WIDEBAND ACTIVE ROD ANTENNA

The starting point for this design is the well-known ⅝-lambda whip antenna with base coil as used for mobile communications in the 2-m VHF band. Interestingly, this type of antenna is readily tuned to 6-metres. Add a wideband low-noise preamplifier and you have a wideband rod antenna for a large frequency range (20 kHz to 150 MHz).

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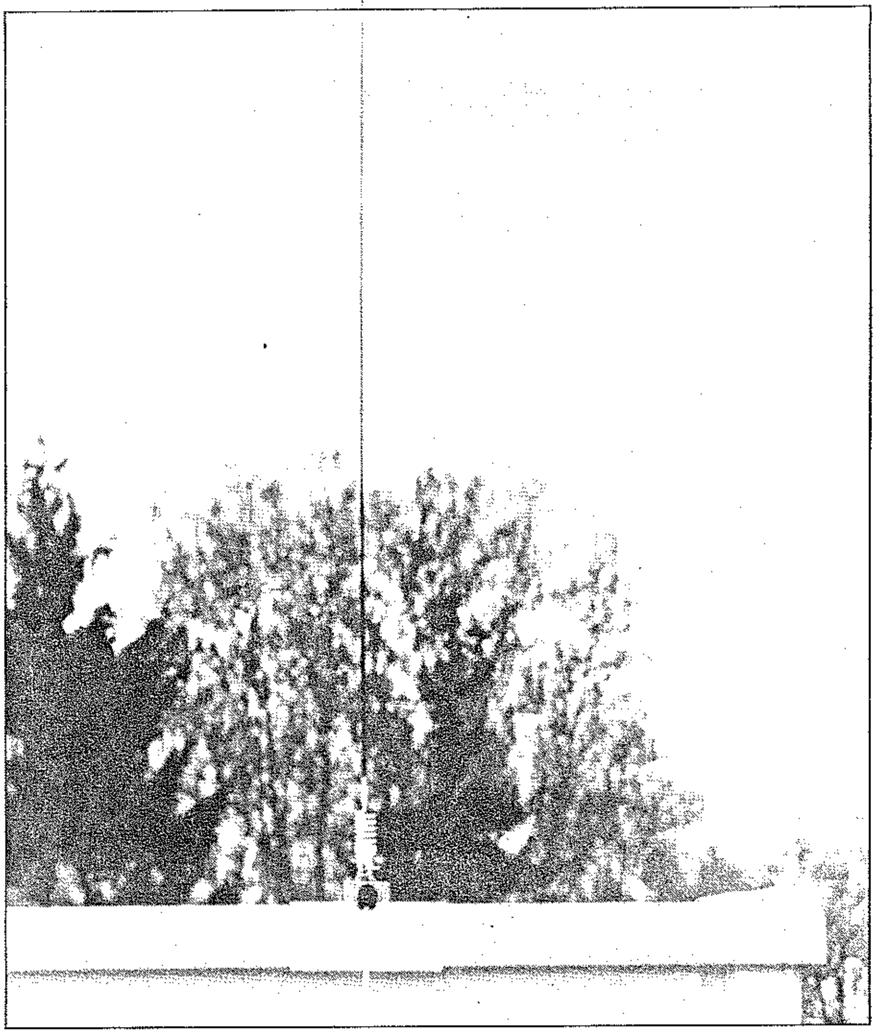


A familiar sight on cars fitted with a VHF band mobile radio, the ⅝-λ whip aerial offers a gain of 2 to 3 dB over the ¼-λ rod, known as the Marconi antenna. The coil seen at the base of the ⅝-λ antenna serves to lengthen it electrically and match it to a 50-Ω coax cable. Most ⅝-λ antennas for the 2-m amateur radio band have a length of about 1.25 m, which is about 0.22 λ in the 6-m band. The additional inductance formed by the base coil gives the antenna an electrical length of a little over 1/4 λ, which allows ready connection to a 50-Ω coax cable.

Active antenna

Long established for maritime radio communications, the active antenna is gaining popularity with users of general coverage receivers (100 kHz to 30 MHz). Compared with the familiar long wire, the active antenna is unobtrusive, small and simple to install (although its final location will have to be given some thought in view of interference). Where a 'full-size' vertical antenna for general coverage reception has a minimum size of about 6 m and a weight of more than 5 kg, the active version presented here weighs a modest 400 g and has a length of only 1.3 m.

