Assembly Manual for the

UHF GaAsFET Preamp

K-6309

Dick Smith Kit

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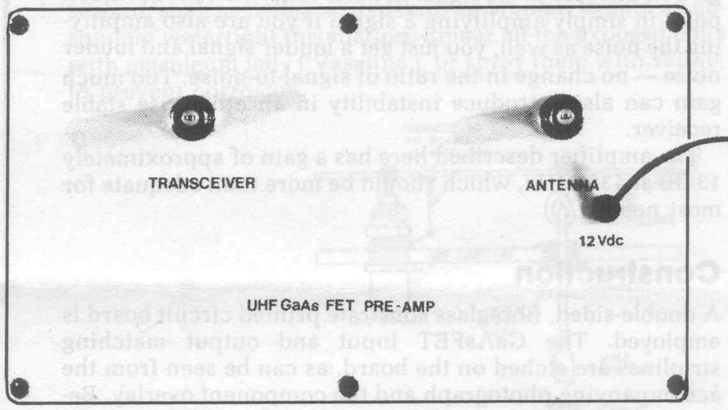
This easily constructed unit will improve the receiver performance of your UHF rig 'out of sight', particularly if you find it necessary to run a long length of feedline between your antenna and your rig.

ONE OF THE MAIN FACTORS that contribute to the 'station system performance' of any UHF communications installation, be it amateur, CB or 'professional', is receiver *front end noise figure*. Two things, primarily, determine this parameter: feedline loss between the antenna and the receiver input, and the noise factor (or noise figure) of the device employed in the first stage RF amplifier. You can virtually eliminate the contribution of feedline loss by mounting the receiver's first RF stage as close as possible to the antenna feedpoint. The next step is to employ a low noise device for that first RF stage.

A problem arises here, in that the vast majority of transceivers available do not have a demountable front end — it's securely built-in with the main equipment. To get around this little inconvenience, one employs an 'outboard' RF stage, or preamp.

Twenty years ago there was little choice in low noise devices for UHF applications. The start-of-the-art was represented by a vacuum tube (or valve) known as the 416B, a specially-constructed 'lighthouse tube' (because that's what it looked like). It could achieve a noise figure in the 400-500 MHz region of "better than 3 dB" when front end noise figures of 6-10 dB were common.

These days, a noise figure around 1 dB or so is regarded as pretty well state-of-the-art in the 400-500 MHz region, readily achievable with a variety of solid-state devices. While bipolar transistors held sway for over a decade in this area, more recently gallium arsenide field-effect transistors (GaAsFETs — "gas FETs" to the congniscenti) have moved to the fore. When first introduced, GaAsFETs for the application were a *fearsome* price — anything from a week's to a month's average take-home pay. But, as is historically the case with most electronic devices, their price has fallen substantially in very recent history and now they may be purchased at a cost similar to many commonplace semiconductor devices.



The preamp is housed in a diecast aluminium box which is mounted as close as possible to your antenna. Note the dc supply lead entering the box at right.

Design considerations

In order to perceive the benefits derived from using a masthead preamplifier it is necessary to understand some of the mechanisms involved. In the lower VHF bands, thermal noise from the sky does not make it worth trying to achieve a noise figure less than about 2 dB for terrestial communications. At higher frequencies however, a low noise figure will give significant improvements in receiver performance as the level of thermal noise is lower and the majority of noise present will be generated in the receiving system itself. The 3SK121 GaAsFET used in this amplifier has a typical noise figure of 1.5 db at 800 MHz.

Many operators would be surprised at the noise figure offered by some commercial transceivers, which, particularly with some UHF CB units, can be up to 5-6 dB. It is the first stage of a receiver which, to a large extent, determines the total noise figure. If an amplifier with a noise figure of, say, 1.5 dB is added ahead of a receiver with a 5 dB noise figure, the resulting noise figure of the system will be only slightly higher than the noise figure of the amplifier itself. Therefore, the signal-to-noise ratio of received signals will be much improved.

It is a popular misconception that a preamplifier fitted inside a transceiver will achieve a similar performance. This is borne out by the number of operators who use the recent breed of RF power amplifiers with in-built GaAsFET receive preamps. These can be considered a singularly useless device when trying to achieve low noise figures, unless mounted

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at your antenna, the reason being that feeder loss is ignored.

