Assembly & Integration (A&I) User Manual (UM)

RF LIMITER TO PROTECT CO-SITE TRANSCEIVERS

Bill of Materials, Assembly, Functional Testing, and System Integration
for Part Number, PN 4000-0076 Rev-B

Final Unit Assembly, PN 4000-0076 Rev. B

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Introduction

Background

The purpose of the RF Limiter is to protect receivers that need to safely function in a high RF environment commonly found at multi-transmitter locations, Field Day operating locations, multi-mode stations operating 2 or more transmitters, remotely operating radio sites, and contesting locations.

It is straightforward to calculate the received power at the receiver using the transmit RF power, RF frequency, coax line losses, antenna gain (both transmit and receiver side), plus the path loss (click to learn more) when in the far-field. The author has done using a custom Excel spreadsheet considering these key parameters. As an example, at 14 MHz and transmitting 1 kW with power with an antenna separation of 100 meters, the power level at the receiver's front-end is approximately +22 dBm (assumes nominal coax cable losses and 0 dB gain antennae). Modeling and examining the results can assist in determining if using an RF Limiter is warranted.

For uncontrolled environments with many unknowns, such as site transmitter management, RF power levels, bands of operation, etc., a safe approach is to add an RF limiter at the receiver.

The design presented here limits the received RF signal power levels to roughly +13 dBm when nearby transmitters are also operational. The limiter design uses of a small light bulb in series with the RF path and back-to-back diodes shunting the receiver input signal to ground. The combination light bulb resistance and the shunt diodes create a lossy resistance (light bulb) and RF voltage clamp (diodes) that limits the maximum power at the receiver's 50-ohm front-end. Since the diodes limit the waveform to roughly ± 1 V peak-to-peak (max.) square waveform across 50 ohms, this is equivalent to +13 dBm.

There are several additional features in this RF limiter design so it can also be used with transceivers. The first is the use of high-speed relay to take the limiter circuitry out of the transmitter's RF path to the antenna. The SEND output line from transceivers (e.g., IC-7300, IC-7610, etc.), normally used to control an external amplifier, is also used to operate this relay.

Some manufacturers offer 12 V keying instead of Grounded key lines to external equipment, such as amplifiers, so the circuit includes an option to add a jumper to enable either Ground or 12 V keying signaling.

Finally, some transmitters, notably the IC-7300, suffer from the RF transmitted waveform continuing several milliseconds after the SEND output is turned off. This can be difficult for attached amplifiers since the extended waveform creates "hot switching" that should be avoided. To counter this effect, the limiter's control circuit can be configured to add a short 4 mS delay at transceiver's SEND signal termination to reduce effects of some equipment having SEND tail-end timing issue. This is also accomplished with a shunt jumper on the circuit board assembly.

Assembly and Integration

This **Assembly & Integration User Manual** provides the following sections to assist the builder of the RF Limiter, PN 4000-0076 Rev-B.

- Image Gallery
- Bill of Materials (BoM) and Sources,
- Aluminum Enclosure Metal Prep,
- Enclosure Labeling,
- Order of Assembly,
- Functional Testing,
- Block Diagram of Insertion into IC-7300/KPA500/KAT500 Connections,
- **Alternate Configuration** for the IC-7610 Transceiver, and
- Schematic Diagrams.

The circuit board layout was created by the author and multiple boards were purchased and assembled for prototype and final tests and system integration.

Information for this design will be added to the author's website, https://www.k5pa.com .

Throughout this document the abbreviation for **Part Number** is given as **PN**.

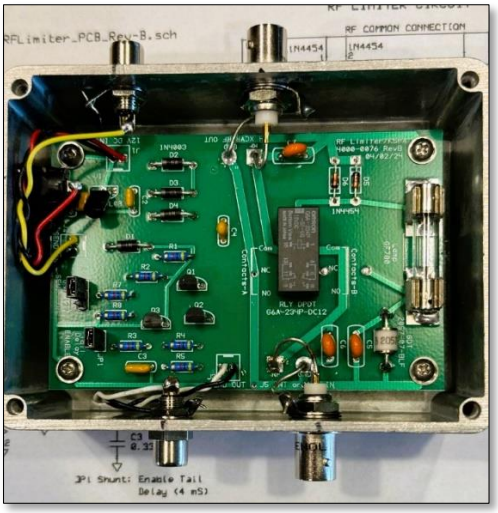
CREDITS

The design is based on the technical article: "*A Transceiver Front-End Protector in High Signal Level Environments*," by AD5X, Phil Salas. His article was downloaded from the DXZONE URL: https://www.dxzone.com/qsy33054-a-transceiver-front-end-protector- .

The printed circuit board (PCB) layout and my documents are the creation of K5PA, Gene Hinkle.

Image Gallery

Front and Side Views with Labeling



External and Internal Views

Bill of Materials Inventory

On-Board Parts

☐	PCB	Bare Circuit Board, PN 4000-0076 Rev-B, 4/2/24
☐	R1, R2, R3, R4, R5, R7	Resistor, 4.7K Ohm, ¼ W
☐	R6	Lamp, GF780 (Requires Fuse Clips, Qty 2)
☐	Fuse Clip	Fuse Clip (Qty 2) for Holding Lamp, GF780
☐	C1, C2	Capacitor, 0.1 uF
☐	C3	Capacitor, 0.33 uF
☐	C4	Capacitor, 0.01 uF
☐	C5	Capacitor, 8.2 pF
☐	C6, C7	Capacitor, 10 pF
☐	D1, D2, D3, D4	Diode, 1N4003
☐	D5, D6	Diode, 1N4454
☐	GDT	Surge Suppressor, 2057-07-BLF
☐	Q1	Transistor PNP, 2N3906
☐	Q2	Transistor NPN, MPSA06
☐	Q3	Transistor NPN, 2N3904
☐	U1	Voltage Regulator, MC78L08
☐	JP1	2-pin Header
☐	JP2	3-pin Header
☐	Shunt	2 pin shunt (Qty 2) for JP1 and JP2
☐	RLY	Relay, 12V, DPDT, G6A-234P-DC12
☐	RLY Socket	16 Pin, Dual In-line, Integrated Circuit Socket

Off-Board Parts

☐	J1	Coaxial, DC Connector (Jack), 5.5/2.1mm (Qty 1)
☐	J2, J3	RCA Connector (Jack) (Qty 2)
☐	J4, J5	BNC Connector (Female), Chassis Mount (Qty 2)
☐	Hardware	Chassis, Hammond, HM158 (4.4” L x 3.2” W x 1.7” D)
☐	Hardware	4-40 x 3/8” L Phillip Head Screw (Qty 4)
☐	Hardware	4-40 x 1/4” L Phillip Head Screw (Qty 4)
☐	Hardware	#4 Star Lock Washer (Qty 12)
☐	Hardware	Standoffs, Threaded 4-40, ½” L (Qty 4)
☐	Hardware	Bumpers, Rubber Feet (Qty 4)
☐	Cable, Power	Coaxial DC Connector (Male, 5.5/2.1mm) to Power Pole, 6 Ft. (Qty 1)
☐	Cable, RF	RG-316 Coax, PL-259 to BNC (Male), 3 Ft. (Qty 2)
☐	Cable, Send	RCA (Male) to RCA (Male), Shielded, 3 Ft. (Qty 2)

