.

Switches

Three switches are associated with operation of the Reference Channel. One of them, the f/2f switch, is located at the front panel. The other two are internal. The front panel switch determines whether the mixer will be driven at the frequency of the applied reference signal or at twice the frequency of the applied reference signal. The "2f" position is used for second harmonic studies. For normal operation, the switch is set to "f". To examine harmonics higher than the second, the operator would have to supply a reference signal at the frequency of the harmonic to be measured. One should check the position of this switch before connecting the Reference signal; when the switch position is changed during operation, the reference channel will unlock, and time will be lost in waiting for it to lock on again. In most situations, the lost time would be but a few seconds and of little consequence. However, if one were operating at a low frequency, it could be lengthy.

The internal switches determine the lock-on range, either .5 Hz – 100 kHz or 5 Hz – 100 kHz. With these switches set to either FAST or SLOW, the unit will lock onto reference signals in the frequency range of 5 Hz to 100 kHz without difficulty. However, only when the switches are set to SLOW will it lock onto reference signals which are below 5 Hz. The switches should be set to SLOW only for operation below 5 Hz, because the time required to achieve frequency lock is longer with the switch set to this position than when it is set to FAST.

Detector Biasing

There is no provision for detector biasing at the Reference Input by means of an internal network. The network is not provided but must be furnished by the operator according to the impedance and voltage requirements of his detector. The parts location diagram on page VII-5 shows where to install the resistors.

Phase Controls

A high resolution potentiometer covering a range of 0-to-100 degrees works in conjunction with a Quadrant switch to determine the phase of the synchronous detection process with respect to the phase of the applied reference signal.

The Phase Sensitive Detector provides a dc output proportional to the amplitude of the input signal. This output varies with the cosine of the angle between the reference and input signals. When the Phase controls are adjusted for maximum output, the signal amplitude can be read from the panel meter and the phase of the signal can be read from the Phase dial.

It may happen that meter fluctuations due to noise will make it difficult to find the setting which gives maximum output. Where this is the case, it will usually prove more accurate and expedient to adjust for the null obtained when the reference phase is set at 90° relative to the signal phase. Once the null is achieved, the Phase Quadrant switch can then be rotated the one position necessary to achieve maximum output so that the amplitude can be read from the meter.

The absolute accuracy and resolution of the Phase controls are stated in the specifications. Figure IV-8 shows the typical net phase shift through the unit. Additional phase shifts are introduced in the Signal Channel at the frequency extremes. Even at middle frequencies, the HI-PASS and LO-PASS filters can have an effect on the signal phase. A phase calibration can easily be made at any frequency by connecting the input signal (noiseless) to both the Signal and Reference Inputs, followed by adjusting the Phase controls for maximum output. The Phase controls then indicate the net phase shift in both the Signal and Reference Channels. This shift can then be subtracted from any phase readings taken while operating at the calibration frequency.

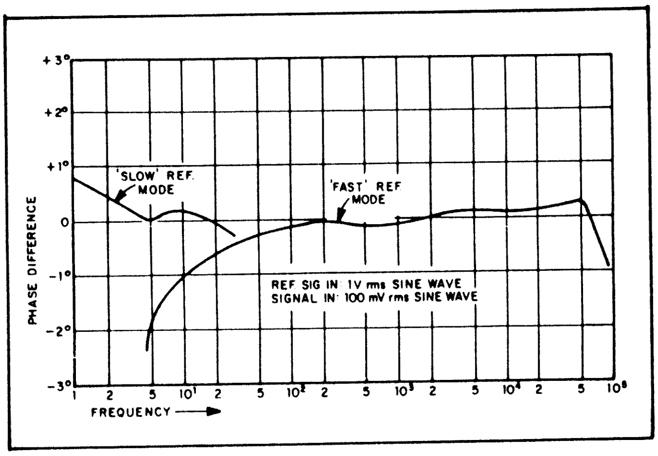


Figure IV-8. NET PHASE SHIFT BETWEEN SIGNAL AND REFERENCE CHANNELS AS A FUNCTION OF FREQUENCY

Reference Monitor Connector

An optional Reference Monitor output can be provided at a rear-panel connector. The Reference Channel output is available at this connector. This signal is a square wave taken from ahead of the Mixer but after the Phase Control circuitry, and so is at the frequency of the applied reference signal (twice the frequency in the case of "2f" operation) and at the phase set with the Phase controls. Standard TTL logic levels are employed. Logic "0" = 0.2 V ±0.2 V and Logic "1" = +3.5 V ±1 V.

4.3C SIGNAL CHANNEL

Introduction

Operation of the Signal Channel controls is straightforward. The Input Selector is set to "A", "A–B", or "–B" as appropriate, the Sensitivity switch is set for as near full-scale output as possible, and the filters are used to narrow the bandwidth ahead of the Mixer. In some applications, it may be desirable to incorporate the optional tuned amplifier into the Signal Channel as well. A further discussion of these topics follows.

Input Selector Switch

With this switch set to "A", the signal applied to the "A" Input is processed by the instrument. Signal applied to the "B" Input is dead-ended. Similarly, when the switch is set to "–B", the situation is the same except that the roles of the "A" and "B" inputs are reversed. Another difference is that the "B" Input is 180° out-of-phase with respect to the "A" Input. In other words, if a signal which yields positive output meter deflection when applied to the "A" Input is applied to the "B" Input, an equal but negative reading will be obtained. In the "A–B" position, the instrument operates differentially, that is, only the difference between the signals applied to the two inputs is processed and read out. As discussed in Subsection 4.2E, it is generally advantageous to operate differentially, even when processing signals from a single-ended source.

Sensitivity Switch

The Sensitivity switch should be set to provide as near full-scale output as possible. In very high noise situations, it may be necessary to operate with less sensitivity than would be employed if processing a noise free signal of the same amplitude. If overload proves a problem at the sensitivity which yields maximum on-scale output meter deflection, there are a couple of things the operator can try before resorting to lowered sensitivity operation. First, he can increase the output filtering using the Prefilter and Time Constant switches. With a very low time constant, output amplifier overload can occur when processing noisy signals. This type of overload problem can generally be resolved by operating with a time constant setting of .3 SEC or higher, and with the Prefilter set to 100 mSEC or 1 SEC, as required. Additionally, one can narrow the noise bandwidth ahead of the Mixer by means of the high-pass and low-pass filters. If neither increased time constant nor the filters brings the overload under control, there still remains the additional step of using the internal tuned amplifier in the case of a unit equipped with this option. Assuming none of these steps helps the overload problem, such as would happen if noise of sufficient amplitude to cause overload is at the frequency of the signal being measured, there is no alternative but to reduce the sensitivity.

Hi-Pass and Low-Pass Filters

The function of these filters is to eliminate as much interference and noise as possible while having minimal effect on the signal of interest. Under most conditions, by setting these filters so that they bracket the signal frequency as closely as possible, the noise tolerance of the instrument will be increased and the noise fluctuations at the output of the Model 128A will be reduced. However, in using the filters, it is important to take their effect on the signal of interest into account. Figures IV-9 and IV-10 show the amplitude and phase characteristics of these filters as a function of switch setting and frequency. To find the net effect in a region where both filters affect the signal, multiply the amplitude transfer fractions and add the phase shifts.

Use of the MIN. and MAX. positions simultaneously provides a flat response curve over the full operating range of the Model 128A (see specifications). A flat response is useful for operation in situations where the signal frequency changes by large factors during the course of the measurement.

In certain applications, the operator might like to have "3 dB down" frequencies other than those provided. This can be done by changing the value of some internal capacitors. Each of the two filters has a separate capacitor for each of the three switch positions. The capacitors which determine the MIN and MAX response characteristics should not be changed. The other two can be. The Parts Location Diagram on page VII-2 can be used to identify these capacitors. Schematically, they are shown on page VII-4. In the case of the Low Pass filter, the relationship between capacitance and 3 dB down frequency is given by:

$$C = 66 \times 10^{-6}/f_{3dB} \qquad \text{IV-4}$$

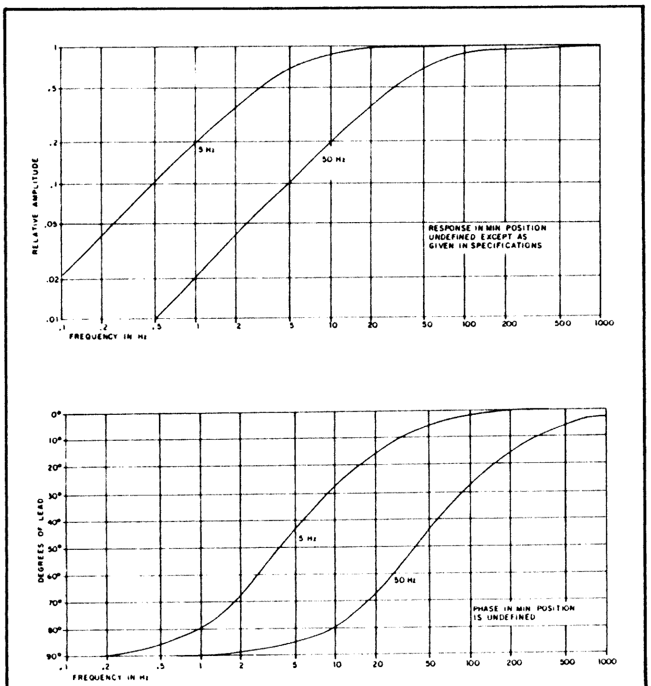


Figure IV-9. AMPLITUDE AND PHASE CHARACTERISTICS OF HI-PASS FILTER

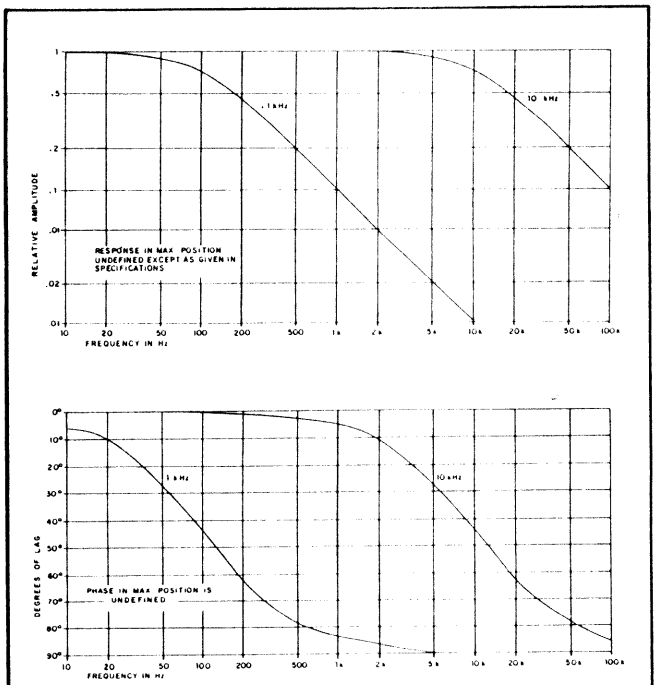


Figure IV-10. AMPLITUDE AND PHASE CHARACTERISTICS OF LOW-PASS FILTER

For the Hi-Pass filter, it is:

$$C = 25 \times 10^{-6}/f_{3dB} \qquad \text{IV-5}$$

where (for both formulas)

C = the capacitance in Farads, and

f_{3dB} = the desired 3 dB down frequency in Hz.

4.3D OUTPUT CHANNEL CONTROLS

Filters

The primary function of the Output Channel is to act as a low-pass filter and eliminate any ac components at the output of the Mixer. Inasmuch as only dc at the Mixer output represents the in-phase component of the signal of interest (the ac results from noise), an improvement in signal-to-noise ratio is obtained. In principle, the signal-to-noise ratio can be improved to any arbitrary degree simply by making the filter time constant long enough. Practical considerations, however, generally set the limit to what can be achieved. The improvement in signal-to-noise ratio varies with the square root of the time constant. As a result, the measurement times rapidly become lengthy as the time constant is increased to obtain better signal-to-noise ratios. As a practical guide, the correct filtering time constant is the one which reduces the noise to an "acceptable" level.

Two separate dc filters are provided. The first, called the DC PREFILTER, provides filtering time constants of 100 ms, 1 s, or OUT, in which the filtering time constant is negligibly small. The second, or main TIME CONSTANT filter, allows filtering time constants from 1 ms to 100 s to be selected, in addition to MIN (time constant about .7 ms) and EXT (time constant determined by external capacitors connected to rear-panel octal sockets). Both filters are single-section filters having a 6 dB/octave rolloff. The filters have an accumulative effect as shown in Figure IV-11.

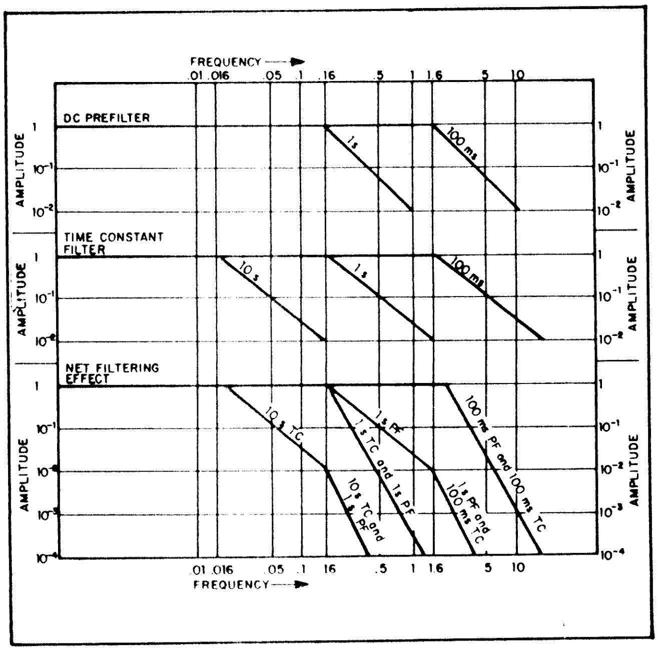


Figure IV-11. EXAMPLES OF OUTPUT FILTER INTERACTIONS

The usual procedure for setting these filters is to leave the Prefilter set to OUT and to adjust the main Time Constant filter as required to reduce the noise to an acceptable level. However, if the noise level is sufficiently high to cause dc amplifier overloading, it will be necessary to set the Prefilter to 100 ms or perhaps even to 1 s to stop the overload. In many instances, use of the Prefilter will prove to be unnecessary. It might be noted that the prefilter is particularly useful when a recorder is being used to monitor the output of the instrument in that recorder "jitter" is significantly reduced. Adjusting the Model 128A's controls is generally easier with the Prefilter OUT.

The equivalent noise bandwidth of a single-section 6 dB/octave filter is 1/4TC. Its rise time from 10% to 90% of full amplitude is 2.2 TC (0% to 95% is 3 TC). If both the Time Constant filter and the Prefilter are set the same, the effect is the same as if one had a single two-section filter with a 12 dB/octave rolloff. The equivalent noise bandwidth of this filter would be 1/8TC and the 10% to 90% rise time would be 3.3 TC (0% to 95% = 4.8 TC). When both filters are used but with different settings, the relationship defining the equivalent noise bandwidth and rise time as a function of time constant is more complex. For all practical purposes, if the time constant of one is a factor of three or more longer than the other, the one with the longer time constant dominates and the single section expressions using the longer time constant characterize the rise time and equivalent noise bandwidth to a good approximation. Nevertheless, even though the prefilter may do relatively little to further reduce the equivalent noise bandwidth if the main Time Constant setting is longer, its effect in smoothing a recording can be significant.

With the Time Constant switch set to EXT, intermediate time constant values or time constants longer than 100 seconds can be obtained by connecting an external capacitor between pins eight and nine of the 11-pin socket at the rear panel. The formula relating the capacitor value and time constant is: $C = TC/100\ \mu F$. Any low-leakage film capacitors rated at 50 V or higher can be used. Do not use electrolytic or tantalum capacitors.

Offset

The ten-turn dial and its associated polarity switch allow calibrated offsets of up to ten times full scale to be applied. Two applications for this feature are that it allows small amplitude variations in a signal to be expanded and examined in detail, and that it allows a signal amplitude to be read with greater resolution than is possible with the panel meter alone. For example, suppose one had a meter indication to the right. To read the amplitude with the greatest possible resolution, the polarity switch would be set to "+" and the dial adjusted for "null", at which time the signal amplitude could be read directly from the dial.

The following example illustrates how the Zero Suppress feature can be used to read signal amplitude variations. Suppose one had a 70 μV signal. Assuming this signal were measured on the 100 μV sensitivity range, the resulting meter indication would be 70% of full scale. To examine small variations in this signal, one would first set the polarity switch to "+" (assume initial meter indication were to the right), followed by adjusting the dial for null. The dial setting required would be 0.70 and the meter sensitivity would be ±100 μV with respect to the 70 μV ambient level. A recorder connected to the output would allow the amplitude variations as a function of some experimental parameter to be recorded.

Because of the Offset dial range, ±10 times full scale, the sensitivity of the measurement could be greatly expanded. In the example at hand, the Sensitivity switch could be set to 10 μV. The signal amplitude (70 μV) would be less than ten times full scale (100 μV) and so would fall within range of the Offset dial. If the dial were adjusted for null (setting 7.00), the meter would read ±10 μV full scale with respect to the 70 μV ambient signal level.

Outputs
The output of the instrument is provided at both the front and rear panels. These two outputs are in parallel. The output resistance is 600 ohms and full scale output is ±1 V, which corresponds to ± full-scale deflection of the panel meter. At the front panel, the output is provided at a BNC connector. At the rear panel, it is applied to one of a pair of binding posts. The second (black) binding post is ground. These binding posts are spaced to accept a standard double-banana connector. It is frequently more convenient to use the rear-panel output when using a strip-chart recorder as the readout device.

Mixer Monitor Output
An optional Mixer Monitor output is provided at the rear panel. The signal applied to this output is taken directly from the output of the Mixer and before any filtering. Figure IV-12 illustrates the Mixer output corresponding to in-phase and quadrature signals respectively. If the signal and reference inputs to the Mixer are either in phase or 90° out-of-phase, the signal at the output of the Mixer will be as shown. For signals 180° out-of-phase, the Mixer output will be the inverse of the in-phase output, and for signals 270° out-of-phase, the output will be the inverse of the 90° output. Taking the maximum possible area which can be enclosed by one cycle (one polarity) as a unit output, the output averaged over a cycle for any Mixer input phase relationship will be the unit output times the cosine of the angle between the input and reference signals.

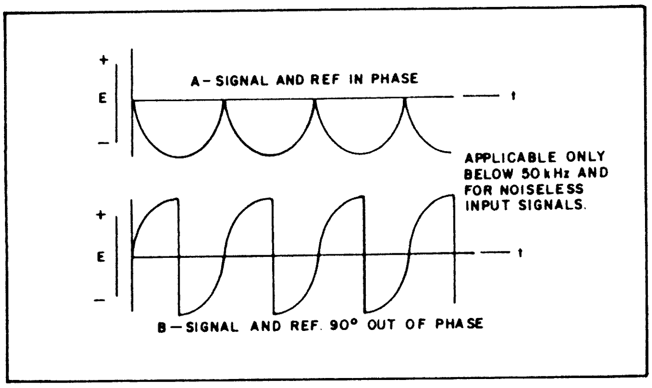


Figure IV-12. MIXER OUTPUT FOR IN-PHASE AND QUADRATURE SIGNALS

The cosine response depends on the sinusoidal nature of the input signal. If the signal were a square wave and the tuned amplifier were not used, the Mixer output would vary linearly with the angle between the signal and reference inputs. Nevertheless, maximum output would still be at 0° and 180°, and zero output would be obtained at 90° and 270°.

It might be mentioned that the waveforms illustrated in Figure IV-12 apply only at frequencies below 50 kHz and with a noise-free input signal. At higher frequencies, switching spikes become visible and some Mixer filtering effects become evident. Even relatively small amounts of noise accompanying the signal could completely obscure it at the Mixer output, especially if one were operating without the tuned amplifier.