In principle, an antenna for the frequency range below 20 MHz or so can be shortened to about 1 m without degrading reception. This is so because the level of man-made and natural noise is then still higher than the noise level of the receiver. However, the problem with such a short antenna is that it has a relatively high radiation resistance. As a rule of thumb, short antennas for the SW frequency range have a capacitive base impedance, C_A, of about 10 pF/m. This means that they must be fitted quite close to an amplifying impedance transformer with a 50-Ω output for the coax cable to the receiver input. This assembly of a short rod and a wideband RF amplifier fitted at its base is called an active antenna. The amplifier is provided with its supply voltage via the coax cable and a simple *L-C* decoupling network at the receiver input.

Transmit/receive operation in the 2-m and 6-m band is enabled by a relay that disconnects the amplifier and connects the antenna to the coax cable when transmitting.

Table 1. Main technical data

- **Passive operation; transmitting or receiving:**
  - VSWR = 1.4 - 1.6 in 2-m amateur radio band
  - VSWR = 1.2 - 1.7 in 6-m amateur radio band
  - Loss introduced by relay and switching circuit: 0.1 dB (2-m band)
  - Permissible transmit power: >50 watt
- **Active operation at U_b = 11 to 15 V (13.5 V typ.)**
  - Current consumption: 60 mA
  - Field strength conversion constant $k_A = U_0 / E = 0.5$ m
  - Ripple of k_A: ±1 dB between 150 kHz and 65 MHz
  - Noise level $P_{N0} / \Delta f = -155$ dBm / Hz ±1.5 dB between 1 and 60 MHz
    $U_{N0} / \sqrt{\Delta f} = 4$ nV / √Hz
  - Equivalent noise level: 8 nV / m × 1 / √Hz
  - Large-signal behaviour: 2nd-order intercept point IP_2 = 48 dBm; 3rd-order intercept point IP_3 = 30 dBm

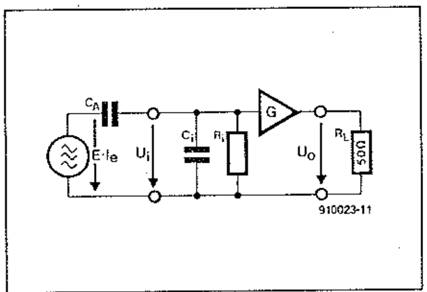


Fig. 1. Basic schematic and parameters of an active antenna.

The relay is controlled remotely from the receiver or transceiver.

As illustrated in Fig. 2, the active rod antenna supplies a virtually constant voltage relative to the field strength of signals in the range from VLF to VHF. It is precisely this characteristic that makes the active rod suited to relative field strength measurement. Fitted on a car roof, it allows the in-band and out-of-band signal levels of SW stations to be monitored. The antenna is also suitable for mobile long-distance SW reception, provided you take the trouble to drive your car as far as possible from large cities, broadcast transmitter sites and industrial sites. At home, the antenna is best fitted to the metal protection parts of the roof (see the introductory photograph). An alternative location is the balcony railing.

Given its small size, the performance of the active antenna is quite impressive, as shown by the measurement data collected in Table 1.

Background noise and background theory

The field strength conversion factor, k_A, of an antenna of effective length $l_e \cong l/2$ (for values of l smaller than $\lambda/8$) is determined with the aid of the basic circuit shown in Fig. 1. As an example, the factor is calculated at a frequency of 10 MHz and at the associated gain, G, measured as 1.91 (see Fig. 2):

$$k_A = \frac{U_o}{E} = \frac{l}{2} \cdot \frac{C_A}{C_A + C_i} \cdot G$$

$$= \frac{1.25\text{m}}{2} \cdot 10^{-2/20} = 0.5\ \text{m}$$

Next, the intermodulation-free drive margin of the amplifier, P_{max}, and the dynamic range, DR, are calculated with the aid of the second-order and third-order intercept points, IP_2 and IP_3. The purpose of this calculation is merely to compare the performance of one active antenna with that of another. For the practical construction, it has no significance.

$$P_{max} = \frac{1}{3}\,(P_{N0} + 2\,IP_3) \qquad \text{[dBm]}$$

$$DR = P_{max} - P_{N0} = \frac{2}{3}\,(IP_3 - P_{N0}) \qquad \text{[dBm]}$$

All power levels in the above equations are entered in decibel-milliwatts (dBm) normalized at 50 Ω for RF; 0 dBm equals 1 mW.