Sources

1. Most components for printed circuit card assembly were ordered from Mouser Electronics (https://www.mouser.com/).
2. The Lamp (GF780) and Chassis (Hammond HM158) were ordered from Digi-Key (https://www.digikey.com/).
3. The printed circuit card (PCB) layout was designed by K5PA, Gene, and was manufactured by *Express*PCB (https://www.expresspcb.com/) using their free PCB CAD software.
4. Coaxial DC Connector (**Search Amazon:** https://www.amazon.com/stores/page/CCAC5CF3-10D6-4EB9-90C4-521124857A1C/search?ingress=2&visitId=a840ae7e-4539-4a16-8146-77867b0072d8&ref_=ast_bln&terms=B0851CBH87)
5. RG-316 Coax, PL-259 to BNC (Male), 3 Ft. (Qty 2) **Search Amazon:** uxcell UHF (PL259) Male to BNC Male Antenna Radio Cable RG316 Coax Cable 3 Feet for Coax Mobile to Base Antenna
6. RG-316 Coax, BNC (Male) to BNC (Male), 3 Ft. (Qty 2) **Search Amazon:** uxcell BNC Male to BNC Male Coax Cable RG316 RF Coaxial Cable 50 Ohm 1 Feet 2pcs for Video Signals,CCTV,DVR,Camera
7. RCA-RCA Male, Shielded (RG-59 cable), 3 Ft., SKU: 25-140-003, https://www.showmecables.com/




Cable Types: You can purchase the **quantity** and **length** needed in your installation from **Amazon** or **Show Me Cable** websites.

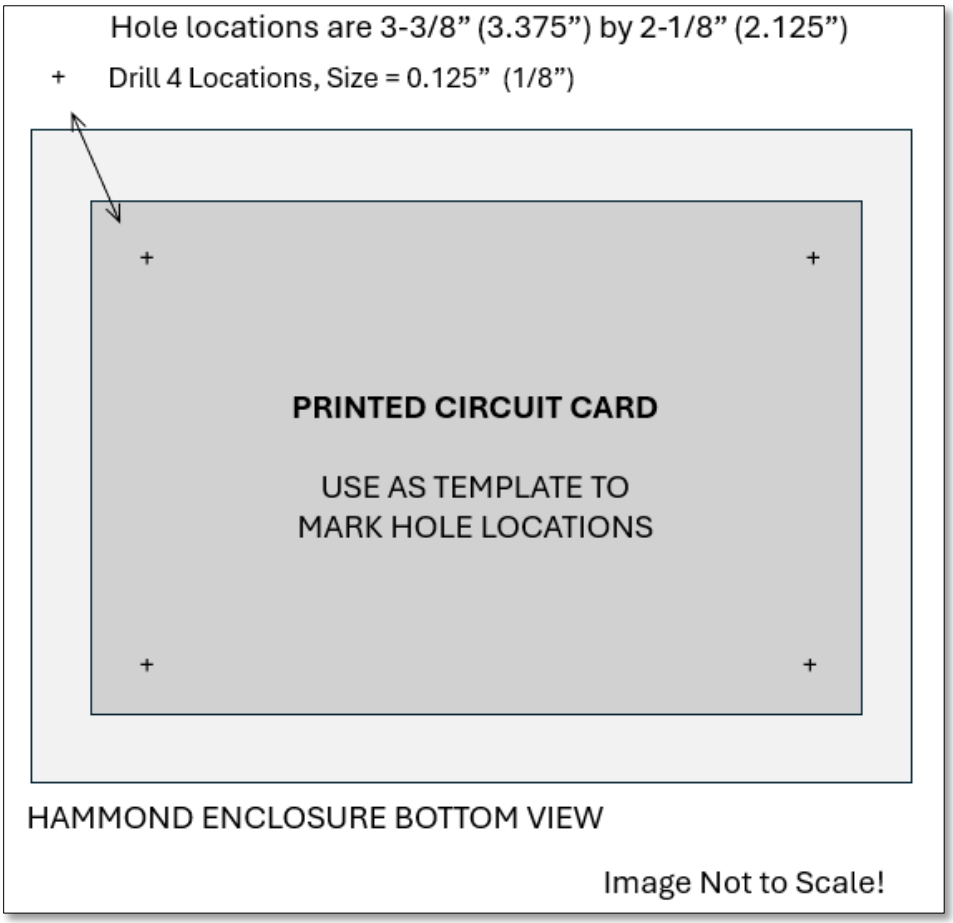
Aluminum Enclosure Preparation

Enclosure Part Number (PN)