4.4 MIXER FUNCTION AND HARMONIC SENSITIVITY

The purpose of the Mixer (Phase Sensitive Detector) is to convolute the input signal in such a way that the output of the detector is the sum and difference frequencies of the signal and the reference. If the input and reference signals are at the same frequency, and they must be for normal lock-in amplifier operation, one of the output frequencies of the detector will be zero, that is, dc. Noise or other interference is not normally at *exactly* the same frequency as the input signal and so does not produce zero frequency at the Mixer output. The dc output is proportional to the amplitude of the in-phase component of the input signal. This dc is passed by the low pass filter(s) which follow the Mixer, while the ac components, representing the input noise and interference, are shunted to ground. Thus the signal-to-noise ratio at the output connectors and front-panel meter is much improved over what it is at the input of the instrument.

The reference input to the detector is a square wave having a fundamental of some fixed amplitude, and odd harmonics of lesser amplitude. From Fourier analysis, the amplitude of the third harmonic is 1/3 the fundamental amplitude, the amplitude of the fifth is 1/5, the seventh is 1/7, etc. Because the detector demodulates with respect to all components of the reference input, any odd harmonic components of the input signal contribute to the output as well. The response of the detector to odd harmonics is in the same proportion as the amplitude of the harmonic in the applied reference. In other words, the Mixer's third harmonic sensitivity is 1/3 its fundamental sensitivity, its fifth harmonic sensitivity is 1/5, its seventh is 1/7, etc. In the case of a square wave input, if the unit does not have a tuned amplifier, and if the Signal Channel filters are set to a frequency far from the principal harmonics of the input signal, then a 180 mV pk-pk square wave will yield full-scale output on the 100 mV sensitivity range. If the unit has a tuned amplifier set to the fundamental frequency so that only the fundamental reaches the Mixer, the input square wave must have an amplitude of 220 mV pk-pk to yield full-scale output on the 100 mV range (the rms value of the fundamental frequency component of a 220 mV pk-pk square wave is 100 mV).

In principle, the instrument does not respond to even harmonics at all because the reference input, being a square wave, does not contain any even harmonics. However, very slight deviations from perfect symmetry in the applied reference square wave result in some even harmonic response, the worst case being about 1%.

Note that the overall instrument response to harmonics is not necessarily as high as indicated in the preceding paragraphs. Phase and pre-mixer attenuation effects cannot be ignored. With either the tuned amplifier or the hi- or low-pass filters in use, input harmonics will be both attenuated and phase shifted. Inasmuch as the reference input to the Mixer is a square wave, the harmonics (all odd) are at the same phase as the fundamental. As mentioned previously, the even harmonic response is quite small, and is seldom of any consequence, particularly if the tuned amplifier is used.

There is one application where one has to be concerned with the "subharmonic response" of the Mixer, and that is when measuring second harmonics using the 2f mode. When the instrument is operating in this mode, it has a fundamental response (the fundamental can be thought of as a subharmonic of the signal of interest, the second harmonic) of about one or two percent. Hence, for accurate second harmonic measurements, it is essential that the fundamental be attenuated ahead of the Mixer. One convenient way of doing this is to use the optional tuned amplifier. By operating in the Notch mode with the Notch tuned to the frequency of the fundamental, the fundamental is reduced to a negligible level with only 1% loss in the amplitude of the second harmonic. It follows that the Tuned Amplifier can also be used to good advantage when measuring harmonics higher than the second.

4.5 INTERFACE CONNECTOR

An 11-pin Interface connector is provided at the rear panel. Table IV-1 indicates the function of each pin. Observing the connector from outside the instrument, the pins are counted counterclockwise from the key.

Pin	Function
1	Chassis Ground
2	+15.5 V OUT (load limit = 20 mA)
3	−15.5 V OUT (load limit = 20 mA)
4	No connection
5	−24 V IN (battery operation, 300 mA req'd)
6	No connection
7	+24 V IN (battery operation, 300 mA req'd)
8	External Time Constant Capacitor
9	External Time Constant Capacitor
10	No connection
11	No connection

Table IV-1. INTERFACE CONNECTOR PIN ASSIGNMENTS

4.6 BATTERY OPERATION

Battery operation of the Model 128A Lock-In Amplifier may be necessary where no ac power is available, or as a last resort where power line interference is a problem. Battery operation of the Model 128A is straightforward because the points to which one must gain access are provided at the rear-panel 11-pin socket. Two batteries are required, one to supply +24 V (300 mA) and the other to supply −24 V (300 mA). The +24 V source should be connected to pin 7. The −24 V source should be connected to pin 5. Ground for both is at pin 1. It is generally a good idea to fuse the battery lines external to the instrument, and to provide an ON/OFF switch as well. The front-panel ON/OFF switch does not control the instrument's power when it is operated from batteries. Nevertheless, the battery drain is minimized if the front-panel power switch is kept in the OFF position so that no current flows through the switch's built-in light. Keep the line disconnected during battery operation.

4.7 OPERATION WITH THE INTERNAL REFERENCE OSCILLATOR

4.7A INTRODUCTION

In some applications, the experimental apparatus does not generate a suitable reference output, but is itself capable of being driven by an external signal source. To facilitate use of the Model 128A in such applications, an internal reference oscillator modification is provided. With this modification installed, a signal of variable frequency and amplitude is generated by a sinewave oscillator inside the Model 128A. The output of this oscillator, in addition to being provided at a rear-panel connector for easy routing to the experiment, can be applied internally to the Reference Channel so that it is directly driven by the same signal a drives the experiment. It is also provided at the front-pane Reference INPUT connector at an impedance of 10 kΩ fo monitoring purposes only. The Phase controls remain full functional, allowing the internal reference signal and th information signal from the experiment to be brought int phase at the mixer.

4.7B OPERATION

Operation of the internal oscillator is straightforward. Tw openings in the rear panel of the Model 128A give access t the adjustments which set the amplitude and frequenc The frequency adjustment allows the frequency to b varied over about a 3:1 range, with the actual ran spanned depending on the value of two capacitors mounte on the oscillator board. Table IV-2 indicates the frequen range of the adjustment as a function of the value of the capacitors. The capacitors can be easily changed; they a held by spring-loaded special clips which release t component lead when pressed downwards. The capacito should be low-leakage types matched to within 5% Myl polystyrene, polycarbonate, teflon, and other film capa tors rated at 50 V or better are all suitable. Do not u electrolytic or tantalum capacitors. Because the oscilla board plugs into the main board, one must remove the t cover of the Model 128A to change the capacitors.

In setting the oscillator frequency adjustment, it is imp tant that the control setting not be changed too rapidly the adjustment is turned quickly, the oscillator will s oscillating, and the operator will have to wait sev seconds for normal operation to be restored. Note that amplitude adjustments affect only the amplitude of

Approx. Freq. Range	Capacitor Value	P.A.R.C. EDP #'s for Osc. (5% match)	P.A.R.C. EDP #'s for Tuned Amp. (1% match)
0.53 Hz to 1.58 Hz	10 μF	1521-0193	1560-0008
1.06 Hz to 3.2 Hz	5 μF	1521-0105	1560-0009
2.7 Hz to 7.9 Hz	2 μF	1521-0207	1560-0010
5.3 Hz to 15.8 Hz	1 μF	1521-0066	1560-0011
10.6 Hz to 32 Hz	500 nF	1521-0061	1560-0012
27 Hz to 79 Hz	200 nF	1521-0208	1560-0013
53 Hz to 158 Hz	100 nF	1521-0186	1560-0014
106 Hz to 320 Hz	50 nF	1521-0184	1560-0015
270 Hz to 790 Hz	20 nF	1521-0209	1560-0016
530 Hz to 1.5 kHz	10 nF	1521-0182	1560-0017
1 kHz to 3.2 kHz	5 nF	1521-0023	1560-0018
2.7 kHz to 7.9 kHz	2 nF	1521-0211	1560-0019
5.3 kHz to 15 kHz	1 nF	1501-0032	1560-0020
10 kHz to 32 kHz	500 pF	1501-0004	1560-0021
27 kHz to 79 kHz	200 pF	1501-0068	1560-0022
44.5 kHz to 130 kHz	120 pF	1501-0034	1560-0023

Table IV-2. FREQUENCY RANGE AS A FUNCTION OF CAPACITORS

signal provided at the rear-panel Ref. Osc. Out connector (impedance 600 ohms). The amplitude can be adjusted from 0 V to 10 V pk-pk. The amplitude of the signal supplied to the Model 128A Reference channel does not change. Neither does that supplied to the Ref. In connector, which acts as a monitor point when the unit is operated in conjunction with the internal oscillator. The monitor signal is a constant 1 V rms and its source resistance is 10 kΩ. The operator is *not* advised to use this monitor signal as the reference drive for his experiment.

The only other operating consideration is that of transferring the Model 128A from external reference operation to internal reference operation or vice versa. Internal wires fitted with quick-disconnect contacts determine whether the Reference channel is driven by the internal oscillator accessory or by an externally derived reference signal applied to the front-panel jack. To gain access to these wires, it is necessary to first remove the instrument's cover, which is secured by four screws. When the cover is removed, locate the three adjacent board contacts, J418, J419, and J420. For operation in the Internal reference mode, the pink wire from the front-panel Ref. In connector is connected to J418. The white/orange wire from the Internal Oscillator is connected to J419. J420 is not used. For operation in the external mode, the pink wire from the front-panel connector is connected to J419. The white/orange wire is connected to J420, and J418 is not used. Also, the two frequency determining capacitors should be removed when operating with an external reference source.

4.7C INSTALLATION

When a Model 128A is ordered with the Internal Oscillator modification, the instrument is shipped with the oscillator installed and the operator need only concern himself with operating considerations. Should he desire to operate without the oscillator, he has only to transfer a few wires as described in the preceding paragraph.

If the Internal Oscillator is ordered separately, the installation is generally made by the customer. Three items are supplied, the oscillator board itself, a BNC connector with two wires attached, and a metal "tag" bearing the word "MONITOR". The oscillator circuit board is secured to the Model 128A by standoffs which plug into openings in the Model 128A Reference board as shown in Figure IV-13. This figure also shows the location of the various interconnecting wires, all of which are terminated in quick-disconnect contacts so that the installation can be completed in a matter of minutes with no special tools or soldering required.* The oscillator adjustments are ordinarily preset at the factory for 100 mV rms out at the frequency specified by the customer. The appropriate frequency range capacitors are factory inserted. The following procedure can be used to make the installation.

(1) Remove the top and bottom covers of the Model 128A. The top cover is secured by four screws, two on each side. The bottom is secured by ten screws.

(2) Mount the BNC connector in the REF. OSC. OUT opening in the rear panel (it will be necessary to first push out the plug, which can then be discarded). Be sure to use the insulating bushings supplied so that there is no contact between the shell of the connector and chassis ground. After the connector is securely mounted, twist the two wires together, moderately tight, over their entire length.

(3) Note the pink wire which extends from the Ref. In connector to J419 near the front of the Ref. Bd. Remove this wire from J419 and allow it to hang free.

*Current production units use a different kind of quick-disconnect pin than was used previously. If a current-production oscillator board is to be installed in an older unit, the quick-disconnect terminals at the end of the involved leads will have to be cut off and new ones installed. The new terminals are supplied with the oscillator board.

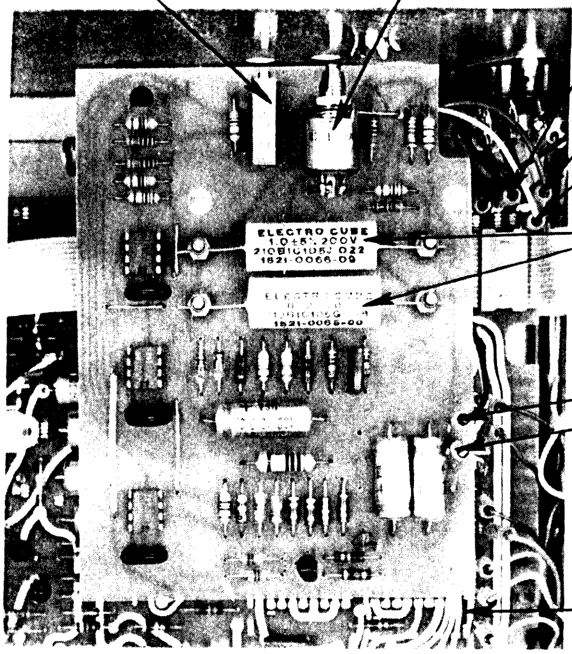


Figure IV-13. INTERNAL OSCILLATOR BOARD INSTALLED

(4) Remove the Reference INPUT connector from the front panel. Then locate the "Monitor" tag over the panel opening and remount the connector so that the tag is secured in place by the connector mounting flange.

(5) Position the oscillator board as shown in Figure IV-13 but do not snap it into place yet. Dress the red, yellow, and black wires out to the right, and the longer white/orange wire towards the front of the instrument.

(6) Connect the red, yellow, and black wires as follows.

red J405
yellow J406
black J404

(7) Connect the pink wire from the Ref. In connector to J418.

(8) Locate the white/orange wire from the oscillator and connect it to J419. Dress this wire along the Ref. Bd.

(9) Press the Oscillator board down until it snaps into place.

(10) Connect the black and white/green twisted leads (from the rear-panel connector) to the Oscillator board quick-disconnect contacts as shown in Figure IV-13.

This completes the installation. The top and bottom covers may now be reinstalled. To check the oscillator, simply turn on the power and monitor the oscillator output with an oscilloscope.

4.8 OPERATION WITH THE INTERNAL TUNED AMPLIFIER

4.8A INTRODUCTION

In some applications it is desirable to narrow the noise bandwidth ahead of the mixer, or to notch out a particular frequency component of the input signal. These operations are made possible if the Model 128A is operated in conjunction with the Model 128A/98 Accessory Tuned Amplifier. With this accessory installed, bandpass or notch operation at a Q of 5 is possible from 1 Hz to 100 kHz.

Note from Figure IV-14, a photograph of the Model 128A with the Tuned Amplifier installed, that there are two trim-adjustments and two switches on the Tuned Amplifier circuit board. In addition, there are the two capacitors, mounted on special spring-loaded terminals, which determine the range of the frequency adjustment. The trim-adjustment accessible through an opening in the rear panel sets the center frequency of the Tuned Amplifier. That which is accessible from the side of the Model 128A sets the Q and amplitude response. These two adjustments interact to some degree. The two switches determine the tuned amplifier function. One of them allows the operator to select either Tuned Amplifier operation or Flat operation. The other gives the choice of Bandpass or Notch operation. These latter two functions have relevance only when the first switch is set to SELECTIVE. If it is set to FLAT, the tuned amplifier circuitry is bypassed and the Model 128A operates exactly as if the Tuned Amplifier had never been installed.

The frequency range of the rear-panel adjustment as a function of the value of the two replaceable capacitors is the same as for the Internal Reference Oscillator. Also, the restrictions as to the types of capacitors which can be used are the same as outlined in Subsection 4.7B. There is, however, one difference, namely that the capacitors used in the Tuned Amplifier must be matched to 1%, whereas in the case of the Oscillator, they need only be matched to 5%. Capacitors purchased from P.A.R.C. for use in the Tuned Amplifier are matched to 1%, even though they may be marked 5%. (This comes about because they are selected from a large stock of 5% capacitors.) Such 1% capacitors are marked by colored tape to prevent them from being confused with any other capacitors with which they might be stored.

4.8B OPERATION

The first step is to set the Tuned Amplifier to the intended operating frequency. An appropriate procedure follows. **NOTE:** Each Tuned Amplifier is preset at the factory to the frequency specified by the customer.

(1) Remove the top cover of the Model 128A. This cover is secured by four screws, two on each side.

(2) Set the Model 128A controls as follows.
Sensitivity: 250 mV
Input: A
Low Pass: MAX
Hi Pass: MIN
Reference Mode: f
Phase
switch: 270°
dial: 90.0°
Time Constant: .3 SEC.
Zero Offset: OFF (dial setting irrelevant)
DC Prefilter: OUT

(3) Select and install the two capacitors which set the frequency range. Be sure to use the capacitors matched to 1%. **NOTE:** One set of capacitors, having the value appropriate to the frequency specified by the customer, is supplied with each Tuned Amplifier.

(4) Turn on the Model 128A power.

(5) Set the Flat/Selective slide switch on the Tuned Amplifier to SELECTIVE.

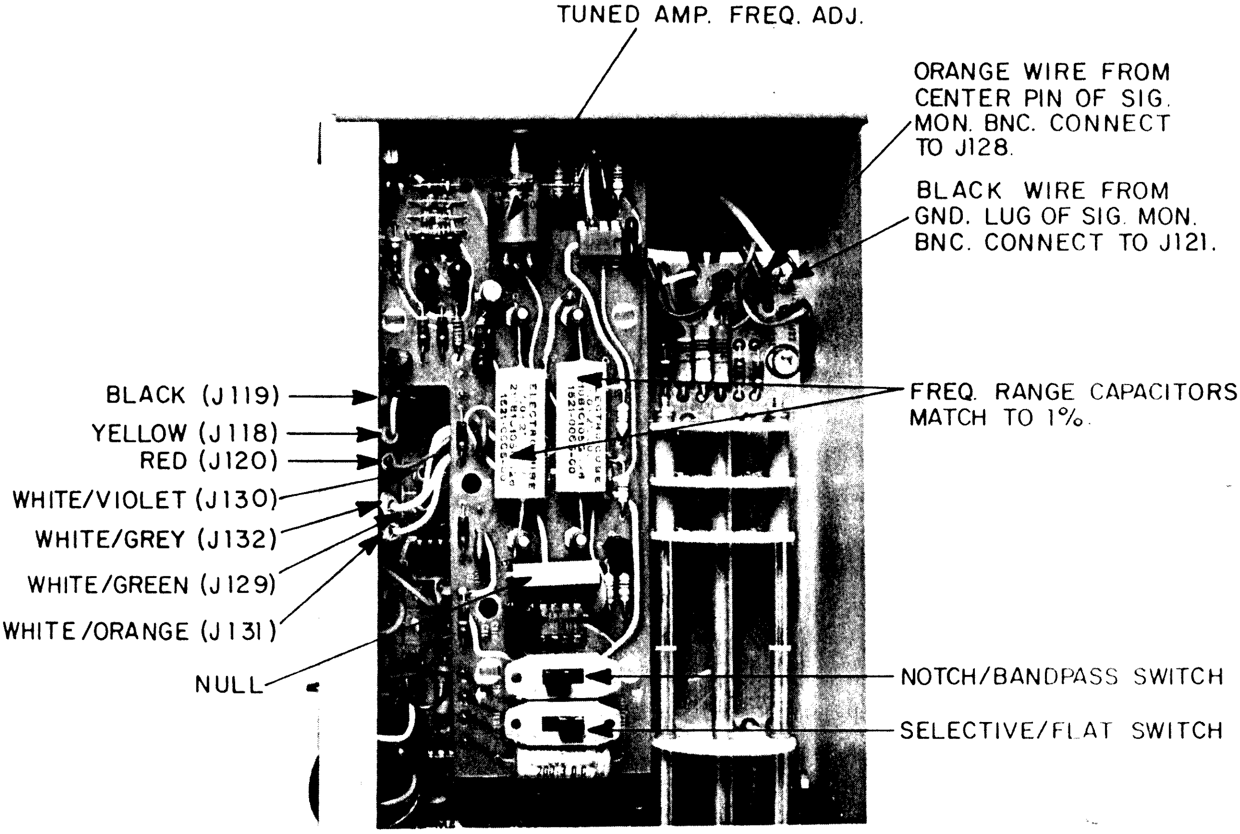


Figure IV-14. TUNED AMPLIFIER INSTALLED

(6) Set the Notch/Bandpass slide switch to NOTCH.

(7) Connect a 250 mV rms sinewave (0.7 V pk-pk) to both the "A" Input and Ref. Input of the Model 128A. This signal should be at the intended operating frequency. **NOTE:** If the unit is also equipped with the internal oscillator modification, use the internal oscillator as the signal source.

