RADCOM CONSTRUCTION FEATURE

HF All-band Antenna for Mobile or Home

The first of a two part article by John Robinson, G3MPO

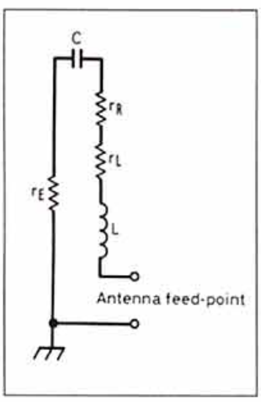


Fig 1: Simplified equivalent circuit of the antenna.

WHEN I RETURNED to amateur radio after a break of thirty years, I decided to look for a less intrusive antenna than before, when setting up my new station. Purchase of a second-hand TS-430S presented me with the option of mobile operation from a car. This would entail no more than designing and manufacturing a suitable aerial and matching unit, and attaching it to the car. An inexpensive and interesting project.

This article attempts to set down what I found out about the hows, whys, and wherefores of mobile operation, and concludes with a practical DIY design for an all-band eight foot whip made from easily obtainable materials. Hopefully, it will encourage others to extend their activities into this highly effective and satisfying mode of operation.

PRACTICAL REQUIREMENTS

These are easily listed (although less easily met):

a) Minimal impact on the car - no big holes or unsightly mountings.

b) As good a performance as is practicable.

c) Easily demounted.

e) Time to change bands of not more than two minutes.

f) Low cost - not more than £50.

g) Operation on the move to at least 60MPH.

h) All parts to fit neatly and quickly into the boot.

i) Minimal impact on XYL's use of the car. Crucial!

j) Simple operation - minimum of knob twiddling, no ATU.

k) At least 150 watts power handling capability.

DESIGN CONSIDERATIONS

PRACTICALLY ALL mobile antennas are 'short' vertical monopoles fed against ground. Such antennas concentrate their power at low angles of elevation, with the radiation pattern shifting slightly upwards as the length of the antenna in relation to the wavelength decreases - in many ways, an ideal specification for general all-round performance. Except perhaps on 10 metres, a full quarter wave on a car is never possible, and the 'missing length' has to be made good with either a series inductance or a capacitance to ground near the top, for each band. For aerodynamic reasons, coil loading is far more practicable for mobile use - at sixty miles an hour an eight foot whip with a saucer-sized capacitive spider mounted on the end is a frightening sight to see - so the inductive method of loading was adopted with little further thought.

The distribution of current along the antenna in-board of the loading coil is the same as that along the inner end of one limb of a dipole, ie it declines along the antenna according to a cosine law. This means that at LF, where the antenna is small compared to a quarter wavelength, it is virtually constant along the length. Outboard of the coil, current distribution is like that at the end of a dipole, and falls off until it reaches zero at the end. The current in the coil is practically constant and equal to the current in the lower part of the antenna, but its passage through the coil creates a large voltage near the end of the whip. At 100 watts, typical values of drive voltage and bottom element current are about 70V and 1.5A RMS respectively, the voltage induced by the coil and fed to the top end rising to several thousand volts at the lower frequencies. (Don't touch the top section or coil with the power on!)

Thus, when fed with 100W, the bottom of the antenna behaves like the inner end of one limb of a dipole fed with 200W - 100W each side - whereas the top section resembles the end of a dipole fed with much higher power - on 3.5MHz for example, the input drive to a half-wave dipole showing these levels of current at the end would be about 60kW!

ANTENNA EFFICIENCY

IN LES MOXON's comprehensive book, *HF Antennas for All Locations* [available from RSGB sales - see 'Bookcase' pages - *Ed*], the simplified equivalent antenna circuit is shown to be completed by current flowing to the car body via the antenna capacitance. This occurs either directly or via the 'car-body to earth' capacity, and thence back to the transmitter. In so doing it encounters resistance in the earth path which unfortunately dissipates some of the radiated power in the form of heat. In my own case, a figure of 20Ω appears appropriate. A simplified equivalent circuit is shown in **Fig 1**, current flowing via the coil inductance (L), whip capacitance (C), radiation resistance (r_R), coil resistance (r_L) and earth resistance (r_E).

