

AN SB-220 COMPENDIUM

MODIFICATIONS & UPGRADES

INSTRUCTIONS

SCHEMATICS

PHOTOS

MATERIAL LISTS

SOURCES of SUPPLY

PERFORMANCE MEASUREMENTS



by

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AN SB-220 COMPENDIUM

INTRODUCTION

This Compendium is a collection of upgrades, modifications and performance measurements applicable to the Heathkit SB-220 RF Power Amplifier. These may be of interest to owners and users of this venerable and popular amplifier.

The authors SB-220 amplifier was purchased from the original owner in 1988. The amplifier was complete, unaltered, fully functional and in very nice condition. Through the years 1992 to 1998 extensive work was undertaken to upgrade operational features, replace aging parts and tame parasitic oscillation tendencies. All changes have been implemented by the author and have been in service for over 10 years. No failures or performance issues have arisen.

Part 1 – UPGRADES and MODIFICATIONS

This part of the document provides a number of upgrades and modifications commonly published, plus some by the author not seen elsewhere.

CREDITS

Allen Harbach WA4DRU of Harbach Electronics <http://www.harbachelectronics.com/> offers kits which come with complete installation instructions. The kits as listed are current whereas the kits used in this amplifier were purchased over 10 years ago. There are likely some differences and probable improvements but functionality is expected to be the same.

Richard Measures AG6K <http://www.somis.org/> provides a wealth of information on most aspects of RF power amplifier operations, modifications and upgrades. AG6K provides information rather than kits in general although many parts are available on his web site.

A special mention of a very nice publication called “Heathkit Upgrades for the Linear Amplifier Model SB-220” by Anton Suarez antonsuarez@free.fr came to my attention after this work was essentially completed.



There are common modifications in both independent works, but there are also unique modifications which expands the scope of the possible re-work that can be done. The manual has been posted on eBay, for about \$10 from time to time. Search under “HEATHKIT SB-220 Amplifier Upgrades”. The seller ID is “tito_de_taboada”

Part 2 – PERFORMANCE MEASUREMENTS

This part of the document provides performance data as measured on this amplifier. RF carrier power output, PEP measurements, as well as spectral harmonic and two tone tests and a unique noise loading test are presented.

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PART 1 - UPGRADES and MODIFICATIONS

1.1 SKILLS and SAFETY NOTES

The modifications listed herein will variously require removal of covers, side panels, the faceplate and disassembly of mechanical parts. There will be reworking of electrical circuits, drilling of holes for new mounting screws in the chassis, and re-dressing of wiring. Some modifications are more complicated than others. In all instances, you should be experienced and comfortable with bench work, have tools for drilling, cutting, filing, soldering etc, possess good workmanship skills, and be able to read schematic diagrams. Note that the QSK section requires some scratch building experience. Use a DVM to check wiring for shorts, opens, continuity, correct resistances, and voltages under powered up conditions. Do NOT try to directly measure the 3.5 kV High Voltage with your DVM. The author does not provide step x step instructions for the mod's and rebuilds herein. Portions of the original Heathkit schematic are presented in black with the modifications indicated in RED.

FIRST and ALWAYS - UNPLUG the 120/240 VAC LINE

Then remove other cables

LAST - Remove the Green Wire Safety Ground from the Chassis Ground bolt.

The amplifier is heavy. Removal of case can be simplified by cutting a 5" long block off a wooden 2 x 6, place and holding it on the rear panel at the back of the power transformer, tip the amp up on end, on the block, until it is upright. The amp will balance on the block because of the heavy power transformer and the connectors on the back will be clear of the bench surface.

Remove the four feet, but before removing the last foot, prevent the cabinet from sliding down off the chassis on to the bench – it may be difficult to lift the cabinet back up and off as the cabinet tends to snag on the chassis. Place a 2" x 2" wooden block on the bench under the edge of the case. Remove the last foot and lift the cabinet straight up off the chassis. The chassis can then be tilted back down to the horizontal for work. Reverse the process for re-installing.

Before proceeding with any modifications, be advised to remove the 3-500Z's from their sockets using a clean cloth to keep finger oils and other contaminants from being deposited on the glass bulb. Then wrap each tube in a protective cloth (towel) and put somewhere out of harms way. The glass bulbs need to be squeaky clean on reinstallation.

Do not leave clippings, drill debris or any other conductive material loose inside the amp. Take care that there is no possibility of short circuits developing between components or circuit boards to chassis or to each other. Ensure that the integrity of wiring insulation and coaxial cable dielectrics are maintained.

There is a High Voltage (HV) safety shorting "switch" in the tube compartment. Do not power up amp with RF compartment screen off as the HV will be shorted to ground. If you defeat this switch when servicing, understand the peril to which you expose yourself should you contact the HV.

**LEATHAL AC and DC VOLTAGES EXIST
USE EXTREME CARE**

Disclaimer

Author only provides best of knowledge information only.

Author makes no warranties or guarantees regarding these modifications.

Author is not liable for costs, loss, damage or injuries due to undertaking such work.

This work should only be done by those who are competent to do so.

High voltages exist and troubleshooting is dangerous.

Check your work before powering up.

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1.2 A QUICK OVERVIEW

Figure 1 gives a quick insight as to the nature and extent of the under-chassis changes described in this document.

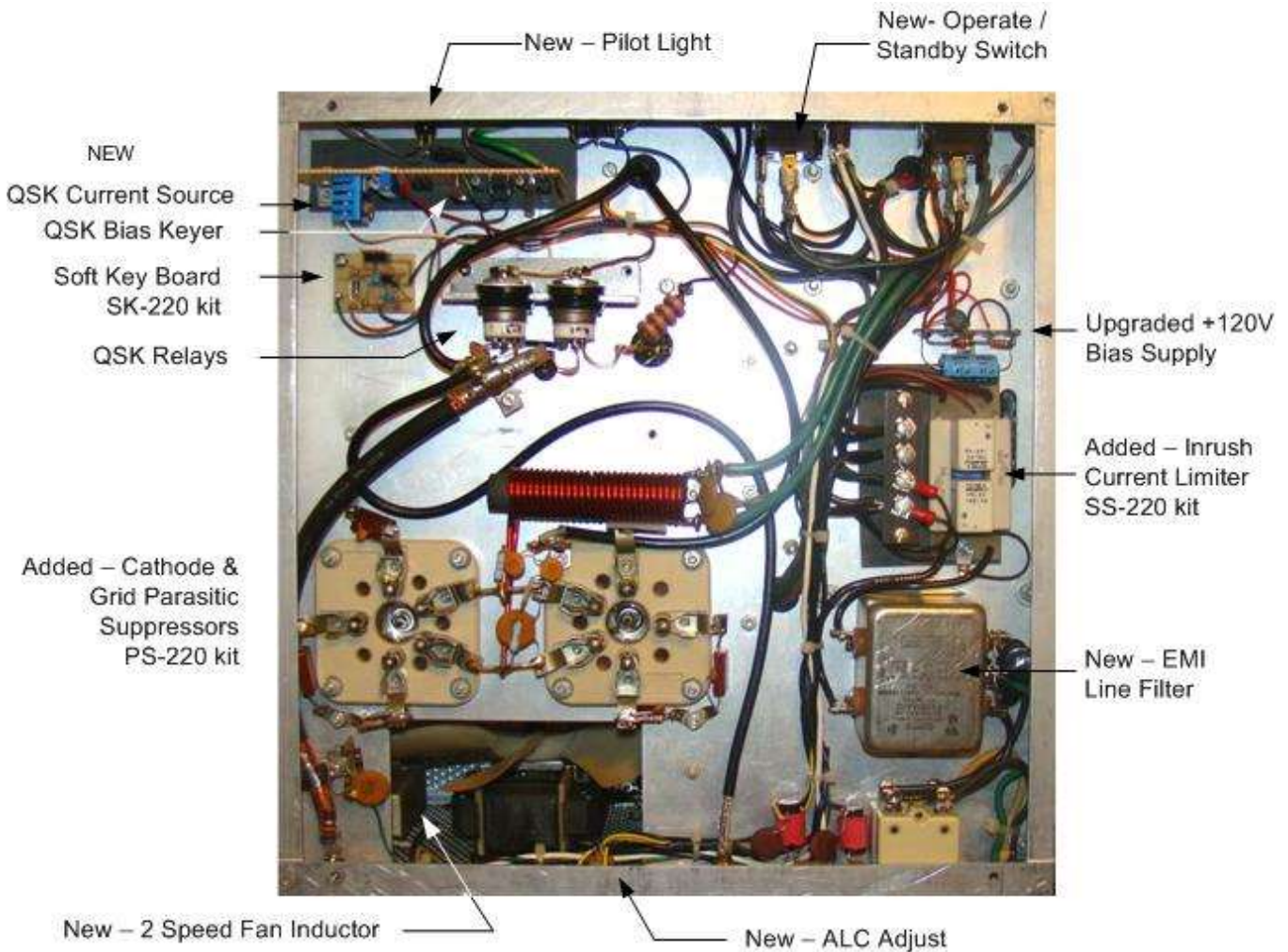


Figure 1.1
UNDER CHASSIS VIEW of UPGRADES and MODIFICATIONS

1.3 PARTS NOTES

A list of materials is provided mostly using Digikey <http://ca.digikey.com/> part numbers. All parts are stock items at the time of writing. Digikey is recommended due to the extensive and diverse stock available and quick, typically overnight shipping by courier.

If parts are not available from Digikey, alternate sources of supply are provided.

Parts used were selected over 10 years ago. Many are still the same with some being slightly different. Form, Fit and Function for current parts are specified to the same requirements.

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1.4 THE PARASITIC SUPPRESSOR KIT

It is a common belief that the SB-220 is vulnerable to uncontrolled high power VHF parasitic oscillations that may occur when the amp is keyed into transmit. Instantaneous destruction of certain components in the cathode circuits follows. The author has experienced this failure mode and application of available VHF Parasitic kits has remedied this problem. Whether it is an oscillation or not is not altogether clear and there is differing opinion as to the actual cause. AG6K supports the VHF position whereas W8JI has differing thoughts on the subject, <http://www.w8ji.com/Amplifiers.htm> . Many other interesting topics are discussed.

The cause will not be debated here but the effect of the failure is not subtle – a loud bang, possibly some smoke, and an amplifier that may have too high an idle current or none at all. The components prone to failure are ZD-1, a 5.1V stud mount zener and R3, 0.82 ohm / 2 W resistor on the rectifier board. They usually blow open circuit but may also short. The stud mount zener is expensive and is most often replaced with a series string of rectifier diodes (Section 1.6 and 1.14, pg 19).

Part	Digikey p/n	Approx Cost
5.1V Zener 1N3996A, (obsolete) 10 watt, 5%, DO-4 case, cathode to stud	None listed	-
	NTE-5177AK *	\$14+
0.82 ohm / 2 W resistor	P0.82W-2BK-ND	0.39
Rectifier Diode, 1N5408G (3A /1000V), qty 8	1N5408GOS-ND	0.60 each

* NTE supplies replacement parts to distributors for obsolete components. Newark Canada, <http://canada.newark.com/> can supply the NTE part under their own part number 29C4650.

The Harbach PS-220 kit is shown below. The plate circuit discrete resistor / coil suppressors are shown going to each plate cap from the plate choke and to the TUNE cap is another L and R suppressor although the R in this case it is a Nichrome (resistance) wire.

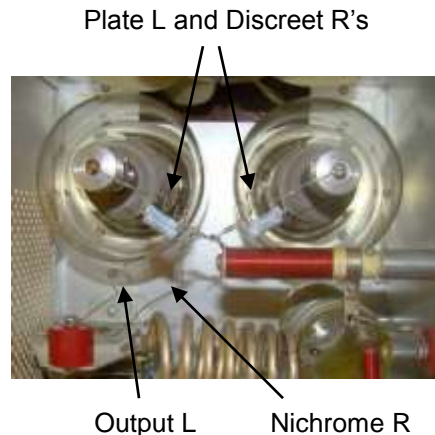


Figure 1.2
PS-220 Parasitic Suppressor Kit – Plate Circuits

Additional suppression components are installed on the tube sockets under the chassis as shown in Figure 1.3. These consist of various R's and C's in the grid and cathode circuits. Note that W8JI and others recommend DIRECT grounding of the grid to chassis using short, wide, multiple copper straps to chassis rather than installing R's and C's.