For SSB in a bandwidth of 2.5 kHz:

$P_{No} = -155\ \text{dBm} + 34\ \text{dB} = -121\ \text{dBm}$
hence $P_{max} = -20\ \text{dBm}$, and $DR = 101\ \text{dB}$

For CW in a bandwidth of 500 Hz:

$P_{No} = -155\ \text{dBm} + 27\ \text{dB} = -128\ \text{dBm}$
hence $P_{max} = -23\ \text{dBm}$, and $DR = 105\ \text{dB}$

To many of you, voltage levels may be more familiar than the above dBm values. Assuming an antenna impedance of 50 Ω, and remembering that

$$U = \sqrt{P \cdot R} \qquad \text{[V]}$$

the resultant figures may have more meaning. The result for SSB is a noise voltage, U_{N0}, of 0.21 µV, a maximum antenna voltage, U_{max}, of 22 mV, and a maximum field strength, E_{max}, of 44 mV/m.

For CW we obtain the following values: U_{N0} = 0.09 µV, U_{max} = 16 mV, and E_{max} = 32 mV/m.

In practice, when the field strength of a received station exceeds E_{max}, the intermodulation and interference signals produced by the amplifier will exceed its own noise. The effects of intermodulation cause a number of spurious signals which may be heard in the receiver if they are strong enough to top the level of the background noise produced by man-made, atmospheric and other natural sources.

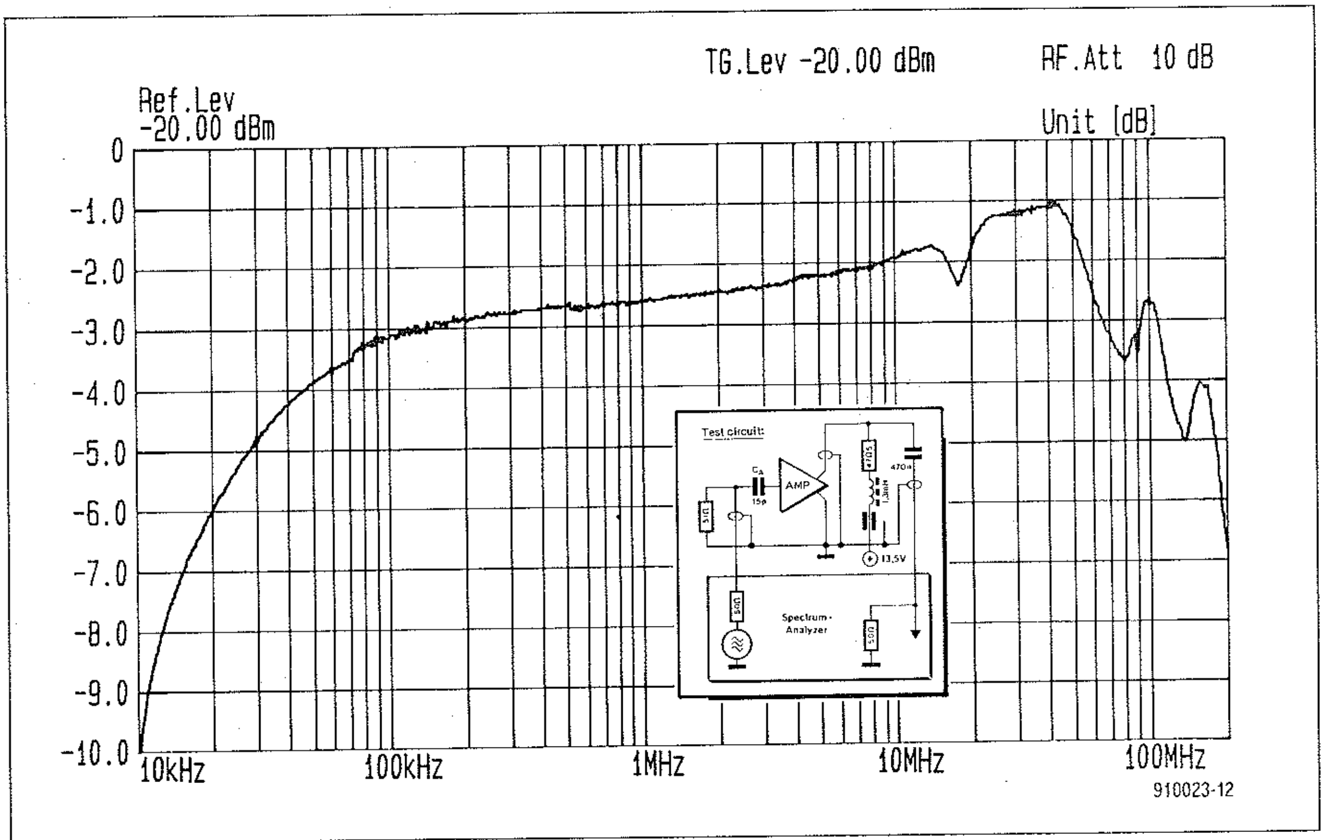
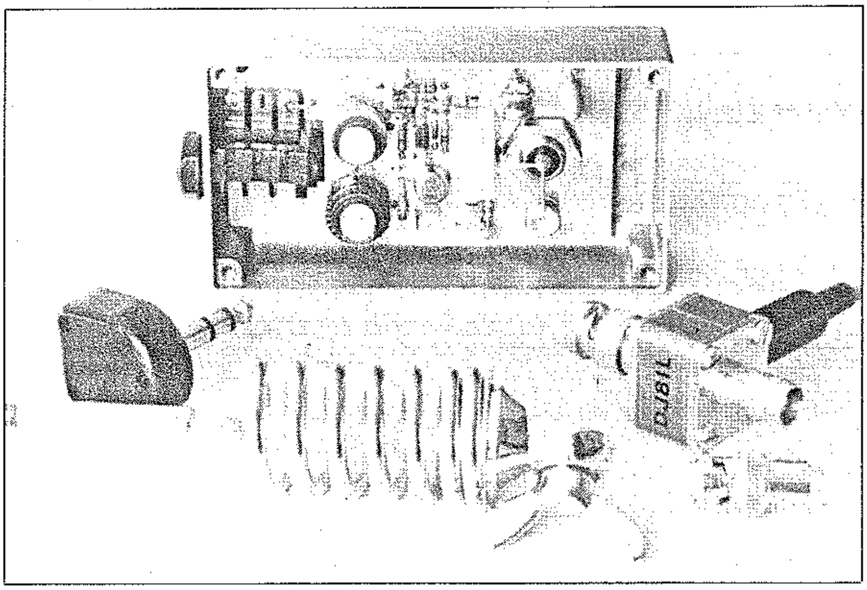