1. Hammond Manufacturing 1590S.
2. Digi-Key HM158-ND.

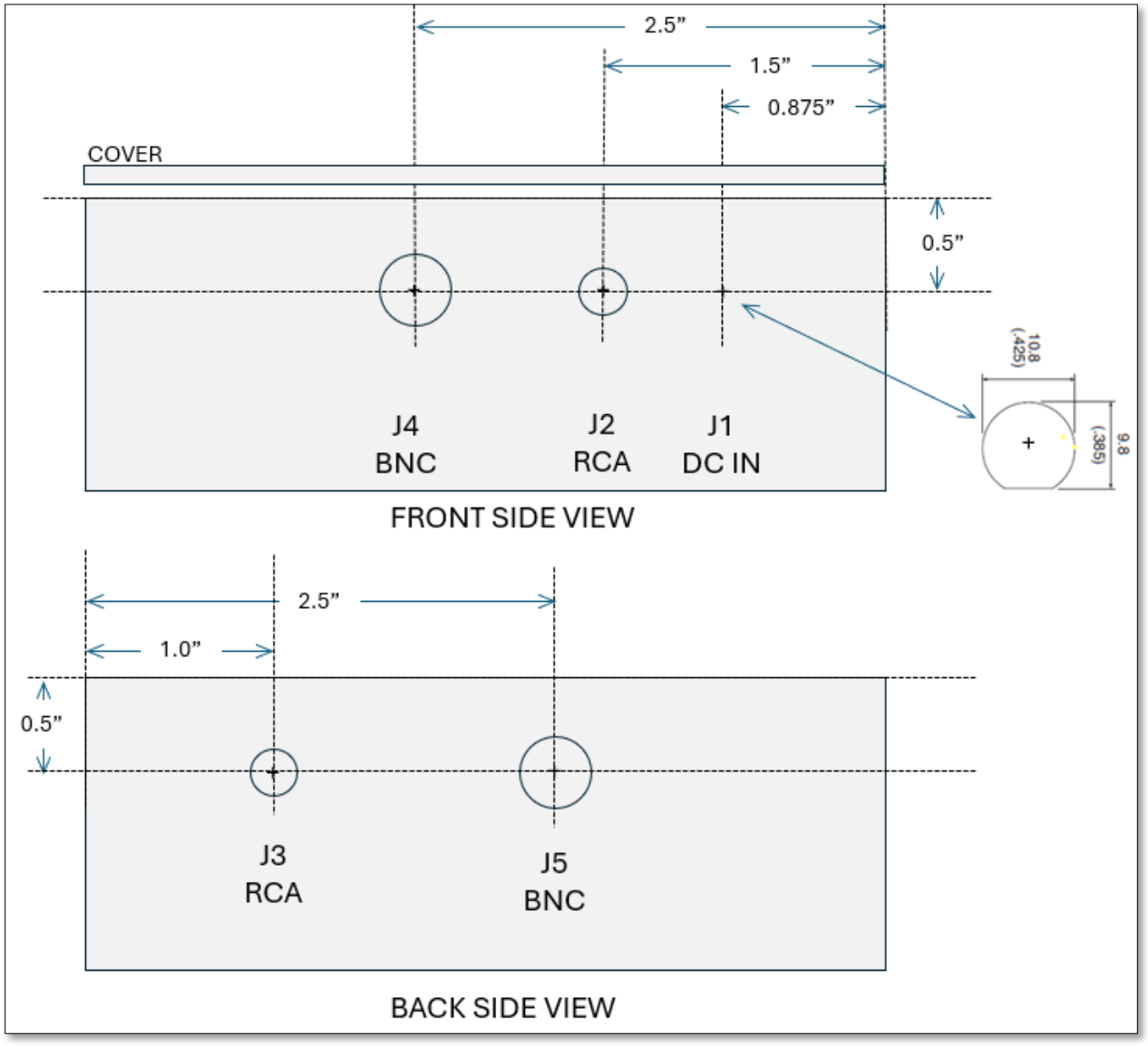
PCB Board Mounting Holes

1. PCB Reference: PN 4000-0076 Rev-B, 4-hole mount.
2. Use Bare Board as template to mark location to drill each hole. ***Do this prior to board assembly!***
3. Turn the Hammond Enclosure upside down, center the PCB on the outside bottom, and mark each hole location. I used a black, permanent marker since the ink will be drilled out.
4. Hole locations are 3-3/8" (3.375") by 2-1/8" (2.125").
5. Drill each hole slightly larger than a 4-40 size screw **using a 1/8" (0.125") drill bit**.



Connector Hole Center Locations, Front and Rear Views

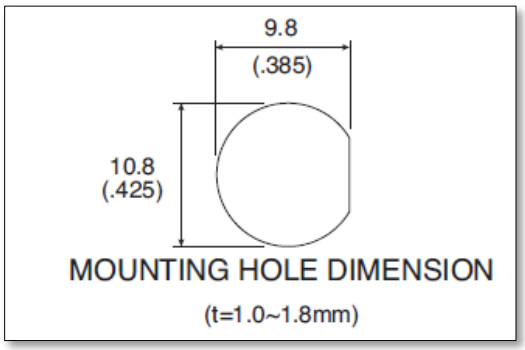
These are the side views of the Hammond enclosure for locating and drilling the pilot holes. Pilot holes are useful prior to drilling the chassis with the larger drill bits. The following pages provide the details about each connector's hole size requirements.



Drawing Not to Scale

J1, Coaxial DC Connector Mounting Hole

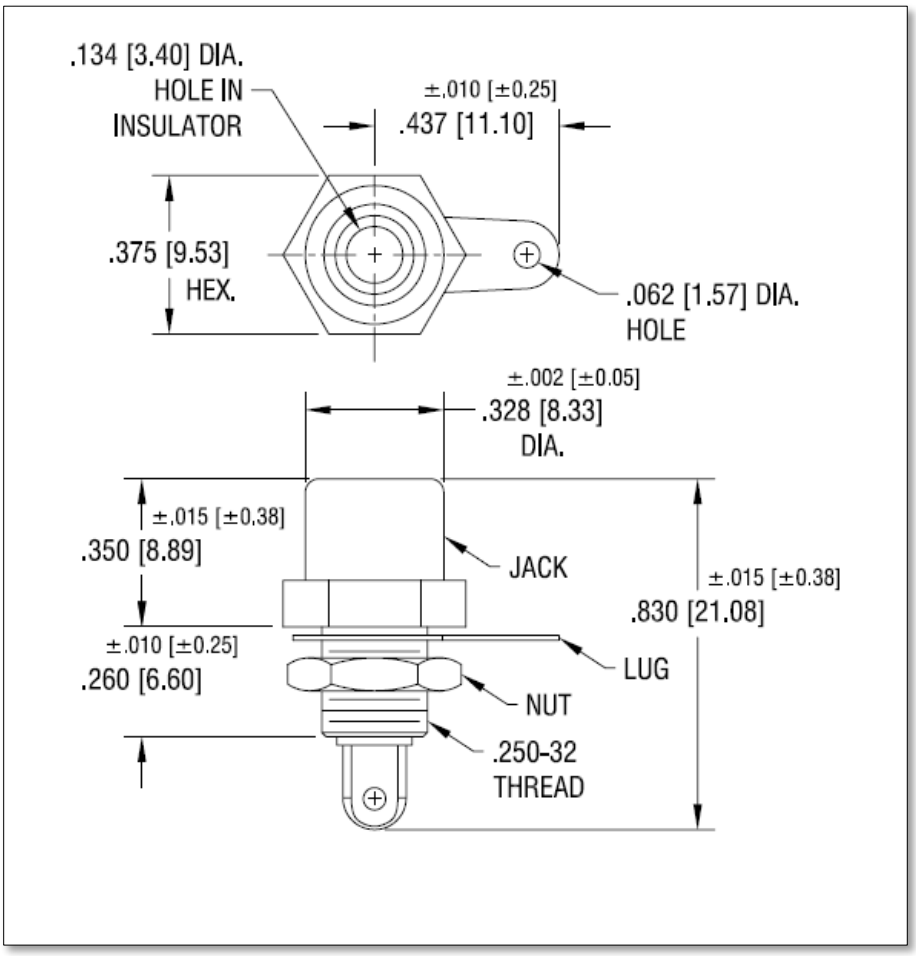
1. KOBICONN PN 163-1060-EX, 5.5/2.1mm
2. Mouser PN 163-1060-EX.
3. This is a D-shaped hole that requires careful forming.
4. Start by drilling a circular hole using a **3/8" (0.375")** drill bit.
5. **Next,** using a small flat file, add the flat side as shown in the drawing. You can use the KOBICONN panel mount jack to judge the proper width.
6. Next, **using a round file**, carefully increase **the circular portion of the hole** to a **0.425" as shown below**.
7. If the hole ends up oversized, you can use a hot gun glue to better secure the connector to the panel.