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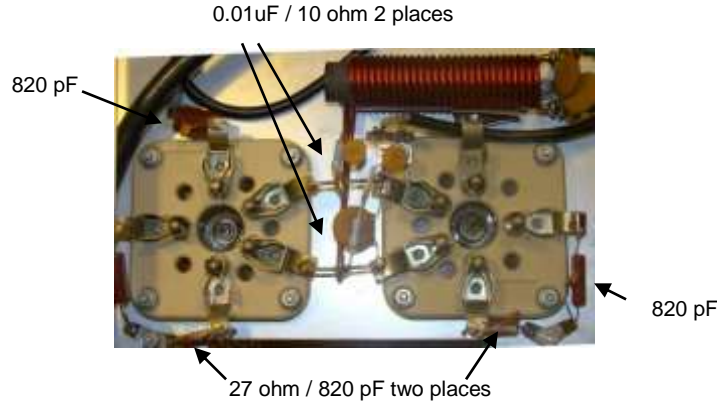


Figure 1.3
PS-220 Parasitic Suppression – Grid- Cathode Circuits

Both kits from Harbach and AG6K have been installed in other SB-220 amplifiers. They are somewhat different from each other but both are supplied with excellent instructions and both have worked reliably.

1.5 HV FILTER CAPACITOR KIT

The SB-220 amplifiers were sold between 1970 and 1978. The follow-on SB-221 was sold between 1978 and 1983. If you are still using the original filter caps it is time for a change before they fail. These caps have a “ripple” current flowing through them as a result of rectification which results in internal heating due to their ESR (Equivalent Series Resistance). External heating is also prevalent in this closed space. Heat is very detrimental to the longevity of components in general and particularly electrolytic caps. They slowly loose capacitance with increasing ESR and may eventually rupture due to heating, possibly explosively. Expected life time of caps of this vintage is in the order of ~ 25 years.

Harbach supplies a complete kit of properly sized capacitors and voltage equalizing - bleeder resistors. AG6K also offers replacement capacitors and resistors as individual components. Be certain the capacitors ordered for the SB-220 amp will fit the Heathkit capacitor “block”.

This mod is requires delving into the power supply – band switch compartment. Good idea to do both capacitors and rectifiers, next section, at the same time if never replaced.

1.6 RECTIFIER – METERING BOARD KIT

Harbach offers the RM-220 kit, an improved PWB metering board with protective diodes for the meters, modern low leakage rectifier diodes, new HV resistors and a diode bias string to replace the 5.1V Zener diode. AG6K also offers components.



Figure 1.4
RM-220 Rectifier and Metering Board Upgrade

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1.7 INRUSH CURRENT LIMITER

The SS-220 kit offered by Harbach limits the inrush current to the filaments of the 3-500Z's. The tubes are rated ~ 15 amps at 5.0 volts each ($R = 0.33$ ohms) when hot. Total current is twice that as there are two tubes. The cold resistance is lower than the hot resistance. On power-up, there is some concern that a high inrush current may shorten the life of the tubes or damage them. AG6K reports that the Heathkit filament transformer T2 has an inherent current limiting capability which limits inrush current and so the usefulness of this modification is debatable. Regardless, the limiter was installed to reduce the stress on components throughout the power system circuits. AG6K also suggests a circuit for reducing inrush current.



Figure 1.5
SS-220 Inrush Current Limiter

The SS-220 kit is mounted close by the input 120 / 240 VAC terminal board. The board is shown strapped for 240 VAC operation with terminal 2 and 3 connected. The two red insulated leads are across the 120 VAC portion of the circuit to the Hour Meter module, Section 1.9.

Ensure the PWB is well insulated from chassis; use tape or insulating paper. Mounting hole drilling of the chassis required to mount the PWB.

1.8 AC EMI LINE FILTER

Overview

There is no effective RF AC line filtering on the SB-220. RF fields and currents inside the chassis can couple to the AC wiring and can be conducted out on to the AC power circuits where the RF can radiate or be conducted elsewhere to cause RF problems within the shack or the household.



Figure 1.6
Curtis RF Line Filter

It would seem prudent to install readily available RF filters in the amplifier to ensure that the AC power systems are eliminated as a source of RFI. A Curtis brand filter rated at 20A / 220 VAC, model number F1700AA20 was used at the time.

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As an additional note, all other leads external to the amplifier ought to be of high quality shielded wire; flexible coax such as RG-58 works well. Bypassing them at the amp apron is a good idea. Refer to section 1.9 following.

Common Mode attenuation is > 30 dB at 1 MHz rising to 40 dB at 30 MHz, and somewhat higher in between these end points. Differential Mode attenuation is 60 dB falling to 55 dB respectively. A better choice would be a (Tyco) TE Connectivity Corcom filter, p/n 20VSB1. Attenuation performance is better than Curtis and about half the price.

Part	Digikey p/n	Approx Cost
Curtis Filter F1700AA	364-1086-ND	\$42
Corcom Filter 20VSB1	CCM9069-ND	\$24

Also installed are Metal Oxide Varistors (MOV's). These devices are surge rated, transient voltage protection devices. They will clamp voltage transients to relatively safe values should they appear on the AC line from external sources. The 240 VAC household branch circuit is not protected / filtered at the wall socket as are the 120 VAC circuits in this shack. The intent is to clamp high voltage AC spikes from over-voltaging components within the amplifier. The packaging is in the form of a ceramic disk and they look like a disc ceramic capacitor, just thicker.

The original MOV's used were type ZNR14K391 where ZNR is an industry recognized prefix for MOV's. The part number deciphers as 14 = diameter of the MOV in mm, and 391 = clamping voltage. Closest equivalent today is the Panasonic ERZV14D431 which is of the same diameter and the clamp voltage is 431volts rather than 390 volts.

Part	Digikey p/n	Approx Cost
Panasonic ERZV14D431	P7267-ND	Qty 3 @ \$1.04 each

Schematic

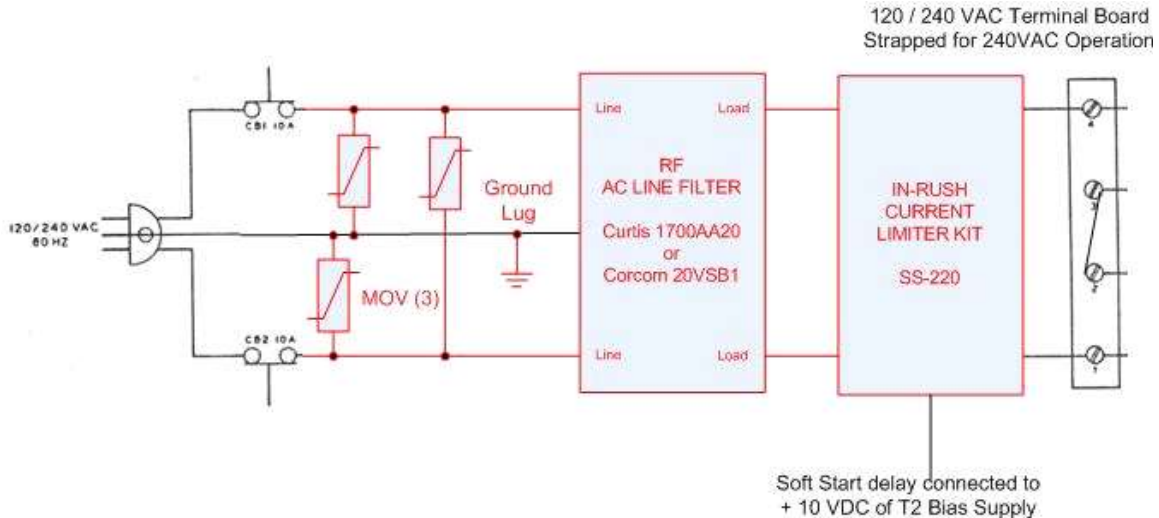


Figure 1.7
Complete Circuit Diagram for MOV, RF Line Filter and Current Limiter

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Installation Photo of Inrush Current Limiter & EMI Filter

The Inrush Current Limiter is on the left and the EMI filter is on the right. Further to the right are the original circuit breakers. The MOV's are on the back of the filter, one just visible as a black object. The three MOV's are mounted on the filter terminals.



Figure 1.8
Inrush Current Limiter & RF Line Filter Installation
Original AC Circuit breakers on right hand side

1.9 HOUR METER

Overview

This device records the hours accumulated on the tube filaments, that is, cumulative time when the amp is powered ON. It is not RF hours which are much less.



Figure 1.9
Curtis LCD Hour Meter

The Hour meter is a Curtis Instruments LCD Hour Meter, Model 701, 3 wire. Hexagonal case code "F". Nominal voltage operation range from 100 to 230 VAC.

Part	Part number	Approx Cost
Curtis 701FR001048150D100230A	DigiKey 267-1004-ND.	\$32
Ferrite Beads, Amidon Assoc. FB-73-801	RPE 73-801	Qty 8 for \$10

Order Ferrite beads direct from Amidon Associates. <https://www.amidoncorp.com/>

Product is also available from RP Electronics in Burnaby. <http://www.rpelectronics.com/>

Beads plus 0.01 uF disk caps to ground make for a reasonable RF filter. The link in Section 1.13 regarding capacitors is a great place to shop for many different capacitor types (mica, disk, poly, electrolytics etc) and values. All new, reasonably priced and some hard to find anywhere else.

The beads were not used to remedy malfunctions due to RF, but were installed as a cautionary measure.

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Schematic

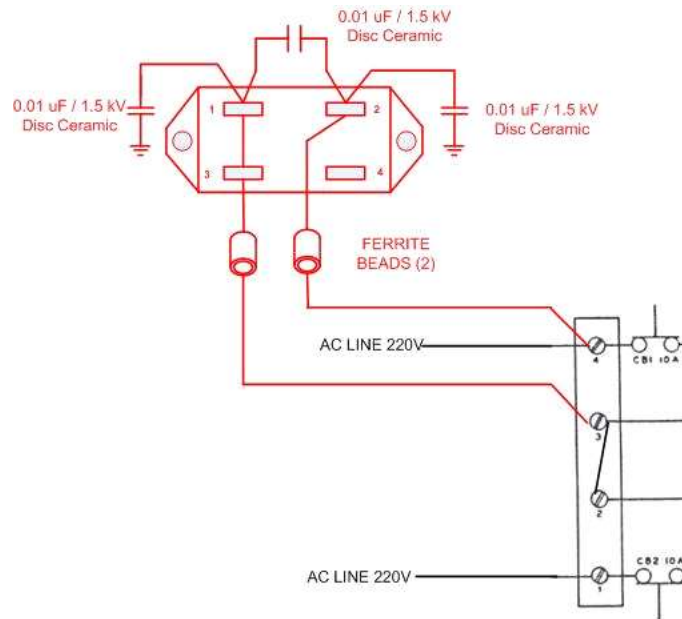


Figure 1.10
Hour Meter Wiring and Bypassing

The wiring is run down through the chassis fan cutout and along underneath the chassis to the input voltage strapping terminal board. Bundle wires with existing filament and power wires for neatness.

Installation Photo

The meter is mounted on rear of amplifier. The screen has to be cut away to fit the body through.



Figure 1.11
Hour Meter Mounted on Rear Panel

1.10 ON / OFF PILOT LIGHT

A green LED lamp is installed on the lower, left hand side of the front panel. The lamp is ON when AC power is ON. It is not a "Transmit On" lamp.

Lamp voltage is taken from the filament AC supply, same as the meter pilot lights. The LED is series connected with a 200 ohm resistor with a 1N4005 diode across the LED to ensure that the LED does not breakdown on AC reverse polarity. The resistor limits the LED current. This circuit

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is connected to the “cold” (RF blocked) side of the filament choke. Junk box parts were used to make this LED lamp but if you buy a lamp assembly, a series resistor is usually incorporated in to that assembly. The product listed below operates from 6 VDC which is fine even though the filament supply is approximately 5 VAC. The lower voltage may result in a slightly dimmer LED. The AC reverse diode should still be installed across the LED assembly to protect it. Ensure that the pilot light case is long enough to mount through the thickness of the front panel + the chassis, about 5 mm is required,

Schematic

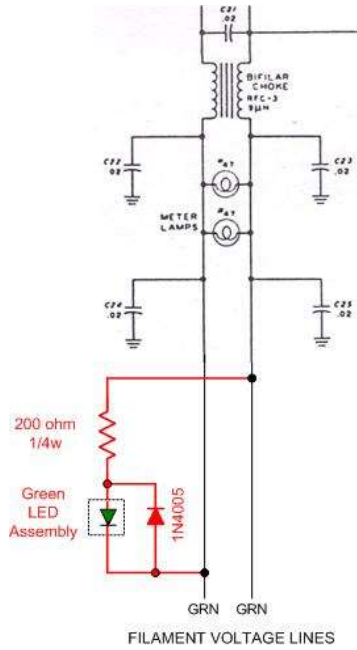


Figure 1.12
LED Pilot Light

DigiKey has a line of Dial Light product under part numbers 350-19XX-ND that appear to have a sufficiently long threaded body (~ 12mm) to pass through the thickness of the faceplate + chassis (~ 5 mm). Look at others in that series for style and color to suit.