Fig. 2. Frequency response of the active antenna. The rod was simulated by a capacitor of 15pF and a resistor of 25Ω.



The active antenna discussed here was tested with a Yaesu FT-757GXII SW transceiver. The noise produced by the active antenna was audible only above 10 MHz. The dynamic range of the receiver with the active antenna switched on is smaller than that of the receiver proper, while the dynamic range of the receiver alone is greater than that of the preamplifier alone.

The achievable signal-to-noise ratio can only be improved by means of a directional antenna, which, as most radio amateurs know, have a size of at least λ/2, and offer a relatively small bandwidth.

From Fig. 2 we could be lead to believe that the active antenna could be used up to nearly 200 MHz. However, when the electrical length of the rod is λ/4 or greater, the antenna starts to form a low impedance. This means that the preamplifier (which is essentially an impedance converter) can be omitted, and the rod connected direct to the input of the VHF receiver. Consequently, the VHF receiver will produce a low noise voltage relative to its own noise level. For an impedance of 50 Ω, the equivalent input noise voltage of the amplifier is 1 nV/√Hz.

Circuit concept

As to the wideband amplifier, if you are after low amplifier noise rather than a high dynamic range, consider the following alternatives:

- a single-stage VMOS-FET based amplifier utilizing, for instance, the VN0808M or the VN66AK from Siliconix;
- a two-stage amplifier with a source follower at the input and an emitter follower with strong feedback at the output.

The second alternative has certain advantages: the input capacitance C_i is small; the