Low radiation resistance is not in itself a bad thing - a transformer can match it to 50Ω - but earth resistance losses are significant.

Since the RF power is shared between earth, coil and radiation resistances, obvi-

TECHNICAL UPDATE

THE POPULAR RF Sniffer construction article in the October issue should have specified a 200μA FSD meter, as shown in the diagram. Also, the author of last month's 'Inexpensive but Effective Wobbulator' was Peter J Lawton, G7IXH (not G7IXK). Apologies to both.

ously only power delivered into the radiation resistance is useful for communication purposes. Nothing much can be done about earth resistance but it will clearly pay to keep radiation resistance as high as possible and coil resistance as low as possible.

For practical reasons, the choice open to the mobile operator is usually one of a roof-mounted, base-loaded whip about four feet long, or a centre-loaded, bumper-mounted eight foot whip, the theoretical ratio of radiation resistance in the two cases being about one to five.

Therefore, I selected a centre-loaded 8ft version of the antenna with its higher radiation resistance and consequent higher performance, in preference to the simpler base-loaded 4ft whip.

From the beginning, the antenna system was designed to operate without an ATU and this in turn meant that the system must resonate in its own right at each frequency. A maximum VSWR of 1.5 was the objective - to match the turn-off characteristics of the TS-430S. To a first approximation, each loading coil resonates with the capacitance of the antenna top section and the required inductance therefore increases inversely as the square of the operating frequency. The resultant operating Q increases as the frequency decreases, to the point that at 7MHz, the 1.5 VSWR bandwidth is only about 25kHz, and at lower frequencies even less. The antenna is therefore tuned by making the top section of the antenna telescopic. A total movement of about 8in allows tuning across all bands except 160, where only about three quarters of the band is covered. To cover the whole band, a second longer/shorter whip can be used. On all bands above 40m, the Q is sufficiently low to make tuning within the band unnecessary.

Positioning of the coil is a subject of some debate. Radiation resistance considerations point towards high mounting, but this increases the inductance necessary which in turn increases coil losses. It must also be possible to reach the telescopic section of the whip to adjust it, and I therefore settled on a more or less central position so that the combined height of mounting point, lower mast, coil and telescopic section just about equalled my reach.

With an antenna such as this, the impedance presented to the transmitter ($r_R+r_L+r_E$) should always be less than the transceiver output impedance of 50Ω, so that a step-down matching unit is required. Of the available choices - base coil, ferrite auto-transformer, and capactive shunt - the latter was the simplest and cheapest to implement, and was therefore selected.

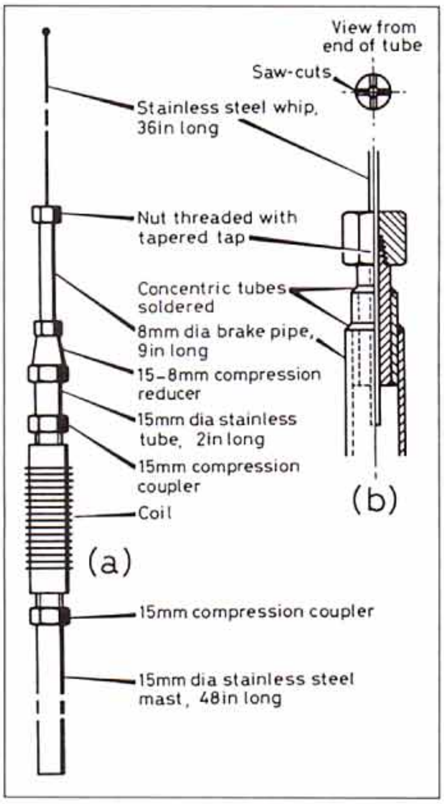


Fig 2: An 8mm diameter brake pipe and stainless steel whip comprise the upper section.

ANTICIPATED PERFORMANCE

THE PERFORMANCE OF the antenna will depend essentially on two things:

a) The gain of the antenna in the important direction - ie towards the horizon for DX and at higher angles for intermediate distances.

b) The efficiency with which power is radiated/received - ie the ratio of the radiation resistance to the total antenna circuit resistance.