Part	Digikey p/n	Approx Cost
Dial Light Green LED / Black Body	350-1908-ND	\$5.27

Installation Photo

Pilot light is mounted on center line of power ON-OFF switch and CW/TUNE SSB switch, and half way between TUNE and LOAD controls



Figure 1.13
Pilot Light Placement

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1.11 ADJUSTABLE ALC

The ALC output voltage from the SB-220 is a negative going voltage which is compatible with most rigs. Many modern transceivers have an ALC adjustment on their rear apron making this mod unnecessary. Check your transceivers' ALC input spec's for compatibility.

This is a simple addition to the back apron of the amp. A 100k pot is wired to the ALC circuit output and the wiper is connected to the ALC jack. The pot can be adjusted such that the amplifier does not saturate with peak drive from the exciter. Saturation is the level at which the amplifier will no longer increase output power levels when more input power is applied.

Schematic

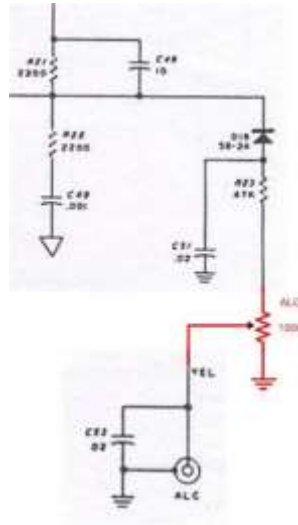


Figure 1.14
ALC Control

This amplifier was seen to saturate at about the 1400 watt level (Refer to Part 2). By convention, the onset of saturation is the point at which the output no longer rises equally, dB out for dB in. At this point the intermod and harmonic content rise very rapidly with increased input (overdrive) causing the distortion products to occupy a greater bandwidth (sideband growth). You may get reports of being "wide" or causing "splatter" as voice peaks overdrive the amplifier.

The ALC control on the amplifier is set to limit the output power to about 1300 Watts, just less than the measured 1400 W saturation point on the author's amplifier. It may be that you do not have to worry about overdriving the SB-220 if your exciter delivers < 150 watts at the amplifier input. It takes something just over about 150 Watts to induce saturation.

Installation Photo



Figure 1.15
Pot Location, Rear Apron, beside RF Input Connector

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Installation Photo, Switch

The switch is mounted on center line of the power ON-OFF switch and CW/TUNE SSB switch, half way between the LOAD and BAND SWITCH controls



Figure 1.17
Position of Operate – Standby Switch

Installation Photo, Fan

In this top view at the back of the amplifier, the inductor is mounted on the left side of the amplifier, along side the fan, and in between the RF compartment and the back plate. The inductor on the left side. The fan motor is in the middle, and the rear of the Hour Meter can be seen on the right. The author used a custom built inductor but the Stancor product is a form, fit, function compatible inductor of the same inductance and current rating.



Figure 1.18
Mounting of Fan Speed Inductor

Part	Supplier	Approx Cost
Stancor-Walden, Choke C-2343	Allied Radio p/n 928-0010	\$18
Standby – Operate Switch suggestion	Digikey EG4823-ND	\$5.31

Allied Radio, <http://www.alliedelec.com/>

1.13 +120VDC BIAS SUPPLY

The bias supply is a half wave rectifier with a 20 uF filter capacitor, suitable for the original relay coil, cut-off bias and ALC threshold. For use with the QSK circuits, a better regulated, lower ripple source of +120V was desired although not altogether necessary. It would however be prudent to replace C4 with a 47uF / 160 electrolytic for the same reasons cited in Section 1.6 regards lifetime of electrolytics. The single diode rectifier was replaced with a diode bridge for full wave rectification.

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Schematic

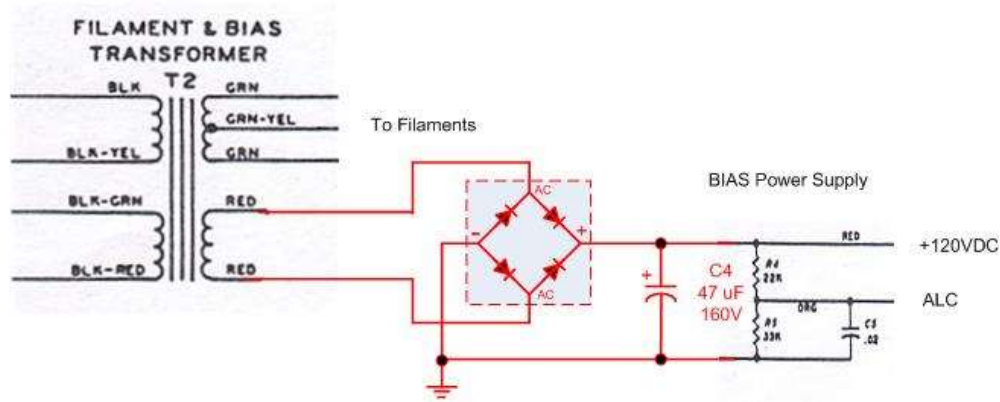


Figure 1.19
Bias Supply Modification

Part	Digikey p/n	Approx Cost
Rectifier Bridge 1.5A 400 V	W04GDI-ND	\$0.53
Capacitor 47uF / 160 V axial leads	4180PHBK-ND	\$4.82
	*	\$1.10

* Alternate less expensive source of capacitors for all types is a Canadian source in Ontario at <http://www.justradios.com/orderform.html>. There is a minimum order of \$15.

Installation Photo

The modified Bias Supply is built on the original tie strip per Figure 1.20. The exact wiring is obscured in the photo and so Figure 21 shows how it is done.



Figure 1.20
Component Placement

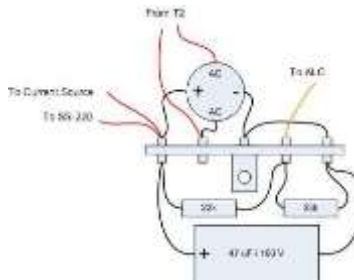


Figure 1.21
Component Wiring

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1.14 QSK CIRCUITS

Introduction

The original Heathkit open frame, RF un-friendly, clunky, mechanical relay is unsuitable for Break In operation. The relay coil is connected to the ANT RELAY jack on the amplifier and presents 120VDC to the exciter keying device on Receive. On Transmit, the antenna relay coil current is ~ 25 mA. More importantly, inductive kickback voltage is developed when the keying line goes open as the coil discharges in to an open circuit where destructive voltages can develop threatening semiconductors. This is OK if the exciter has a relay output for keying amplifiers but may not be acceptable to modern solid state keying circuits in the exciter.

The QSK circuit will allow fast switching of new antenna relays which replace the Heathkit relay. As well, the keying line has only ~ 1.5V present on receive and < 1 mA of keying current on transmit.

The QSK feature will allow Break-In CW operation. Relay switching times are spec'd at 8 ms maximum with typical < 5 mSec for the relays chosen per Section 1.14. Receiver recovery time and keying delay in the transceiver will also affect the ultimate Words Per Minute (WPM) that this system will support.

According to W4JBM, <http://www.hamuniverse.com/w4jbm/emission.html>, $WPM = 1.2 / (\text{dit length})$. A series string of "dits" of 30 mSec (0.030 second) duration each would be equivalent to ~ 40 WPM. The CW keyer was set up to deliver "dits" of ~ 30 mSec. A Tek 465 'scope was connected to the dummy load to view the RF with the scope triggered from the keying line. Figure 1.22 shows the timing of the keying line and the RF.

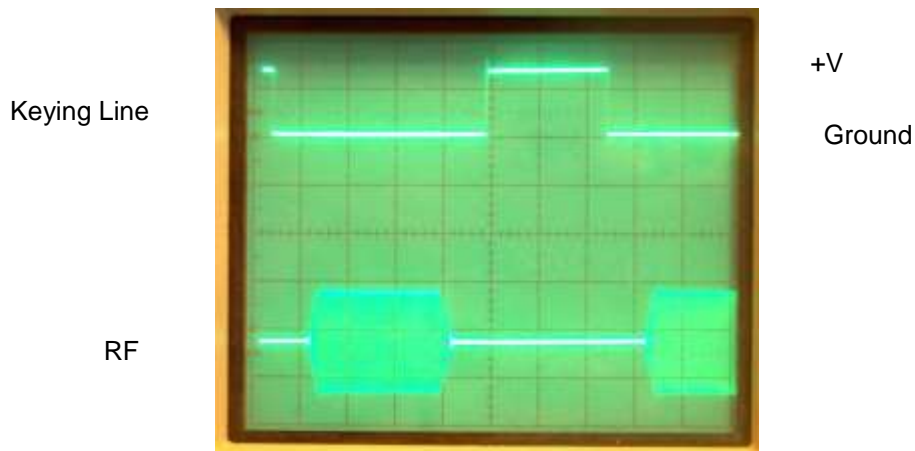


Figure 1.22
Relay Timing

The 'scope sweep was set to 10 mSec / div. Top trace is keying Line and the bottom trace is RF out of the amplifier. "Dit" length is about 30 mSec. Note that the keying line activates first, the +V to ground transition and about 5 mSec later, the RF output appears and looks clean on the leading and trailing edges as it should. The exciter has an embedded 5 mSec delay from onset of keying to RF out and this appears to be reflected in the traces above. Similarly, when the key is opened, the RF is turned off and the keying line is delayed about 5 mSec as well. This system allows the relays to cold switch, i.e. no RF on the contacts either on leading or falling edges.

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Figure 1.23 shows that signal is heard between the “dits” at the same speed on Full Break In. This photo is taken from the SB-614 in-line monitor scope. The time base is not calibrated.

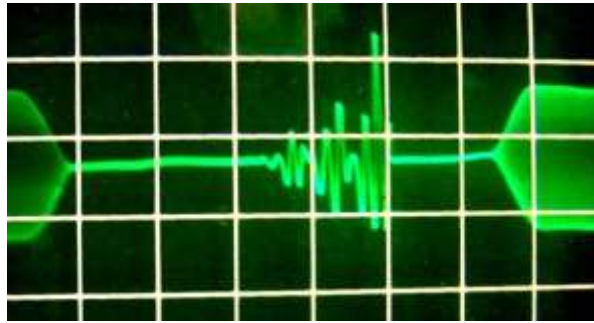


Figure 1.23
Full Break In Noise between “dits”

Figure 1.24 is a block diagram of the QSK system. This provides a top level view of the functional “blocks” that will be installed.

Installing the QSK circuits is an undertaking. It requires the assembly of various purchased parts and kits and the scratch building of the current source per Appendix II.

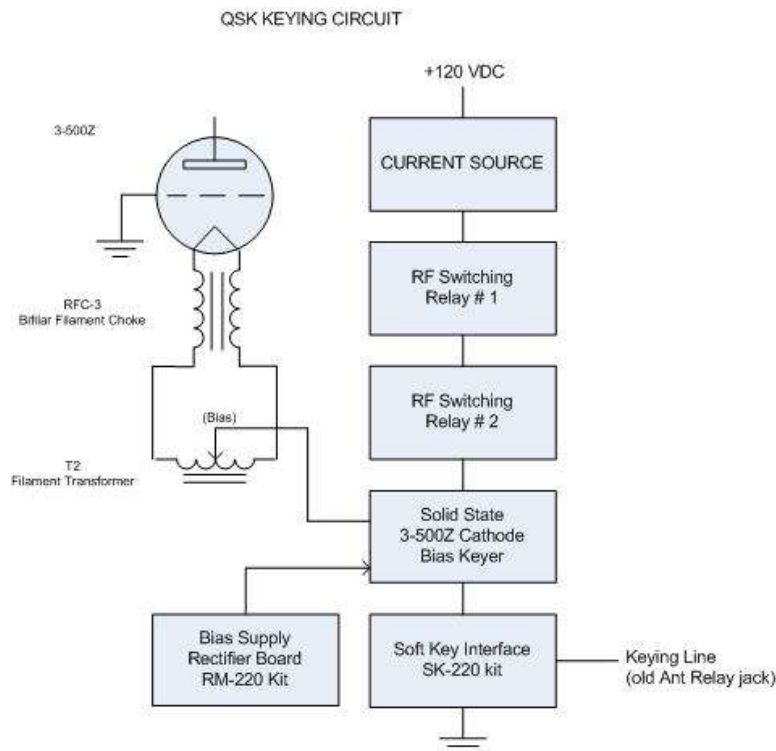


Figure 1.24
QSK Block Diagram

You will need to buy the Harbach Soft Key SK-220. You will also have to scratch build the Cathode Bias Keyer as AG6K has designed. The QSK feature also requires removing the original

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Heathkit antenna relay and the installation of the high speed switching relays. The rectifier circuit board will also require modification although replacement using the Harbach RM-220 Rectifier and Metering Board kit is recommended as it will ease this task. Also recommended is the upgrade of the +120V PS of Section 1.13 to provide a better quality +120V which the QSK circuits will use.

