Construction Project

Improved VHF-UHF Masthead Amplifier

Here's a design for an improved and updated masthead amplifier, to boost signal strength and improve reception of TV and other signals in the VHF and UHF bands. It's not hard to build and will cost you much less than commercially available units.

by Andrew Palmer

For good TV and FM reception, your receiver needs signals that are as strong as possible compared with atmospheric noise and the noise that is inevitably generated inside the receiver's own 'front end'. Otherwise, in striving to amplify the weak signals, the receiver will have to amplify the front-end noise to the point where it will become evident on your TV picture as 'snow', and/or audible as 'hash' in your FM stereo program.

There are various kinds of situation where achieving a satisfactory signal-to-noise ratio can be a problem, but three of the most typical are as follows:

1. You are in a 'fringe area' with respect to the reception of the signals concerned, making it difficult to achieve sufficient signal strength — even with a large and elaborate antenna system.
2. You are in a reasonable signal area, but it isn't feasible to use an antenna system capable of producing the strongest possible signals, and your TV or FM receiver is a little elderly. Although too good to throw away, its RF front end has a fairly high noise level — enough to cause an obvious deterioration in reception.
3. You are in a reasonable signal area and your antenna is producing fairly strong signals, but you need to feed a number of sets in various rooms of the house. After passing through the necessary splitters and cable runs, with their inevitable losses, the signal levels reaching the receiver(s) are not strong enough.

In all of these common situations, reception can generally be improved quite noticeably by fitting a wideband RF preamplifier, preferably at the top of the antenna mast. In other words, a 'masthead amplifier'.

But why should it be at the top of the mast? Basically, because this allows it to amplify the signals picked up by the antenna *before* they suffer from any attenuation or other deterioration due to the cable and things like splitters.

The amplifier itself is housed in a length of 32mm OD PVC tubing, with close-fitting end caps (front). The matching power feed unit is in the small utility box at rear, which connects at the foot of the co-axial downlead.

Fairly obviously, the masthead preamp can't improve the basic ratio between signals and noise as picked up by your antenna. In fact it will inevitably make things slightly worse, by contributing some extra noise of its own. But by placing it as near to the antenna as possible, we maximise the ratio between received signal strength and amplifier noise, and at the same time boost the strength of the signals to be pumped down the cable. Any attenuation introduced by the cable system will therefore affect both the amplified signal and amplifier noise equally, without affecting the ratio between them.

With the alternative approach of fitting an amplifier down at the receiver end of the cable, the signals will already have suffered some attenuation by the time they reach it.

This will immediately provide a poorer ratio between the signal at the input to the amplifier, and its own inherent noise — preventing it from giving as much improvement.

By the way, although a masthead amplifier inevitably contributes some noise of its own, this is quite small and typically rather less than that added by the tuner section of a TV receiver — particularly if the receiver is not one of the latest models. And of course fitting it to the top of the mast allows it to operate on the signals at the most favourable point.

So if you're in a fringe area, or have a less-than-ideal antenna system with a slightly older receiver, or need to feed the signals through quite a few splitters and cables, a masthead amplifier could well give you noticeably better reception.

The flip side

Does a masthead amp have any drawbacks? Certainly. Because they're a wideband amplifier, handling all the channels together, a really strong signal on one channel can cause amplifier overload and produce interference with the other channels. So a masthead amp is *not* likely to be of much benefit if you're in a strong signal area, or where you have one really strong local signal and you're trying to improve the reception of much weaker signals. Unless you take special steps to prevent the strong signal from overloading the amplifier, it could well make things *worse* rather than better.

The same tends to apply where you have a strong local VHF signal from a primary transmitter, and some weaker UHF signals from translators.

Of course a masthead amplifier can't in itself do much with other kinds of reception problems, either — like 'ghosting', which is caused by multiple versions of the same signal reaching the antenna via different paths. With this kind of problem, all the amplifier might let you do is swing the antenna around to a position which minimises the ghosting, making up for the reduction in wanted signal strength with its additional gain.

A masthead amplifier isn't a universal cure-all, then, although it can improve reception in a lot of situations.

About masthead amps

There have been quite a few designs published for VHF-UHF masthead amplifiers, in various magazines. I described the last one published in *EA*, in the December 1988 issue. Like earlier designs it was based on the OM350, a hybrid VHF/UHF wideband amplifier IC manufactured by Philips Components. However this device is no longer being made, it seems, and even before this happened it had become quite expensive. It's therefore been necessary to revamp the design using a newer, cheaper and readily available device.