At the higher frequencies, the first of these approximates to that of a free space dipole mounted on end, with the polar diagram becoming slightly more rounded at the lowest frequencies as higher angle radiation increases and power at the horizon falls by about half an S-point. With full 360° coverage, this represents a good compromise for general purpose communications and is better than many home-based dipoles can achieve in practice. The theoretical efficiency - power radiated as a proportion of total power generated - is less favourable, falling short of the conventional dipole by about half an S-point at 10 metres and by as much as three to four S-points at 160 metres.

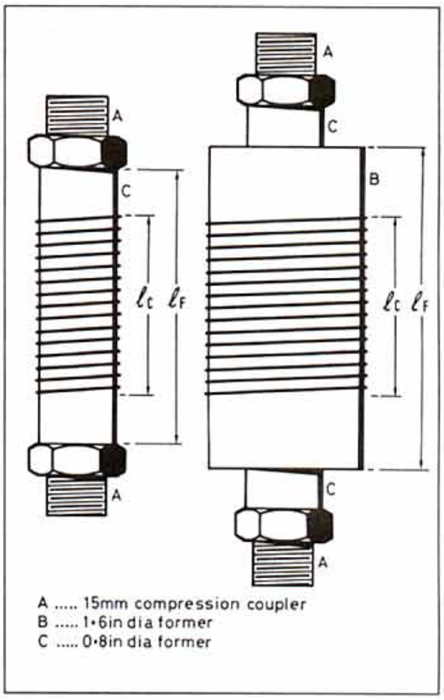


Fig 3: Coil former construction and dimensions will depend on the frequency in use.

This means that overall, in relation to a home station dipole radiating the same power, we can expect signals to be comparable at the higher frequencies, but falling off by as much as four S-points at the lowest frequencies. Fortunately, signal levels between home-based stations of S9+20 are common on 80 and 160 metres and four S-points down still leaves us with a respectable S7 to 8 report.

ENGINEERING

AS MY WORKSHOP FACILITIES were little more than a 'Workmate' and electric drill, the mechanical design presented some problems. Fortunately, the local plumber's stockists provided a suitable source of ready-made brass, stainless steel and plastic bits and pieces. 15mm plumber's brass compression couplers were selected as both coil terminations and the means of fixing them into the antenna. The bottom section of this is made from a length of 15mm stainless steel central heating tubing.

Selection of a coil former material presented potential pitfalls as PVC can be comparatively lossy. Fortunately, a range of white polypropylene waste pipe was found to be commonly available, and this has subsequently proved a good choice. The thread of the brass 15mm compression couplers can be screwed (with some difficulty) into the end of the 0.75in (19mm) version of this tubing to make a very strong joint. The ends of the tube can be pre-heated in hot water if necessary. Even better, a 0.5in (12.5mm) BSP taper tap can be used to cut a starting thread in the tubing. A second coupler screwed into the other end gives an excellent coil former with ready-made 15mm connections at each end which fit and clamp directly onto the 15mm lower mast.

The coil structure had to be strong to support the considerable wind drag of the antenna top section. In several thousand miles of motoring it has proved completely secure. Varying lengths of former are used for the higher frequency coils, and where a greater diameter is needed for the lower frequencies, the same 0.75in (19mm) former is used as a spine. This runs up the middle of a larger diameter tube to which it is attached by packing the space between them at each end with postage stamp size pieces of car-repair glass mat soaked in resin. It should then be waterproofed with a silicone rubber sealant.

Above the coil former, a length of stainless steel whip was required (obtainable from most amateur radio suppliers), a short length of small diameter tube into which the whip can slide, and a means of connecting this tube to the top 15mm coil coupler. The most difficult to achieve was the telescopic section, but the local car accessories shop had a range of copper brake tubing in concentric sizes from 8mm OD down. A 9in (230mm) length of 8mm diameter pipe, with one end plugged by short lengths of the next two sizes down and soldered into position, gave a nice sliding fit to the 2.5mm diameter whip. Some sort of quick release lock was now required to hold the whip, once set, in position, and this called for a degree of ingenuity and precision. The solution was to cut a thread on the last half inch of the end piece of tubing with a thread-cutting die, and make cross cuts down its length with a mini-hacksaw.