For example, assume that you have a typical UHF setup of a Yagi antenna, 15 m (50 ft) of 'good quality' coaxial feedline (RG213), a linear amp with GaAsFET preamp and your rig. Now, reading the manufacturer's blurb on the preamp gives a noise figure of under 1 dB (typically). You would be wrong to assume that this is essentially the noise figure of your system.

At 420 MHz, RG213 has a loss of about 1.6 dB per 10 m (4.8 dB per 100 ft). So, for the 15 m (50 ft) of feeder you would have to *add* 2.4 db to your noise figure, i.e: it would be effectively greater than 3 dB — not too bad, but not what you would expect when you think about your low-noise preamp.

Suppose you were using RG58A instead (worse than wet string at UHF), with a loss of 3.46 dB/10 m (10.4 db/100 ft). This would result in an effective noise figure in excess of 6 db.

The answer, of course, is to put the preamplifier at the other end of the feedline (i.e: at the antenna) then, provided the amplifier has more gain than the feeder has loss, the noise figure of the system will be largely determined by that of the amplifier.

Another misconception with preamplifiers is "the more gain they have the better". This is not necessarily true. As can be seen from the above, decreasing the noise figure will give an increase in the signal-to-noise ratio. There is not much point in simply amplifying a signal if you are also amplifying the noise as well, you just get a louder signal and louder noise — no change in the ratio of signal-to-noise. Too much gain can also introduce instability in an otherwise stable receiver.

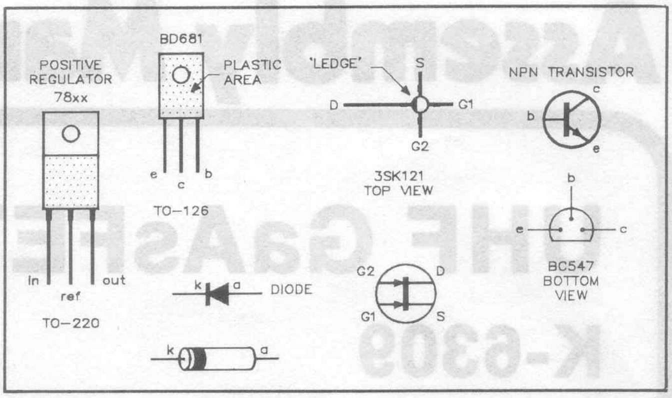
The amplifier described here has a gain of approximately 13 dB at 438 MHz, which should be more than adequate for most needs.

Construction

A double-sided, fibreglass substrate printed circuit board is employed. The GaAsFET input and output matching striplines are etched on the board, as can be seen from the accompanying photograph and the component overlay. Because of this, any attempt to construct the amplifier without using this pc board is almost doomed to certain failure.

Construction is quite straightforward. Before assembling the components to the board, check that all the required holes are drilled and that there are no small copper 'bridges' between closely-spaced pads or tracks. This will obviate any problems later. The components can generally be mounted in any order you wish, but it's advisable to leave the GaAsFET till last. Also, diodes D6 and D7 are best mounted before mounting the coaxial relay RLA, which partially obscures them. As always, care should be taken that the polarised components are all mounted with the correct orientation.

It is essential that the minor components are mounted with the *absolute minimum lead length*, especially the ceramic capacitors C3, C6, C8, C9, C10 and resistor R2. Note that some components are soldered to the top surface tracks or groundplane of the pc board and do not have holes drilled through for all leads. These include Q3, C3, C6, R2, C8, TC1,