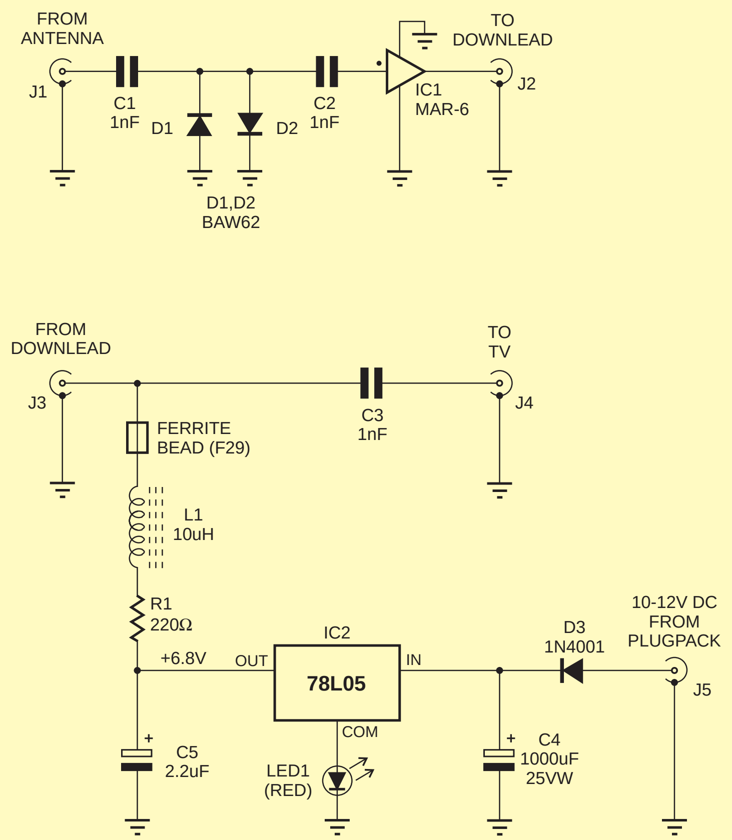


Fig.1: As you can see, the new amplifier is very straightforward. A Mini Circuits MAR-6 chip provides the wideband amplification (top), while the power feed circuitry is based on a 78L05 regulator.

The amplifier I've chosen is the MAR-6, made by New York based firm Mini-Circuits and available in Australia from Clarke & Servern Electronics. The MAR-6 is an excellent wideband amplifier, providing stable amplification of at least 9dB up to 2GHz, combined with a low noise figure (about 3dB).

Incidentally, *noise figure* is a measure of the noise introduced by the amplifier itself. It is actually the ratio of *input* signal-to-noise ratio to *output* signal-to-noise ratio, so that the lower the noise figure the better. An ideal amplifier would inject no additional noise of its own, so that the ratio between input and output signal-to-noise ratio would be unity or 0dB.

The UHF tuners in many older TV receivers typically have a noise figure of somewhere between 11 and 14dB, so that the 3dB figure of the MAR-6 is obviously rather better. Since the overall noise performance of a receiving system is determined almost entirely by the noise figure of its input circuitry, this gives the MAR-6 the potential to give quite a significant improvement when used 'up front' in a masthead amplifier.

The MAR-6 comes in a very small cylindrical package, about 2mm in diameter and 2mm high. It's fitted with four radial leads at 90° (two of which are earthed), and is basically a two-transistor amplifier with untuned and low value loads in order to achieve the required wide bandwidth and be capable of driving a co-axial cable.

Because the MAR-6 is designed to receive its power via the signal output pin, it's very suitable for use as a masthead amplifier. It requires about 3.5V DC, at a working current of around 16mA.

Mini-Circuits recommends that the MAR-6 should be mounted on a small double-sided PC board, and gives a suggested layout. Although superficially there's not much involved in using the device in this kind of application, it's actually a good deal more critical than you'd think. At UHF, an extra millimetre of lead length or PCB pattern can resonate with stray capacitance, to produce quite significant changes in gain at certain frequencies. Similarly even short lengths of signal path which do not maintain the correct characteristic impedance level can produce mismatch reflections, setting up standing waves and again producing undesirable peaks and notches.