(8) Monitor the rear-panel SIG. MON. connector with the oscilloscope and alternately adjust the two Tuned Amplifier trim-adjustments for a null in the observed signal. The rear-panel accessible adjustment sets the center frequency. The one which is adjusted from the side sets the Q and amplitude response. These adjustments do interact so it will be necessary to go back and forth until no further improvement in the observed null can be obtained. **NOTE:** Any time the operating frequency is changed, the Null/Amplitude adjustment must also be reset. If the Null/Amplitude adjustment is properly set for one end of the frequency range, and the tuned frequency is then shifted to the opposite end of the same range, the amplitude response of the Tuned Amplifier will be in error by about 20% unless the Null/Amplitude adjustment is reset.

(9) Set the Notch/Bandpass switch to BANDPASS. Then, using an accurate ac voltmeter, establish the rms amplitude of the *input* signal at 250 mV ±1%.

(10) Adjust the Phase dial (and Phase switch if need be) for peak panel meter indication (alternatively, one could use a digital voltmeter connected to the front-panel OUT connector).

(11) Adjust the Model 128A GAIN CAL. trim-potentiometer, R143, for exactly full-scale panel meter indication (+1.000 V on a DVM). R143 is mounted on the Signal Amplifier board.

The Model 128A is now tuned for bandpass operation at the intended operating frequency, and is normalized for operation with the tuned amplifier. Figure IV-15 shows the phase/amplitude response of the Selective Amplifier in both Notch and Bandpass operation. For bandpass operation, the Notch/Bandpass switch should be set to BANDPASS. For Notch operation, it should be set to NOTCH. Neither position of the Notch/Bandpass switch has any relevance unless the Selective/Flat switch is set to SELECTIVE.

Note that this procedure must be modified somewhat for notch operation, where the frequency component to be

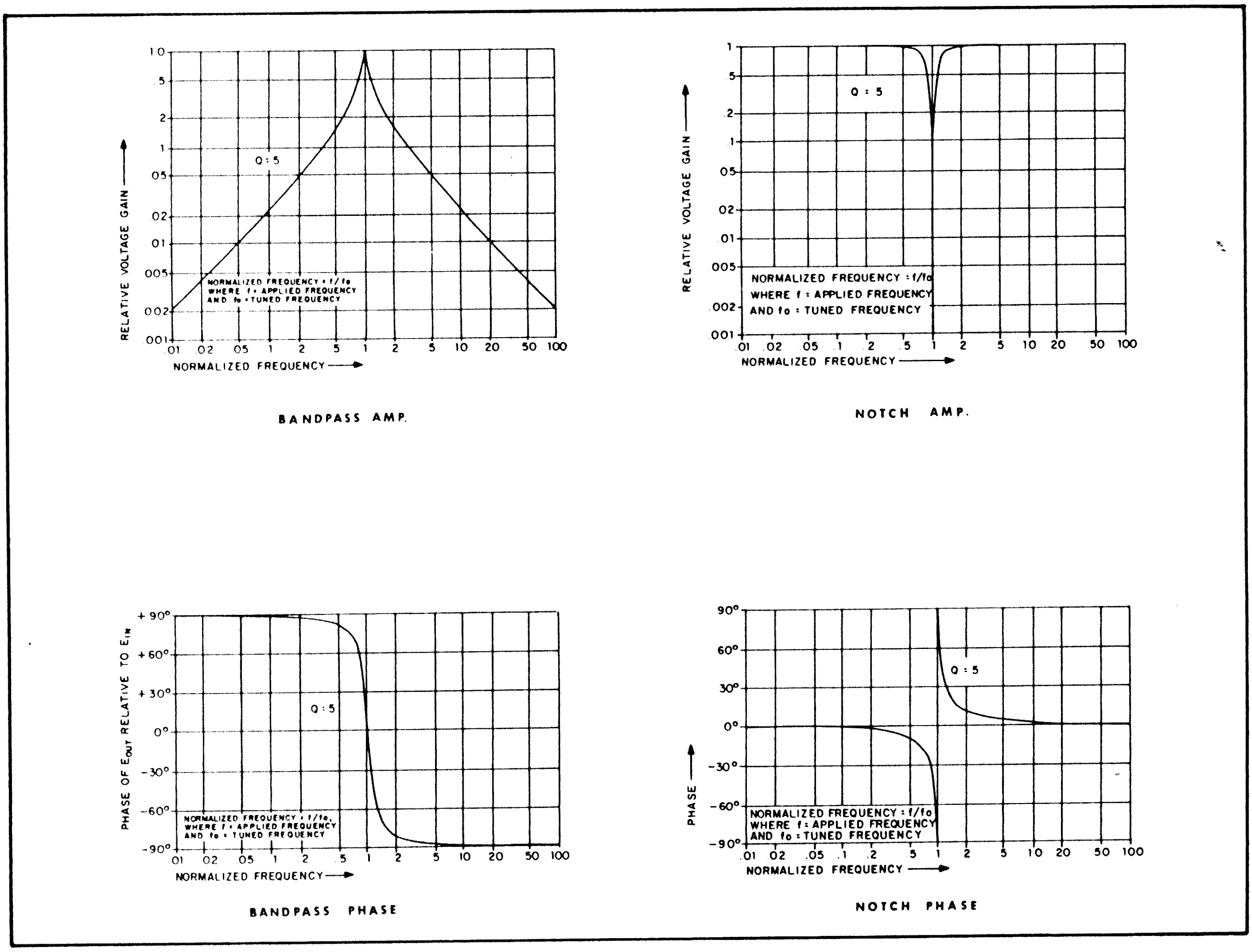


Figure IV-15. PHASE/AMPLITUDE CHARACTERISTICS OF TUNED AMPLIFIER

removed is other than the one to be measured. As a result, the signal frequency used for setting up the Tuned Amplifier should be the one to be notched out, and not the one to be measured.

As can be seen from Figure IV-15, the Notch response is a sharp function of frequency. Hence, any slight frequency difference between the "setup" signal and the "real" signal to be notched out may result in the notch not being as deep as it could be. Hence, when the setup for notch operation is completed, it is generally a good idea to connect the signal produced by the experiment to the input of the Model 128A and then, while monitoring the signal at the SIG. MON. connector, to adjust the Null/Amplitude adjustment on the Tuned Amplifier as required to make the signal being nulled disappear into the noise. It might be mentioned that the "appearance" of the signal may not be as expected. For example, in measuring harmonics, it is generally desirable to notch out the fundamental. Many observers are quite surprised at the appearance of a square wave, for example, that has had its fundamental frequency component removed.

4.8C INSTALLATION

When a Model 128A is ordered with the Tuned Amplifier modification, the instrument is shipped with the amplifier already installed and the operator need only concern himself with operating considerations. If he should wish to operate without the Tuned Amplifier, there are no changes to make other than to set the Selective/Flat switch to FLAT, although it may be desirable to touch up the setting of R143 using a test signal of accurately known amplitude.

In the case of a Tuned Amplifier which is ordered separately, the installation is generally made by the customer. Two items are supplied, the first being the Tuned Amplifier itself, and the second a BNC connector with two attached wires that terminate in quick-disconnect contacts. All of the interconnections between the Tuned Amplifier and the Model 128A are by means of wires attached to the Tuned Amplifier. These wires also terminate in quick-disconnect contacts.* The following procedure can be used to make the installation.

(1) Remove the top cover from the Model 128A. This cover is secured by four screws, two on each side.

(2) Mount the BNC connector in the SIG. MON. opening in the rear panel. (It will be necessary to first push out the plug, which can then be discarded.) Be sure to use the insulated bushings supplied so that there is no contact between the shell of the connector and chassis ground. Then connect the orange wire (attached to the connector) to pin J128 (rear edge of Signal Amp. Bd.) and the black wire to J121.

*Current production units use a different kind of quick-disconnect pin than was used previously. If a current production tuned amplifier board is to be installed in an older Model 128A, the quick-disconnect terminals at the end of the involved leads will have to be cut off and replaced by the new type terminals (supplied with the Tuned Amplifier board).

(3) Position the Tuned Amplifier as shown in Figure IV-14 but do not snap it into place yet. (It is easier to make the wire connections first.)

(4) On the Model 128A, remove the jumper (white/orange) which interconnects J129 and J130. Also remove the jumper (white/violet) which interconnects J131 and J132. It may be a good idea to tape these jumpers somewhere to a chassis surface inside the Model 128A to prevent their becoming lost.

(5) Make the wire connections from the Selective Amplifier to the following listed pins.

Wire Color	Connect To
black	J119
red	J120
yellow	J118
white/violet	J130
white/green	J129
white/orange	J131
white/gray	J132

(6) Press the Tuned Amplifier circuit board down so that it snaps into place.

This completes the installation. The Tuned Amplifier can now be operated as described in Subsection 4.8B.

4.9 MORE REFERENCE CHANNEL OPERATING HINTS

4.9A REFERENCE CHANNEL SLEWING RATE

When the input frequency to the Reference channel changes, the internal Reference circuitry automatically tracks so that detection is always with respect to the applied frequency. However, the tracking is not instantaneous, with the result that there is some phase difference between the applied signal and the reference drive to the detector while the frequency is changing. The maximum rate at which the Reference Input frequency can change depends on how much phase shift one is willing to tolerate. The relationship linking these factors is $df/dt = kf\theta$, where df/dt is the slewing rate in Hz/s, k is a constant $= .3 \times 10^{-3}$, and θ is the phase lag. Example: If the operating frequency were nominally 1 kHz, and the maximum θ one could accept were 1°, then the maximum allowable df/dt would be 3 Hz/s. One could as well use this equation to solve for the angle θ given some value of df/dt.

4.9B PHASE ERRORS WITH SMALL REFERENCE SIGNALS

With reference signals on the order of 1 V rms, the firing point is very near 0° (with respect to the zero crossover of the reference input sinewave). However, as smaller and smaller reference signals are applied (speaking of sinewaves), the firing point becomes further and further from the crossover point, introducing phase error. For sinewaves just barely large enough to provide proper reference channel operation, the error will be much nearer to 90° than to 0°. Any instability in the amplitude of the reference signal will only compound the problem. Consequently, in any application where phase accuracy is important, use of a 1 V rms sinewave reference signal is advised. Other waveforms can of course be used. With a square wave, this problem is minimized. With a triangular wave, it is even more severe than with a sinewave.

SECTION V WARNING!

POTENTIALLY LETHAL VOLTAGES ARE PRESENT INSIDE THIS APPARATUS. THESE SERVICE INSTRUCTIONS ARE FOR USE BY QUALIFIED PERSONNEL ONLY. TO AVOID ELECTRIC SHOCK, DO NOT PERFORM ANY SERVICING UNLESS YOU ARE QUALIFIED TO DO SO. ANY ADJUSTMENT, MAINTENANCE, AND REPAIR OF THE OPENED APPARATUS UNDER VOLTAGE SHALL BE AVOIDED AS FAR AS POSSIBLE AND, IF UNAVOIDABLE, SHALL BE CARRIED OUT ONLY BY A SKILLED PERSON WHO IS EXPERIENCED IN WORKING ON ELECTRONIC APPARATUS AND WHO IS AWARE OF THE HAZARD INVOLVED. WHEN THE INSTRUMENT IS CONNECTED TO A POWER SOURCE, TERMINALS MAY BE LIVE, AND THE OPENING OF COVERS OR REMOVAL OF PARTS IS LIKELY TO EXPOSE LIVE PARTS. THE APPARATUS SHALL BE DISCONNECTED FROM ALL VOLTAGE SOURCES BEFORE IT IS OPENED FOR ANY ADJUSTMENT, REPLACEMENT, MAINTENANCE, OR REPAIR. CAPACITORS INSIDE THE UNIT MAY STILL BE CHARGED EVEN IF THE UNIT HAS BEEN DISCONNECTED FROM ALL VOLTAGE SOURCES. USERS ARE ADVISED TO WAIT SEVERAL MINUTES BEFORE ASSUMING THE CAPACITORS ARE DISCHARGED.

SECTION V
ALIGNMENT

READ SAFETY NOTICE ON FACING PAGE BEFORE PROCEEDING

5.1 INTRODUCTION

The Model 128A Lock-In Amplifier is a reliable conservatively designed instrument. High quality stable components have been used throughout in its construction and one can reasonably expect a long period of troublefree operation without any need for realignment. However, to be assured of continued high confidence in the experimental data obtained with the Model 128A, it may be advisable to run through the following alignment at one year intervals, and after doing a repair on the instrument. Due to possible interactions between some of the adjustments, it is necessary that they be carried out in the indicated sequence. Any decision to make a partial alignment should be reserved to someone having sufficient knowledge of the Model 128A to fully understand all possible interactions. Figure V-1 identifies the adjustments and testpoints.

Note that this alignment is not intended to be used in troubleshooting. If the instrument is suspected of malfunctioning, go directly to Section VI, which deals with troubleshooting. The instrument must be working properly before it can be aligned.

5.2 REQUIRED EQUIPMENT

(1) General purpose oscilloscope having a sensitivity of at least 1 mV/cm with a 10:1 attenuator probe.

(2) Sinewave oscillator, providing both an adjustable output and a fixed amplitude output, with the two *to be in phase.* The fixed output is used as the reference drive to the lock-in amplifier and need not be a sinewave. One suitable oscillator would be the Krohn-hite Model 4200. One could also use a single output oscillator followed by a 10:1 attenuator.

(3) Digital Voltmeter such as the Fairchild Model 7000.

(4) Two shorting plugs, CW-159/U (Amphenol or equivalent).

(5) Cables for interconnecting the above items.

(6) Three small jumper cables.

5.3 PRELIMINARY STEPS

(1) Remove the top cover, which is secured by four screws, two on each side.

(2) If the unit contains a tuned amplifier or an internal oscillator, take the necessary steps to render these accessories inactive, that is, the Model 128A should be operated in the external reference mode and the signal channel response should be flat.

(3) Check and, if necessary, adjust the mechanical zero of the panel meter. Then plug in the Model 128A, turn on the power, and allow a fifteen minute warmup.

(4) Connect BNC shorting plugs to both inputs.

5.4 PROCEDURE

5.4A +15 V ADJUST (R310), –15 V CHECK, and +5 V CHECK

(1) Connect the DVM to the positive end of capacitor C309. Then adjust R310 (+15 V ADJ) for a DVM reading of +15.50 V.

(2) Remove the DVM from C309 and transfer it to the negative end of C310. The voltage should be –15.5 V ±0.2 V.

(3) Remove the DVM from C310 and transfer it to the positive end of C312. The voltage should be +5 V ±0.2 V. Remove the DVM.

5.4B REFERENCE BOARD ADJUSTMENTS

(1) Set the controls as follows:

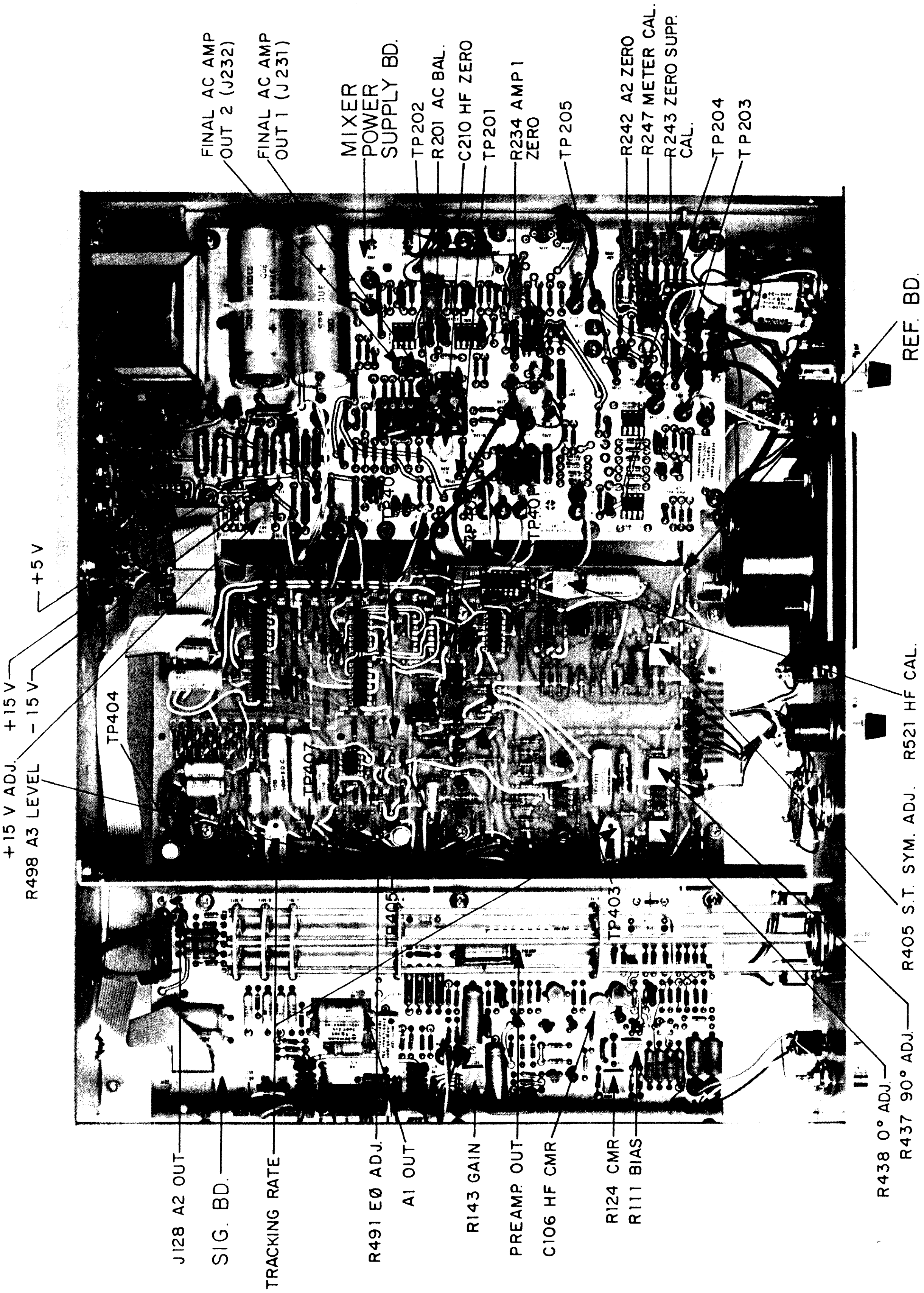
Sensitivity: 100 mV
Input Selector switch: "A"
Lo Pass switch: MAX.
Hi Pass switch: MIN.
Phase switch: 270°
Phase dial: 90°
Reference Mode switch: f
Time Constant: MIN.
Zero Offset
  switch: OFF (center position)
  dial: 0.00 (fully counterclockwise)
Fast/Slow switches (located on Ref. board): FAST
DC Prefilter switch: OUT

(2) Schmitt Trigger Symmetry Adjust (R405)

(a) Connect the oscillator to the Ref. In connector. Set the amplitude to 3 V pk-pk at 400 Hz.

(b) Monitor the signal at TP401 with the oscilloscope. The observed signal should be a 400 Hz square wave with a pk-pk amplitude of about 3 V.

(c) Gradually reduce the amplitude of the applied signal until "rounding" of the square wave is observed. As the amplitude is further reduced, the symmetry of the observed waveform may become degraded. Adjust R405 (Schmitt Trigger Symmetry Adj) as required so that ideal symmetry is maintained. Keep reducing the amplitude of the input signal to the point where R405 is adjusted for best symmetry with the lowest possible reference input which gives proper operation.