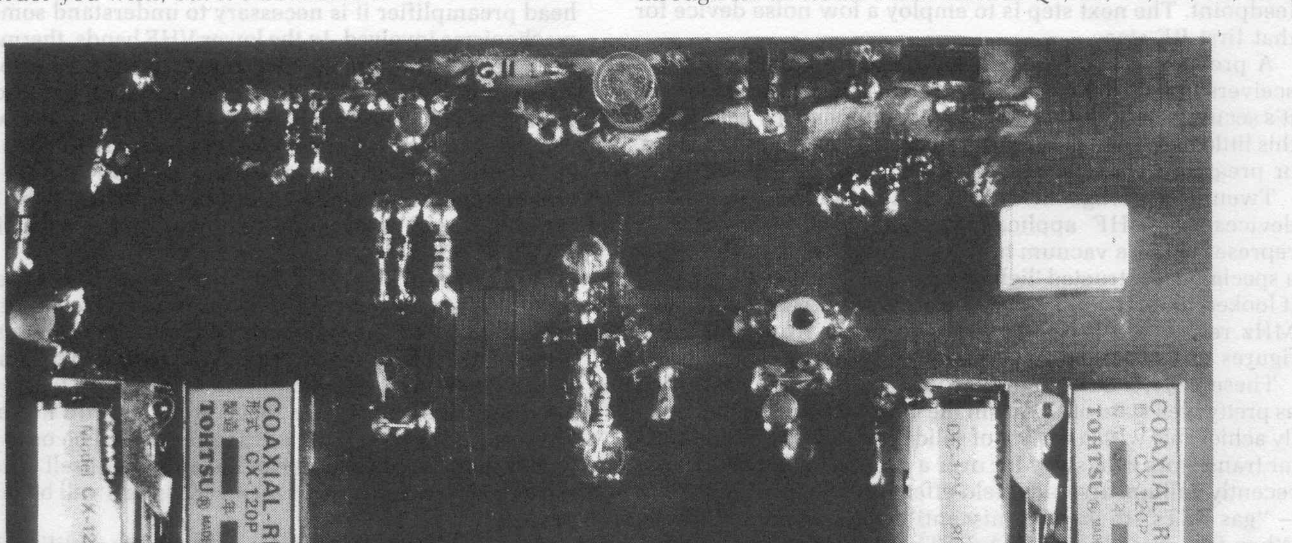
A WORD ON GaAsFETS

FET devices employing gallium arsenide (GaAs) first appeared around a decade ago. They are depletion mode field-effect devices, similar to depletion metal oxide silicon (MOS) FETs.

A moderately doped n-channel runs between heavily doped drain and source regions. Without gate-to-source bias, a current will flow from drain to source. If the gate is now made negative, the resultant electric field will force electrons out of the channel, 'depleting' the channel of charge carriers, reducing the drain-source current flow. When a positive voltage is applied to the gate, the channel will be 'enhanced', increasing drain-source current flow.

Single gate types are not as linear as enhancement types, but having two gates on the channel overcomes this. Hence, dual-gate types are widespread. Gallium arsenide is an inherently lower noise, higher speed semiconductor, though devices employing it are generally costlier to manufacture than silicon-based semiconductor devices. However, their cost has dropped considerably in recent times.

Typically, they are employed as low noise amplifiers and mixers in UHF circuit applications. For this reason, they are generally housed in a "macro-X" stripline package as illustrated in the 3SK121 pinout.



View of the completed preamp.

C10 and RFC2. Also, while the pc board is double-sided, topside and bottomside component pads are not plated-through so, where necessary, components should be soldered on *both* sides of the board. This is especially important where one leg of the component connects to the groundplane on both sides. i.e: Diodes D1 to D4, D5 and D6; RFC1: transistors Q1 and Q1; capacitors C3, C5, C6, C10, C11 and C12 plus the trimmer TC1; resistors R1, R2 and R6; and the 'ref' (centre) leg of the 5 V regulator, IC1.

The usual electrostatic discharge (ESD) safety precautions should be observed when soldering the GaAsFET. i.e: use an iron with an earthed tip, don't use too much or too little heat and don't run around on nylon shag pile carpets beforehand. It will probably be necessary to trim the drain lead of the GaAsFET before soldering. Gently tin the device's leads and the tracks on the pc board to which they mount before soldering it in place. To solder it in position, hold it in place with needle-nosed pliers or a pair of tweezers, making sure it's correctly oriented (see the pinout diagram). Then apply the flat of the iron tip to each lead in turn, applying a little pressure, so that the device's leads are *sweat-soldered* to the tracks.