Panel Mount DC Power Jack
PN 163-1060-EX, 163-1061-EX

J2, J3, RCA Jack Mounting Holes

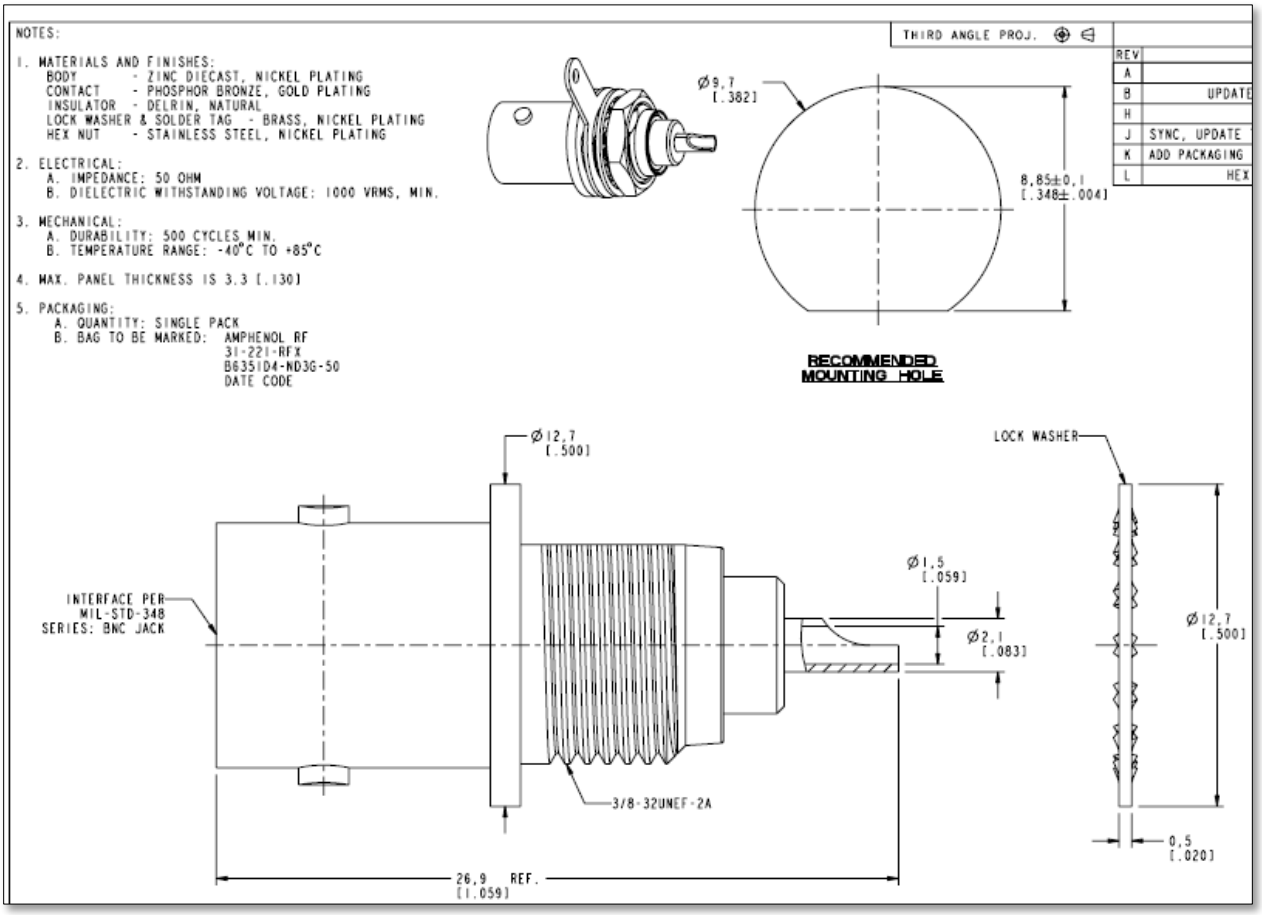
1. Keystone Electronics PN 576 RCA Phono Connectors.
2. Mouser PN 534-576.
3. Hole size, using a **1/4" (0.25") drill bit**.



Mounting Hole Size = 0.25"

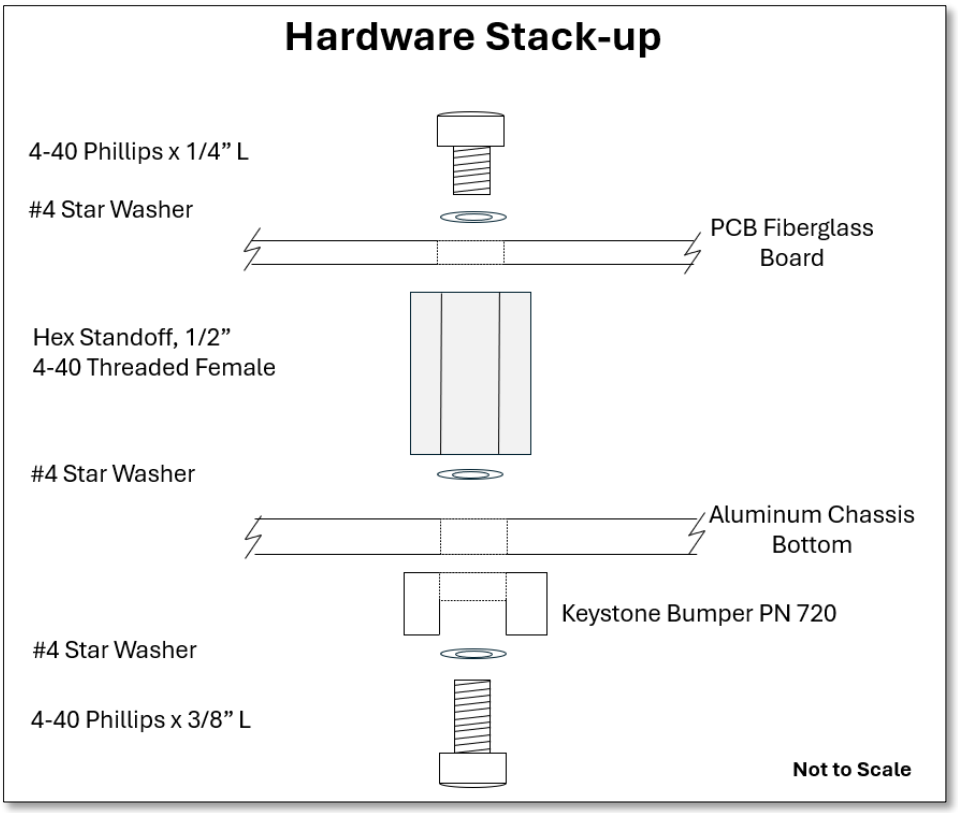
J4, J5 BNC Mounting Holes

1. Amphenol RF, BNC Bulkhead Receptacle Jack, PN Amphenol 031-221-RFX.
2. Mouser PN 523-31-221-RFX.
3. The hole size needed is 0.382" Dia, so **use a 3/8" (0.375") Drill bit** to drill each hole.
4. Use a **round file to slightly increase the diameter to 0.382"** allowing the jack to slip into the hole.