A matching taper tap and a short length of brass rod allowed me to make a nut with a tapered thread which would close the tube down onto the end whip as it was screwed on, thus locking it. Some patience and a degree of luck were required before a satisfactory nut was obtained, but once made, the arrangement worked well. Subsequently, the brake-pipe components were replaced with stainless steel which required a visit to a specialist steel supplier and the assistance of a local handyman. The whip structure was completed by connecting the telescopic section onto the coil using a 15mm-to-8mm (microbore) brass reducer and a 2in (51mm) length of 15mm tubing, as shown in **Figs 2 and 3**.

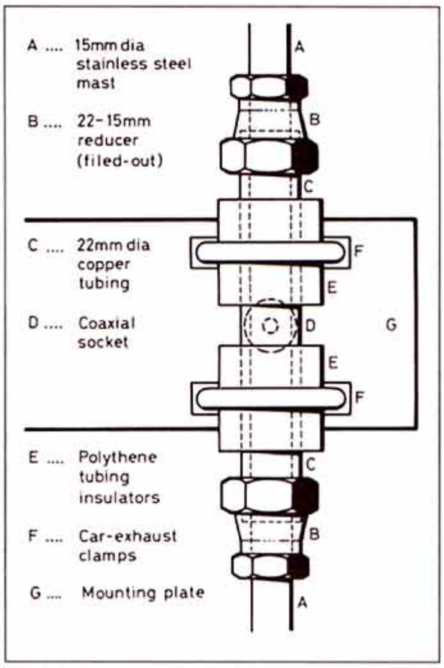


Fig 4: Electrical connection and mounting details for mobile or fixed-station operation.

The base mount fitting between the antenna and the car needs above all to be strong, for this is where the main mechanical load appears. The solution selected depends upon the car in question, but it is unlikely that the antenna can be mounted through the bodywork like a car aerial. If you have a tow bar with a bolt-on hitch, the simplest arrangement is to sandwich a steel plate between the hitch and its fixing, and fix the mount onto this adjacent to the hitch. Failing this, most cars have a rear towing loop of metal to which an outrigger can be bolted.

Many commercial systems mount the whip on a spring, but this was rejected since it seemed likely that a spring strong enough to prevent the antenna thrashing about at speed was also likely to be too strong to prevent impact damage. Also I had no ready source of suitable springs, and it was therefore decided to fix the antenna rigidly to the car.

. . . to be concluded

HF All-band Antenna for Mobile or Home

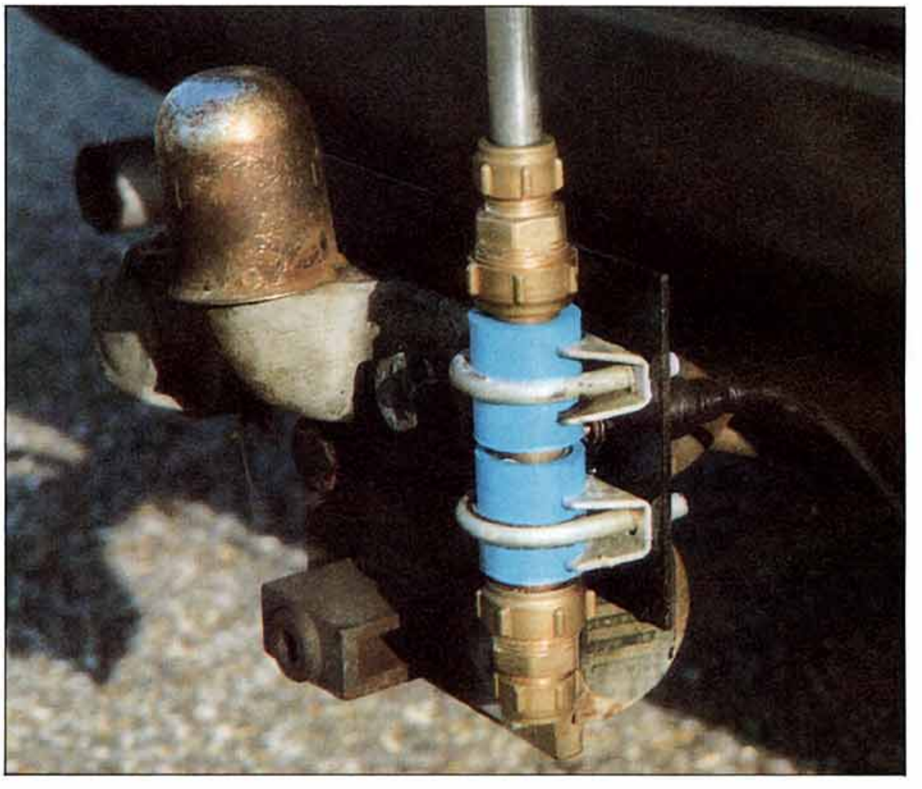
Concluding the article by John Robinson, G3MPO