The lead to the +12 V supply is attached last of all. It is soldered on the *rear* (non-component) side of the board, on the pad adjacent to C5 (see the overlay drawing). Use medium or heavy duty hookup wire (preferably with insulation colour-coded red).

As you can see from the lead photograph, the unit is housed in a diecast box. This comes pre-drilled. The pc board is held in place by the two BNC coaxial connectors. Mounting the board to these is the only 'difficult' part of the construction. the two BNC sockets are mounted to the lid of the box, in the holes provided. Solder lugs are mounted under the securing nut and washer on each. About 20 mm of heavy gauge tinned copper wire should be soldered to each lug which needs to be oriented such that the wire can be soldered to the rear (non-component) side groundplane of the pc board adjacent to the pads for the coax sockets' centre conductor pins. The +12 V supply input wire passes through a small grommeted hole in the diecast box lid adjacent to the ANTENNA socket. First tie a knot in it about 20-30 mm from the board to prevent any strain being put on the pc board joint whenever the wire is tensioned. The accompanying diagram shows the general arrangement. A small amount of silicone sealant should be applied to the grommet, as indicated, to prevent moisture ingress following installation.

There is not much space between the board and the case lid to solder the two coax sockets, but a fine-tipped iron should manage it. You could heat each socket's centre conductor pin from the component side of the board, applying the solder to the pin and board pad on the opposite (non-component) side. It would be a wise idea to tin the BNC socket centre conductor pins first. Don't forget to solder the wires from the coax socket lugs to the non-component side ground-plane.

Finished? Give everything a thorough visual check.

A mounting bracket, as shown in the accompanying drawings, may be needed to secure the completed unit to your antenna mast, unless you have some other arrangement in mind. This can be bent up from a scrap piece of metal, as shown here, and attached to the box with a pair of large, galvanised bolts and nuts. The bracket should be attached before final assembly.

Initial tests

Test the unit 'on the bench' before attempting to mount it up your antenna mast. Apply +12 V to the supply lead, the supply negative going to the case. Ensure that the relays energise when the supply is connected, and de-energise when it's disconnected.

Attach either a dummy load or an antenna to the ANTENNA socket and your transceiver to the other coax connector. Apply the 12 V supply, energising the three relays. See that the relays de-energise when you key the transmitter.

Alignment

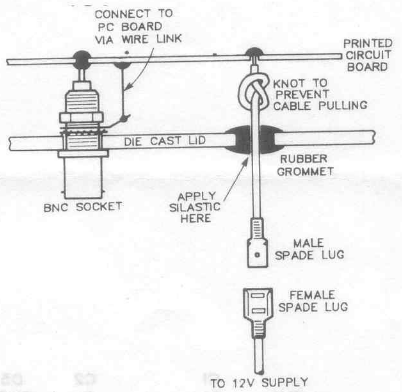
This can be carried out on the test bench, too. There is only one adjustment — this involves trimmer capacitor TC1, which resonates the GaAsFET's drain circuit. How you do the alignment depends on the test equipment you have at your command. Ideally, an automatic noise factor analyser should be used (expensive and rare). Failing that, excellent results were obtained with the prototypes by the simple expedient of aligning TC1 for best signal strength reading on an S-meter while tuned to a weak signal. You can check that this delivers the required signal-to-noise ratio improvement by alternately energising and de-energising the relays.

With the alignment completed to your satisfaction, screw the lid in place, putting silicone sealant around the rim to prevent the ingress of moisture.

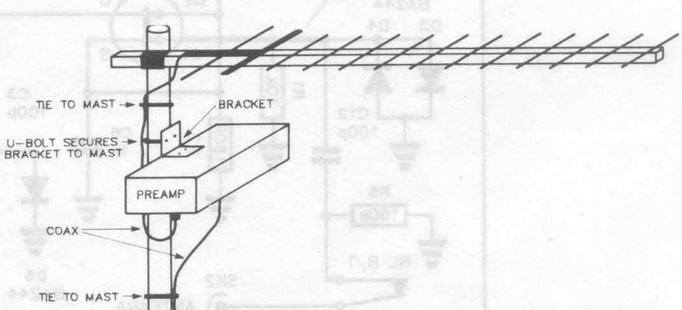
Installation and use

The completed and aligned unit should be mounted on the antenna mast and the ANTENNA socket linked to the antenna feedpoint with a short piece of good quality coax. The feedline to the transceiver is then connected to the TRANSCEIVER socket of the unit and a line run from the unit's +12 V lead to the power supply in your shack.