The Antenna Relay jack on the back of the amplifier was used to switch the antenna relay from a pass-through-on-receive position to inserting the amplifier in-circuit on transmit. The Antenna Jack function is now changed to a "Keying Line" input and is connected to an electronic interface that keys the amplifier in a QSK mode when the amplifier switch is in the OPERATE position. For this reason, it is required to install the Standby-Operate Switch feature of Section 1.12. The QSK system still provides the same function of switching the "antenna" as did the old relay.

Operation

A full schematic of the QSK circuit appears in Appendix I

The current source takes the unregulated +120 VDC bias supply and outputs a constant current of about 80 mA in the OPERATE mode when the Keying Line is grounded on Transmit by the exciter. The current is adjustable and is set up just once with the potentiometer on that board. This current drives all the circuits down the QSK totem pole circuit. Refer to Appendix II for construction and current setup detail.

Two relays are required to switch the antenna path from bypassing the amp to through the amp. In this implementation the relays are Jennings RJ1A with the 26.5V / 335 ohm coils. The higher coil resistance provides a higher voltage drop than would 12 V coils with 80 mA flowing. This lowers the voltage drop across the current source transistor thus easing its power dissipation requirements. Even so, a heat sink on the transistor is required. If 12V coils are used, then the power dissipation of the current source transistor will increase and a larger heat sink would be required. The diodes across the coils absorb the inductive voltage kick-back as the coil's magnetic field collapses when the relays are de-energized; that stored energy can result in very high voltages developing if the energy has no where to go. The installation of the Vacuum relays is covered in Section 1.15 following.

The Cathode Bias Keyer is a solid state switch that controls the bias current flowing in the tubes. The transistor switch Q3 is turned on or off by the opto-isolator diode due to on or off current flowing through the QSK Totem Pole circuit. This applies or removes bias to the 3-500Z tubes. When the amp is in the STANDBY or OPERATE mode, but not keyed on, Q3 is off (open circuit). Unlike the original Heathkit design where +120V is applied to the tube cathode (actually the filament) to turn the tube off and prevent conduction, this circuit simply goes high impedance with Q3 being off. However, Q3 is never perfectly off as there is always a leakage current through Q3, which can be represented by a high resistance of some megohms. Current from the tube will flow through this high R developing a self biasing voltage that acts to turn the tube off. This self off-biasing technique works very well. Interestingly the voltage required to cut off the tube is only in the order of +25 VDC.

When the amplifier is in the OPERATE mode and the Keying Line is grounded, the 80mA flows through the relays, and the opto isolator turns on Q3 (closed circuit). Q3 is connected to the bias voltage developed on the Rectifier board. This voltage is in the range of 5 to 6 VDC and is low enough to just put the tubes into conduction. This places the tubes in Class AB₂ linear operation for SSB. The tubes will of course fully conduct when RF is applied to the amp in the case of carrier such as CW, RTTY and when speech is present for SSB.

Note that 5.1V Zener ZD-1 on the original rectifier board is replaced with a series diode string to develop the bias voltage needed to establish resting anode current on transmit with no signal present if the RM-220 kit is installed. This tube current is approximately 120 mA or 60 mA per

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tube. The higher the current the more linear is the amplifier performance. A range of 100 to 200 mA is acceptable.

The Harbach SK-220 Soft Key kit is used for the interface to the Keying Line. In the STANDBY mode, the keying line is switched open so that the amp cannot be turned on. In the OPERATE mode, the amp will not come on in the presence of an open circuit on the keying line as presented by the transceiver. When the keying line is grounded, the amp will transmit RF in response to the signal presented by the transceiver. The voltage on the keying line presented by the SK-220 to the transceiver is about 1.5V on Receive, and when grounded for Transmit, the current is ~ 1 mA. This greatly reduces stress on the transceiver amplifier keying line output.

The Harbach RM-220 Rectifier – Metering board provides the bias voltage needed by the Bias Keyer. It is recommended that this kit be purchased although it is not absolutely necessary. The original board can be used but the 5.1V Zener is removed and replaced with a more robust power diode string of up to eight forward biased 1N5408's. One can tap off between the diodes to adjust the idle current as desired although between 7 and 8 at the top of the string usually works out quite OK.

1.15 ANTENNA RELAYS

Overview

The original 120V relay is replaced with a pair of fast switching, RF, high speed vacuum relays.



Figure 1.25
Typical Vacuum Relay

Manufacturers are Jennings Technology, model RJ 1A, Gigavac model GH3 and Kilovac Technologies model HC-3.

These are essentially interchangeable. This implementation used a pair of used Jennings RJ 1A vacuum relays, SPDT. Typically all of these relays are available on eBay from about \$40 to \$100 US each, new & used.

Schematic

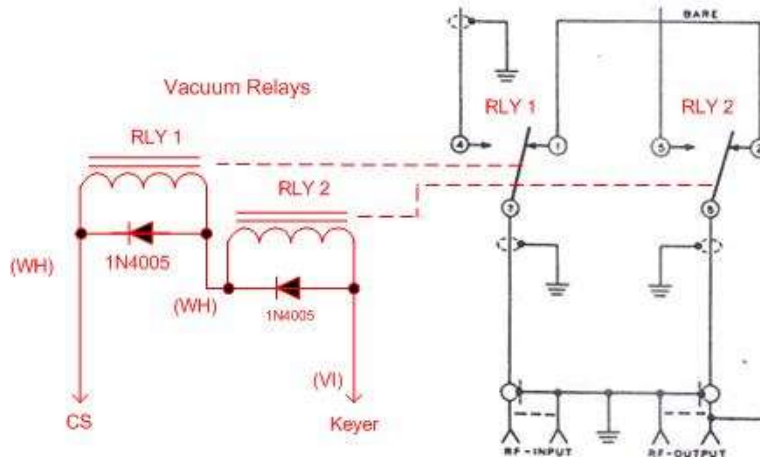


Figure 1.26
Antenna Relays

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NOTE: 26V / 335 ohm coils were used for reasons cited (higher voltage drop) in Section 1.14. One can use 12V / 80 ohm coils but a modification to the constant current circuit will have to be made. Refer to Appendix II.

Installation Photo

Two relays are required to perform the Antenna – Amplifier, In or Bypass, function.

The relays are acoustically isolated from the chassis to minimize contact switching noise. The relays are not silent when switching and while this is not an issue with SSB or other forms of carrier transmission, CW can be otherwise noisy if using Break-In.

A relay mounting bracket is custom fabricated from a piece of 1/8" x 3/4" x 1" aluminum angle. Two "U" shaped slots are cut into the bracket to hold the relays. The bracket is NOT screwed to the chassis but is acoustically isolated through use of a foam pad with double sided adhesive tape as shown by the cross shaded area at the bottom of the bracket, Figure 1.28. Refer to Figure 1.1 for approximate positioning.

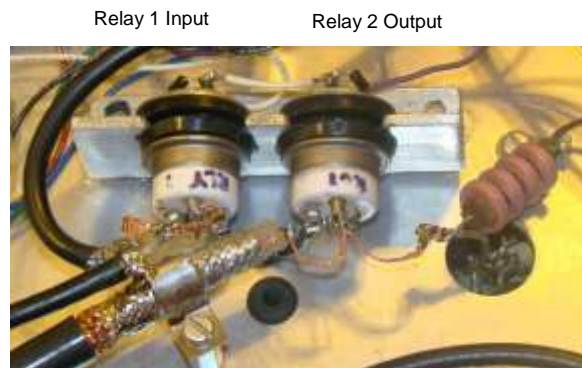


Figure 1.27
Relay Installation

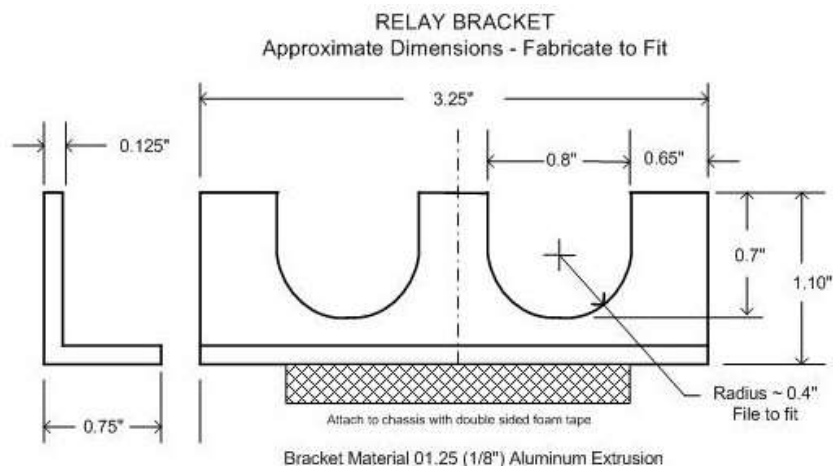


Figure 1.28
Relay Bracket Fabrication Drawing - Typical

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The relay bodies slide into the two “U” shaped slots. The slots are wider than the threaded part of the relays. An “O” ring is slipped on to the threaded body which sits *in* the slot. Flat 1” rubber hose washers are placed on either side of the “O” ring such that the relay body has no metallic connection / acoustic path to the bracket. A flat thin metal washer provides a smooth hard surface for the relay nut to tighten up against. The assembly is then lowered in to the slot and the nut is done finger tight only. The washer materials were sourced at Home Depot.

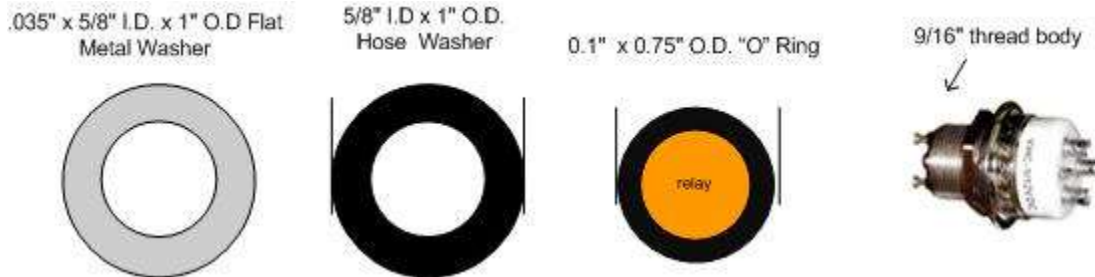


Figure 1.29
Washer and “O” Ring Components

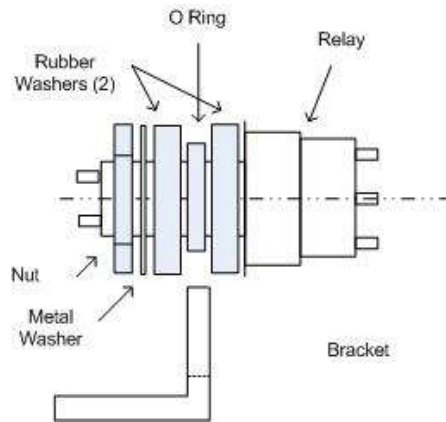


Figure 1.30
Side View Relay Mounting

Overall, the relay switching noise is probably acceptable to most. Coincidentally, the April 2011 issue of RADCOM magazine makes similar statements in their review of the ALPIN 100 HF amplifier. “The switching speed between receive and transmit was extremely fast, settling in under 3 ms. The Gigavac vacuum relay used in the amplifier is specified at less than 6 ms switching speed”. Also stated, “The relays are quiet for normal use but become rather noticeable with full QSK”.