BLUE-COLOURED polythene tubing comes in a range of concentric sizes, and is held by all plumbing suppliers. One size is a tight fit over 22mm copper central heating tubing. Two 1.5in (38mm) lengths of this plastic tubing fitted inside two similar lengths of the next size up make excellent base insulators and can be fitted over a 5.5in (140mm) length of copper 22mm central heating tubing, with a two-inch pigtail of wire soldered to the mid-point (**Fig 4** see part one).

Leave an inch of copper protruding at each end. Pre-heat the polythene tubing or slit it lengthways to aid fitting. The resulting gap in the insulator is electrically and mechanically unimportant. This insulated tube can be rigidly fixed to the mounting plate using exhaust pipe clamps available in a range of sizes from the local car accessory shop. A 22mm to 15mm brass reducer fitted top and bottom allows the antenna bottom section to pass right through the mount and be compression clamped into position. The shallow ring of brass machined into the bore of each reducer to prevent 15mm tubing going right through, must be filed or drilled away. Discard the brass sealing ring (called an 'olive') from the bottom reducer - the mast is clamped only by the olive in the top one. Finally, a panel-mounting coaxial socket is fixed to the plate, and the centre pin soldered to the mid-point pigtail on the 22mm mount copper tube. A short coaxial cable goes from this connector, through a small hole in the car bodywork, into the matching unit in the boot.

A good earth to the car body is essential and this is best achieved by cutting off half an inch or so of the cable outer insulation just inside the boot, and making up a small clip to fix it to the car body. Remember to scrape the paint off well, and seal with a little grease.

At 80 and 160m, the voltage induced across the coil can cause corona at the tip of the whip, with consequent loss of power and matching. This is easily cured by forming a small button on the end of the whip using self-amalgamating tape or epoxy resin, to reduce the surface electrical field strength.



DESIGN DETAIL

DETAILS AND DIMENSIONS OF the various elements of the antenna were given in Figs 2 and 3. The length of whip above the coil determines the capacity to ground and hence the coil inductance required. In this case, it is about 11.5pF. Even a straight wire has inductance (and capacitance to ground), and the inductance of a 4ft (1.2m) length of 15mm tube - the lower half of the whip - is about 1.5 μH. The coils, therefore, have to have an inductance which when added to the base mast inductance of 1.5 μH, resonates with the 11.5pF capacitance at the required frequency. These values, together with the radiation resistance, coil and matching data are given in **Table 1**. It may be necessary to alter the length of the upper whip by a few inches to resonate the antenna.

High efficiency coils for the lower frequencies can get embarrassingly large, and since antenna efficiency also drops off with reducing frequency, (as r_R falls), performance here is most difficult to maintain. To keep coil losses within acceptable bounds, the gauge of wire used must not become too small nor the length too great, which requires larger diameters of former. Even so, other measures may be necessary to reduce coil losses. For example, 95 close-wound turns of 22SWG wire on a 1.6in (41mm) diameter former will resonate nicely with 11.5pF at 80m. The necessary length of wire is about 40ft (12.2m) and the straight-wire RF resistance of this at 3.5MHz is only about 2.4Ω. RF resistance is much increased, however, when the wire is formed into a coil, and unless care is taken, the unloaded Q of the coil can be as low as 120, giving an equivalent loss resistance of nearly 32Ω. This more than doubles the antenna circuit losses causing most of the power to be dissipated as heat in the coil. Coil losses can be reduced by increasing the wire gauge or winding the coil with spaced turns even though a greater length of wire is required to achieve the inductance. I found the second of these to be the most effective, and have chosen this method of construction for all coils even though it is not strictly necessary above 10MHz.