The new design

To avoid these pitfalls, the design described here has been based fairly closely on the December 1988 amplifier, which was originally developed by the R&D people at Dick Smith Electronics. That design was tested very thoroughly, and turned out to be very stable and reliable. All I've done, basically, is adapt the same techniques to use the MAR-6 instead of the OM-350.

The actual circuit is quite straightforward, as you can see (Fig.1). The MAR-6 itself (IC1) forms the heart of the masthead amplifier proper, with the only other components being a pair of high-speed diodes D1-D2 to protect its input from damage due to corona discharge, etc, and coupling capacitors C1-C2 to block DC and prevent the diodes from disturbing by the MAR-6's internal biasing.

Power to the MAR-6 is sent up the co-ax cable from a small matching feed unit. Here the amplified RF from the amplifier is passed through blocking capacitor C3 to your TV receiver or whatever, while DC is fed to the amplifier via shunt inductor L1 and load resistor R1. A ferrite bead is used on one of L1's leads to ensure stability.

The DC power is derived from a standard 9-12V DC plug pack supply, with a small three-terminal regulator chip IC2 used to provide smoothing and regulation. A small red LED is connected in series with the regulator's common lead, and serves two purposes: it both acts as a pilot light, and also 'bootstraps' the regulator so that its output becomes just under 7V. This ensures that the working voltage at the MAR-6 is very close to 3.5V, at its nominal current of 16mA.

Series diode D3 is used to prevent damage to the regulator if the plug-pack polarity is accidentally reversed.

As you can see there's nothing terribly different about the new design in terms of its circuit. It's in the area of physical layout that it differs, particularly for the masthead unit itself. Great care has been taken to minimise excess lead lengths, and reduce any discontinuities in terms of characteristic impedance.

As with the 1988 design a double-sided PCB is used, with the copper on one side used as a 'ground plane'. The MAR-6, diodes and input capacitors are all mounted on the copper track side, to allow the shortest possible lead lengths. A hole 2mm in diameter is drilled in the board where the MAR-6 is fitted, to allow it to be mounted with its leads flush with the copper surface.

This approach allows the main RF signal tracks to function as microstriplines of the correct impedance, to provide fewer discontinuities in the signal path. Note that the amplifier PCB has been designed to allow C1 and C2 to be either SMT devices, or standard small disc ceramics with their leads cut very short.

Inside the power feed unit, all of the smaller components are on a small double-sided PCB supported by the two Belling-Lee type coax sockets. Note that when this photo was taken, a 150-ohm resistor was fitted for R1 — the final value is 220 ohms.

To improve the performance still further, the PCB has a large 'notch' at each end, so that the co-ax connectors mount directly to it in axial fashion, again with minimum disturbance to the characteristic impedance in the signal path. The outer earthed sleeves of the sockets can also be bonded directly to the ground plane copper on each side of the board, for minimum inductance.

And finally, to make sure that the 'ground' copper on both sides of the PCB does indeed provide a true unipotential ground, the two are bonded firmly along both sides by lengths of copper shim soldered full length.

All of these steps have produced a design that although not exactly pretty, is straightforward and quite easy to reproduce, and provides a consistent high order of performance.

The board is designed to be housed in a 145mm length of 32mm OD PVC electrical conduit, with matching tightly fitted end caps to keep it waterproof. The idea is that the input and output co-ax cables pass through close-fitting holes in the end caps, and then terminate in plugs which mate with the sockets on the PCB. The complete assembly can then be put together inside the PVC tube, with 'Silastic' or similar sealant around the cable entry holes and the end cap edges. A strap clip can then be used to mount the amplifier on the mast, near the antenna terminals.

The power feed unit is housed in a small 'UB5' size utility box, measuring 83 x 54 x 28mm. As there are a few more components in this unit compared with the 1988 design, I have designed a second small PCB to make it easier to assemble.