Mount the unit with the connectors facing *downwards* to prevent the ingress of water. If desired, the whole unit, including the coax connectors, can now be painted with a sealant, such as Selley's "Redskin" or similar, to gain an absolutely watertight installation. Smear all the exposed bolts with petroleum jelly ('Vaseline'), or spray them with WD40, to prevent corrosion.



Showing arrangements for the +12 Vdc supply lead. Care should be taken that, when mounting the preamp on your mast, the spade terminals should be prevented from shorting against the case or the metal mast. Slip plastic 'spaghetti' insulation or heatshrink tubing on one lead, then smear petroluem jelly ('Vaseline') on the assembled spade connector before covering it with the spaghetti or heatshrink.



General mounting arrangement. The unit should be mounted as close as possible to the antenna feedpoint with the connectors facing downwards to prevent moisture ingress. Care should be taken to securely strap the coaxial feedline cable to the mast so that the full weight of the cables is not taken by the preamp's coax connectors.

STRIPLINE

A 'stripline' consists of a thin conducting strip spaced from a 'groundplane' by a layer of dielectric material, as the figure here shows. Microstrip can be understood by either an evolution of the coaxial line or a modification of a parallel wire line. Propagation down the line, in the case of a single uniform dielectric and a lossless conductor, is via the transverse electromagnetic (TEM) mode. In this mode the electric and magnetic fields are at right angles to each other and at 90° to the direction of transmission. However, in a practical stripline the field lines are not entirely contained within the substrate, generally occupying a region of the groundplane approximately three times the strip width for large width:height ratios.

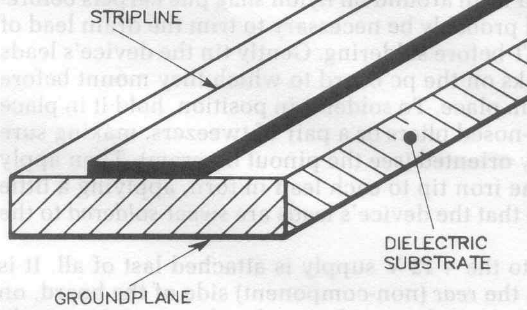
Striplines came about from the development of printed circuits which sharply accelerated after World War II. In 1949, Robert M. Barrett of the US Air Force Cambridge Research Centre, proposed the adaptation of printed circuit techniques to transmission line applications. Interest accelerated in the early '50s and in the spring of 1952 Sanders Associates, Inc, began investigations into a dual groundplane, solid dielectric form of transmission line called "tri-plate". Around the same time other investigators were working with different configurations. Airborne Instrument Laboratories developed techniques using air dielectric called "stripline" while ITT introduced a single groundplane, solid dielectric called "microstrip".

By 1955, a wide range of strip and microstrip components had appeared in microwave and UHF applications. Improvements had also been made in line dielectric materials. Early materials such as Teflon, fibreglass and rexolite were complemented with Teflon fibreglass, beryllia, quartz, alumina, sapphire and magnesium titanate.

Development of miniature coaxial connectors and stripline transistor packages that were compatible with the flat nature of strip transmission lines, were major breakthroughs. They permitted low VSWR transitions and easy mechanical construction.