PCBA Standoff and Rubber Feet Installation

1. Total of 4 Standoffs to mount PCBA inside enclosure and 4 rubber feet outside enclosure.
2. Hardware Needed:
    a. 4-40 Phillips x ¼" L Screw, Qty 4.
    b. 4-40 Phillips x 3/8" L Screw, Qty 4.
    c. Hex Standoff, 4-40 x ½" L Threaded, Female, Qty 4.
    d. Keystone Bumper PN 720, Black Rubber Feet, Qty 4.
    e. #4 Star Washers, Qty 12.
3. Insert 4-40 x 3/8" L Screw and #4 Star Washer into Keystone Rubber Bumper foot.
4. Pass screw/washer/rubber foot into bottom side of chassis and into a #4 Star Washer and Hex Standoff as shown below. Loosely tighten to allow a little movement. Repeat this stop until all 4 Standoffs are in place.
5. Place PCBA over the 4 Standoffs and loosely screw in-place using 4-40 x ¼" L Screws with #4 Star Washers.
6. Once all screws are attached, finger tighten all screws until snug. Do not over-tighten the screws holding the Keystone Bumper feet.



Enclosure Labeling

Refer to Image Gallery for Suggested Label Placements

Location: J1, 5.5/2.1mm DC Front Panel Connector
J1 +13.8V
INPUT

Location: J2, RCA Phono Front Panel Connector
J2 SEND
IN

Location: J3, RCA Phono Rear Panel Connector
J3 SEND
OUT

Location: J4, BNC Front Panel Connector
J4 XCVR
RF OUT

Location: J5, BNC Rear Panel Connector
J5 ANT or
AMP IN

Location: Top
RF LIMITER
RX MAX +13 dBm

Location: Top
CAUTION: 13.8V & SEND IN
MUST BE APPLIED WHEN IN USE

Location: Left Side Panel
RF LIMITER PN 4000-0076-B

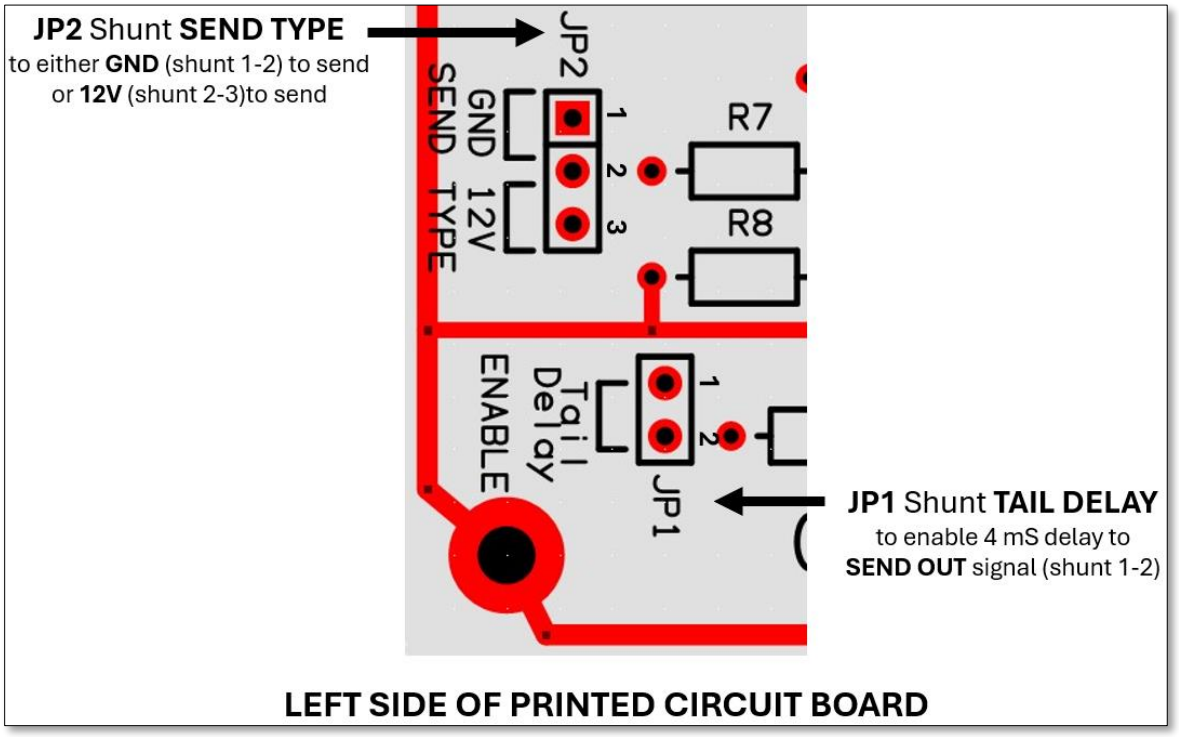
Order of Assembly PN 4000-0076 Rev-B

On-Board Parts Soldering

NOTE: Prior to board assembly, consider using the bare board for locating the 4-mounting hole locations on the Hammond enclosure as described earlier!

1. Fuse Clips X 2
2. 16-pin IC Socket
3. 2-pin and 3-pin Headers
4. R1-R5, R7 Resistors (4.7K Ohms)
5. C1-C7 Capacitors (See BoM)
6. GDT Surge Suppressor
7. U1 Voltage Regulator (MC78L08)
8. Solder Diodes, D1-D4 (1N4003)
9. Solder Diodes, D5-D6 (1N4454)
10. Solder Transistors Q1 (2N3906), Q2 (MPSA06), and Q3 (2N3904)
11. Install GF-780 Lamp into Fuse Clips
12. Install G6A-234P-DC12 Relay into 16-pin Socket
13. Install Shunts (2) into 2- and 3-pin Headers
14. Solder Red/Blk Wire to **J1/12V DC IN** Pads
15. Solder Yellow/Blk Wire to **J2 / SEND IN** Pads
16. Solder White/Blk Wire to **J3 / SEND OUT** Pads
17. Solder #16 Solid Wires to **J4 / XCVR RF OUT** (**RF** and **GND**) Pads
18. Solder #16 Solid Wires to **J5 / ANT or AMP IN** (**RF** and **GND**) Pads

Jumper JP1 and JP2 Settings



NOTE: **JP1** and **JP2** are pin headers than can accept a shunt to connect pins together for configuring options. The shunt part number is given in the material list.

Shunt Settings JP1 and JP2

JP Name	Jumper	Comments
ENABLE Tail Delay, Disable	**JP1**, No Shunt Used	Sets no additional delay
ENABLE Tail Delay, Enable	**JP1**, Shunt Pins 1-2	Adds additional 4 mS delay on **SEND OUT** after **SEND IN** is not asserted
SEND TYPE, GND	**JP2**, Shunt Pins 1-2	**SEND IN** Ground asserts **SEND OUT** line and on-board relay
SEND TYPE, 12V	**JP2**, Shunt Pins 2-3	**SEND IN** +12 Volts input asserts **SEND OUT** line and on-board relay

Various Transceiver and Shunt Settings

Model	JP1: TAIL DELAY	JP2: SEND TYPE	Comments
IC-7300	Shunt Pins 1-2	Shunt Pins 1-2	Uses GND on SEND IN
IC-7600	No Shunt	Shunt Pins 1-2	Uses GND on SEND IN
IC-7610	No Shunt	Shunt Pins 1-2	Uses GND on SEND IN
IC-7610 ALT	Not Used	Not Used	**Alternate configuration** (refer to section later in this document)
IC-706MKIIG	Shunt Pins 1-2	Shunt Pins 1-2	Uses GND on SEND IN
IC-706	Shunt Pins 1-2	Shunt Pins 1-2	Uses GND on SEND IN
IC-7000	Shunt Pins 1-2	Shunt Pins 1-2	Uses GND on SEND IN
Kenwood Radios	TBD	Shunt Pins 2-3	Uses +12V Keying for SEND IN