FINAL AC AMP OUT 2 (J232)
FINAL AC AMP OUT 1 (J231)
MIXER POWER SUPPLY BD.
TP202
R201 AC BAL.
C210 HF ZERO
TP201
R234 AMP 1 ZERO
TP205
R242 A2 ZERO
R247 METER CAL.
R243 ZERO SUPP. CAL.
TP204
TP203
REF. BD.
R521 HF CAL.
R405 S.T. SYM. ADJ.
R437 90° ADJ.
R438 0° ADJ.
J128 A2 OUT
SIG. BD.
TRACKING RATE
R491 EØ ADJ.
A1 OUT
R143 GAIN
PREAMP. OUT
C106 HF CMR
R124 CMR
R111 BIAS
+15 V ADJ.
R498 A3 LEVEL
TP404
+15 V
−15 V
+5 V
TP405
TP407
TP403
TP401

(d) Increase the amplitude of the reference input to about 3 V pk-pk.

(3) A3 Level Adjust (R498)

(a) Being sure to use the 10:1 attenuator probe, connect the oscilloscope to TP407. The oscilloscope should be dc coupled.

(b) Adjust R498 (A3 Level Adj) for an indicated voltage of –4 V. Then wait a minute. If the voltage changes, readjust R498 as required to obtain the desired –4 V reading.

(4) EØ Adjust (R491)

(a) Transfer the oscilloscope to ac coupling and transfer it from TP407 to TP405. The suggested horizontal sensitivity is 1 ms/cm.

(b) Rotate R491 (EØ Adj) fully counterclockwise.

(c) Increase the vertical sensitivity of the oscilloscope until small spikes are observed. Then adjust R491 (EØ Adj) until the spikes disappear. If the adjustment is turned too far, the spikes will reappear but with reversed polarity. Remove the oscilloscope.

5.4C SIGNAL BOARD ADJUSTMENT

(1) Preamp DC Bias Adjust (R111)

(a) Connect the DVM to TP101.

(b) Adjust R111 (Preamp. DC Bias Adj) for +3 V. Remove the DVM.

5.4D MIXER ADJUSTMENTS

(1) DC Amp. 2 Zero Adj (R242)

(a) Connect a jumper from J221 to J223 (ground).

(b) Connect the DVM to the front-panel OUT connector.

(c) Adjust R242 (DC Amp 2 Zero Adj) for "0" on the DVM.

NOTE: If the instrument has been repaired and Q206 A-B replaced, the following procedure should be used to select R273 (select-by-test resistor).

1. After performing steps a and b, connect a jumper from TP204 to TP205.

2. Connect another jumper from TP203 to J223 (or any ground).

3. Adjust R242 (DC Amp 2 Zero Adj) for "0" panel meter indication. **NOTE:** This is a sensitive high-gain adjustment and setting a true zero will probably prove impossible. Initially, the meter will probably be against one "stop" or the other. As the adjustment is turned, a point will be reached where the meter indication "snaps" to the other extreme. If the adjustment is then turned in the opposite direction, about a half turn will typically be required to make the indication "snap back". The correct setting is midway through the "dead zone". In other words, one must adjust the pot until the indication "snaps" to the other extreme, then stop, and go back half way to the setting required to make the meter snap back.

4. Remove the two jumpers connected in steps 1 and 2.

5. Select for R273 that resistor which yields a DVM indication of "0" ±0.2 mV. The resistor value should be one megohm or smaller.

(2) DC Amp. 1 Zero Adj. (R234)

(a) Set the Sensitivity switch to 2.5 mV.

(b) Remove the jumper from J221.

(c) Adjust R234 (DC Amp. 1 Zero Adj) for "0" on the DVM.

(d) Set the Sensitivity switch to 100 mV.

(3) Meter Cal. Adjust (R247)

(a) Set the Zero Offset Polarity switch to "–".

(b) Adjust the Zero Offset dial clockwise (about one full turn) for a DVM indication of +1.00 V.

(c) Adjust R247 (Meter Cal. Adj) so that the panel meter reads exactly full scale to the right.

(d) Set the Zero Offset Polarity switch to the center (OFF) position.

(e) Remove the DVM.

(4) AC Bal. Adj. (R201)

(a) Set the Sensitivity switch to 2.5 mV.

(b) Connect the oscilloscope to the front-panel OUT connector.

(c) Decrease the reference frequency to 40 Hz.

(d) Adjust R201 (AC Bal. Adj) for minimum square wave signal observed at the oscilloscope. **NOTE:** This square wave will drift around because of short term temperature fluctuations caused by air currents on the components. Remove the oscilloscope.

(5) HF Zero Adj. (C210)

(a) Increase the reference signal to 100 kHz.

(b) Adjust trim-capacitor C210 (HF Zero Adj) for "0" panel meter indication.

(c) Reset the reference frequency to 400 Hz.

5.4E OTHER ADJUSTMENTS

(1) Reference 0° Phase Adj. (R438)

(a) Set the Sensitivity switch to 100 mV.

(b) Remove the shorting plug from the "A" Input. Then connect the signal generator output (400 Hz; 280 mV pk-pk) to the "A" Input. The Reference Input should still be driven from the same signal generator. Set the Input switch to "A".

(c) Note the panel meter indication. It should be near full-scale to the right.

(d) Set the Phase switch to 90° and the Phase dial to 0° (fully counterclockwise). The meter indication should go to very near "0".

(e) Adjust R438 (0° Adj) for exactly "0" on the panel meter.

(2) Reference 90° Phase Adj. (R437)

(a) Set the Phase switch to 0° and the Phase dial to 90.0° (nine turns clockwise from the fully counterclockwise position).

(b) Again the panel meter indication should be approximately "0". Adjust R437 (90° Adj) for exactly "0" panel meter indication.

(3) Gain Adj. (R143)

(a) Connect the DVM to the OUT connector.

(b) Adjust the level of the input signal to exactly 100 mV rms. If necessary, use a calibrated ac voltmeter to be assured that the input signal level is accurate to at least 1%.

(c) Set the Time Constant switch to .3 SEC.

(d) Set the Phase switch to 270° and the Phase dial to 90°. Then adjust the dial for peak output as indicated by the DVM.

(e) Adjust R143 (Gain Adj) for 1.000 V at the DVM.

(4) Zero Offset Cal. (R243)

(a) Set the Sensitivity switch to 10 mV. (The 100 mV rms signal should still be applied.)

(b) Set the Zero Offset Polarity switch to "+". Then rotate the Zero Offset dial to the fully clockwise position.

(c) Adjust R243 (Zero Offset Cal.) for 0.00 V on the DVM. The panel meter will also indicate "0".

(d) Set the Zero Offset Polarity switch to OFF and the Sensitivity switch to 100 mV. The DVM should indicate 1 V ±5 mV. If it does, go on to the following step. If it does not, it is because of interaction between R143 (Gain Adj) and R243 (Zero Offset Cal). If necessary, repeat steps 3 and 4 as required to achieve the desired adjustment objectives.

(e) Reset the Sensitivity to 100 mV. Also, set the Offset Polarity switch to the center (OFF) position and rotate the Offset dial fully counterclockwise. Remove the DVM.

(5) Low Frequency CMR Adj (R124)

(a) Remove the shorting plug from the "–B" Input. Then connect the 100 mV rms signal from the generator simultaneously to both inputs.

(b) Set the Input Selector switch to "A–B".

(c) Increase the level of the input signal to 1 V rms (2.8 V pk-pk). The Sensitivity should remain set to 100 mV.

(d) Set the Sensitivity switch to 100 μV. Then adjust R124 for "0" panel meter indication.

(e) Increase the Sensitivity to 10 μV. Again adjust R124 for "0" panel meter indication.

(6) High Frequency CMR Adj (C106)

(a) Set the Sensitivity switch to 250 mV.

(b) Increase the signal frequency to 100 kHz and set the amplitude of the input signal to 250 mV rms (0.7 V pk-pk).

(c) Set the Sensitivity switch to 25 μV.

(d) Connect the oscilloscope (with probe) to J128 (quick-disconnect at rear of Signal board).

(e) Adjust trim-capacitor C106 for minimum observed signal. It should be possible to adjust the observed signal to less than 60 mV pk-pk.

(f) Set the Sensitivity switch to 100 mV.

(7) High Frequency Phase Adj (R521)

(a) Make provision for supplying in-phase signals to the Model 128A. The signal to be applied to the Reference Input should have an amplitude of nominally 1 V rms, while that applied to the Signal Input should be 100 mV rms. It is absolutely essential that the two signals be in phase. This is assured by using a single source and a simple series 10:1 divider. A 910 ohm composition resistor in series with a 100 ohm composition resistor makes a suitable divider. No great divider accuracy or precision is required. Ordinary 5% resistors are quite adequate. A signal having a nominal one volt rms amplitude is applied to the divider and to the Reference Input of the lock-in amplifier, while the signal applied to the Signal Input connector is taken from the junction of the two divider resistors.

(b) Set the signal frequency to 100 kHz and adjust the signal source output amplitude so that the signal applied to the Model 128A "A" Input is 100 mV rms.

(c) Set the Input Coupling switch to "A". Then remove the cable connected to the "B" Input.

(d) Set the Phase switch to 0° and the Phase dial to 90.0°.

(e) Adjust R521 (High Freq. Phase Adj) for "0" on the panel meter.

(f) Set the Sensitivity to 10 mV and adjust R521 again, this time for a −10% of full scale meter deflection. This is a meter indication to the left of "0" (−.1 on the upper meter scale).

This completes the alignment. The test equipment can now be removed and the cover secured in place.

SECTION VI WARNING!

POTENTIALLY LETHAL VOLTAGES ARE PRESENT INSIDE THIS APPARATUS. THESE SERVICE INSTRUCTIONS ARE FOR USE BY QUALIFIED PERSONNEL ONLY. TO AVOID ELECTRIC SHOCK, DO NOT PERFORM ANY SERVICING UNLESS YOU ARE QUALIFIED TO DO SO. ANY ADJUSTMENT, MAINTENANCE, AND REPAIR OF THE OPENED APPARATUS UNDER VOLTAGE SHALL BE AVOIDED AS FAR AS POSSIBLE AND, IF UNAVOIDABLE, SHALL BE CARRIED OUT ONLY BY A SKILLED PERSON WHO IS EXPERIENCED IN WORKING ON ELECTRONIC APPARATUS AND WHO IS AWARE OF THE HAZARD INVOLVED. WHEN THE INSTRUMENT IS CONNECTED TO A POWER SOURCE, TERMINALS MAY BE LIVE, AND THE OPENING OF COVERS OR REMOVAL OF PARTS IS LIKELY TO EXPOSE LIVE PARTS. THE APPARATUS SHALL BE DISCONNECTED FROM ALL VOLTAGE SOURCES BEFORE IT IS OPENED FOR ANY ADJUSTMENT, REPLACEMENT, MAINTENANCE, OR REPAIR. CAPACITORS INSIDE THE UNIT MAY STILL BE CHARGED EVEN IF THE UNIT HAS BEEN DISCONNECTED FROM ALL VOLTAGE SOURCES. USERS ARE ADVISED TO WAIT SEVERAL MINUTES BEFORE ASSUMING THE CAPACITORS ARE DISCHARGED.

SECTION VI
TROUBLESHOOTING

READ SAFETY NOTICE ON FACING PAGE BEFORE PROCEEDING

6.1 INTRODUCTION

This section consists of a series of procedures to be followed in troubleshooting the Model 128A. The purpose of the procedure is to narrow the trouble down to one of the three plug-in circuit boards by making voltage and waveform checks at critical points. Once the faulty board has been identified, the operator can contact the factory or the authorized representative in his area for advice on how to get the instrument back into operation in the shortest possible time. In the case of units still in Warranty, it is particularly important that the factory or one of its representatives be contacted before doing any work on the board itself, because any damage that occurs as a result of unauthorized work could invalidate the Warranty.

Although past experience indicates that some instrument failures turn out to be the fault of a specific component failure on one of the boards, it is of course perfectly possible that some component other than one located on a circuit board could go bad. Where this is the case, the person troubleshooting will have to appropriately adapt the procedure to isolate the faulty component.

6.2 EQUIPMENT REQUIRED

(1) Digital Voltmeter such as the Fairchild Model 7000.

(2) Oscillator (sinewave) to provide a 100 mV rms signal at 400 Hz.

(3) General purpose oscilloscope with 10:1 probe.

6.3 INITIAL STEPS

(1) Remove the top cover, which is secured by four screws, two on each side.

(2) If the unit contains a tuned amplifier or an internal oscillator, take the necessary steps to render these accessories inactive, that is, the Model 128A should be operated in the External Reference mode and the signal channel response should be flat.

(3) Plug in the Model 128A, turn on the power, and allow a fifteen minute warmup.

6.4 POWER SUPPLY CHECKS (schematic on page VII-11)

(1) On the Power Supply board, check for: (a) +15.5 V ±0.1 V at the positive end of capacitor C309, (b) −15.5 V ±0.2 V at the negative end of capacitor C310, and (c) +5 V ±0.2 V at the positive end of capacitor C312. If these voltages are correct, go to Subsection 6.5. If any of these voltages are incorrect or missing, proper power supply operation must be established before any further checks can be made. Note from the schematic on page VII-11 that the +15 V regulator supplies the reference voltage for both the +5 V and −15 V regulators. Thus, any trouble with the +15 V regulator would cause loss of regulation in the −15 V and +5 V circuits as well.

(2) If the unregulated supply levels are incorrect (nominally ±24 V), check the unregulated supply components (line fuse, transformer, rectifiers, and filter capacitors). Note that the pass transistor for each of the three regulator circuits is bolted directly to the rear chassis, which acts as a heat sink.

6.5 REFERENCE CHECKS (schematics on pages VII-6 and VII-7)

(1) Set the controls as follows.

Input Selector: A
Sensitivity: 100 mV
Phase
  switch: 0°
  dial: 0°
Reference mode: f
Zero Offset
  switch: OFF (center position)
  dial: fully counterclockwise
Time Constant: .3 SEC.
DC Prefilter: OUT
Power: ON
Reference Tracking-Rate switches (internal): FAST

(2) Set the oscillator controls to provide a 280 mV pk-pk (100 mV rms) sinewave at 400 Hz.

(3) Connect the output of the oscillator to the Reference Input of the Model 128A.

(4) Connect the oscilloscope (use 10:1 probe) to TP401. The observed signal should be a 400 Hz square wave having its lower level at about −0.6 V and its upper level at +2.5 V. If this signal is as indicated, one can assume that the Input Schmitt Trigger circuit is working correctly. **NOTE:** Here and throughout the remainder of the troubleshooting procedure the operator should concern himself primarily with gross discrepancies. Generally, when a circuit malfunctions, the "error" in the output signal of that circuit is so great as to leave no doubt of a malfunction. Much time may be saved by going through the checks fairly rapidly, without wasting undue time and effort trying to verify that each signal of voltage conforms to the value indicated down to the "last decimal point".

(5) Connect the DVM to TP403. The voltage should be −4.5 V ±0.1 V. If this voltage is correct, one can reasonably assume that the AMP 1 circuit, the AMP 2 circuit, and the U401 switching circuits at the output of the Input Schmitt Trigger are all working normally. Remove the DVM.

(6) Connect the oscilloscope to TP402. The observed signal should be a negative sawtooth at 400 Hz. The upper "plateau" should be at +10 V and the lower "points" should be at +4.5 V. The "plateau intervals" should have the same duration as the sawteeth. If this signal is as indicated, one can reasonably assume that all of the circuits depicted on the page VII-6 schematic are functioning normally.

(7) Connect the oscilloscope to TP404. The signal there should be a 1600 Hz square wave having its upper level at about +4 V and its lower at 0 V. If this signal is as indicated, one can reasonably assume that the "4f Oscillator" and the oscillator control circuitry (Q427-Q428 and all components to the "left" on the schematic) are working properly.

It might be instructive to check the voltage at TP407. The allowable voltage range at this point extends from 0 V to −8 V. However, under the measurement conditions established, this voltage is nominally −4 V. The voltage at TP406 should be about −0.6 V relative to that at TP407.

The correction signal can be observed at TP405. However, when the loop is operating correctly, there is little to observe. One might see small amplitude "fuzzy blips" at 400 Hz. When the loop is perturbed by changing the frequency of the applied reference signal, these blips transform into definite spikes which can be either positive or negative according to the sense of the correction to be made.

(8) Monitor J413 with the oscilloscope. One should observe a 400 Hz square wave having its upper level at +4 V and its lower level at 0 V. If this waveform is as indicated, one can conclude that the logic circuits which provide the Ref. Mon. output are working normally.

If all of these voltages and signals are as indicated, one can reasonably assume that all of the tracking circuits are functioning normally. The only remaining reference circuit is that which controls the Reference Unlock lamp.

6.6 SIGNAL CHANNEL AMPLIFIERS

6.6A PREAMPLIFIER (schematic on page VII-3)

(1) Connect the oscillator output (still set to 280 mV pk-pk at 400 Hz) to the "A" input of the Model 128A. This signal should still be applied to the Reference Input as well.

(2) Connect the oscilloscope to the negative end of capacitor C111. **NOTE:** This capacitor is shown schematically on page VII-4. The observed signal should be a sinewave with a pk-pk amplitude of 2.8 V, indicating that the preamplifier has the expected gain of ten.

6.6B INTERMEDIATE AC AMPLIFIERS (schematic on page VII-4)

(1) Connect the oscilloscope to disconnect-pin J128. The observed signal should be a 400 Hz sinewave with a pk-pk amplitude of 130 mV. If this signal is as observed, one can go on to 6.6C. If the signal is not as indicated, the following checks can be made to determine in which of the two Intermediate Amplifiers the trouble is located.

(2) First connect a 1 kΩ resistor in series with the oscilloscope probe. Then monitor the signal at the negative end of capacitor C135. The signal observed should be a sinewave with a pk-pk amplitude of 1.4 V. If this signal is as indicated, one can conclude that the first Intermediate Amplifier is working correctly.

(3) Connect the oscilloscope to quick-disconnect pin J131. The signal there should be a sinewave with a pk-pk amplitude of 1.4 V. If this signal is as indicated, the second Intermediate Amplifier is also functioning normally.

6.6C FINAL AC AMPLIFIER (schematic on page VII-10)

Connect the oscilloscope to each of the two outputs of the Final AC Amplifier. The signal observed at both points should be a .7 V pk-pk sinewave at 400 Hz. If this signal is as indicated, one may conclude that all of the Signal Channel ac amplifiers, including the two final amplifiers, are functioning normally.

6.7 MIXER (schematic on page VII-10)

(1) Set the Phase switch to 270° and the Phase dial to 90°

(2) Verify that the 280 mV pk-pk signal from the oscillator is still applied to both the Signal and Reference inputs of the Model 128A.

(3) Connect the oscilloscope to TP201. The observed signal should be a positive full-wave rectified sinewave with a peak amplitude of +0.35 V. A slight adjustment of the Phase dial may be required to obtain this waveform. If this signal is as indicated, one may conclude that the Mixer circuit (Q201 through Q204) is functioning normally.

If this signal is incorrect or missing, check the Mixer Reference drive signal, which can be monitored at TP202. One should observe a 400 Hz square wave having its upper level at +6 V and its lower level at −12 V. If this signal is as indicated, one may conclude that the Reference Schmitt Trigger, which directly supplies the reference signal to the Mixer circuit, is functioning normally.

6.8 DC AMPLIFIERS (schematic on page VII-10)

(1) Connect the DVM to quick-disconnect pin J222. With

the Phase dial adjusted for maximum DVM indication, the voltage at J222 should be −5 V ±.2 V. If this voltage is as indicated, the First DC Amplifier is functioning normally.

(2) The output of the final amplifier can be measured at either the Recorder Output or at the front-panel Output connector. At either place the voltage should be +1 V ±50 mV (assuming the input signal is the specified amplitude). Also, the panel meter should indicate full scale. If readings other than those indicated are obtained, the trouble is associated with the final dc amplifier.