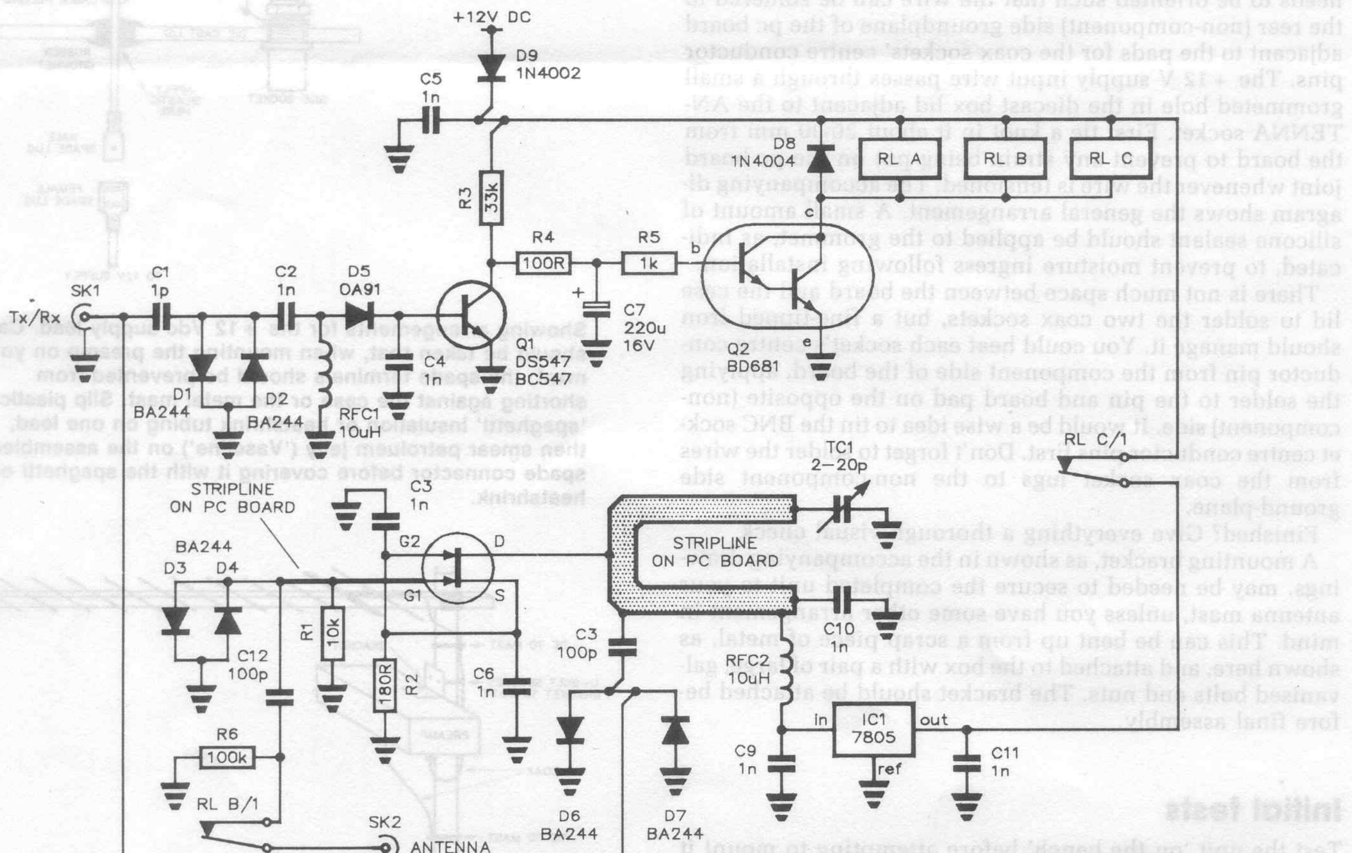
Tri-plate is used extensively in directional couplers and other VHF/UHF circuits were shielding is paramount, while stripline has found application in high power VHF/UHF amplifiers and FM broadcast transmitters.

Microstrip has found applications in matching networks, filters, mixers, frequency counters and solid state amplifiers. It has the advantages of low cost and ease of manufacture, yielding consistent results.