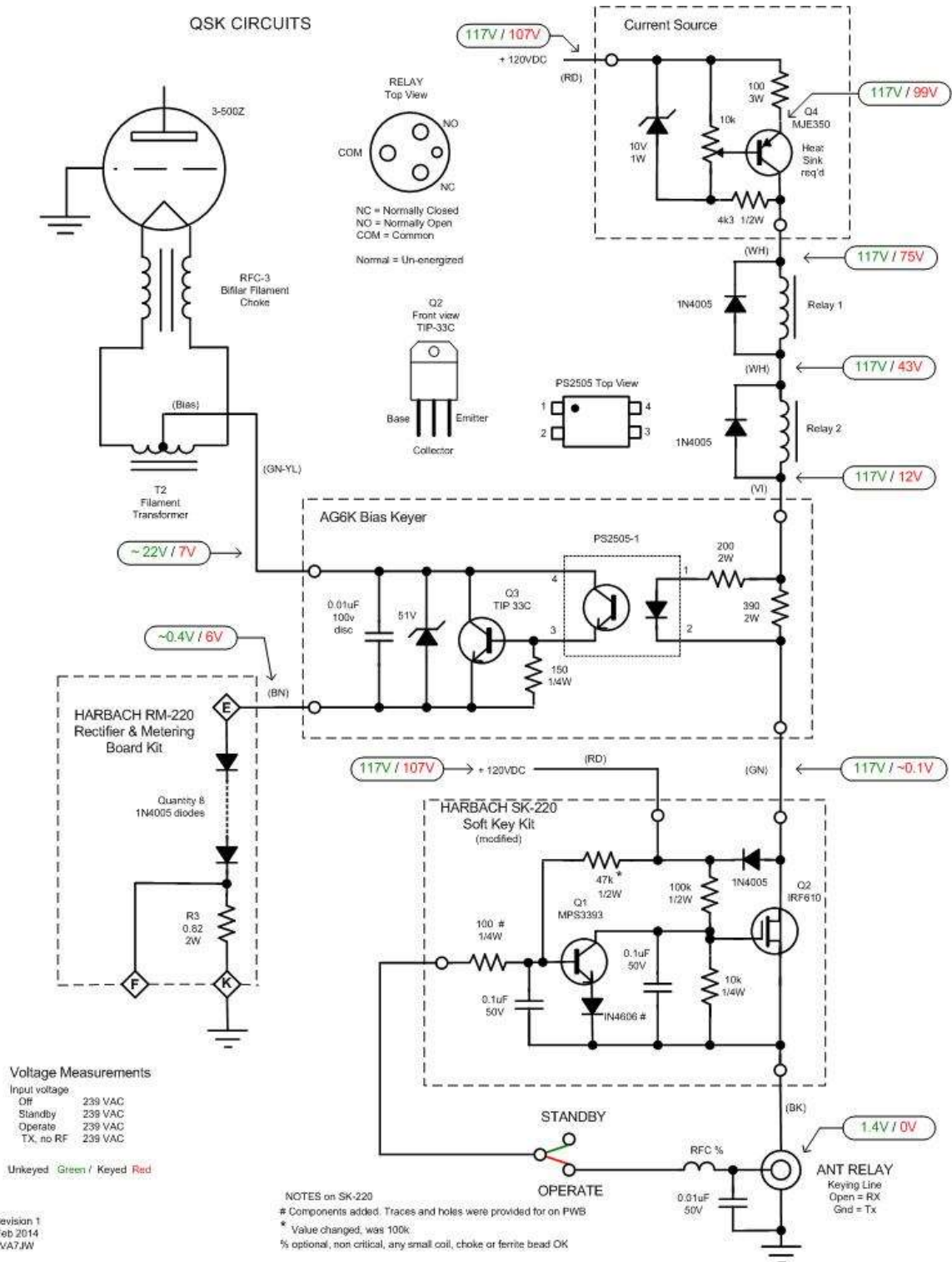
Wiring

Wire / Coax connection to the relay contact lugs should be made using a length of flexible “wire”. De-soldering braid makes such a connection. Refer to Figure 1.27. This relieves stress on the lugs from stiff coax as well as providing acoustic isolation. The coil wiring should be made with #22 or # 24 AWG, stranded, insulated wire.

Part	Digikey p/n	Approx Cost
No Clean De-Solder Wick 5' x 0.080"	82-150-ND	\$3

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APPENDIX I QSK KEYSER SCHEMATIC

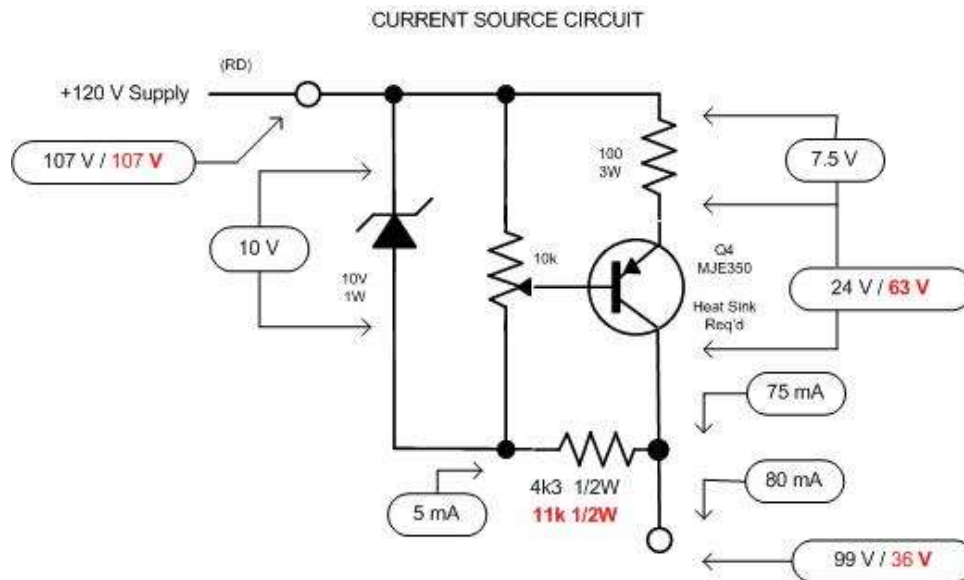


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APPENDIX II CURRENT SOURCE DETAIL

This QSK design has used 26V / 335 Ω relay coils. Voltages and currents were measured and are indicated in BLACK. If 12 V / 80 Ω relay coils are used, which have not been done in this implementation, a (calculated) resistor change is made from 4k3 to 11k to maintain ~ 5 mA current. Calculated voltage readings are in RED. These may differ somewhat depending on actual coil resistances affecting voltage drops in the totem pole chain. Other voltages / currents that stay the same remain as BLACK.

The Current Source will not change output current if 12V relays are used, but Q4 will have a much higher voltage drop across it given the lower voltage drop across the two 12V relays. This increases the power dissipation in Q4 and a larger heat sink is required. Refer to the notes below.



Red voltage readings are estimated voltages if 12 Volt / 80 Ohm relays are used.

4k3 changes to 11k for 12V coils

Q4 Dissipated power for 335 ohm / 26V relay coils is $24\text{ V} \times 0.075\text{ A} = 1.8\text{ W}$
Heat Sink Wakefield type 290-2AB rises ~ 40 degree C at 1.8 W

Q4 Dissipated power for 80 ohm / 12 V relay coils is $63\text{ V} \times 0.075\text{ A} = 4.7\text{ W}$
Heat Sink Wakefield type 647-10ABEP rated 42 degree rise at 6W.
Digikey p/n 345-1031-ND. \$2.65

Circuit Operation

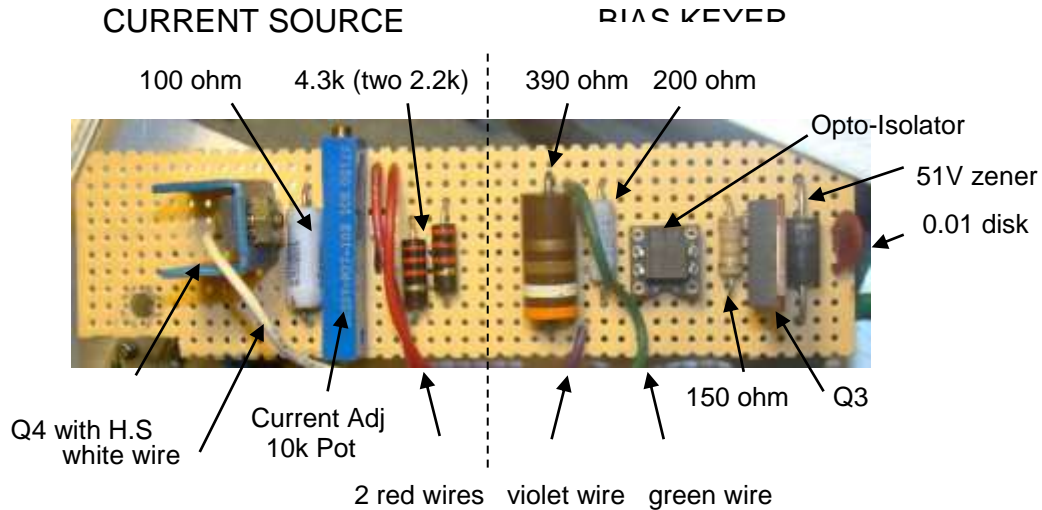
A 10 volt Zener diode is connected across a 10k pot which in turn is connected to base of transistor Q4. There is a 100 ohm resistor in the emitter of Q4 across which is impressed a constant voltage made up of the Zener voltage, as adjusted by the pot, plus the constant B-E voltage of ~ 0.7V. A constant voltage across the 100 ohm resistor means that there has to be a fixed current flowing through that resistor. That current is determined by the pot setting. Using a DVM, adjust the voltage across the 100 ohm resistor to ~ 7.5 VDC for ~ 75 mA of current. An additional 5mA of current from the Zener circuit plus ~ 1 mA from the pot circuit are added giving a total current through the totem pole circuit of ~ 80 mA.. This is not a critical setting.

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APPENDIX III CURRENT SOURCE / BIAS KEYER CONSTRUCTION DETAIL

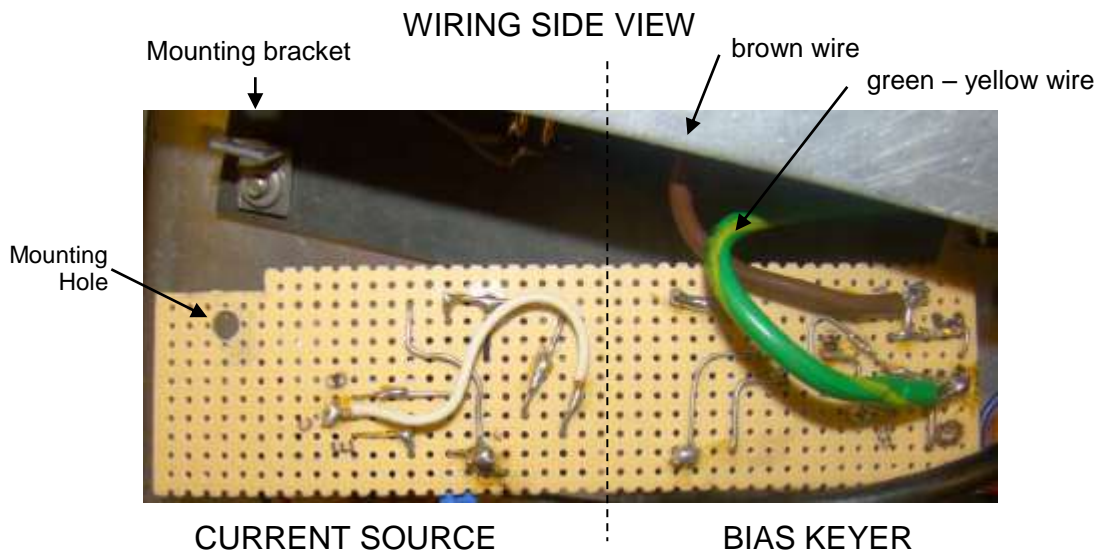
The current source and bias keyer circuits are constructed on the same piece of "holey" board. The board size is approximately 1-1/4" x 4-1/2". Component layout as shown and is not critical.

COMPONENT SIDE VIEW



Note that two 2.2k resistors are connected in series in this view as they were available components at the time. They can be replaced with a single 4.3k 1/2W resistor

The QSK schematic has wire colors notated. The wire colors can be seen here and will aid in assuring the connectivity. White wire to Relay 1. Red wire to +120VDC (in) & second red wire (out) to SK-220. Green wire to SK-220. Violet wire to Relay 2.