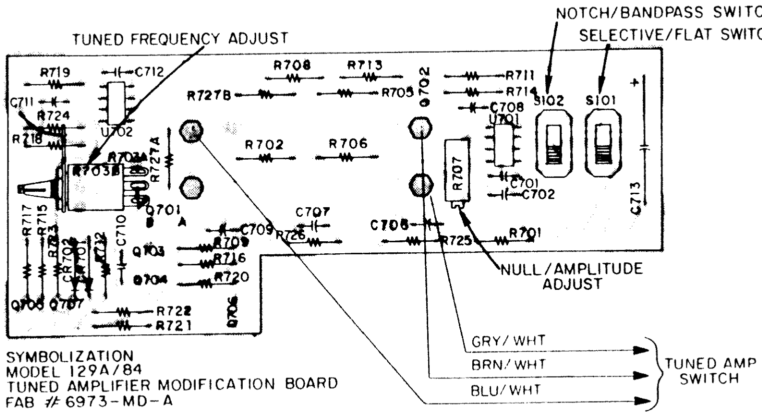
This completes the troubleshooting procedure. If no indication of trouble has been found to this point, the instrument is either functioning normally, or the problem is beyond the scope of this procedure. For additional aid or advice, the operator is advised to contact the factory or the authorized representative in his area.

APPENDIX A
MODEL 128A/90A MODIFICATION

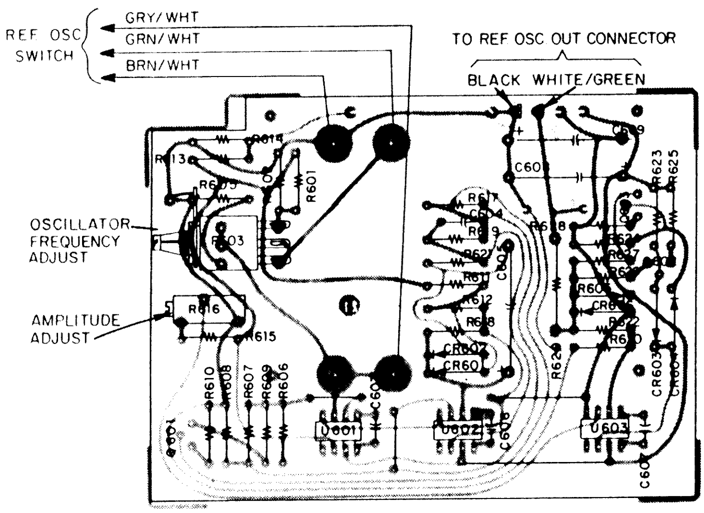
The Model 128A/90A is a Model 128A modified to operate at two different combinations of frequencies. Both a Tuned Amplifier and an Oscillator are incorporated into the Model 128A/90A. However, instead of setting the tuned frequency of these accessories by means of capacitors mounted on the accessory boards themselves as explained in the instruction manual, the capacitors are mounted on rear-panel switches. One switch allows the Tuned Amplifier to be tuned to either 2 kHz or 17 kHz. Another allows the oscillator frequency to be set to either 1 kHz or 17 kHz. The two are operated together so that, when the oscillator frequency is 1 kHz, the tuned amplifier is tuned to 2 kHz, and when the oscillator frequency is 17 kHz, the tuned amplifier frequency is also 17 kHz.

In addition to the changes required to achieve two-frequency operation, changes have also been made in the time constant circuitry. The range of available time constants is changed and the External Time Constant capability is eliminated. A plate with the new Time-Constant switch symbolization is added to the panel so that the Time-Constant switch pointer/symbolization indicates correctly. The new range extends from 300 μs to 30 s in 1-3-10 sequence. Several component-value changes have been made in implementing the new time constants. Resistors R239 and R235 are changed in value to 3 MΩ and 301 kΩ respectively. Capacitors C1 through C9 are all decreased in value by a factor of ten, and a new capacitor, one microfarad, has been added to achieve the 30 SEC time constant (EXT. position in standard instruments).

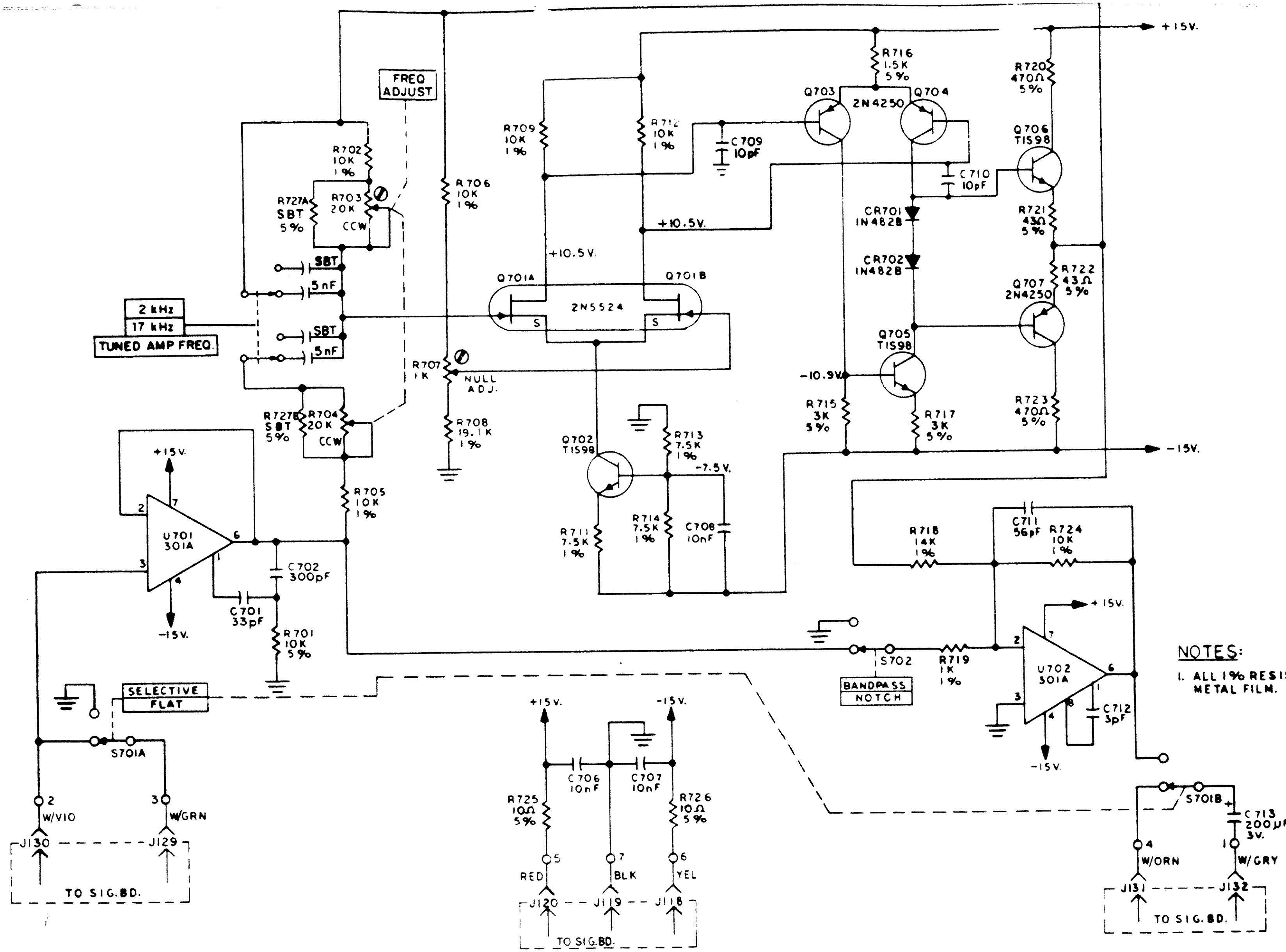
The diagrams below illustrate the wiring of the rear-panel switches to the spring-loaded contacts of the individual accessory boards. Schematics of the affected circuits are also provided. Because the time-constant changes only involve component-value changes as described above, no separate schematics are furnished for the Time-Constant circuits.



SYMBOLIZATION
MODEL 129A/84
TUNED AMPLIFIER MODIFICATION BOARD
FAB #6973-MD-A



SYMBOLIZATION
MODEL 129A/95 MODIFICATION
INTERNAL OSCILLATOR BOARD
FAB 6662-MD-B



NOTES:

1. ALL 1% RESISTORS 1/8W METAL FILM.

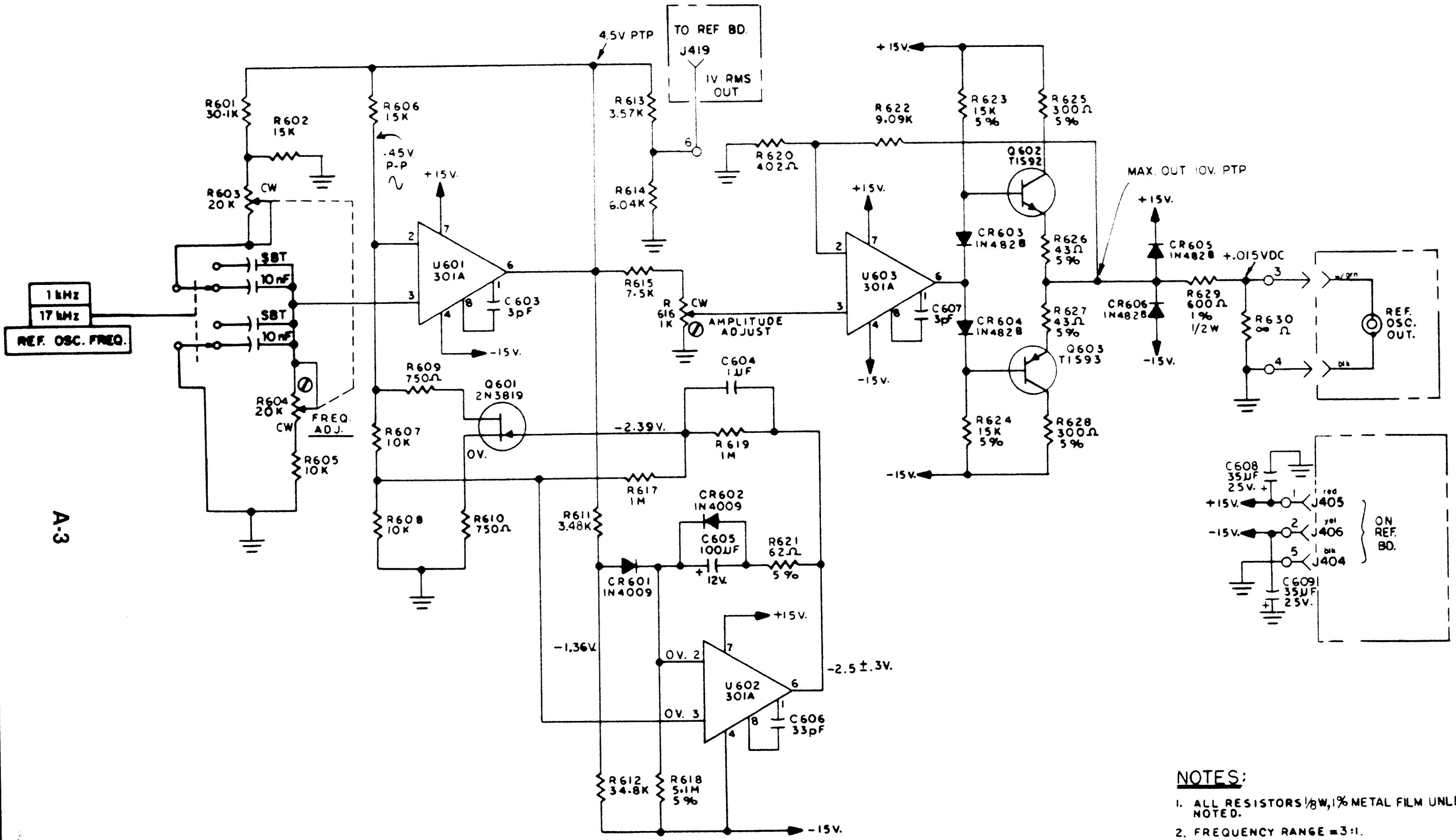
TUNED AMPLIFIER MODIFICATION

128/98

128A/90A MODIFICATION ADDED

MODEL 128

6646	C	SD



NOTES:

1. ALL RESISTORS 1/8W, 1% METAL FILM UNLESS OTHERWISE NOTED.
2. FREQUENCY RANGE = 3:1.
3. C≅10/f µF.
4. ALL 5% RESISTORS 1/4W CARBON COMPOSITION

INTERNAL OSCILLATOR MODIFICATION

128/99

128A/90A MODIFICATION ADDED

MODEL 128

6645 | C | SD

APPENDIX B
MODIFICATION 1281/70

INSTRUCTIONS FOR OPERATING THE MODEL 128A OR MODEL 129A WITH THE MODEL 189 INCORPORATED AS A TUNED AMPLIFIER

NOTE: Before proceeding, first verify that the lock-in amplifier is in good working order. One way of doing this is to run through the initial checks procedure provided in the lock-in amplifier instruction manual. Since the underlying assumption is that the lock-in amplifier has been specifically modified for operation in conjunction with a Model 189, be sure the rear-panel switch is in the FLAT position in performing the Initial Checks.

TUNING PROCEDURE
The procedure that follows is written in terms of tuning the system to 450 Hz. This same procedure could be used to tune the system to other operating frequencies. The only difference would be that the oscillator and the Model 189 would be set to the new frequency instead of to 450 Hz.

(1) Set the lock-in amplifier controls as follows.

(a) CONTROL SETTINGS FOR M128A ONLY

Input switch: A
Sensitivity: 100 mV
Filters: MIN and MAX
Phase switch: 270°
Phase dial: 90° (9 turns from fully ccw position)
Reference Mode: FUND. f
Zero Offset dial: 0.00 (fully ccw)
Zero Offset switch: OFF
Time Constant: 0.3 SEC.
dc Prefilter: OUT

(b) CONTROL SETTINGS FOR M129A ONLY

Input switch: A
Sensitivity: 100 mV
Filters: MIN and MAX
Phase switch: 270°
Phase dial: 90° (9 turns from fully ccw position)
Reference Mode: FUND. f
Vector switch: 2 PHASE
Zero Offset dial: 0.00 (both channels)
Zero Offset switch: OFF (both channels)
Time Constant: 0.3 SEC. (both channels)
Output Expand: × 1 (both channels)
dc Prefilter: OUT (both channels)

(2) Set the SELECTIVE/FLAT switch (on the rear panel of the modified Model 128A or Model 129A) to the SELECTIVE position.

(3) Connect a cable from the Model 189 INPUT connector to the "TO M189 IN" connector on the rear of the lock-in amplifier.

(4) Set the controls of the external oscillator as required to provide a 100 mV rms sine wave output at 450 Hz. Then connect this signal to both the "A" and Reference Inputs of the lock-in amplifier.

(5) Set the Model 189 controls as follows.

Pushbuttons: all to OUT position
Frequency control: 4.50
Frequency range: × 100

(6) Turn the power on at both the Model 189 and lock-in amplifier.

(7) Monitor the Bandpass output of the Model 189 with an oscilloscope. The observed signal should be a 450 Hz sine wave. Carefully adjust the inner dial of the M189 dual-concentric Frequency control for maximum observed signal. The amplitude of the observed signal should be about 125 mV pk-pk.

(8) Remove the oscilloscope and connect a cable from the BANDPASS output of the Model 189 to the "TO M189 OUT" jack on the rear panel of the modified Model 128A or Model 129A.

(9) The panel meter on the Model 128A (IN PHASE meter in the case of a M129A) should indicate near full scale to the right.

(10) Adjust the lock-in amplifier Phase dial for peak meter indication.

The lock-in amplifier M189 system is now tuned to 450 Hz. As explained previously, this same procedure could be used to tune to other frequencies as well.

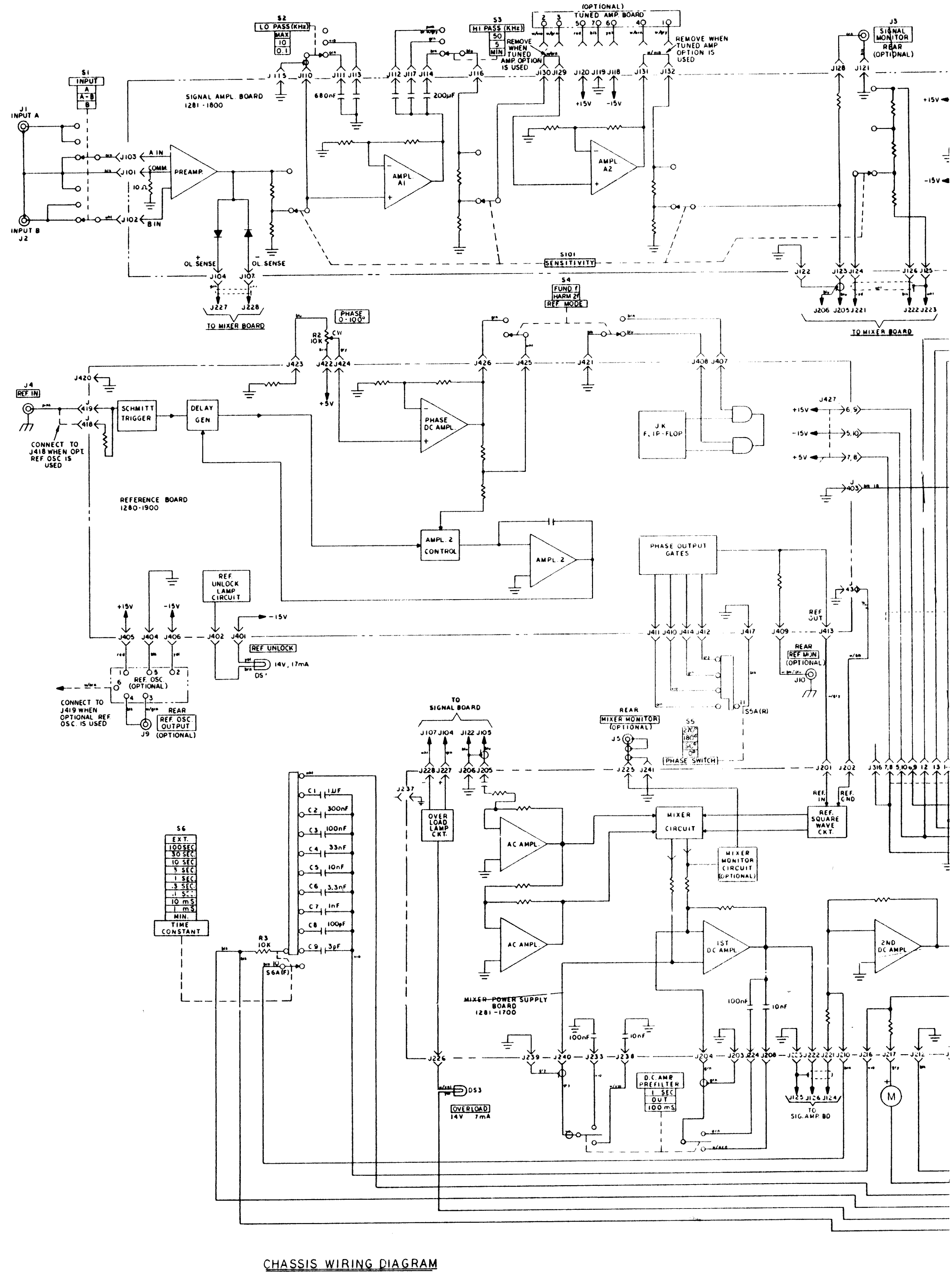
If the lock-in amplifier is to be operated as a flat frequency-response instrument, simply set the switch at the rear panel of the lock-in amplifier to FLAT. It is not necessary to disconnect the Model 189, although it can be disconnected, if desired. With the switch in the FLAT position, the lock-in amplifier functions as described in the instruction manual.

AC LINE FREQUENCY OPERATION

It is never a good idea to operate a lock-in amplifier at the power line frequency or one of its harmonics. This is particularly true if a tuned amplifier such as the Model 189 is incorporated into the system. Significant pickup and measurement error will occur if operation at the power frequency or its harmonics is attempted.