Functional Testing of Assembly PN 4000-0076 Rev-B

Circuit Board Assembly Testing

1. Start-up conditions: Relay installed, lamp installed in fuse holder, Shunt in place on **JP1 Tail Delay ENABLE** and **JP2 SEND TYPE** selection of **GND** position (not **12V** position).
2. Measure resistance between **J3 RF** pin and **J4 RF** pin (use the solid wire to reach these pin positions). Resistance should be approximately 8 ohms due to the lamp being in series with this path. If not, measure resistance directly across the lamp to resolve the problem.
3. Verify the Power Supply (PS) is OFF and connect leads to **13.8 VDC** (or nominally 12 VDC) to Red and Black wires.
4. Turn PS on and verify +8 VDC is present across capacitor C2 found on PCBA near voltage regulator. If not, turn off PS and check for shorts or solder connections.
5. Measure again the resistance between the **J3 RF** pin and **J4 RF** pin and verify about 8 ohms.
6. Connect **SEND IN** (Yellow/BLK) wires together and verify the relay is activated.
7. Measure again the resistance between the **J3 RF** pin and **J4 RF** pin and verify about 1 ohm. This is the resistance due to the path of the relay contacts directly that bypasses the lamp circuitry.
8. Turn off the PS and move the **Shunt** on **JP2** from the **GND** to the **12V** position.
9. Disconnect any connection to **J2 SEND IN** and turn on the PS. The relay should not be activated. This can be verified by measuring the resistance between **J3 RF** and **J4 RF** pins as being about 8 ohms. Turn off the PS connected to the circuit board Red/BLK wires.
10. Attach a variable output voltage PS to the **J2 SEND IN** terminal. Plus connects to the yellow wire and Negative to the black wire. Set the variable PS to 0 Volts. The maximum voltage it will be adjusted to will be 12 V later. Now turn on the 13.8VDC PS that powers the circuit board.
11. First, verify the relay is not activated by measuring about 8 ohms resistance between **J3 RF** and **J4 RF** pins.
12. Raise the variable output voltage PS and watch for the relay to click on that can be verified by measuring the voltage between **J3 RF** and **J4 RF** pins. The voltage when the relay toggles should be greater than 2 to 3 volts. This voltage can be raised as high as 12 VDC and the relay should remain toggled on.
13. Turn off all PS connected to the board. Verify the **JP2** shunt is in the position needed for the connection to the host transceiver. ICOM typically will use a **SEND IN** voltage of 0 volts (**GND**

setting on 2-pin header). Some other manufacturers will use a **SEND IN** voltage of 12V to invoke a transmit condition.

14. For the IC-7300 transceiver, the **JP1** Shunt should be left in the **ENABLE** position. This will create a 4 mS delay on the **J3 SEND OUT** pin driving an external amplifier. The IC-7610 could be set with the delay not selected by removing the shunt completed or letting it rest on only 1 of the pins so it does not connect the 2 pins together.
15. This completes the functional readiness tests for the PCBA. It is now ready to be installed in the metal enclosure. Afterward, the tests can be re-run if desired.
16. Additional tests can be run to measure the dynamic delay time of the **JP1 Shunt** by using a 1 second period, 50% duty cycle waveform as the **J2 SEND IN** signal and measuring the delay at the **J3 SEND OUT** pin. With the **JP1 Shunt** in the circuit, the delay is approximately 4 mS. Without the shunt, there should be no delay.

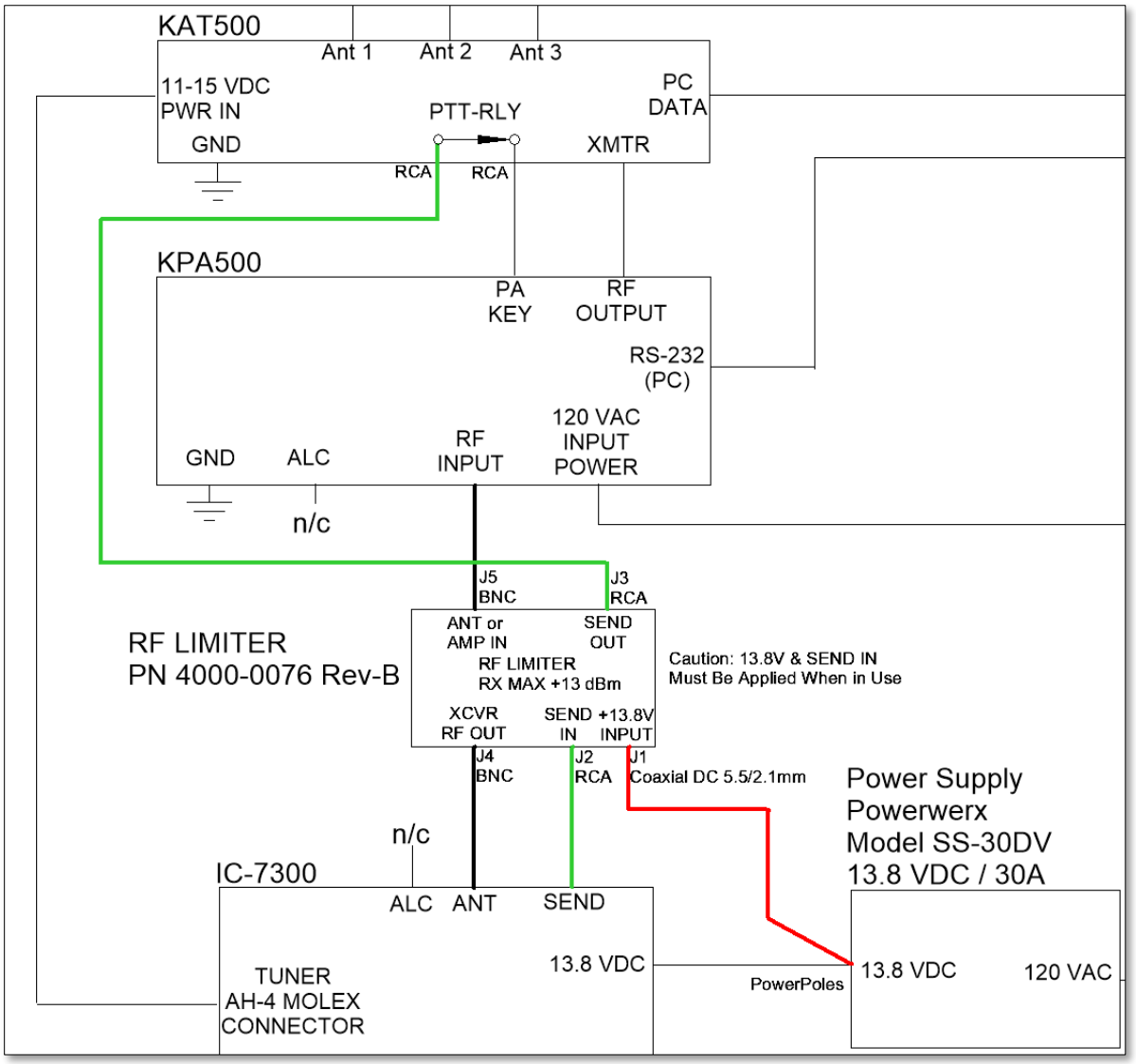
System Integration with Transceiver, Amplifier and Tuner at Remote Site

The partial block diagram is from the interconnection of equipment at several of the remote radio sites consisting of ICOM and ELECRAFT equipment. The RF LIMITER is shown with its 5 inputs/outputs connected to the IC-7300 transceiver, KPA500 power amplifier, and KAT500 antenna tuner.