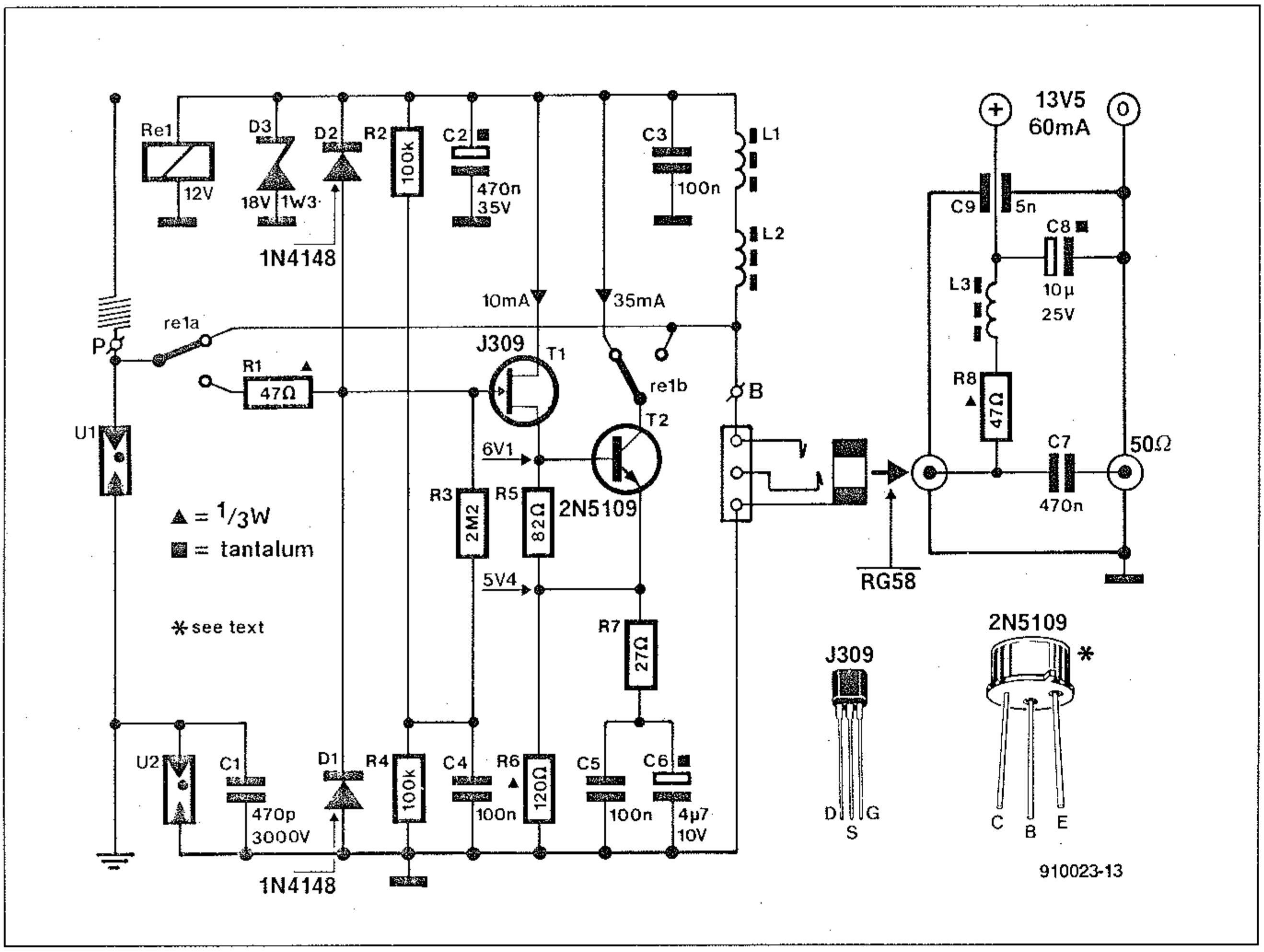


Fig. 3. Circuit diagram of the active antenna, consisting of a ⅝-lambda whip with base coil, a wideband RFamplifier and a supply voltage coupling circuit. Relay Re1 is actuated in receive mode only when the amplifier is functional also. During transmit operation, the supply voltage to the amplifier is switched off, so that the whip antenna is connected direct to the transceiver.