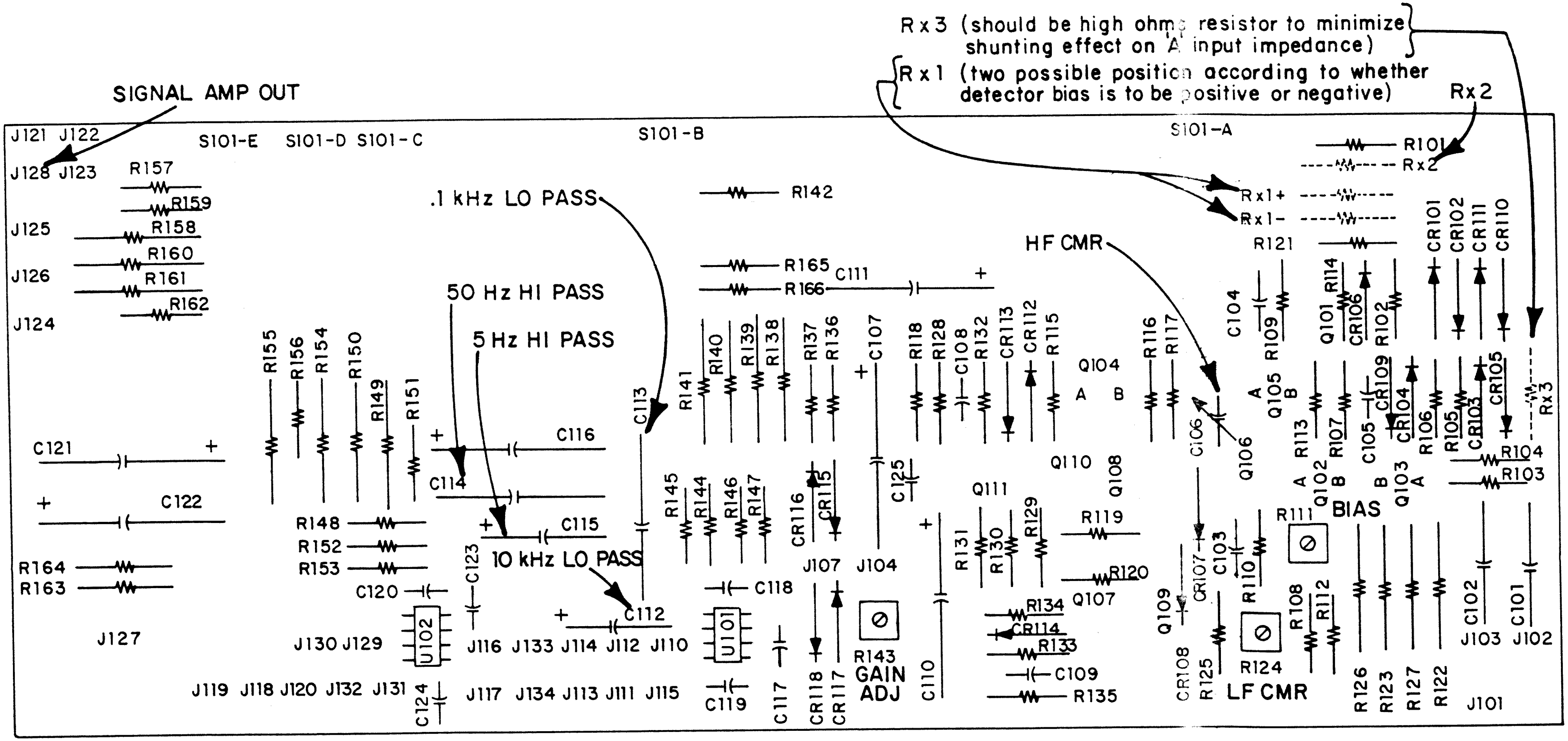
EXTRA GAIN-OF-TEN OPERATION

The Model 189 has a gain-of-one when both of the Model 189 GAIN pushbuttons are in the out position. The maximum sensitivity that can be selected at the front panel of the lock-in amplifier is one microvolt. By operating with the Model 189 PREAMP GAIN pushbutton depressed, this sensitivity can be increased to 100 nV. Do not operate the system with the Model 189 BANDPASS GAIN pushbutton depressed. The result will be significantly increased noise and, at high frequencies, increased phase shift.

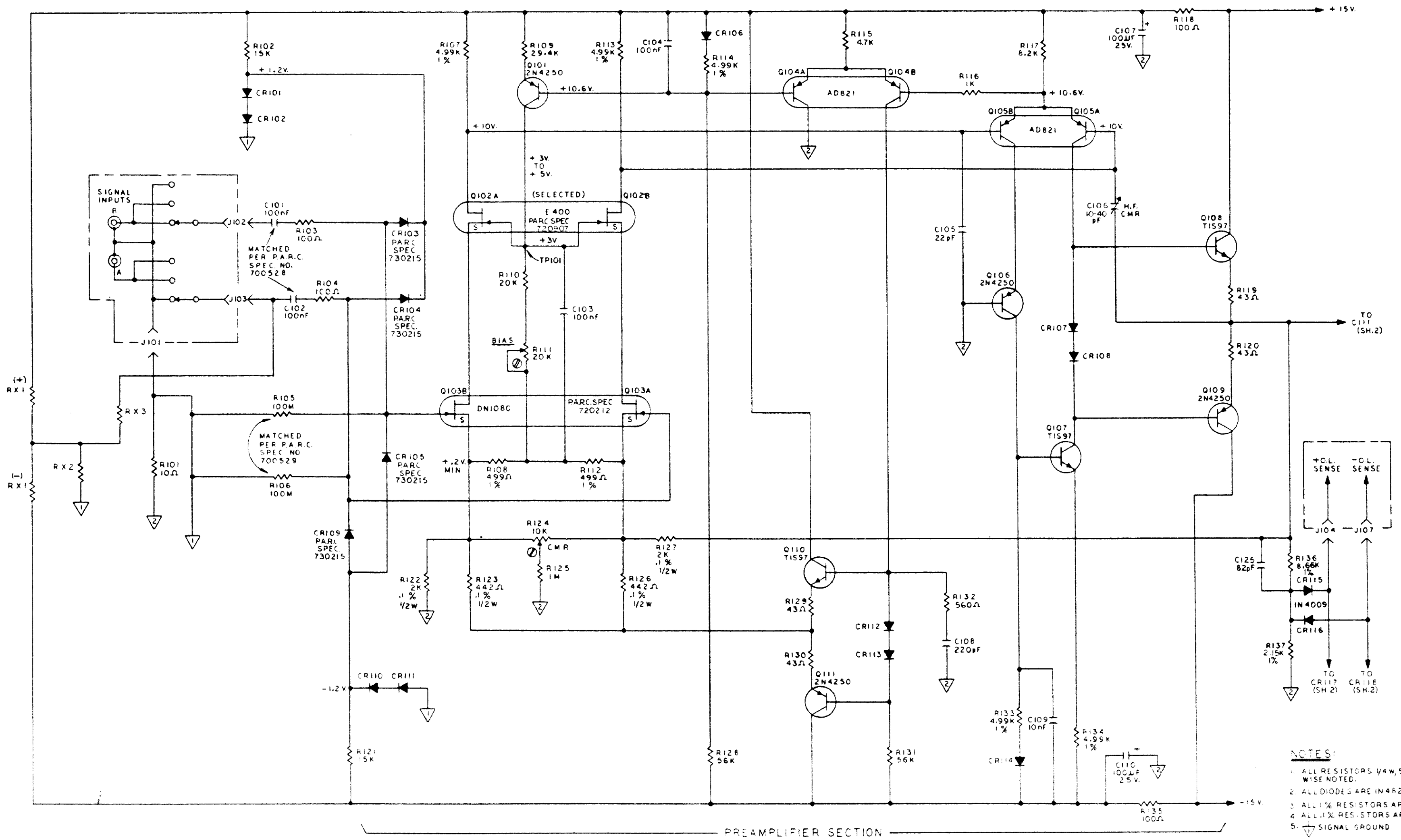


CHASSIS WIRING DIAGRAM

SECTION VII
SCHEMATICS



SYMBOLIZATION
MODEL 128A, 129A,
SIGNAL AMP. BD.
FAB. # 7484-C



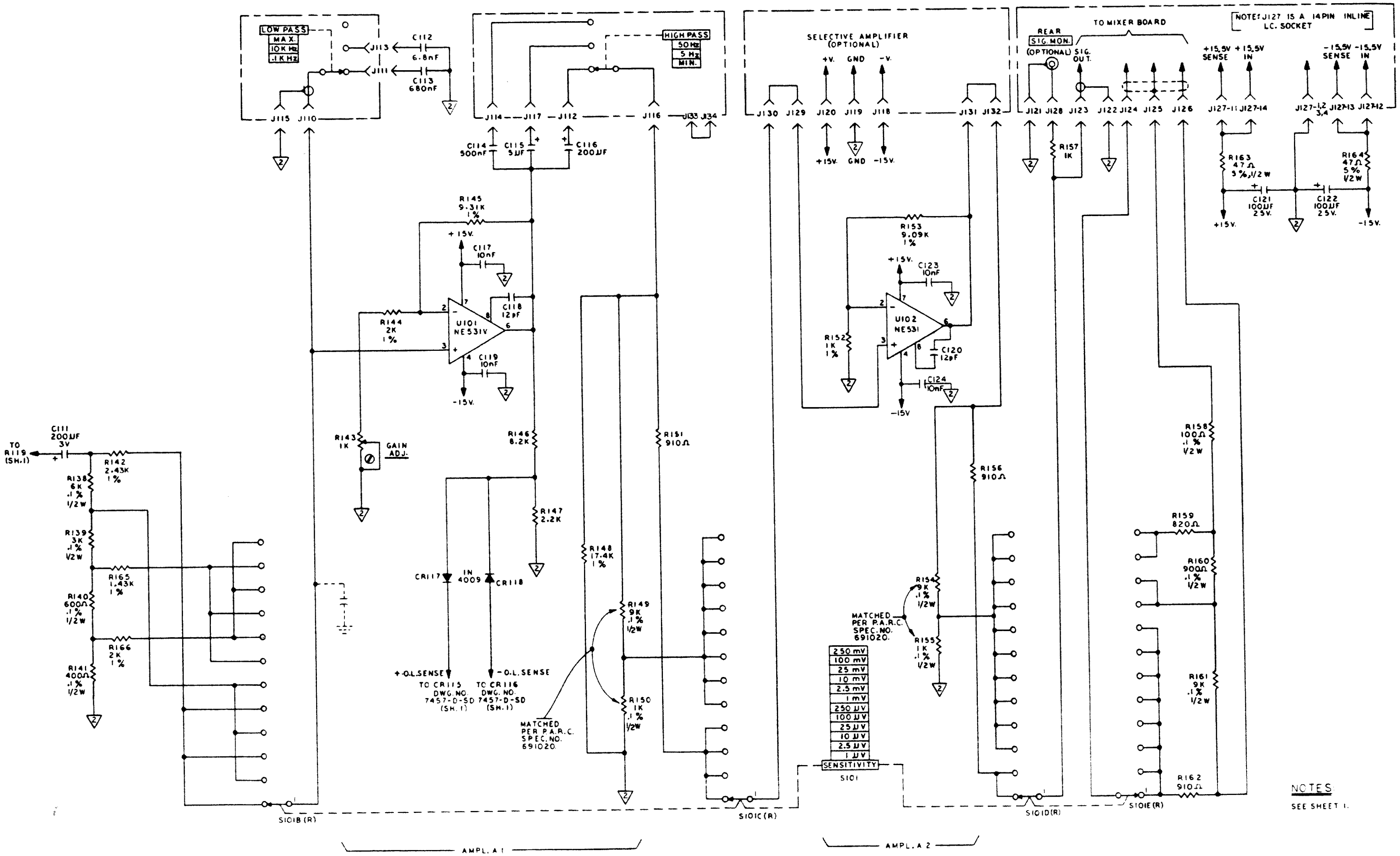
SIGNAL AMPLIFIER BOARD
1281-18-0008S(PARTIAL)

MODEL 128A

NOTES:

1. ALL RESISTORS 1/4W, 5%, COMPOSITION UNLESS OTHERWISE NOTED.
2. ALL DIODES ARE IN4828 UNLESS OTHERWISE NOTED.
3. ALL 1% RESISTORS ARE 1/8W METAL FILM.
4. ALL .1% RESISTORS ARE 1/2W METAL FILM.
5. (1) SIGNAL GROUND. (2) GROUND PLANE.

SHEET 1 OF 2 | 7457 | D | SD | D

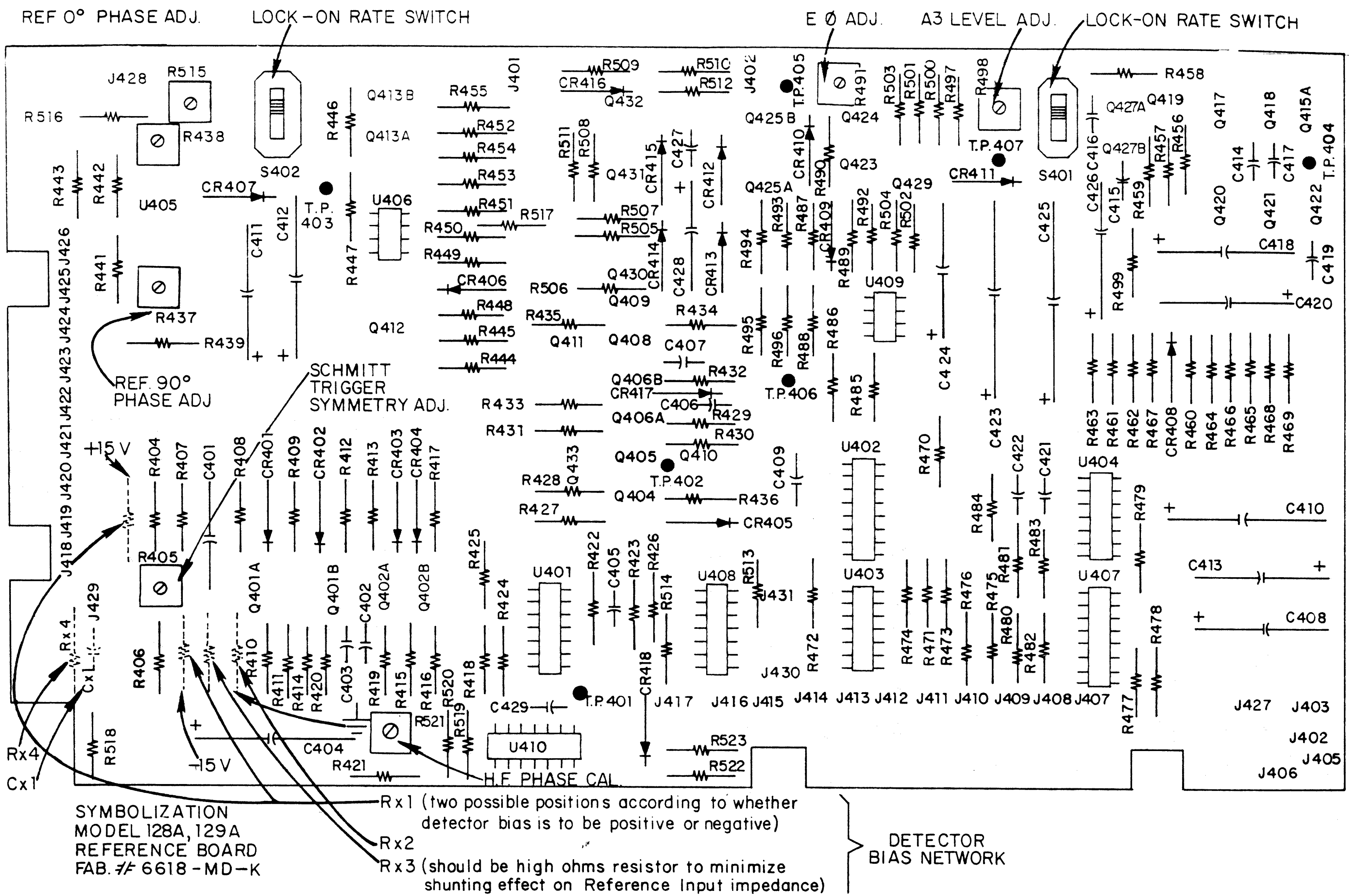


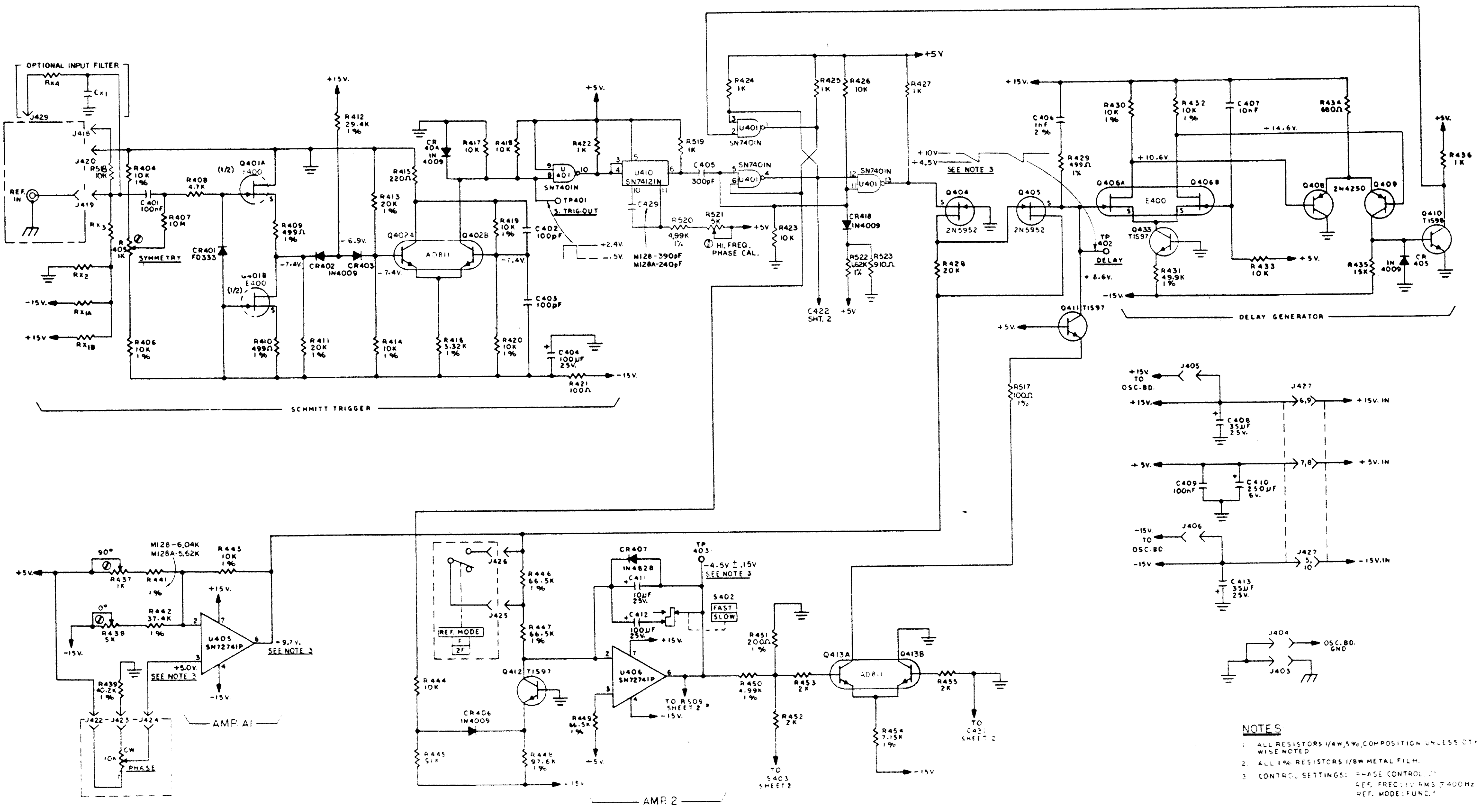
NOTES
SEE SHEET 1.

SIGNAL AMPLIFIER BOARD
1281-18-0008S (PARTIAL)

MODEL 128A

SHEET 2 OF 2 | 7457 | D | SL..