Heavy Brown wire to 6V bias on RM-220 Rectifier board. Heavy Green-Yellow to T2 Filament transformer.

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APPENDIX IV KIT LISTINGS

This table is a summary of products currently offered by Harbach and AG6K. (as of Oct 2011)

Description	HARBACH ELECTRONICS			AG6K			Notes
	P/N	USD	Stock Status	Part Number	USD	Stock Status	
Parasitic Suppression Kit	PS-220	\$50	out of stock	3-500Z	\$16.50	stock	
Rectifier / Metering Board Kit	RM-220	\$35	stock	1N5408	\$0.22 ea	stock	
Filter Capacitor Kit	FB-220	\$130	stock	560 uF/450V	\$11 each	stock	check physical size. Equalizing R's re'd
Electronic Keying Interface	SS-220	\$33	stock			no kit	
Current Inrush Limiter	SK-220	\$27	stock			no kit	

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APPENDIX V BILL OF MATERIALS for QSK SYSTEM

Designation	Description	Quantity	Type	Source	Cost
Q4	CURRENT SOURCE BOARD				
	Transistor, PNP 300V, 0.5A, 20 W	1	MJE350	DigiKey MJE350STU-ND	\$0.60
	Diode, Zener, 10V, 1 watt. 5%	1	1N4740A	Digikey 1N4740A-ND	\$0.40
	Resistor, 100 ohm 3 W 5%	1		Digikey 43J100E-ND	\$0.80
	Resistor, 4.3k 1/2 W, 5%	1		Digikey CF12JT4K30CT-ND	\$0.15
	Trim Pot. 10k 1/2W multiturn	1		Digikey CT94EZ103-ND	\$1.43
	Heat Sink, Wakefield 290-2AB (see note)	1		Dikikey 345-1021-ND	\$0.59
RLY 1, 2	VACUUM RELAY				
	Vacuum Relay SPDT Jennings or Vacuum Relay SPDT Gigavac or Vacuum Relay SPDT Kilovac	2	RJ-1A GH3 HC-3	eBay	\$40- \$70
	Diode, Rectifier, 1A, 600V	2	1N4005	Digikey 1N4005GOS-ND	\$0.35
Q2	BIAS KEYSER BOARD				
	Transistor, NPN 100V, 10A, 80 W	1	TIP33C	DigiKey TIP33CGOS-ND	\$2.00
	Opto Coupler, 80V, 50mA, Isolation 5kV	1	PS2505-1	Digikey PS2505-1A-ND	\$0.64
	Zener Diode, Surge rated 51V / 5 kW	1	5KP54A	Digikey 5KP51ALFCT-ND	\$3.35
	Capacitor, 0.01 uf 100V ceramic. 20%	1		Digikey 399-4262-ND	\$0.32
	Resistor, 150 ohm, 1 watt, 5%	1		Digikey PPC150W-1CT-ND	\$0.35
	Resistor, 200 ohm, 2 W, 5%	1		Digikey PPC200W-2CT-ND	\$0.56
Resistor, 390 ohm, 2 W, 5%	1		Digikey PPC390W-2CT-ND	\$0.56	
	SOFT KEY BOARD				
	Parts are as supplied in Harbach SK-220 kit Values shown on schematic are for reference only Values are for kit dated 1997	1			
	RECTIFIER and METERING BOARD				
	Parts are as supplied in Harbach RM-220 kit Values shown on schematic are for reference only Values are for kit dated 1997	1			

Digikey price subject to change

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PART 2 – PERFORMANCE MEASUREMENTS

2.1 INSTRUMENTATION

For a tutorial on Power, definitions and measurements have a look at page 35, Appendix VI. This may be helpful in understanding the differences in power ratings for CW, PEP, RMS and Average.

For an accurate measurement of output power, two measurements were taken to confirm each other. Primarily, we depend on the inherent accuracy of a quality external wattmeter, and not the rig's built-in wattmeter. Secondly, we measure the voltage across the 50 ohm dummy load and then calculate the power to confirm the wattmeter measurement.

The voltage measurements were taken with an oscilloscope capable of accurate level measurements at RF frequencies, i.e. 14 MHz. At a 1500 watt level, the voltage across a 50 ohm load resistor would be 274 Volts RMS or ~ 390V peak. This is too high to apply directly to the input of most scopes even using a 10X probe, as the maximum deflection on screen is limited to 200 V. Because of this, a precision attenuator is required between the dummy load and the scope to reduce the voltage to a safe and accurate level. One solution to this is to use a high power, 50 ohm, lab quality attenuator. The attenuator presents a 50 ohm load and so acts as the dummy load, and has the added feature of having an output that presents a calibrated output level, in this case 30 dB (1000 X) less than the input.

Figure 2.1 below is the test setup for measurements presented in Sections 2.2 and 2.3

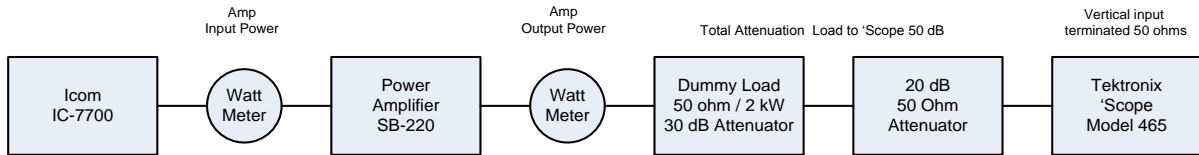


Figure 2.1
Power Measurements Test Arrangement

The exciter is an Icom IC-7700 capable of delivering ~ 200 Watts of RF output.



Figure 2.2
Icom IC-7700

The amplifier under test is the SB-220 featured in this article.

The wattmeter is a Coaxial Dynamics Model 83000-A. This meter is much the same as a Bird wattmeter using the same Bird "slug" except that it has the additional feature of being able to measure Peak power as well as Average power. The meter display is much larger than the Bird instrument which is nice. The instrument has a fast attack time and a longer decay time (seconds) to sample PEP which makes it easy to observe RF peak power.

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SPECIFICATIONS: MODEL 83000-A	
Power Range, Peak or Average	100mW - 10kW
Peak Only	2.5kW, 5kW, and 10kW
Frequency Range	2 - 2300 MHz
Insertion VSWR	1.05: 1 Max, with type "N" Connectors
Impedance	50 ohms
Finish	CDI Blue
Weight	4.5 lbs. (1.35kg) Element Weight .125 oz. (.035 kg)
Power Requirements	ONE 9V alkaline "transistor" batteries supplied
Battery Life	EST 90 days normal use
Accuracy	Average (CW) mode $\pm 5\%$ of full scale Peak-Pulse or Envelope-Power mode $\pm 7\%$ of full scale
Pulse Parameters	
Square Pulses:	Minimum Pulse Width: .5 μ sec 100-1000 MHz
	2 μ sec 26-99 MHz
	15 μ sec 2-25 MHz
Minimum Repetition Rate:	30 pps
Gaussian Pulses:	Minimum Pulse Width: 5 μ sec 25-1000 MHz
	15 μ sec 2-24 MHz
	Minimum Repetition Rate:

Figure 2.3
Coaxial Dynamics Wattmeter

Output power from the exciter is measured in to the amplifier as a function of the RF POWER control setting on the IC-7700. This ranges from a minimum of setting of ~ 5 watts to a maximum of ~ 200 Watts. The "dots" on the control are assigned numbers, minimum (fully CCW) being 1 and maximum (fully CW) being 11. For example, the control is set to 6 in Figure 2.4



Figure 2.4
RF POWER control on the IC-7700

All power tests were conducted on the 20 meter band at 14.129 MHz. Once the Tuner on the IC-7700 was matched to the SB-220 on the 20m band, it was found unnecessary to readjust the tuner at the various power levels over the exciter range of 5 to 200W for these tests. Since the input power levels were stable and repeatable at all output power levels, only one set of power input levels were recorded for all tests and the wattmeter was moved permanently to the output power position to measure amplifier output power vs RF POWER settings from 1 to 11.

The dummy load is a 50 ohm, BIRD Tenuline Coaxial 30 dB Attenuator, model 8329-300, serial # 4372. It is rated at 2kW continuous at 45 °C ambient. Thanks to Nick Massey, VA7NRM, of Ionocom (<http://www.ionocom.com>) in North Vancouver for the loan of this monster.



Figure 2.5
2 kW Dummy Load / 30 dB Attenuator

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The output of the attenuator is connected to another device, seen on the right, a Narda 20 dB / 20 watt, 50 ohm in-line attenuator that further reduces the high power transmit signal level to a level suitable for input to the 'scope. The input to the scope is terminated with 50 ohms to preserve the load impedance requirements of the attenuators. The voltage across this 50 ohm termination is 50 dB down from the voltage that appears at the 50 ohm input Z to the Bird Dummy Load / attenuator.

The 'scope is a Tektronix Model 465 with a bandwidth exceeding 100 MHz so that the accuracy of a voltage reading at 14 MHz is good.

All coax's are 50 ohms using Belden FR-1 or Times LMR-400 product.

Formulas used to calculate Output Power as follows,

1. Average Power, $P_{avg} = (V_{rms})^2 / R_L$: also read as AVG on power meter.
2. Peak to Peak (pk to pk) voltage is read on the 'scope.
3. $V_{rms} = [V_{pk-pk} / (2)] / 1.414$
4. R_L was as measured at 51.4 ohms with a Fluke DVM.
5. The voltage out of the amplifier is attenuated by 50 dB. The load voltage is therefore 316 times greater ($10^{50/20}$) than measured on 'scope.

$$RMS \text{ Load Voltage} = (V_{pk-pk} \times 316) / 2.828$$

$$Load \text{ Power} = (RMS \text{ Load Voltage})^2 / 51.4$$

Refer to Appendix VI for details on power measurement.

2.2 CARRIER RF POWER OUTPUT

This test measures the key down, steady state, maximum output level of carrier at the highest power, SSB setting rather than the CW/Tune setting. N.B. The PA is NOT left running between power settings. The SB-220 is not designed, or rated for, continuous "Key Down" operation. Each reading represents a momentary operation where the reading is obtained.

RF PWR	Wattmeter		Calculated	Scope	Load	Error
Control	PWR IN	PWR OUT	Output	Voltage	Voltage	
IC-7700	AVG	AVG	PWR	peak to peak	RMS	
1	4	75	66	0.52	58.2	12.2%
2	7	105	94	0.62	69.4	10.8%
3	15	252	220	0.95	106.3	12.8%
4	24	430	412	1.30	145.5	4.3%
5	42	625	563	1.52	170.1	9.9%
6	66	750	704	1.70	190.2	6.1%
7	92	950	974	2.00	223.8	-2.6%
8	118	1150	1179	2.20	246.2	-2.5%
9	150	1300	1289	2.30	257.4	0.9%
10	187	1460	1462	2.45	274.2	-0.2%
11	195	1500	1523	2.50	279.8	-1.5%

(A)

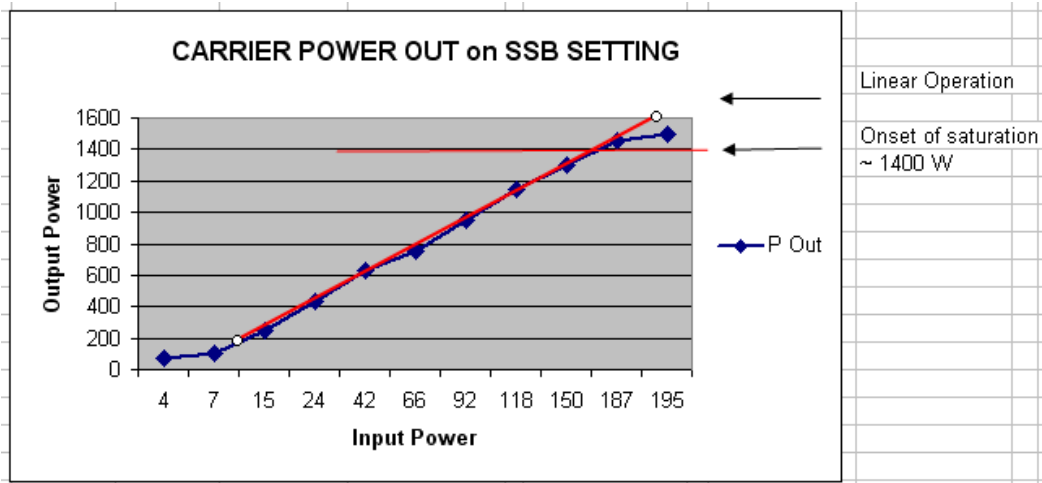
(B)

(C)

TABLE 2.1
RF POWER OUT

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Table 2.1 (A) summarizes the Measured and Calculated CW average power output. Table 2.1 (B) lists the measured peak to peak voltage and the calculated RMS voltage across the load resistor from which the calculated output Power is derived. Table 2.1 (C) shows the error noted between the wattmeter reading and the computed wattage.