In applications not using an amplifier and/or tuner, the RF LIMITER'S **J5** BNC (labeled **ANT or AMP IN**) would be simply connected to the antenna feedline.

BLOCK DIAGRAM OF INTEGRATION WITH **IC-7300/KPA500/KAT500**

(Standard Configuration)



Black Bold: RF Cables, BNC to PL-259

Green Bold: RCA Cables, RCA to RCA Shielded

Red Bold: 13.8 VDC Power Cable, Coaxial Power 5/2.1mm to PowerPole

To reduce the opportunity for the PowerPole to accidentally pull away from the power supply, a tie wrap strap can be used to tie both the Powerwerx front panel connectors together. This should keep on or the other PowerPole connector from pulling away from the power supply (and if they do, then both will pull away). This assures the integrity of the power supply connection to the transceiver plus the RF Limiter.

A similar tie of the RCA cables that plug into the SEND IN and SEND OUT jacks can be done to keep either one from pulling away. In particular, the SEND IN, should not ever be removed from the limiter while it is in use.

Alternate *Receive-Only* Configuration

The **Alternate *Receiver-Only* Configuration** can be used with a receiver or receiver-side of a transceiver that allows filters or other devices to be inserted inline with the receiver's front-end path. An example is the ICOM IC-7610 transceiver.

In this configuration, only the circuit board's receive RF pathway is used. The unit's internal switching relay, SEND IN, SEND OUT, and 13.8VDC Power are not used. This greatly simplifies the wiring to the unit. Also, all the circuit components "could" be left off the circuit board that relates to power, relay control, and send in/out! Only the RF coax connections to the 2 BNC connectors, **J4 to RX** and **J5 to ANT**, are needed. Therefore, the enclosure just needs to have the BNC connectors mounted along with the internal circuit board assembly. This is shown below as an example.

Alternate Configuration Build Showing Top, Front, and Rear Panel Views

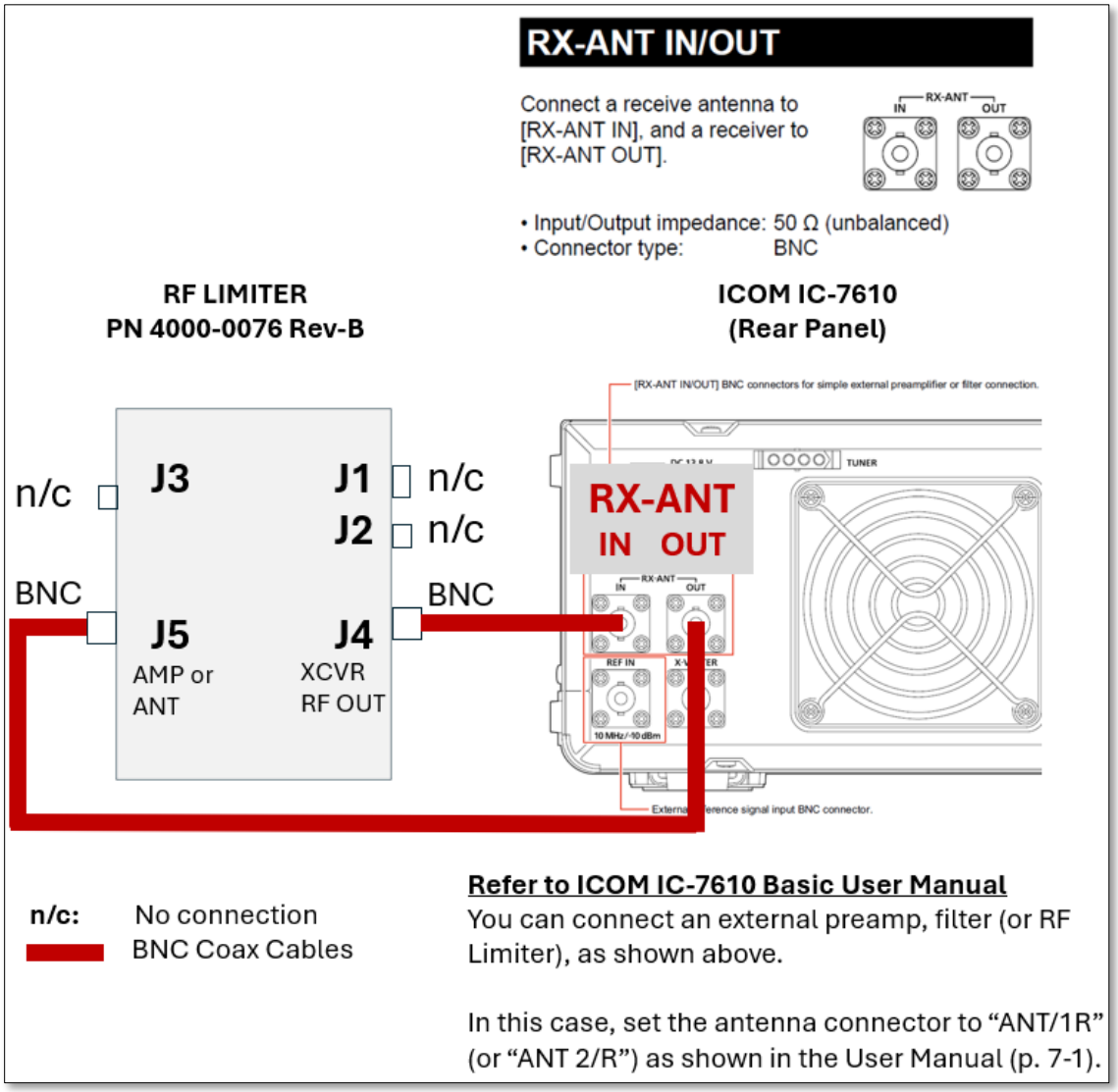
Restating this, the **Alternate Configuration** only needs the receive side RF pathway where there is no possibility of transmitter output connections. Otherwise, the internal diodes and lamp would be damaged and would have to be replaced. The Rx Only aspect of this configuration is attractive for transceivers, like the IC-7600 or IC-7610, that allow external receive path modules to be inserted. The next section will describe how to use it with the IC-7610. The last section of this document shows the **Alternate Configuration** schematic of the components used.