REF 0° PHASE ADJ.
LOCK-ON RATE SWITCH
E Ø ADJ.
A3 LEVEL ADJ.
LOCK-ON RATE SWITCH
REF. 90° PHASE ADJ
SCHMITT TRIGGER SYMMETRY ADJ.
H.F. PHASE CAL.
+15 V
-15 V
Rx1 (two possible positions according to whether detector bias is to be positive or negative)
Rx2
Rx3 (should be high ohms resistor to minimize shunting effect on Reference Input impedance)
Rx4
Cx1
DETECTOR BIAS NETWORK
SYMBOLIZATION
MODEL 128A, 129A
REFERENCE BOARD
FAB. # 6618-MD-K

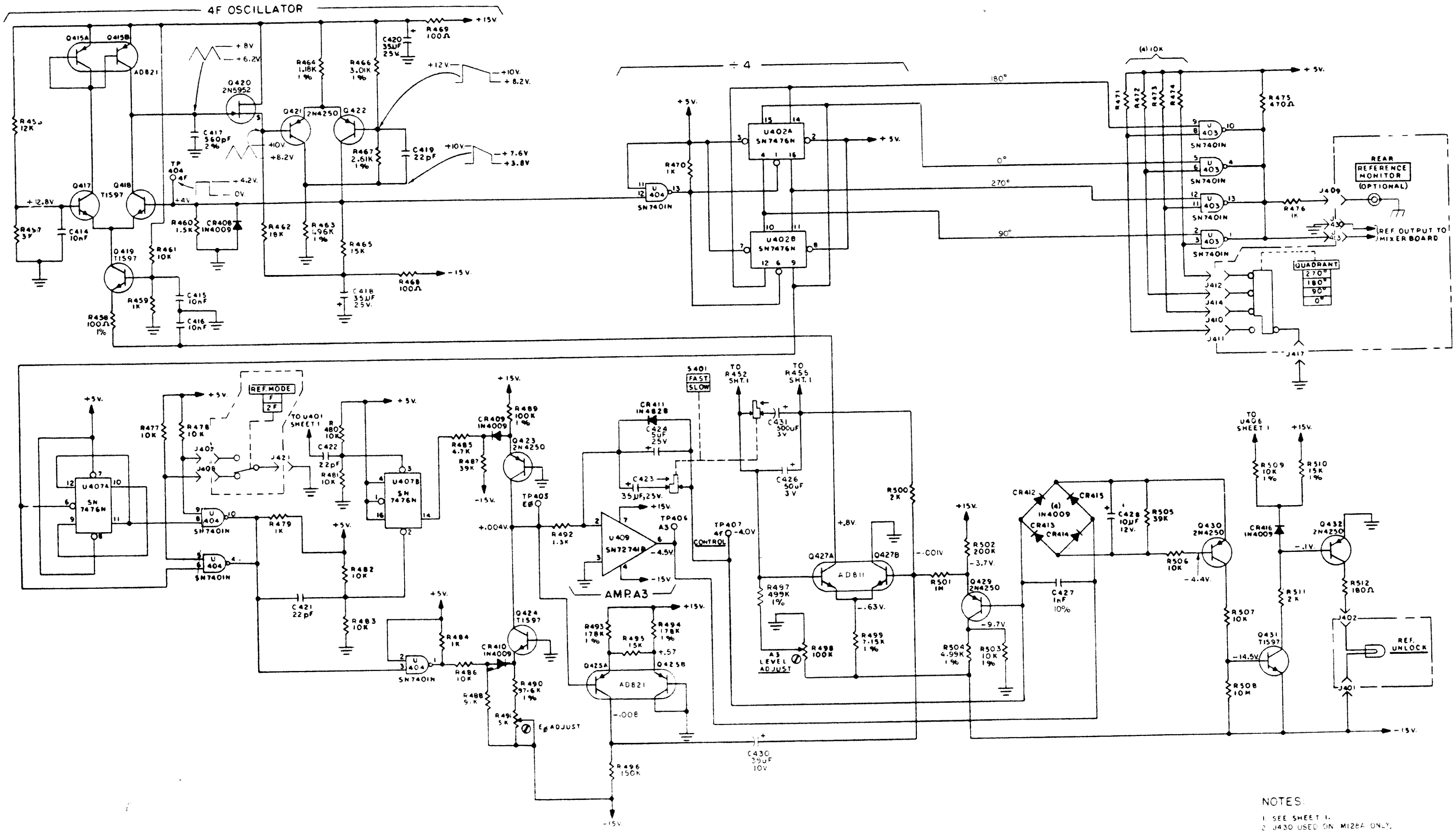


NOTES:
1. ALL RESISTORS 1/4W, 5%, COMPOSITION UNLESS OTHERWISE NOTED
2. ALL 1% RESISTORS 1/8W METAL FILM.
3. CONTROL SETTINGS: PHASE CONTROL: [illegible]
REF. FREQ: 1V RMS, 400Hz
REF. MODE: FUNC.

REFERENCE BOARD SUB ASSEMBLY 1281-19-0007S (PARTIAL)

MODEL 128 & 128A

SHEET 1 OF 2 | 6622 | D | SD | L

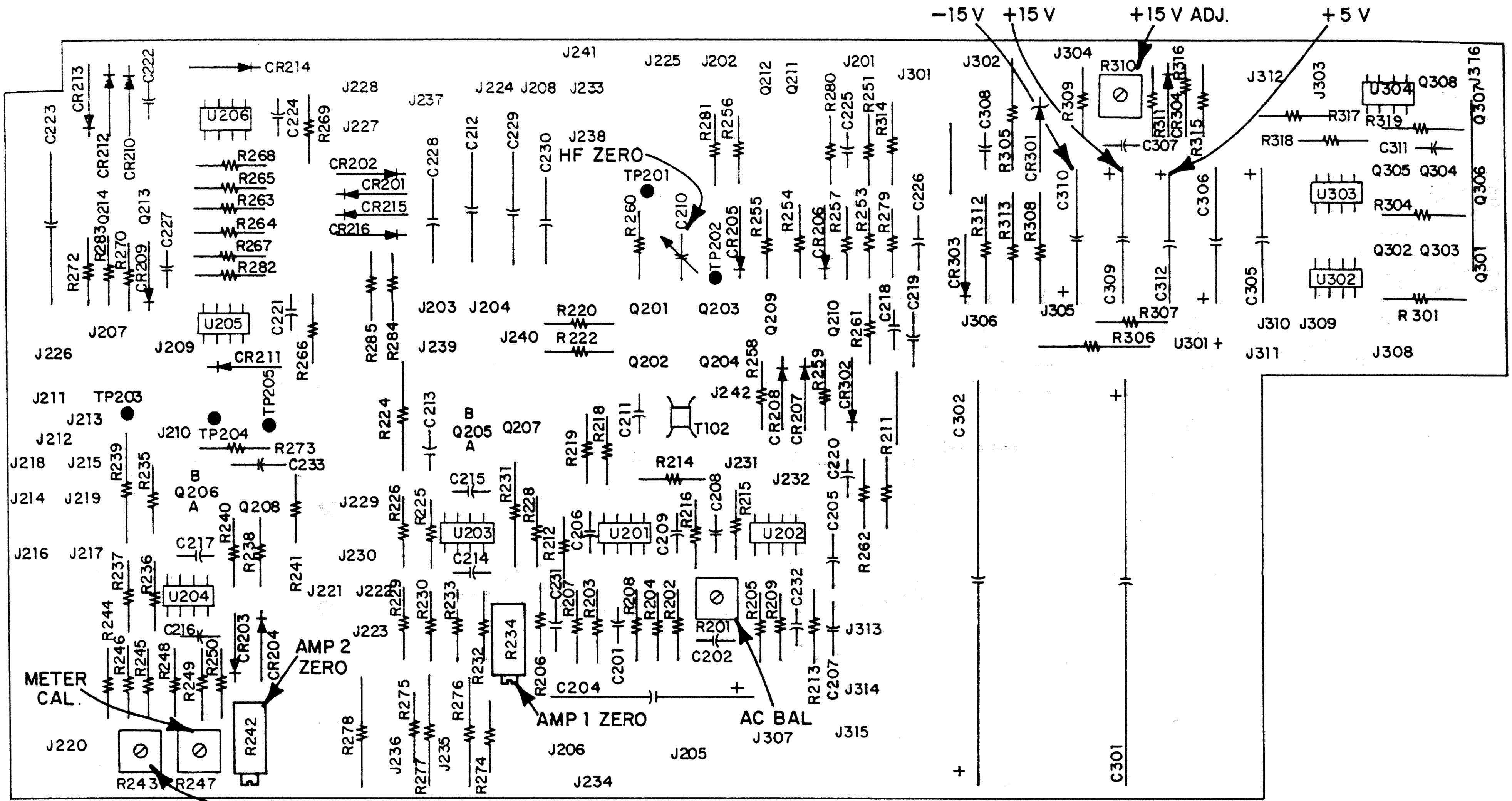


NOTES:
1. SEE SHEET 1.
2. J430 USED ON M128A ONLY.

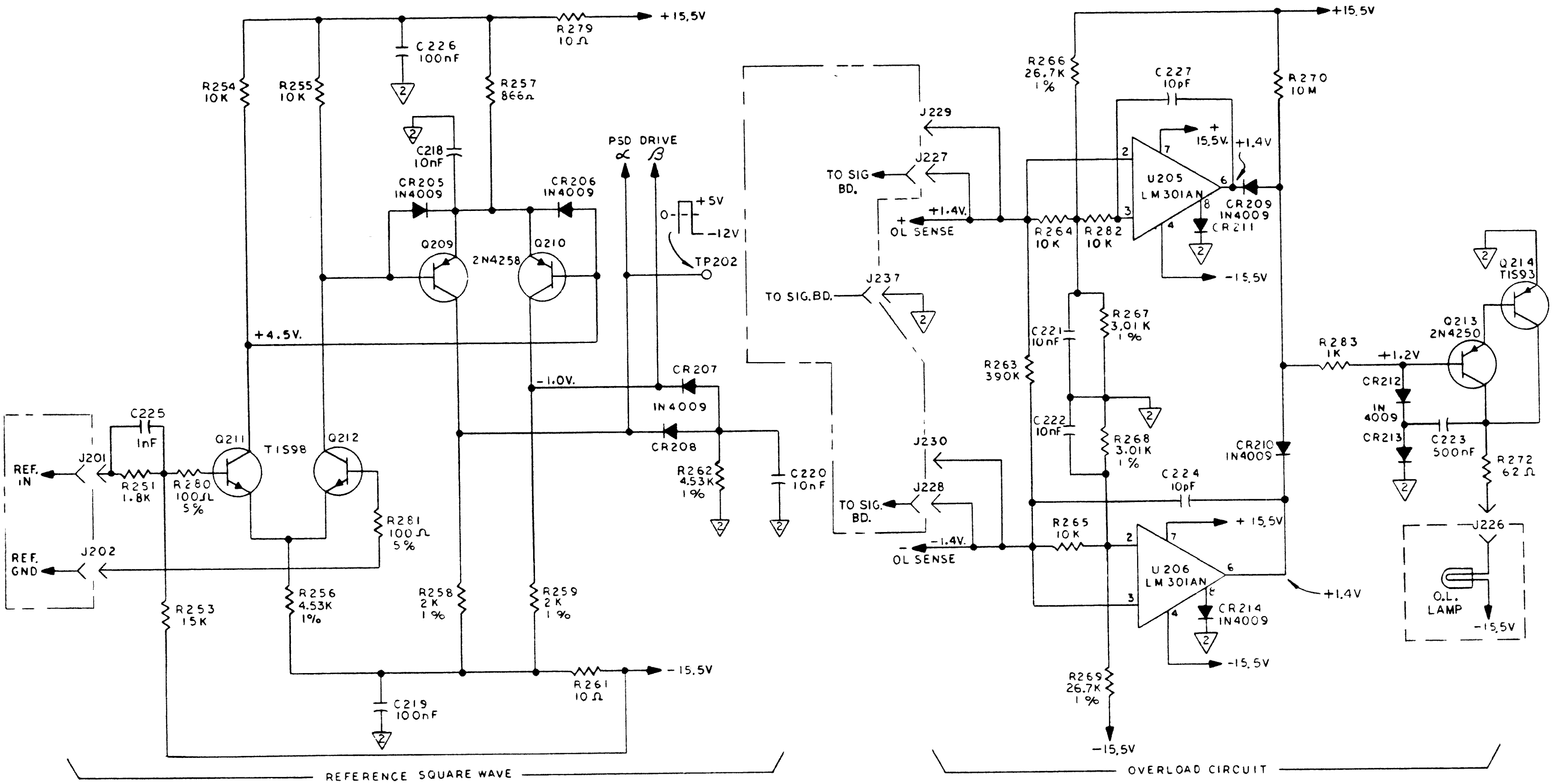
REFERENCE BOARD SUB ASSEMBLY 1281-19-0007S (PARTIAL)

MODEL 128 & 128A

SHT 2 OF 2 | 6622 | D | SD | SH



SYMBOLIZATION
MODEL 128A, 129A
MIXER POWER SUPPLY BOARD
FAB# 7487-MD-A



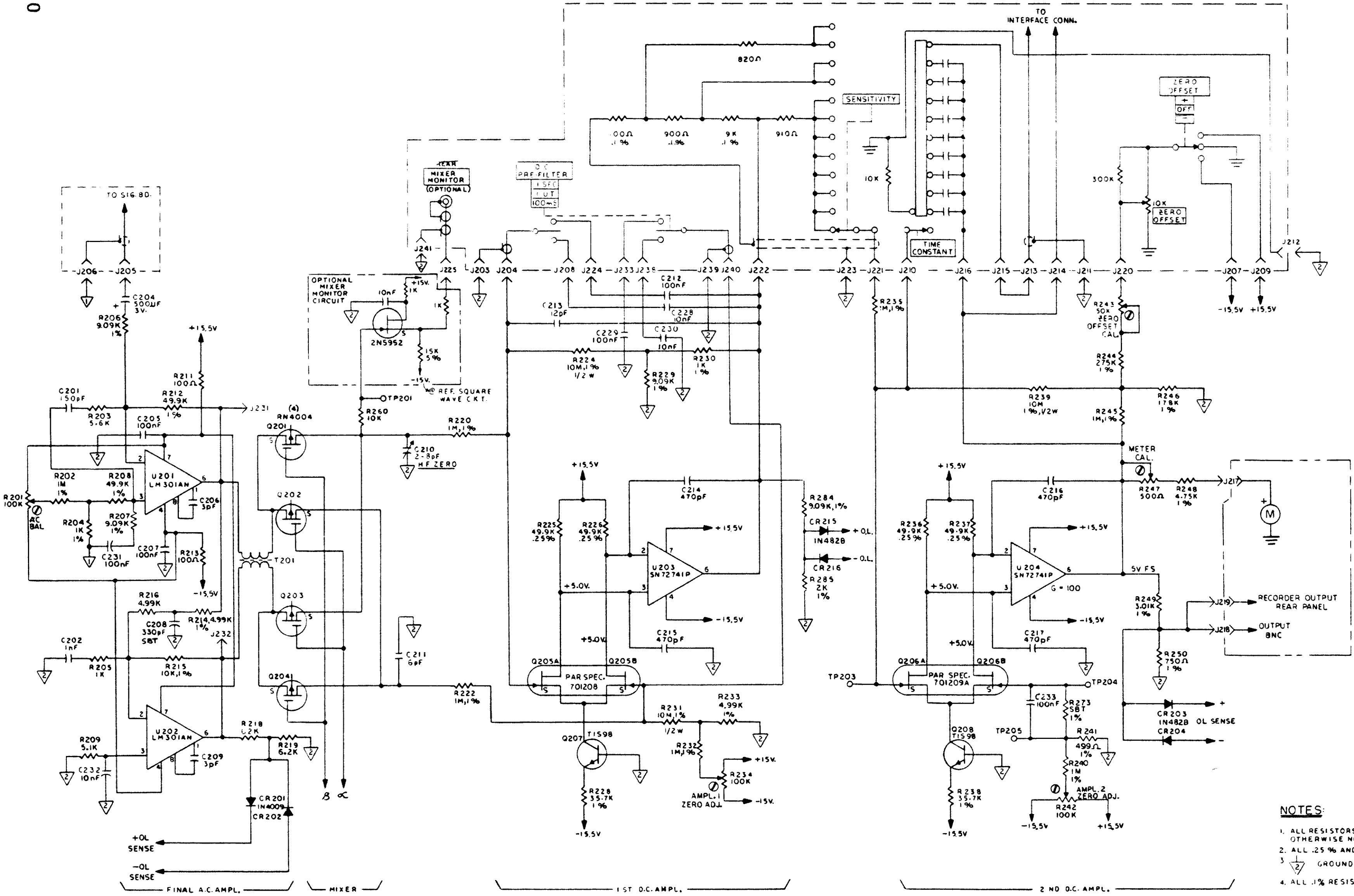
NOTES:

1. SEE SHEET 2 OF 3.

MIXER - POWER SUPPLY BD. MODEL 128A

SUB ASSY 1281-17-0009 (PARTIAL)

SHEET 1 OF 3 | 7444 | C | SD | C



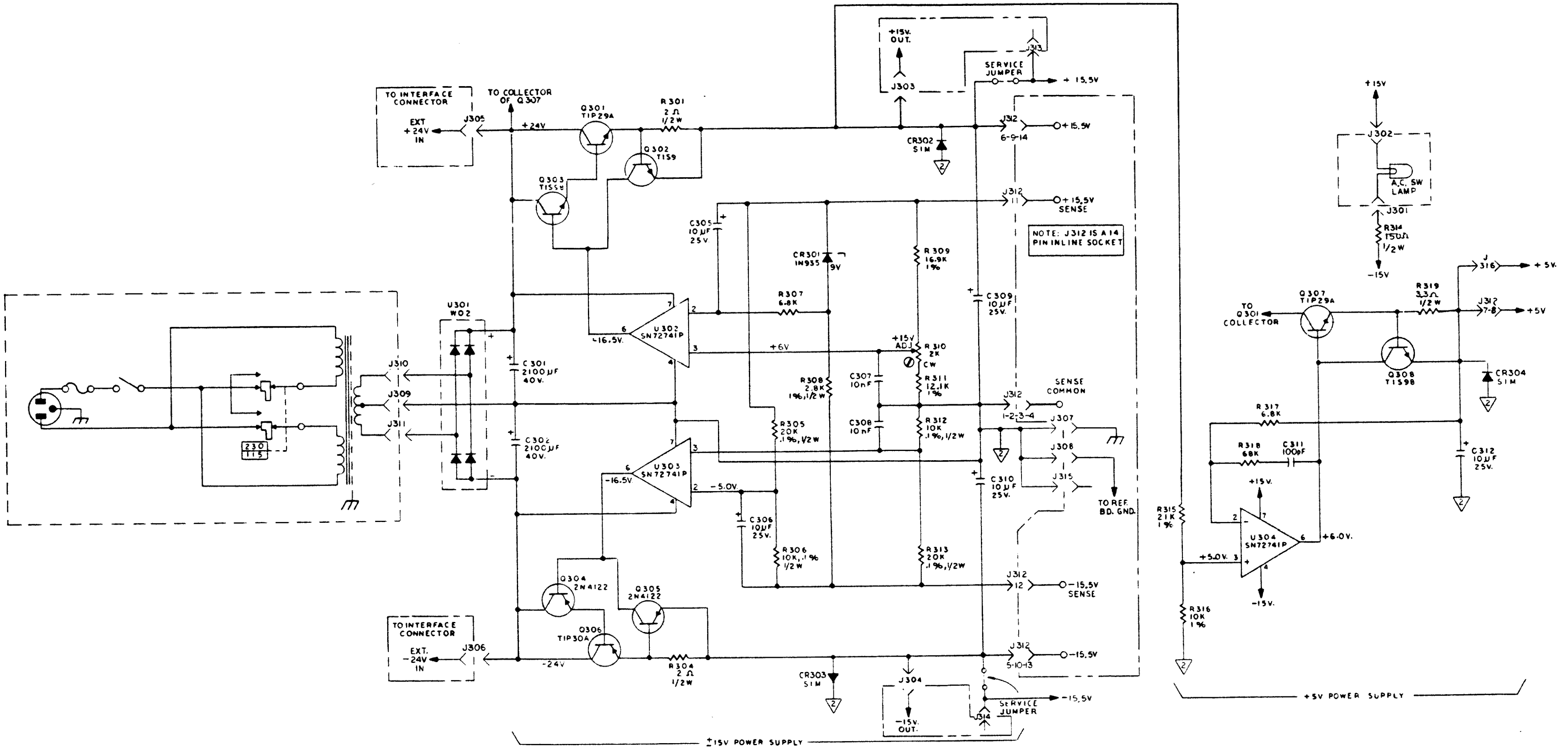
MIXER POWER SUPPLY BOARD
SUB ASSY 1281-17-0009s (PARTIAL)

MODEL 128A

NOTES:

1. ALL RESISTORS 1/4W, 5% COMPOSITION UNLESS OTHERWISE NOTED.
2. ALL .25% AND 1% RESISTORS 1/8W, METAL FILM.
3. GROUND PLANE. SIGNAL GROUND.
4. ALL .1% RESISTORS ARE 1/2 W METAL FILM.