GRAPH 2.1
CARRIER SATURATION CURVE

Comment:

1. The amplifier will produce 1 kW of output with 100 Watts of input as is commonly assumed.
2. The (red) Linear Operation line shows where the amplifier departs the linear region and begins to saturate at ~ 1400 W out when driven in excess of approximately 150 watts input.
3. Agreement between the wattmeter and 'scope is good at the higher power levels but degrades at the lower power levels. This coincides with the changing of the "slug" from 250W to 2500W. Calibration error in the 250 W slug perhaps.

2.3 PEP RF POWER OUTPUT

Peak Envelop Power (PEP) is the power measured at the peak of the RF sine wave.

It was thought that perhaps the RF peak power on SSB would be somewhat higher than the CW peak power due to the lighter loading on the HV power supply since the average power is quite a bit less on speech due to the nature of the peak to average levels. These tests indicate that the peak to average is about 11 dB. Note that IC-7700 compression was ON and set up for ~ 6 dB as measured by the IC-7700 meter function.

Using the same setup as the Carrier test, the peak voltage across the dummy load was measured again using on the 'scope and using a consistent repeated speech pattern.

Capturing the peak voltage on the 'scope is a fleeting exercise since the Tektronix 465 is not a storage scope, but the peak voltage results correlate well with the carrier voltages in Table 2.1 for CW.

The wattmeter was used to measure both AVG and PEAK with the results per Table 2.2.

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Table 2.2 (A) summarizes the Calculated and Measured PEP. Table 2.2 (B) lists the measured peak to peak voltage and the calculated RMS voltage across the load resistor from which the calculated PEP was derived. Table 2.2 (C) shows the peak watts as measured on the wattmeter.

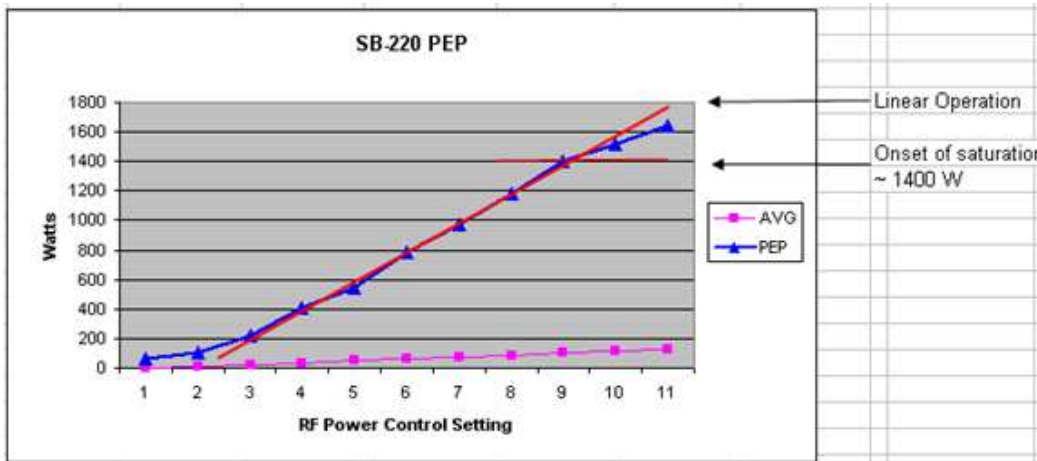
RF PWR	Wattmeter	Calculated	Wattmeter	Scope	Load	Wattmeter
Control	PWR OUT	PWR OUT	PWR OUT	Voltage	Voltage	Variance
IC-7700	AVG	PEP	PEP	peak to peak	RMS	Factor
1	5	61	115	0.50	56.0	1.9
2	10	100	160	0.64	71.6	1.6
3	20	225	350	0.96	107.4	1.6
4	30	412	525	1.30	145.5	1.3
5	55	548	725	1.50	167.9	1.3
6	60	789	900	1.80	201.4	1.1
7	75	974	1150	2.00	223.8	1.2
8	85	1179	1450	2.20	246.2	1.2
9	100	1403	1650	2.40	268.6	1.2
10	115	1523	1950	2.50	279.8	1.3
11	125	1647	2000	2.60	290.9	1.2

(A)

(B)

(C)

TABLE 2.2
PEP on SSB SETTING



GRAPH 2.2
PEP SATURATION CURVE

Comments:

1. The point at which voice peaks show amplifier saturation onset is about the same, at 1400 Watts. The peak carrier level is essentially the same for CW or SSB
2. Note that there is considerable difference between the calculated PEP based on measured peak voltage and the wattmeter peak. The wattmeter spec states that PEP is accurate within 7% of full scale. For a 2500 Watt slug, and running the maximum available power, ~ 1600 watts to minimize error, this computes to a max error of 175 Watts. The discrepancy is considerably greater than that. The reason for variance has not been determined but the greater confidence resides with the measured voltage technique as equipment is verifiable, whereas the wattmeter, on the Peak setting, is not. This is a probable calibration issue requiring further investigation.

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The following sections, 2.4 thru 2.6, were performed using an HP8562A spectrum analyzer and an HP 9872C plotter in 1992 when the equipment was then available .

2.4 HARMONIC DISTORTION

This test measures the harmonic content of the carrier at 3.7 MHz. Choosing the lowest band gives a wider view of the harmonic content throughout the higher HF bands. The amplifier was driven hard, near saturation.

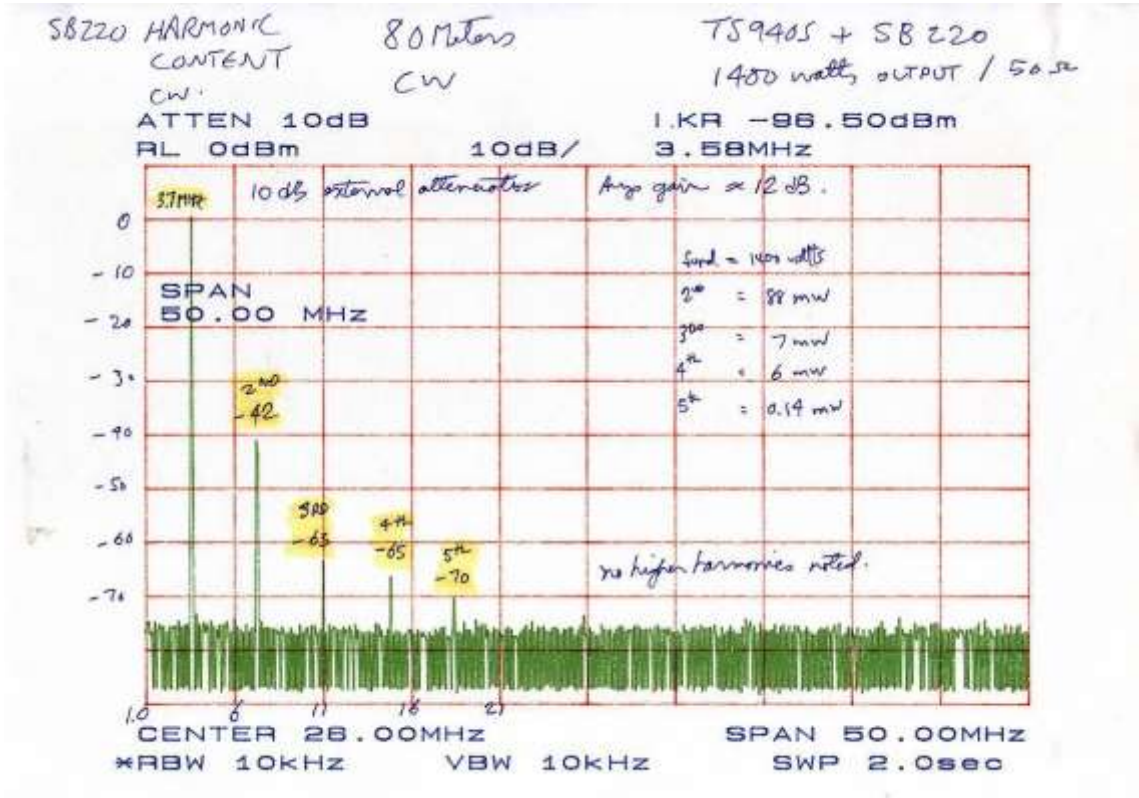


FIGURE 2.6
HARMONIC DISTORTION

Comment

There is no Heathkit specification for harmonic distortion products. The second harmonic at -43 dBc (dB with respect to carrier) is seen as quite acceptable given that the amplifier was driven very hard.

2.5 TWO TONE TEST

Tests 2.5 and 2.6 are described in detail in the March 1992 QEX feature article "Transmitter Noise Loading" by this author, who was then licenced as VE7AAL at that time.

Two audio tones of 1.2 kHz and 2.2 kHz at the same level were fed into the exciter. The amplifier was loaded to about the 1.2 kW carrier level.

Intermodulation Distortion (IMD) products are measured in dB below the single tone level. With a single tone, there are no IMD products to display as two tones are required to produce IMD.

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In this case, the two tones are at the zero reference level. The IMD products are easily read from the graph but one must add 6 dB to reference these to the single tone = carrier level, i.e. the first intermod product above the tones reads ~ 25 dB below the reference. With respect to carrier, the IMD product is $25 + 6 = 31$ dB down.

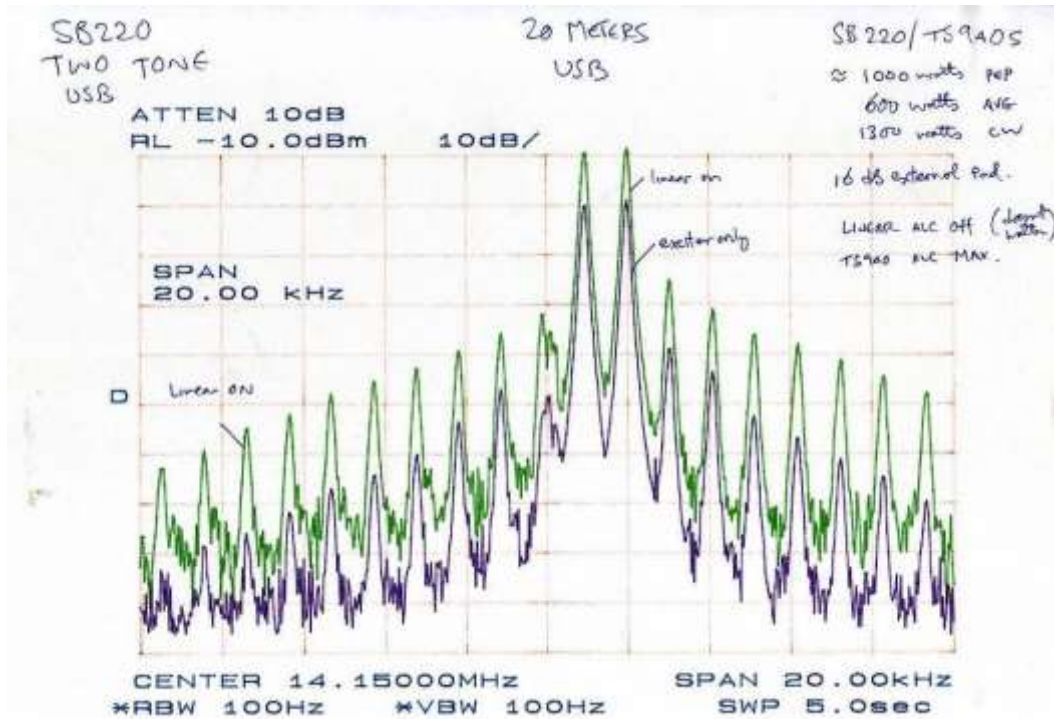


FIGURE 2.7
TWO TONE DISTORTION PERFORMANCE

Comment

The first IMD product, on the upper side, is about 28 dB below carrier. The Heathkit specification calls for -30 dB so the amp is performing to spec.

2.6 NOISE LOADING TEST

This is a rather unique test in that white noise is loaded into the exciter MIC jack. This produces a broadband signal more closely simulating voice. Obviously voice is not simulated by a steady tone although the tone test is easy to do and provides specific levels that can be measured and compared. However the noise test is informative as a simulation of actual service.