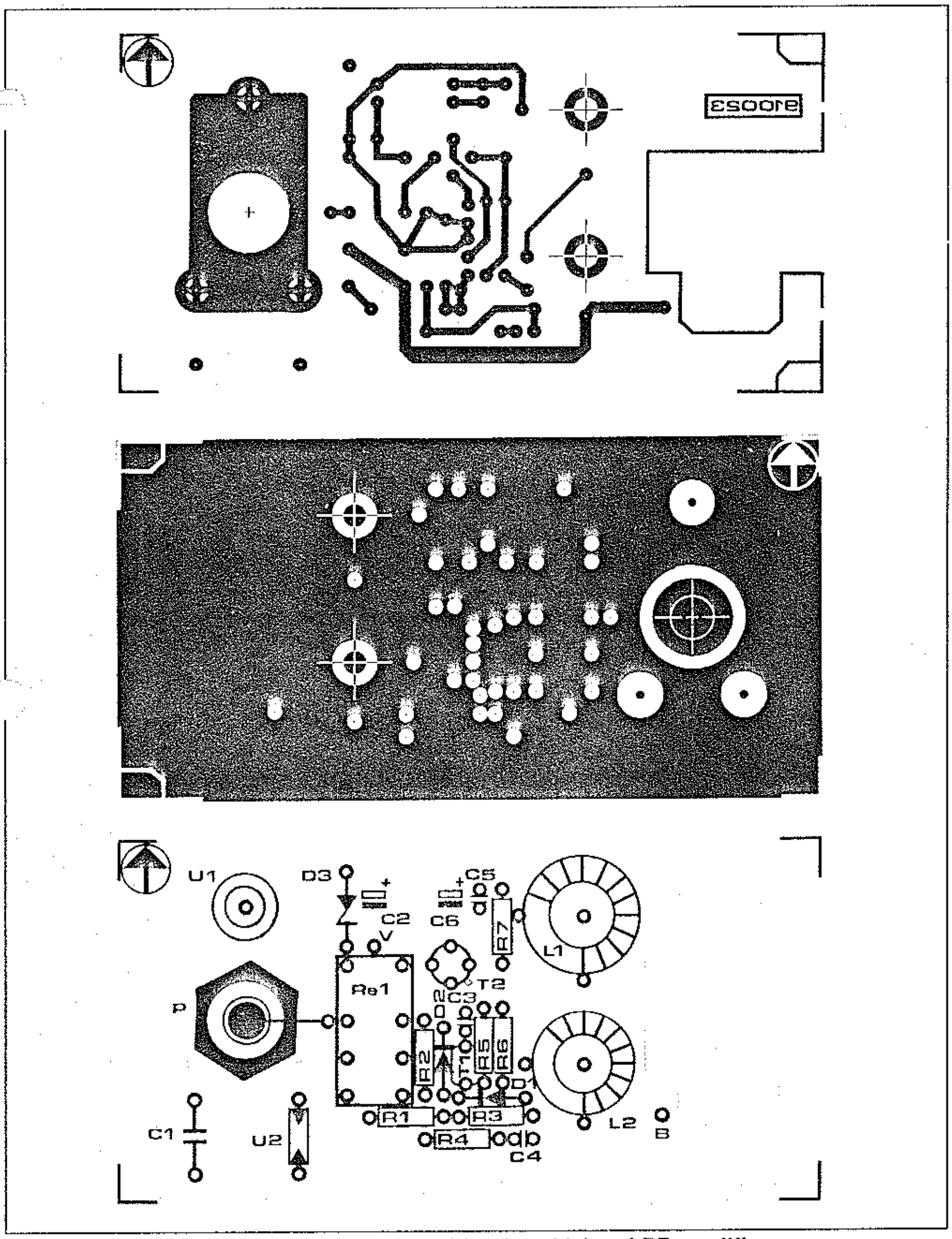


Fig. 4. Double-sided printed circuit board for the wideband RF amplifier.

COMPONENTS LIST

Resistors:

1	27Ω	R7
2	47Ω 0.3W	R1,R8
1	82Ω	R5
1	120Ω 0.3W	R6
2	100kΩ	R2,R4
1	2MΩ2	R3

Capacitors:

1	470pF 3kV ceramic	C1
1	5nF feedthrough	C9
1	100nF 10 V ceramic	C5
2	100nF 35V ceramic	C3,C4
1	470nF ceramic	C7
1	470nF 35V tantalum	C2
1	4µF7 10V tantalum	C6
1	10µF 25V tantalum	C8

Semiconductors:

2	1N4148	D1,D2
1	18V 1.3W zener diode	D3
1	J309 (Siliconix)	T1
1	2N5109 (Motorola)*	T2

Miscellaneous:

1	12V relay with 2 c/o contacts (SDS** type DS2E-12V)	Re1
1	noble-gas surge arrester 145V @ 5,000A	U1,U2

* Cricklewood Electronics.
** SDS Relays Ltd. • 17 Potters Lane • Kiln Farm • Milton Keynes MK11 2HF • Tel. (0908) 567725.

...oise level U_N is low; the current consumption is modest and, importantly, the amplifier has no adjustments.

The circuit shown in Fig. 3 is a source follower based on a Type J309 n-channel junction FET (T_1) from Siliconix or National Semiconductor. This transistor offers a good large signal performance by virtue of the relatively high and constant drain current. To stabilize the drain current, the source resistor, R_5, is not connected to ground but in parallel with the base-emitter junction of the output amplifier transistor, T_2. This is a Type 2N5109 medium-power wideband transistor designed for use in CATV head-end stations. The transistor (manufactured by Motorola) is marked by low noise and excellent linearity. If you can not get hold of the 2N5109, you may use the 2N5943, 2SC1252 or 2SC1253 as a near equivalent.