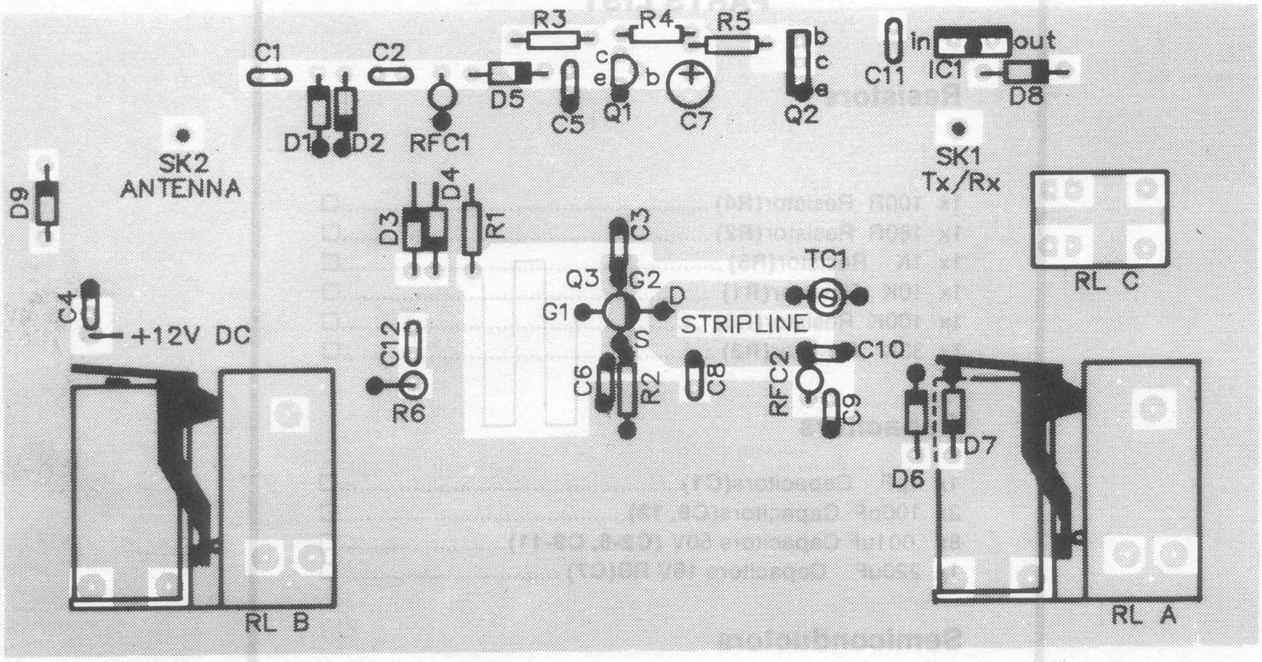
Stripline or microstrip transmission line consists of a thin conductor placed on one side of a dielectric substrate having a groundplane on the other side. The characteristic impedance of such lines is a function of the ratio of the strip width to the dielectric thickness.

CIRCUIT DIAGRAM

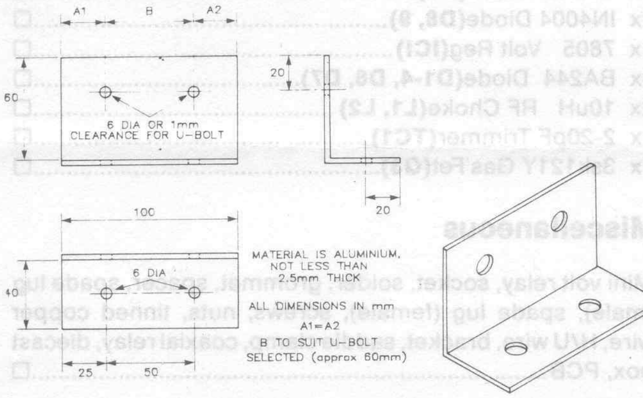


Circuit of the low-noise UHF GaAsFET preamp. Note the 'stripline' input and output matching lines for the GaAsFET. These are etched on the pc board.

COMPONENT OVERLAY



Component overlay. A double-sided pc board is employed, only the topside copper area is shown here, for clarity. Note that diode D7 is obscured by the coaxial relay RLA.



CIRCUIT OPERATION

The 'heart' of the amplifier is the Toshiba 3SK121 GaAsFET. Input and output to the device is by means of printed circuit board stripline circuits. The output tuned circuit is resonated by TC1, a 2-20 pF trimmer.

In the 'through' mode, the antenna input is connected via the two coaxial relays and 50 ohm stripline to the output socket.