SHEET 2 OF 3 | 7444 | D | SD



MIXER-POWER SUPPLY SC.

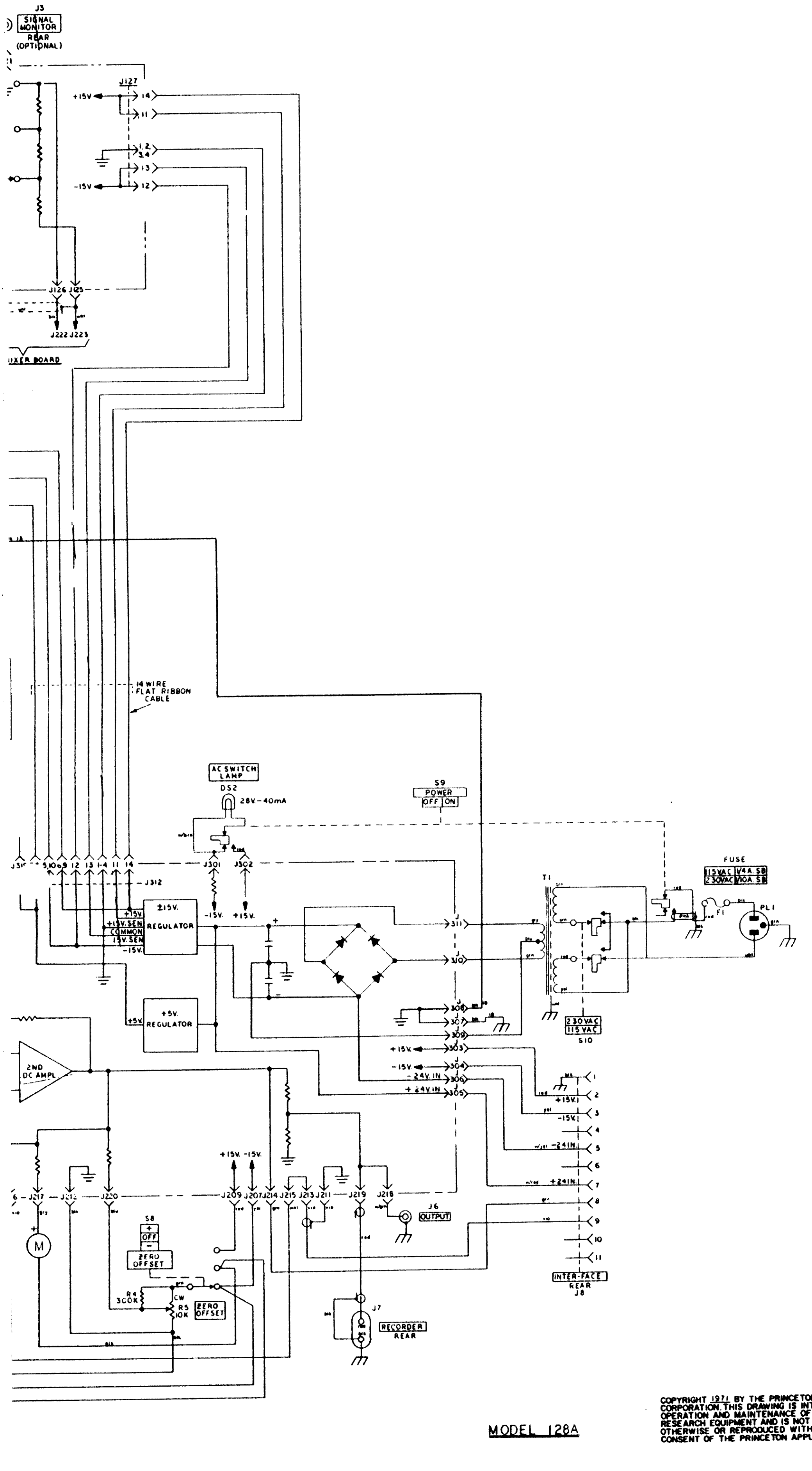
SUB ASSY 1281-17-0009s (PARTIAL)

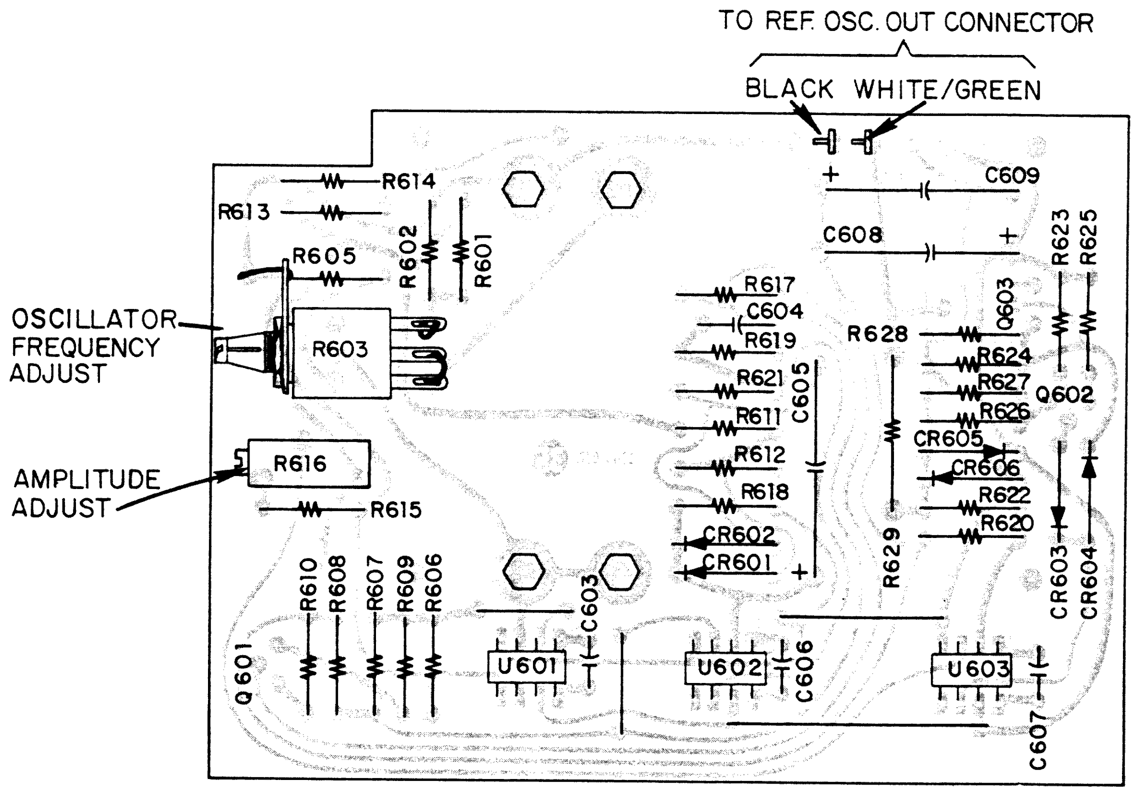
MODEL 128A

NOTES:

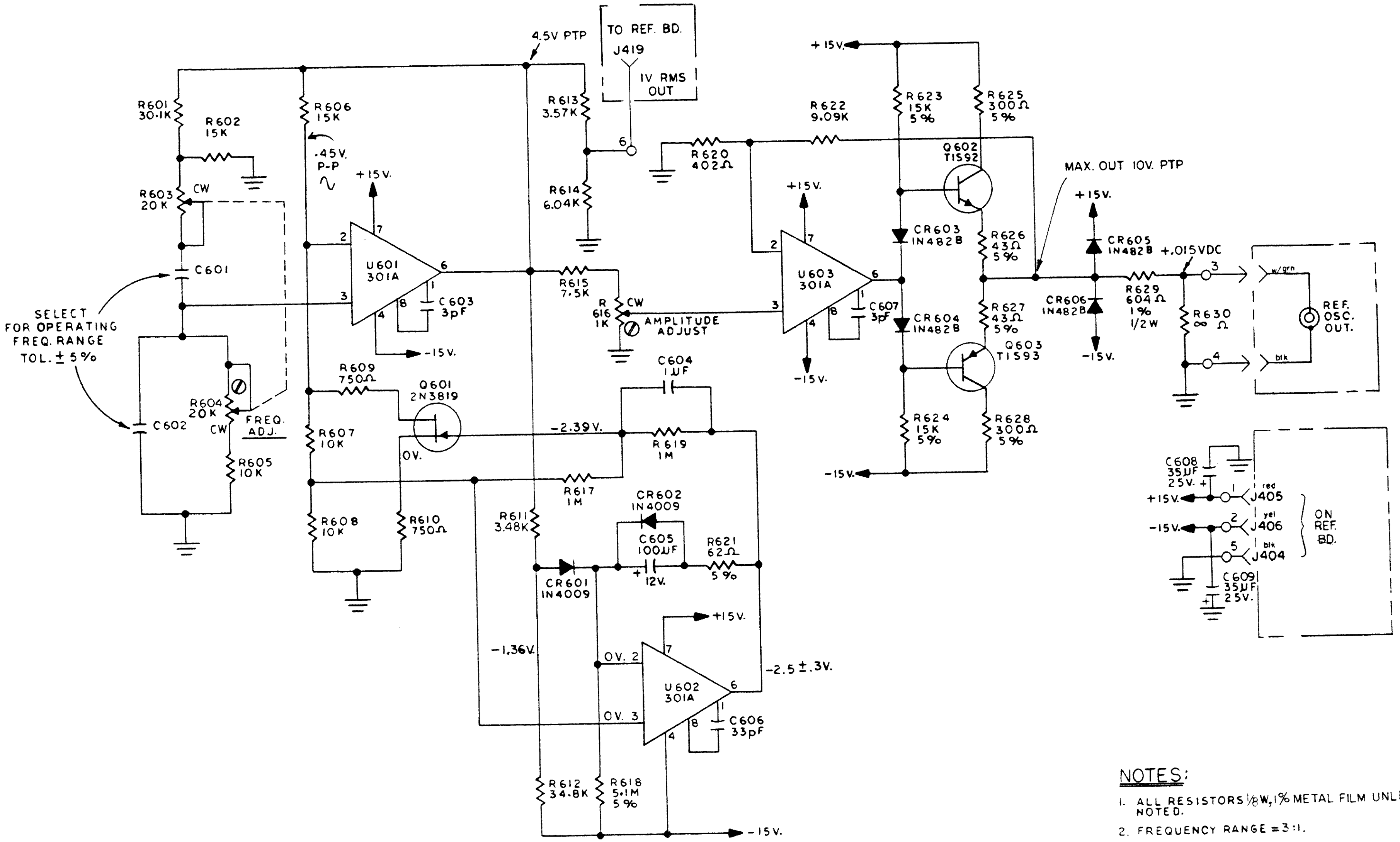
1. ALL RESISTORS 1/4W, 5%, COMPOSITION UNLESS OTHERWISE NOTED.
2. ALL .1% RESISTORS 1/2W METAL FILM.
3. ALL 1% RESISTORS 1/8W METAL FILM.
4. ▽ = GROUND PLANE

SHT 3 OF 3 | 7444 | D | SD


J3
SIGNAL MONITOR
REAR (OPTIONAL)
J127
+15V
-15V
J126 J125
J222 J223
MIXER BOARD
14 WIRE FLAT RIBBON CABLE
AC SWITCH LAMP
DS2
28V.-40mA
S9
POWER
OFF ON
J301 J302
J312
±15V. REGULATOR
+15V.
+15V SEN
COMMON
-15V SEN
-15V.
+5V. REGULATOR
+5V
FUSE
115VAC 1/4A. SB
230VAC 1/10A. SB
F1
PL1
T1
230VAC
115VAC
S10
+15V.
-15V.
-24V. IN
+24V. IN
INTER-FACE REAR
J8
2ND DC AMPL
M
S8
OFF
ZERO OFFSET
R4 300K
CW
R5 10K
J6
OUTPUT
J7
RECORDER REAR



SYMBOLIZATION
MODEL 129A/95 MODIFICATION
INTERNAL OSCILLATOR BOARD
FAB. 6662—MD—B



NOTES:

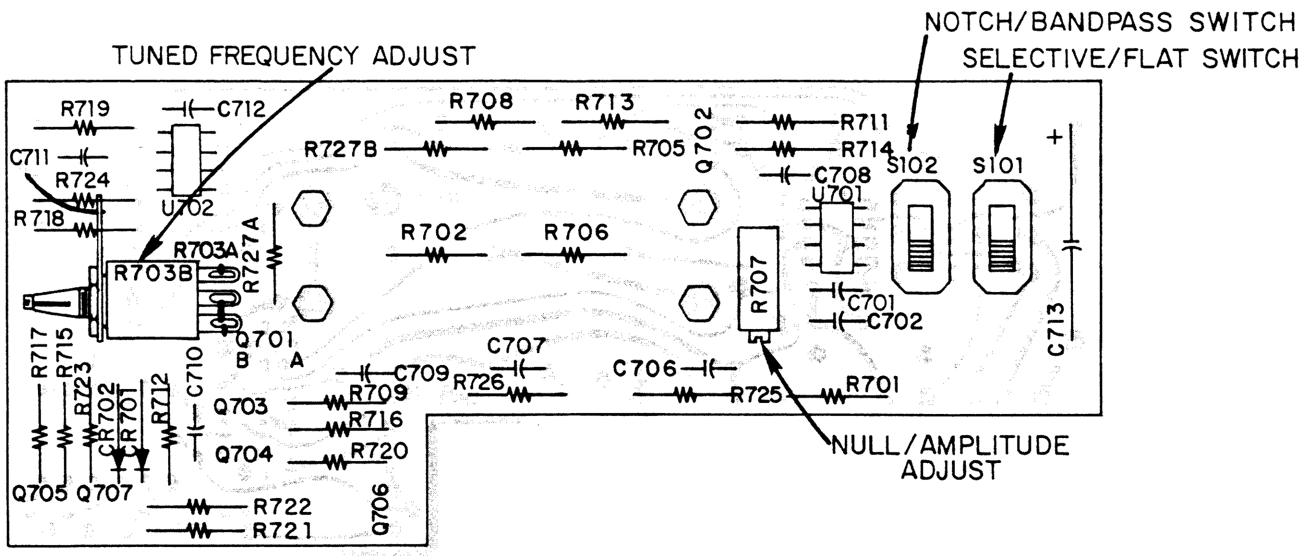
1. ALL RESISTORS 1/8W, 1% METAL FILM UNLESS OTHERWISE NOTED.
2. FREQUENCY RANGE = 3:1.
3. C≅10/f µF.
4. ALL 5% RESISTORS 1/4W CARBON COMPOSITION

INTERNAL OSCILLATOR MODIFICATION

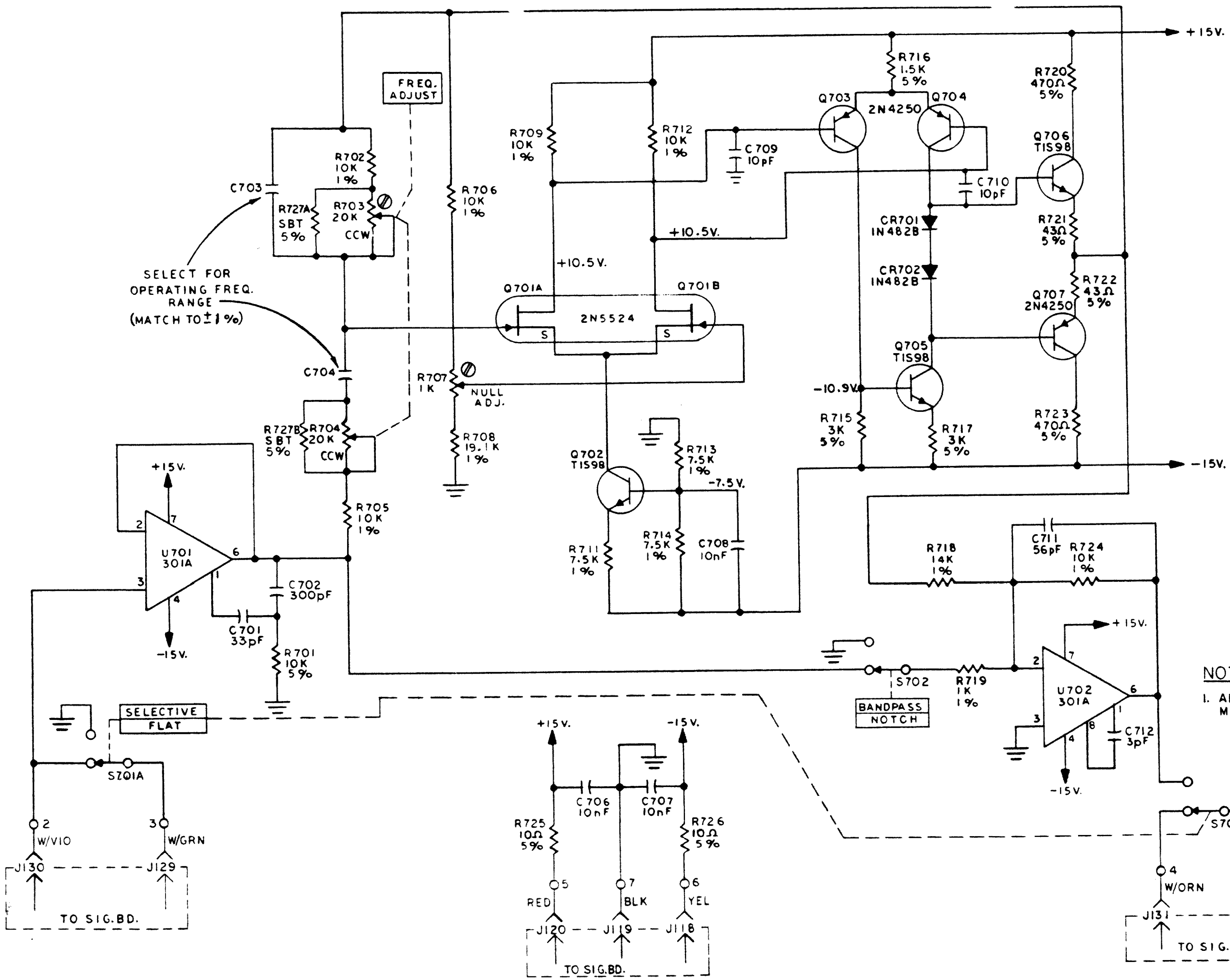
128/99

MODEL 128

6645	C	SD	A



SYMBOLIZATION
MODEL 129A/84
TUNED AMPLIFIER MODIFICATION BOARD
FAB. # 6973-MD-A



NOTES:

1. ALL 1% RESISTORS 1/8W METAL FILM.

TUNED AMPLIFIER MODIFICATION

128/98

MODEL 128

6646	C	SD