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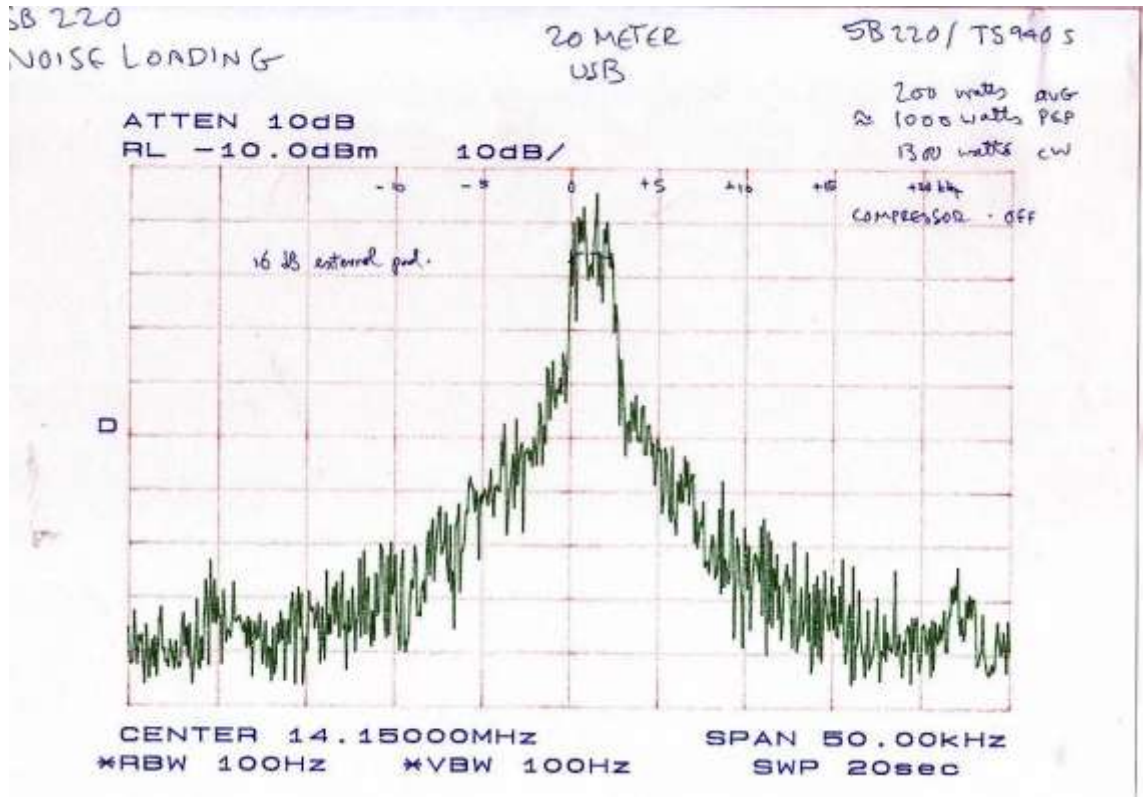


FIGURE 2.8
NOISE LOADING INTERMODULATION

Comment

It is apparent that the sideband "growth" is much less than that seen in the two tone testing. At +/- 2.5 kHz to the side, the IMD products are down about 40 dB. This is likely attributable to the modulating energy being spread out as a continuum rather than concentrated as two tones.

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APPENDIX VI POWER TUTORIAL

UNDERSTANDING POWER

DC Power is easy to understand. Multiple the DC Voltage x DC Current and you have Power in Watts.

AC Power is not so simple since the AC waveform varies with time. When the waveform crosses zero, the power = 0, at its peak the power is highest, and in between it is something else, instant by instant.

The equivalence between a DC voltage or current and an AC (sine wave) voltage or current is called the *effective* value of the AC sine wave meaning that the AC waveform " would generate the same amount of power = heat as the DC value for a given resistive load.

The effective value is referred to as the RMS (Root Mean Square) value and is calculated simply as,

$$V_{\text{RMS}} = \frac{V_{\text{P}}}{\sqrt{2}} \quad (\text{equation 1})$$

where V_{p} is the peak value of the sine wave. I_{RMS} would be similarly calculated from I_{p}

The power developed by a sine wave is then given by

$$P_{\text{avg}} = V_{\text{RMS}} I_{\text{RMS}} \quad (\text{equation 2})$$

where P_{avg} is the average or effective power.

P_{avg} may also be referred to as RMS power or mean power.

Fortunately we do not have to measure both RMS voltage and current. The measurement of peak voltage along with knowledge of the value of resistance that the voltage is developed across will give P_{avg}

$$P_{\text{avg}} = \frac{(V_{\text{RMS}})^2}{R} \quad (\text{equation 3})$$

where $R = 50$ ohms

WATTMETER

The more common method of measuring RF power is to use an In-Line RF wattmeter such as the Bird or Coaxial Dynamics products. The "slugs" or more correctly "Plug-In Detector Elements" are calibrated to read Average Power.

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CW POWER

Figure VI.1 shows a CW signal, being an unmodulated RF carrier of unvarying amplitude

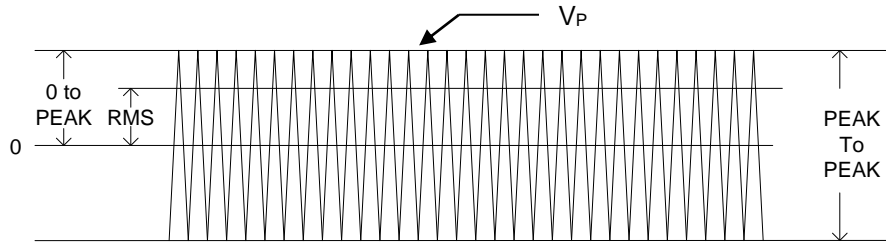


Figure VI.1
Unmodulated Carrier

The RMS voltage of the carrier developed across a 50 ohm non-inductive resistor can be measured by measuring the peak to peak voltage which is easy to do on a 'scope. The peak voltage will be one half the peak to peak voltage and so equation 1 is used to calculate the RMS voltage. Equation 3 will then give the average power.

MODULATED POWER

When the carrier is amplitude modulated as in AM or SSB, the RF sine wave varies in amplitude and the above RMS calculations do not readily apply because the carrier power is varying with time, that is, with the modulation. Since the modulation envelop being voice (SSB) and essentially random, we cannot determine what power the modulation is developing.

Figure VI.2 illustrates this difficulty as one can see the modulation envelop is varying continuously and variously with time.

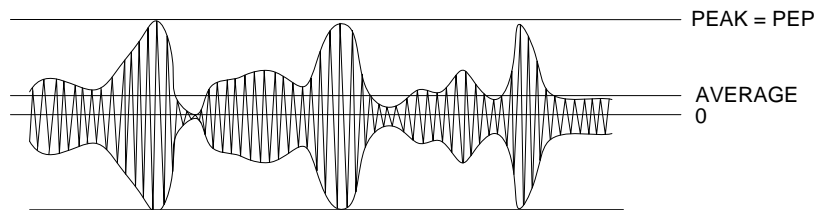


Figure VI.2
Voice Modulated Carrier

We can avoid the RMS approach by introducing the Peak Envelop Power (PEP) power concept where only the peak of the modulation envelope is measured, that is, V_{peak} . Strictly speaking, Peak Envelope Power (PEP) is defined as the average power supplied to a load by a transmitter during one radio-frequency cycle at the crest of the modulation envelope taken under normal operating conditions. Refer to <http://www.ab4oj.com/test/peptest.html>

PEP is instantaneous power and in the case of our transmitters / amplifiers, is a measure of the peak power capability of the transmitter P.A.. This is actually of more interest and is not so hard to measure. Again, measuring the peak to peak voltage as before, and using the peak voltage, the peak power can be calculated at the voltage peak by simply using the familiar power formula,

$$P_{peak} = (V_{peak})^2 / R$$

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2.7 HEATHKIT SPECIFICATIONS

As per the authors Heathkit SSB Manual dated 1969 ©

Band Coverage	80, 40, 20, 15 and 10 meter amateur bands.
Driving Power Required	100 watts.
Maximum Power Input	SSB: 2000 watts P.E.P. CW: 1000 watts. RTTY: 1000 watts.
Duty Cycle	SSB: continuous voice modulation, CW: Continuous (maximum key-down 10 minutes), RTTY: 50% (maximum transmit time 10 minutes).
Third Order Distortion	-30 dB or better.
Input Impedance	52 Ω unbalanced.
Output Impedance	50 Ω unbalanced; SWR 2:1 or less.
Front Panel	Tune. Load. Bandswitch. Sensitivity. Meter switch. Power. CW/Tune - SSB. Plate meter. Multi-meter (Grid mA, Relative Power, and High Voltage).
Rear Panel	Line cord. Circuit breakers (two 10 A). Antenna Relay (phono). ALC (phono). RF Input (SO-239). Ground post. RF output (SO-239).

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Tubes	Two 3-500Z.
Power Required	120 VAC, 50/60 Hz, at 20 amperes maximum. 240 VAC, 50/60 Hz, at 10 amperes maximum.
Cabinet Size	14-7/8" wide, 8-1/4" high, 14-1/2" deep.
Net Weight	50 lbs.

The Heath Company reserves the right to discontinue instruments and to change specifications at any time without incurring any obligation to incorporate new features in instruments previously sold.

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2.8 A LITTLE HISTORY

According to WA7ZZE, Chuck Penson's book "Heathkit – A guide to Amateur Radio Products" the SB-220 was in production from 1970 to 1978. In 1972 alone, 1,341 units were sold. Pricing in those days was \$369.95 USD. To quote Penson, "The SB-220 is probably the second most popular amplifier on the planet". The most popular amateur Heathkit product was the famous Antenna, the HN-31. For details on this product, refer to "Notes on the Heathkit HN-31 Antenna" also by this author.



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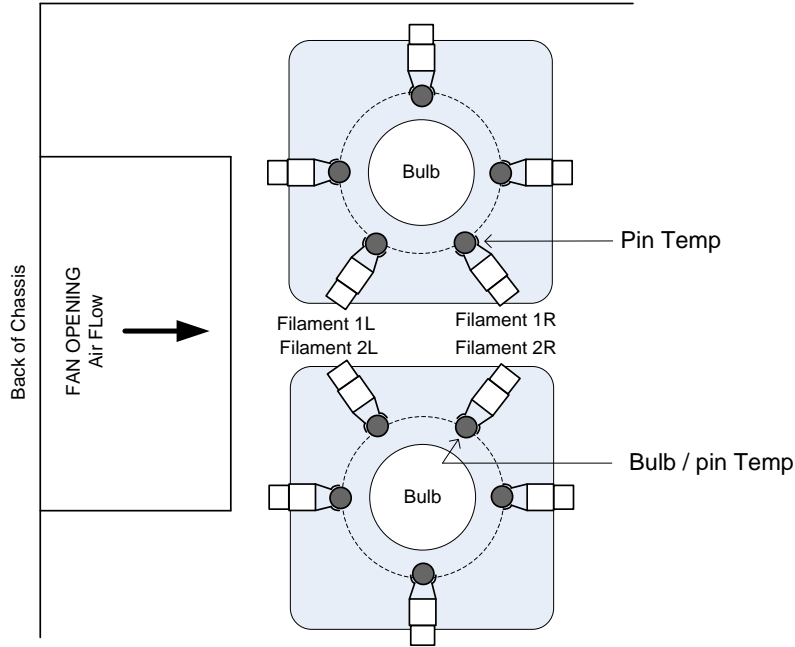
604-936-2367

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2.8 Revision History, Errata, & Feedback Notes

19 June 2013

1. Error in Appendix V. QSK Zener diode was 60V, Should be 51V, Digikey Part # 5KP51ALFCT-ND
2. Thermal question regarding 3-500Z pin temperature on Standby when fan is running at low speed was raised. Would it exceed the rated 200degrees C due to lower air flow? Tests indicated bulb temp on standby was 115 C max so it is OK



Room temp is 21 C / 70 F

Location	1L	1R	2L	2R
On tip	81	100	80	96
On pin in clip	82	105	86	96
On bulb by pin		110		115

3. Feb 2014

There was an error in schematic of Appendix 1, page 23.

The common circuit (BN) of the AG6K Bias Keyer was shown to connect straight through to the high voltage (117V) series string. This is wrong. There is not supposed to be a connection from the HV Keying circuit to the Bias circuit as that is the purpose of the Opto-Isolator. The corrected schematic is now shown. Apologies for the error.