The linearity of the output stage is ensured by a relatively high degree of feedback. The gain of the stage is set to about 1.9, allowing k_A factors of between 0.2 and 0.5 to be achieved. The output impedance of the amplifier is 50 Ω to allow conventional coax to be used. The output signal is fed to the receiver via a diplexer consisting of R_8, L_3, C_7 and the input impedance of the receiver.

The supply voltage arrives at the amplifier and the transmit/receive relay via chokes L_1 and L_2. The chokes must be capable of withstanding the transmit power while not introducing significant losses or resonance at any frequency within the range covered by the active antenna.

Two small gas-filled surge arrester tubes are provided to protect the amplifier against voltage peaks caused by lightning and 'electrostatic rain'. In addition, two diodes, D_1 and D_2, and a series resistor, R_1, protect the

Table 2. Inductor winding data

L1: 22 turns of 0.2 mm dia. copper enamelled wire on a ferrite ring core of o.d./i.d.=16 mm/9.6 mm; h = 6.3 mm; type B64290-K45-X830 from Siemens.
L2: 20 turns of 0.2 mm dia. copper enamelled wire on a ferrite ring core of o.d./i.d. = 14 mm/9 mm;h = 5 mm; type 43220209718 from Philips Components. Alternative type: FT50A-61 (Micrometals/Amidon).
L3: 21 turns of 0.2 mm dia. copper enamelled wire on a ferrite ring core of o.d./i.d. = 16 mm/9.6 mm; h = 6.3 mm; type B64290-K45-X830 from Siemens.

Main electrical data of the ferrite cores:
L1, L3: material N30; μ_i=4,300; A_L=2.77 µH. L1=1.3 mH; L3=1.2 mH.
L2: material 4C6; μ_i=120; A_L=53 nH; L2=21 µH.

Siemens distributor in the UK is ElectroValue Limited • 28 St Judes Road • Englefield Green • Egham • Surrey TW20 0HB. Telephone: (0784) 33603. Telex: 264475. Fax: (0784) 35216. Northern branch: 680 Burnage Lane • Manchester M19 1NA. Telephone: (061 432) 4945.