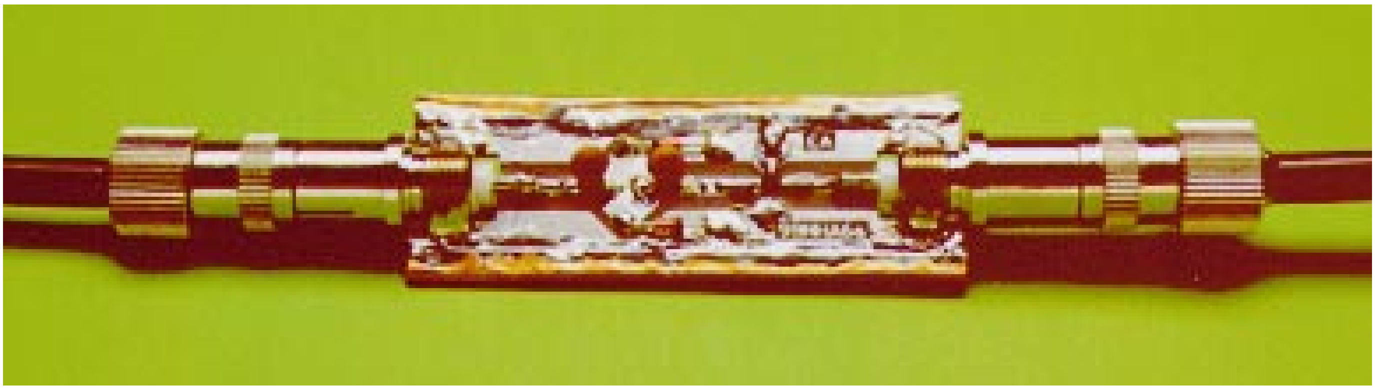
The power board is again double sided, with one side used largely as a ground plane. The board is again notched to take the co-ax connectors, although as you can see here they're both on one longer side so the PCB can be supported by the connectors when they're mounted on the case front panel. Again the body of the connectors is soldered to the earth copper on both sides, and as the board is very small and light, this gives it more than adequate support.

All components except the DC blocking capacitor mount on the 'top' of the board, with C3 mounted on the track side to again minimise its lead length. As before you can use either an SMT component for C3, or a small disc ceramic with its leads cut as short as possible.

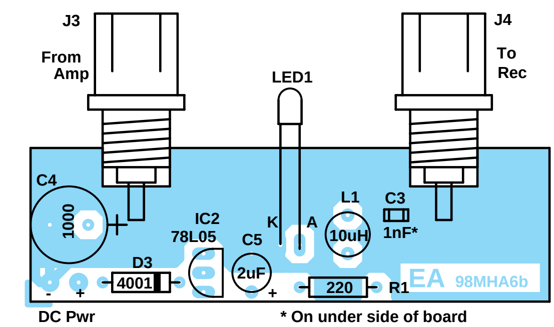
Construction

The most critical part of the project is the actual masthead amplifier assembly, of course. But this needn't present any problems, provided that you tackle it in a logical fashion.

First cut the copper shim into two strips 67mm long by 15mm wide. Crease these down the centre, and bend them around the edges of the PCB so that they lie flat on the copper of both sides. Then solder both of them carefully along the full length of both sides, so that they each bond the two copper



Above is a view of the track/components side of the amplifier PCB, showing just about everything. It isn't pretty, but this construction gives stable amplification.



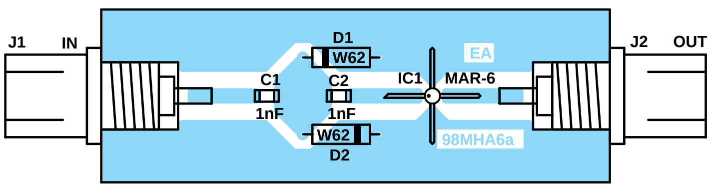


Fig.3 (left) shows the overlay for the power feed PCB, while Fig.2 (above) shows the amplifier PCB.

laminates together.

Next take the two Belling-Lee sockets, and solder them carefully into the appropriate cutouts at the ends of the PCB. Take care to position them with the centre (insulated) spigot just resting on the central stripline track, so that it won't be moved out of position during the soldering. Note that the outer sleeves of the sockets should be soldered to the adjacent 'ground-plane' copper along *both* sides of the sockets themselves, and on both sides of the PCB as well.

With all of this 'heavy' soldering done, you can now solder in the two diodes D1 and D2. These mount on the track side, but the PCB has 1mm holes to allow you to locate the diode leads by bending them down at 90°. After soldering carefully, the excess leads are cut off flush on the underside of the board.

Input coupling capacitors C1 and C2 can then be fitted. If you're using SMT parts for these, they're placed carefully over the small track gaps and soldered first at one end and then at the other, holding the body down with a toothpick or similar and making the joints as quickly as possible to avoid overheating the component.