Larger diameters of coil would reduce losses further, but only at the expense of size, and it is a matter of personal choice exactly how far one goes down this line. Coil losses at the lower frequencies mean that the design must be adjusted for an acceptable compromise between loss and physical size. Data on my choice of coils is given in Table 1, with losses reduced to the point where, except on 1.8MHz, they are no longer significant.

Matching the antenna base impedance to the transmitter's 50Ω is easily done by shunting the antenna feed point with a 150V mica or polystyrene capacitor whose value will vary between zero and about 1000pF depending on antenna impedance, frequency, ground conditions and type of car. Figures for my installation are given in Table 1. This matching method requires the antenna impedance to be slightly inductive which is simply achieved by extending the whip slightly from its self-resonant length.

The matching capacitor is switched in, and the whip moved in and out for minimum VSWR. If the VSWR is still too high, the value of the matching capacitor is changed and the whip retuned until an acceptable match is obtained. I bought a small aluminium box, fitted two connectors into opposite sides, joined the centre pins together with a short length of 16SWG wire, and arranged a rotary switch to connect any of nine different capacitors across the feed. A cheap switch will do, so long as it is not operated with the transmitter on.

As the coax between antenna and matching unit can carry currents up to double that on the matched line itself, the matching unit-to-antenna cable should be kept reasonably short to minimise losses.

COIL CONSTRUCTION

I FOUND THAT THE BEST METHOD of attaching the wire to the end couplers was to drill two small holes through the polypropylene just beyond where the end of the coil would lie, and pass the wire into the tube and out through the coupler to which it was then connected. It was found best to solder a hairpin of wire onto the inside of the coupler before fitting it into the plastic former. The coil wire was then easily soldered onto this pigtail at the appropriate time.

The coil former was covered in two or three lengths of double-sided tape, and a sufficient length of enamelled copper wire cut for the coil in question. Seven x number of turns x diameter of former allows a comfortable amount of spare. The coil was spaced by winding two lengths of wire onto the former side by side and subsequently removing one of these. Double-sided tape held the remaining one in position. Half an inch or so was wound beyond the holes through which the wire endings were taken and, after removing the spacing wire, the winding was coated with polyurethane varnish. When dry, the coil was wound back at each end until the required number of turns was obtained, and the ends fed through into the former, out through the end couplings and soldered to the coupling hairpins. The two small holes in the former were sealed with varnish or mastic and the winding bound with a double layer of self-amalgamating tape.

COMPLETION AND WATERPROOFING

SOLDERED CONNECTIONS WERE pushed well down into the coupling, out of the way, and the coil was given two coats of polyurethane varnish to finish the job. The self amalgamating tape can be omitted if you prefer the appearance of varnished copper coils, but it is easy to use and provides additional protection against knocks and bangs. It is available from some electricians or more likely, yacht chandlers. Do not be tempted to use PVC insulating tape - it can be very lossy. Make sure there is not the smallest hole left for water to get in. I did not find it necessary to seal off the internal bore of the couplers.