Alternate Configuration for the ICOM IC-7610

With the Alternate configuration, the RF input/output connections are controlled by the internal circuits of the IC-7610 transceiver. These must be correctly set and must not be changed inadvertently since it might take the RF LIMITER out of the RF path.

In this alternate configuration, the RF LIMITER module connections **J1**, **J2** and **J3** are not connected since only the receiving path of the limiter is being used (as opposed to the transmit path) and all RF switching is handled by the transceiver's internal circuits. Also, the internal shunt settings or **JP1** and **JP2** for setting **SEND TYPE** (*GND* or *12V*) type and **ENABLE** (*Tail Delay*) are not being used in this alternate configuration.

You must configure the IC-7610 according to the Basic ICOM Manual instructions so it can perform the correct sequencing (see Chapter 7, p. 7-1). I have summarized these instructions on the next page.



Alternate Configuration Programming the ICOM IC-7610 for Using the RX-ANT I/O Connections

Hardware Cables

On the Rear Panel of IC-7610 (BNC Male to BNC Male Cables)

Connect **RX-ANT**, **IN** to **RF LIMITER**, **J4 XCVR RF OUT**

Connect **RX-ANT**, **OUT** to **RF LIMITER**, **J5 AMP or AMP IN**

ICOM IC-7610 Settings

On the IC-7610 Front Panel Buttons or Display

Press the **MENU** (physical hardware) button then Press the soft button **ANTENNA** (showing on display screen).

To the upper right side of the table, is a **TYPE** heading with an entry setting displayed below it. To change this entry to the desired one, you must press the soft button at the extreme right-lower side of the display, entitled: **TYPE**. So, press **TYPE**.

A menu will appear entitled: **RX-ANT Connectors** that will show **Connect Receive Antenna** (or Connect External RX Device) as the current setting. You will want it set to **Connect External RX Device** as the entry, since the RF Limiter is considered a device, similar to a filter. On the **RX-ANT Connectors** heading, press it and then press the **Connect External RX Device**.

You may receive a warning screen if your selection changes the current setting in the main table. If you do and are sure of the change, press **YES,** otherwise press **NO**.

Press the soft button (like this ⮌) to go back to the table entries.

You should now see the **TYPE** entry in the table that you selected: **RX-I/O**.

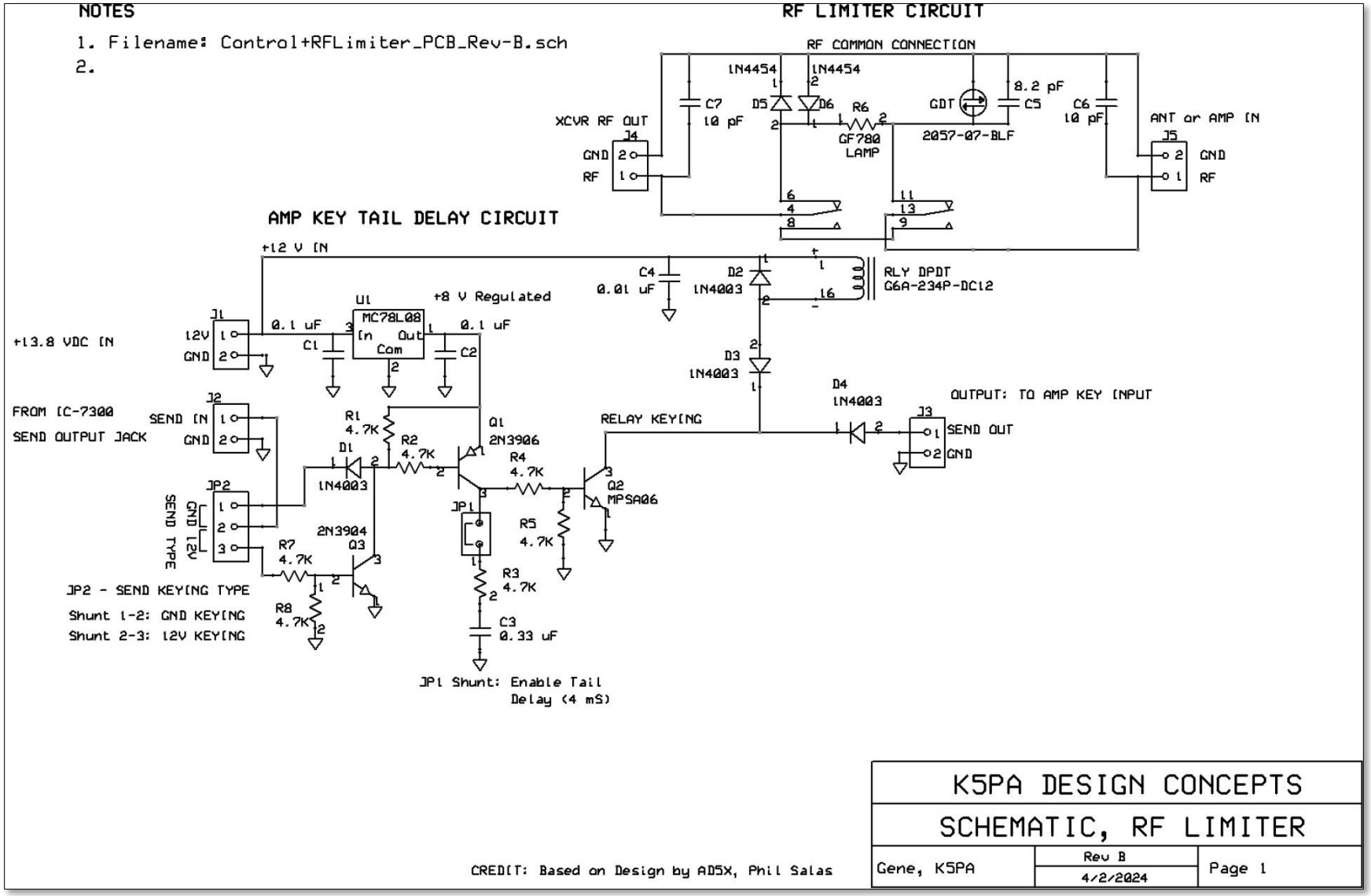
Now go to each frequency range segment by pressing on the IC-7610 Frequency Display and select a main frequency that is included in the next segment you want to modify in the table. For example, if you are already in the 11.0-15.00 segment, and want to move to the 8.00-11.00 segment, then move the frequency knob or press on the MHz range of the band segment.

Press the **RX-IO** soft-button to select it for this frequency segment. When you press the **RX-IO** button, the entry has a star (*****) after it indicating it is temporary. Save it to memory by **pressing and holding for 2 seconds** the **ANT MW** soft button.

Repeat for all segments where the RF LIMITER will be used, mostly likely all the frequency band segments!

Once completed, the RF LIMITER will have to be always connected to leave it in the RF receiver path. You can use a coax jumper cable at the rear BNC connectors on the IC-7610 if you need to temporarily remove the RF LIMTER for service. Otherwise, you will need to change the settings in the table back to their original settings.

SCHEMATIC DIAGRAM PN 4000-0076 Rev-B



ALTERNATE CONFIGURATION
RECEIVE ONLY