If you're using standard disc ceramics, as shown in the photo, the idea is to trim their leads as short as possible, while still providing *just enough* exposed metal for soldering to the PCB tracks (say 1.5 to 2mm at most). Then you do the actual soldering as quickly as possible, so that the components are again not damaged.

The final step is to fit the MAR-6 amplifier. If you examine this closely, you'll find that it has a small white dot on the top, near one of the four leads. The lead concerned is also cut on the end diagonally, whereas the others have a double chamfer. This lead is the input lead, and the MAR-6 must be fitted with this lead soldering to the signal track from C2. The overlay diagram should make this clear.

As with the other components solder the four leads of the MAR-6 quickly and carefully, to avoid overheating it.

Assembly of the power feed unit is little more involved than with the previous design, but again not difficult if you tackle things in the right order. The first step is to drill and ream out the holes in the front panel for the sockets and LED, using a photocopy or tracing of the front panel artwork as a template. Then you can carefully stick on the Dynamark dress panel and mount the sockets (the LED comes later).

Most of the smaller components can now be mounted on the PCB, although reservoir capacitor C4 and the LED are not fitted as yet. But you can fit R1, L1 (with the ferrite bead on its 'uppermost' lead), C5, D3 and IC2 to the top of the board — in that order, I suggest — and then C3 to the underside.

Although the LED isn't fitted as yet, you should fit a pair of PCB terminal pins to the two pads concerned. This will allow the LED to be added much more easily later. Two further terminal pins can be fitted at the lower left-hand corner of the board, for the

PARTS LIST

Resistors

R1 220 ohms 1/4W carbon.

Capacitors

C1,2,3 1nF ceramic (disc or SMT)
C4 1000uF 25VW RB electrolytic
C5 2.2uF 35VW TAG tantalum

Semiconductors

D1,2 BAW62 diode
D3 1N4001 or similar power diode
LED1 3mm red LED
IC1 MAR-6 wideband amplifier
IC2 78L05 regulator (TO-92)

Miscellaneous

L1 10uH RF inductor

Plastic utility box, 83 x 54 x 28mm; 145mm length of 32mm (OD) PVC conduit, with two end caps to suit; two PC boards one 71 x 25mm coded 98MHA5A, the other 69 x 20mm and coded 98MHA5B; four co-axial sockets, Belling-Lee single hole panel mount type; one 2.5mm power socket, panel mount type; four PCB terminal pins; one ferrite bead, F29 material; length of copper shim, 70 x 30mm; dress front panel for utility box; 80mm length of two-core cable; machine screws and nuts, etc.

wires from the DC input socket.

With these components all fitted, you should now be able to offer up the PCB assembly to the back of the RF sockets, and proceed with soldering the two together. Before doing so, though, you may need to trim-file the notches to allow everything to fit together.

As you can see, the board is mounted so that the insulated socket spigots solder to the signal tracks on the PCB, while the socket bodies solder to the surrounding copper on both sides, as before.

When this is done, the remaining steps are to fit revervoir electro C4 and the LED. The electro is fitted in the usual way, as you can see, while the LED is fitted with its body protruding through the hole in the front panel and its leads soldered to the tops of the terminal pins you fitted before. Make sure you orientate it so that the longer anode lead mates with the terminal pin nearest L1.

You may want to apply a small amount of glue around the LED body at the rear of the front panel, to ensure it's held firmly in place.

The final step is to use a short length (say 80mm) of two-conductor cable, to connect the board's DC input pins to the lugs of the power input connector. Make sure that you fit these so that the positive side of the incoming DC connects to the pin marked '+' on the PCB overlay diagram (the one nearer D3).

Testing & installation

When both units are finished in the electrical sense, I suggest that you first connect the power feed unit to your plug-pack supply, and do a quick check to ensure that everything is in order — before connecting it to the amplifier unit. With power applied, the LED should glow reassuringly and you should be able to measure about 6.8 - 7V DC at the end of R1 nearer IC2 and C5 (with respect to the earthy side of the RF sockets). You should also get virtually the same reading at the insulated pin of the 'amplifier' socket.

If the LED doesn't glow and you get no voltage reading, chances are that you've wired the DC input with reverse polarity. On the other hand if the LED doesn't glow but there's almost the full plug-pack voltage present at R1, you've almost certainly wired the LED in backwards. In either case, it shouldn't take long to fix the mistake.