COIL DATA

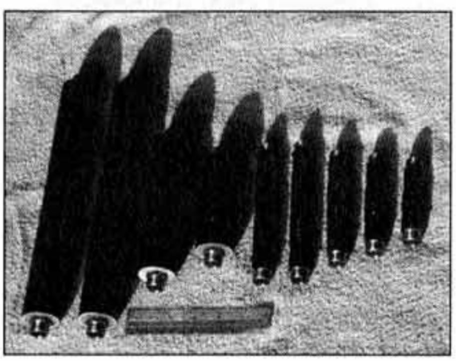
F MHz	D ins	l_F ins	Wire SWG	N	l_c ins	L µH	r_R* ohms	r ohms	C_M pf
29.0	0.8	3.0	18	9	1.1	0.9	35	48	18
24.9	0.8	3.5	18	15	1.7	1.7	29	48	27
21.2	0.8	4.5	18	23	2.6	3.0	22	47	37
18.1	0.8	5.75	18	34	3.75	4.5	17	43	74
14.25	0.8	5.5	20	45	3.6	8.4	11	34	150
10.13	1.6	4.5	20	31	2.6	19	6	26	300
7.05	1.6	6.5	20	58	4.6	41	3	20	544
3.65	1.6	12.0	22	160	10.1	153	0.8	21	1000
1.9	1.6	11.0	28	294	9.3	558	0.2	37	1000

F=frequency (MHz)
l_F=length of coil former tube (inches)
l_c=length of coil winding (inches)
r_R=theoretical radiation resistance (ohms)
C_M=matching capacitor (picofarads)
D=coil former diameter (inches)
N=number of turns
L=coil inductance (microhenries)
r=antenna load, $(r_R+r_L+r_E)$, (ohms)
*=theoretical value

TABLE 1

Water cannot get in very readily, and if it does, it drains out easily. It is the small nooks and crannies in an otherwise sealed item that present the danger since sealing always seems to keep water in easier than it keeps it out!

Self-amalgamating tape was used to waterproof the antenna feed cable connector where it fits onto the antenna mount. All other parts of the mount - outrigger, insulator etc, - were given a generous coating of polyurethane varnish to prevent corrosion.



RESULTS

BECAUSE A MOBILE STATION is small, simple, and cheap, there is a tendency to assume that it is therefore ineffective. In fact, the ability to change to a better location, does much to counter any shortfall in performance. In practice, it is rare when, as a member of a mixed home base/mobile net, I am unable to work a station, and on occasions, because of the low level of background noise and all-round directivity of the antenna, readability is better than at a home station. Reports are normally two or three S points lower than those of big home stations with their beams and linears, but in practice, I have rarely felt seriously disadvantaged.

In the course of one year of rather low-key operation from the car, I have been able to enjoy Q5 SSB contacts with countries in all continents, (except Antarctica), from home, holiday and business locations. Above 7MHz and when the band is open, world-wide coverage is to all intents and purposes routine - solid QSOs with ZL, VK, JH, PV, W, K, etc - and on holiday 7MHz has proved good for UK coverage (including mobile to mobile), much of the continent, and the occasional early morning VK. Performance noticeably degrades on 80 and 160 metres, but even so, I have worked ZL4 on 80 metres although 300 miles is more usual. On Top Band, ranges up to 200 miles are typical.

Thus for a very modest outlay of less than £50, I am able to work all HF bands, take my hobby around with me wherever I go, and avoid annoying the neighbours. The antenna, fixed to a balcony railing or with a counterpoise, has also been used, with a home station. Overall, I have been surprised and delighted with the performance and capability of this highly cost-effective antenna.

ACKNOWLEDGEMENTS

MY GRATEFUL THANKS GO OUT TO G4WEY, G0GKT, G4AQ, G3MDH, G4XYX and other friends too numerous to mention, without whose generous help, advice and patience this article could not have been written.

USEFUL EQUATIONS

$L = N^2D^2 / (18D + 40l_c)$

where:

L = inductance of a coil (microhenries)
N = number of turns
D = diameter of coil (inches)
l_c = winding length of coil (inches)

$C_m = \sqrt{(Rr-r^2)}/0.00000628FRr$

where:

C_m = matching capacitor (picofarads)
R = output impedance of transmitter in ohms, (usually 50)
r = resistance (impedance) of antenna (ohms)
F = frequency (MHz)

USEFUL FURTHER READING

Radio Communication Handbook (RSGB)
ARRL Handbook (ARRL)
The ARRL Antenna Book (ARRL)
HF Antennas for All Locations, Les Moxon, G6XN (RSGB)
'A Mobile Antenna for 1.8 to 28MHz', Mike Grierson, G3TSO, *RadCom*, Feb 1988