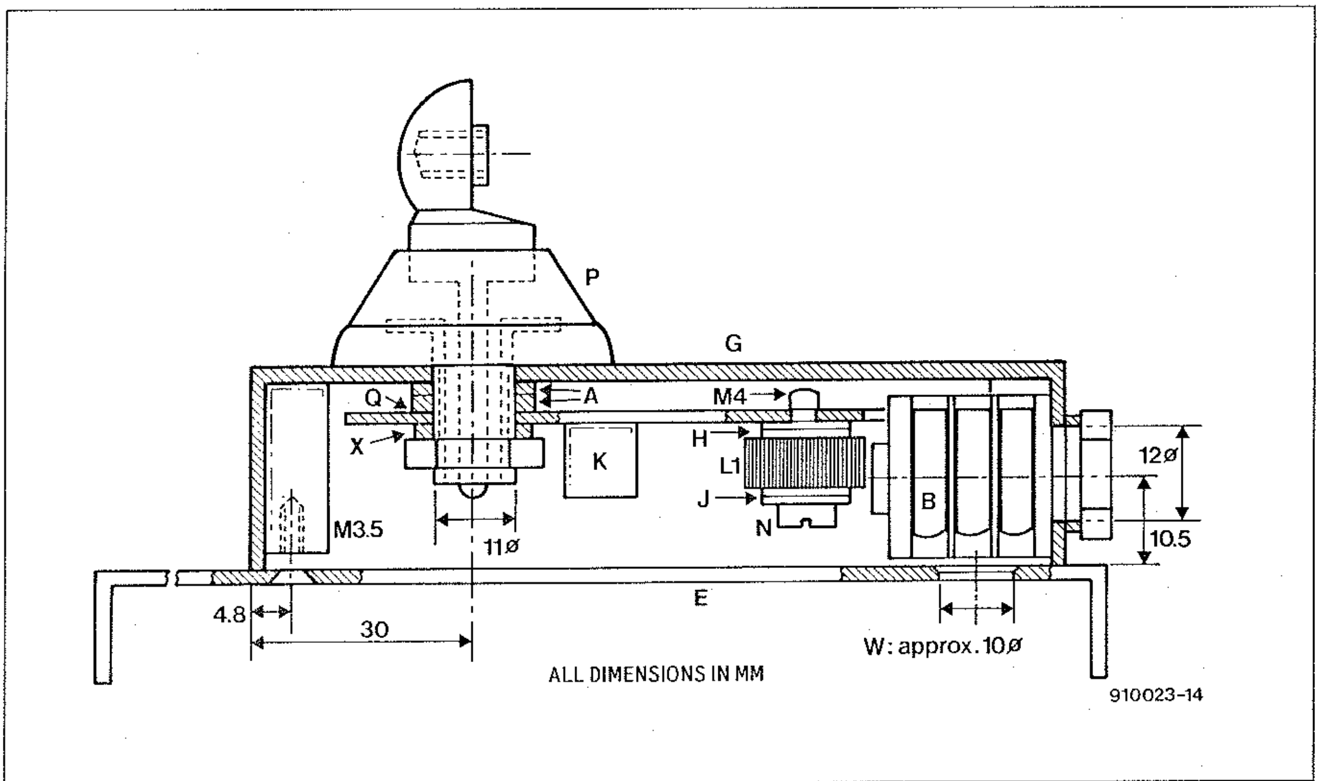


Fig. 5. Mechanical outline of the active antenna. The whip antenna is bolted to the top part of the base, P.

gate of the J309. The zener diode, D3, has three functions: first, it limits the maximum supply voltage; second, it prevents back-e.m.f. from the relay coil; and third, it acts as a protection against polarity reversal of the supply voltage.

Construction and earthing

Figure 4 shows the double-sided, not through-plated, printed circuit board for the amplifier. The component side is largely unetched to allow it to function as a ground plane. All component terminals that are connected to ground are soldered at both sides of the PCB. Note that all component terminals, whether grounded or not, must be kept as short as possible.

The construction of the board is largely apparent from the photograph of the prototype. Note the orientation of the tab on the case of T2. If you use a transistor with a terminal connected to the case (the near equivalents of the 2N5109), this terminal is soldered to ground.

The FET, T1, is fitted with its flat side facing D2, R2 and the relay. The centre terminal of the FET (source) is not indicated on the component overlay. The outer two terminals are the drain (near C3) and the gate (near D1).

The frequency response of the amplifier will be a little smoother than shown in Fig. 2 when toroid core L3 is allowed more space than in the 'cramped' prototype shown in the photograph. The supply/coax connection should be sealed to prevent rain or dew entering the coax cable or the amplifier enclosure. An N-type plug and socket may be used because they are waterproof. The disadvantage however is the relatively high cost. The author used a cheaper alternative in the form of a jack socket and a mating plug. After 1½ years of continuous use on the roof no traces of corrosion could be detected inside the amplifier enclosure.

In the introductory photograph the antenna is seen attached to the zinc rim (of width *w*) on the edge of a flat roof. The antenna is secured to a 2-mm thick U-shaped chrome-plated aluminium piece (E) that is clamped on to the metal rim of the roof. The size of the aluminium plate is 200 (L) × (100+*w*+100 mm) (W) mm. The zinc rim on the roof is connected to the lightning conductor system. It should be noted that there may exist a up to a few 100 mV of hum between the lightning conductor system (which is earthed) and the protective earth on the mains system, to which the RF equipment is connected. To prevent a stray current flowing via the relay coil and L1, L2 and L3 (as a result of the potential difference, which is essentially hum), the two earthing systems are capacitively coupled via C1 The value of C1 is 470 pF, which is much greater than C_A. The capacitor effectively prevents harmonics of the hum voltage occurring in the VLF range of the receiver. Finally, use insulating spacers between the PCB and the metal enclosure, as shown in Fig. 5. This is done to ensure that the two earth systems are not interconnected. ■

Table 3. Mechanical parts

o.d. = outside diameter
i.d. = inside diameter

A: Metal washer o.d./i.d.=16/11 mm; 4 mm thick.
B: 6.3 mm dia. jack socket.
E: chrome-plated aluminium support plate.
H,J: Isolating washer o.d./i.d.=12/4 mm; 2 mm thick.
K: relay.
N: nylon screw M4×15 mm.
Q: stainless steel spring washer o.d./i.d.=16/11 mm; 0.2 mm thick.
S: 6.3 mm dia. angled jack plug.
X: isolating washer o.d./i.d.=16/11 mm; 2 mm thick.
W: water exhaust
G: diecast case 111×60×27 mm (Eddystone Radio 27134P).
P: antenna base.

Note:
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