Once everything seems OK, try connecting the amplifier and power feed boards temporarily together via a short length of co-ax, and try them out to make sure everything is working correctly. It's better to do this *before* you fit the amplifier unit into its protective tube, and mount it up on the mast!

First check the DC voltage at the centre spigot of the 'amplifier' socket. If all is well it should read very close to 3.5V. Then try hooking the combination of units temporarily into the antenna lead, right at the receiver, so that you can use the receiver to check that they're working. With power supplied the signals fed to the receiver should be noticeably stronger via the amplifier setup than with direct input from the antenna. (The noise will also be stronger, with this temporary setup.)

If all seems well, you're now ready to fit the amplifier unit into its housing and instal it up on the masthead.

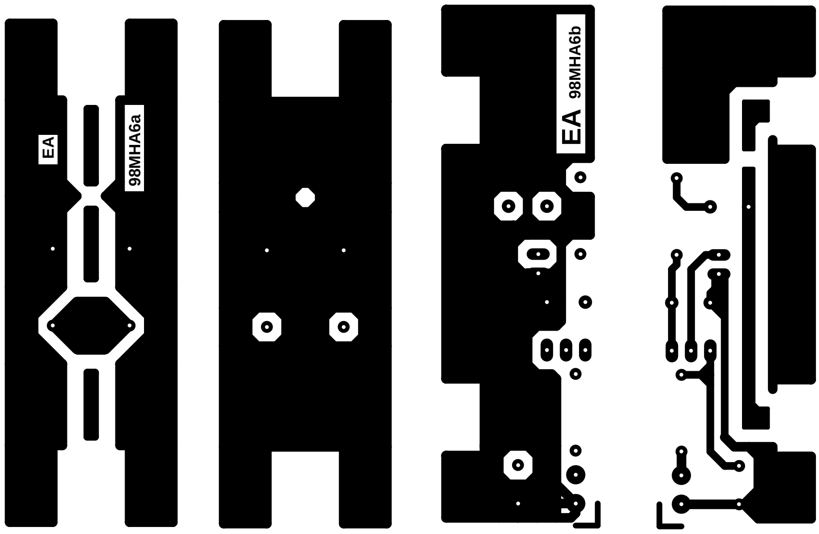
The procedure here is to first drill a hole in the centre of each of the PVC end caps, just large enough to take the co-ax cable snugly. Then you'll need to cut the antenna downlead, say 30cm or so from the antenna end, and poke each of the two cable ends through a cap (from outside to inside).

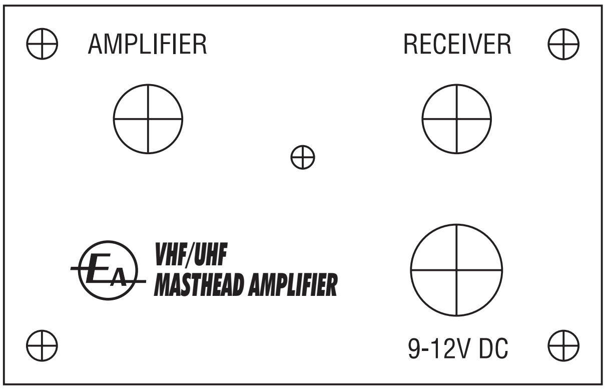
This done, you then fit a Belling-Lee type co-ax plug to each one, soldering the connections carefully if they're of the solder type. The PVC tube is then slipped over the amplifier board, and the plugs fitted into the appropriate socket at each end of the board to complete the connections. After this the end caps can be slid along the cables and over the ends of the PVC tube, to complete the housing and hold everything together. The length of the tube is carefully set so that when the caps are fully on, they will hold the co-ax plugs quite firmly in the amplifier sockets.

The final step is to add fillets of 'Silastic' or similar sealant around the cable entry points and the edges of the caps, to seal the complete unit and keep out moisture. It would be a good idea to add a dollop of the same sealant to the antenna end of the short input cable, to prevent moisture from seeping down inside the co-ax.

Needless to say the amplifier unit is mounted up on the mast near the antenna terminals, using a strap clip around the outside. The power feed unit is located down at the receiver end of the cable for a single-cable system, or just before the first splitter unit if you have a multiple-set situation.

That's about it. There's nothing to adjust — just hook it all up, apply the DC power to the feed unit and away it goes. ❖





Above: The artwork for the amplifier and power feed PCBs, actual size and showing both sides of each. At left is the artwork for the power feed unit front panel, also actual size.