In 'receive' mode the three relays, RLA-RLB-RLC, are energised. This is done to provide 'fail-safe' operation so that if the 12 V supply to the amplifier should fail or be inadvertently turned off, the amplifier will assume the 'through' mode.

Coaxial relays RLA and RLB connect the antenna to the input of the amplifier and the output to the receiver or transceiver. The miniature relay, RLC connects the supply from the five volt regulator ICI, to the GaAsFET. The 3SK121 is self-biased via R2 in the source circuit.

The antenna is coupled to the amplifier via C12. The 100k resistor, R6, are used to provide a dc path to ground to prevent build-up of static voltages on the antenna.

The unit employs RF sensing to switch between receive (preamp) and transmit (through mode). Fast-switching diodes D3-D4/D6-D7 (BA244s) are used at the input and output of the amplifier itself to shunt excessive RF whenever the transmitter is activated.

When the transmitter is activated, the RF signal is coupled to the sensing circuit by C1 (1 pF). Again, fast-switching diodes, D1/D2, prevent excessive RF voltage appearing here. The RF is rectified by a germanium diode, D5, and the resultant dc turns transistor Q1 on. Capacitor C7 (100 uF) discharges quickly through R4 and Q1, thus turning the Darlington transistor Q2 off and relays, RLA, RLB and RLC de-energise.

In the de-energised state the coaxial relays switch the transmitter straight through to the antenna while relay RLC removes the 5 V supply to the GaAsFET.

When the transmitter is turned off, transistor Q1 will turn off also, allowing C7 to charge slowly via R3 (100k) and R4 (100 ohms). When C7 has charged sufficiently, transistor Q2 will turn on again, thus energising the relays. The delay in turning on is provided to prevent relay 'chatter' when using SSB or CW modes. The delay may be shortened if desired by reducing the value of R3 (100k).

Some operators may prefer to use hard switching in lieu of RF switching. This can be accomplished by ommitting C1, D1, D2, C2 etc, and connecting the switching voltage (usually 12 V via a suitable resistor to the base of Q1. It would be wise to retain C4 (1n), and also feed the switching voltage into the enclosure via a suitable feedthrough capacitor.

The unit is powered from an external 12 V dc (nominal) supply and consumes about 200 mA in receive mode. If extremely long runs of cable are used, it would be advisable to check that the supply is not below 12 V at the amplifier or the 12 V coaxial relays may not switch reliably

It is important to remember that the dc return (-ve side of supply) is via the outer braid of the coaxial feedline, from the transceiver to the amplifier, and if a separate supply is used to power the amplifier, a connection should be made between the negative side of the supply and the braid of the feedline. If the same supply is used to power both the amplifier and the transceiver this will probably be unnecessary as the coax outer braid connection of the transceiver will usually be common to the negative supply.

PARTS LIST

Resistors

- 1x 100R Resistor(**R4**) ☐
- 1x 180R Resistor(**R2**) ☐
- 1x 1K Resistor(**R5**) ☐
- 1x 10K Resistor(**R1**) ☐
- 1x 100K Resistor(**R6**) ☐
- 1x 33K Resistor(**R3**) ☐

Capacitors

- 1x 1pF Capacitors(**C1**) ☐
- 2x 100pF Capacitors(**C8, 12**) ☐
- 8x .001uF Capacitors 50V (**C2-6, C9-11**) ☐
- 1x 220uF Capacitors 16V RB(**C7**) ☐

Semiconductors

- 1x DS547 Transistor(**Q1**) ☐
- 1x BD681 Transistor(**Q2**) ☐
- 1x OA91 Diode(**D5**) ☐
- 2x IN4004 Diode(**D8, 9**) ☐
- 1x 7805 Volt Reg(**ICI**) ☐
- 6x BA244 Diode(**D1-4, D6, D7**) ☐
- 2x 10uH RF Choke(**L1, L2**) ☐
- 1x 2-20pF Trimmer(**TC1**) ☐
- 1x 3sk121Y Gas'Fet(**Q3**) ☐

Miscellaneous

Mini volt relay, socket, solder, grommet, spacer, spade lug (male), spade lug (female), screws, nuts, tinned copper wire, H/U wire, bracket, saddle clamp, coaxial relay, diecast box, PCB ☐

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