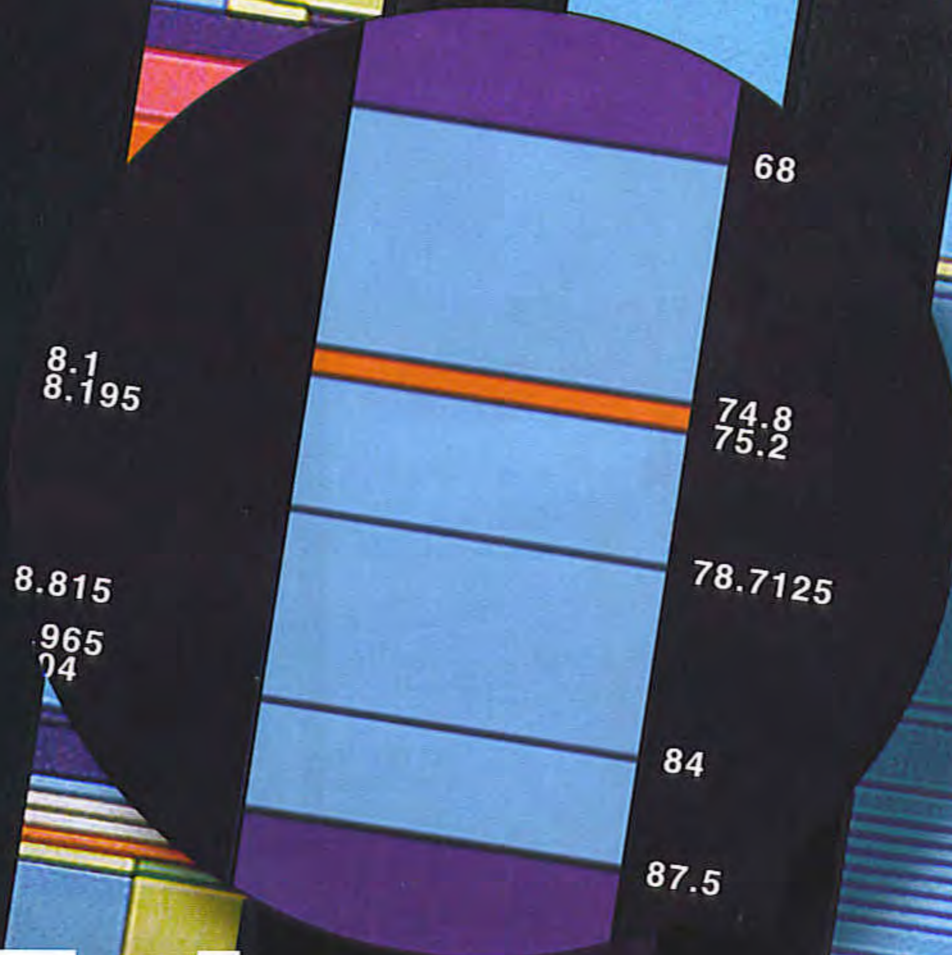


Gert Baars

VHF-Low Explorer

A low-cost NBFM receiver for 68-88 MHz

This article, we hope, will have serious consequences. Not negative, mind you, because apart from enabling beginners to experience the thrill of picking up radio traffic in a generally neglected band, the arrival of this inexpensive 4-m receiver should help to get the IARU section of the 4-m band released to radio amateurs in countries all over the world in due course.

For many decades the UK has been home to the 4-m amateur radio band, also known as '70 MHz', and the IARU-approved band plan shown in **Figure 1** is on the wall in many a radio shack up and down the country. So far, only a few other countries including Ireland, Denmark and — quite recently — Croatia have followed suit by releasing the frequency range between 70.000 and 70.5000 MHz for use by licensed radio amateurs. Unfortunately, in many other countries the relevant frequency range is in use by government or military services which need to have a few arms twisted (pun intended) before they move out. Although it is too early to say whether or not the arrival of new communication systems like Tetra, C2000 and Astrid on the European Continent and elsewhere will free up the 70 MHz band to amateurs, there can be no harm in increasing the pressure on various national radio regulatory authorities to do the necessary paperwork. At least in Holland and Poland, the word is out that amateurs are 'interested' in the 70 MHz band. Let's hope the pressure rises as the 4-m band is fantastic for VHF DX-ing. *Elektor Electronics* being an international publication, we will gladly assist in spreading the word in as many countries as possible.

70MHz (4m)

Licence Notes: Amateur Service: Secondary. *Available on the basis of non-interference to other services (inside or outside the UK).*
Power limit: 22dBW PEP.
Permitted modes: Morse, telephony, RTTY, data, fax, SSTV

IARU	U/A Rem Ctrl	U/A Digital	U/A Beacon	UK Usage	
70.000 – Beacons				*70.030*	*Personal beacons*
70.030 – SSB and CW only				*70.150*	*Meteor scatter calling*
				70.185	*Cross-band activity centre*
				70.200	*SSB/CW calling*
70.250 – All modes				*70.260*	*AM/FM calling*
70.300 – Channelised operation using 12.5kHz channels	✓		✓	*70.3000*	*RTTY/fax calling/working*
		✓		*70.3125*	*Digital modes*
		✓		*70.3250*	*Digital modes*
		✓		*70.3375*	*Digital modes*
		✓		*70.3500*	*Emergency comms priority*
		✓		*70.3625*	*Digital modes*
		✓		*70.3750*	*Emergency comms priority*
		✓		*70.3875*	*Digital modes*
		✓		*70.4000*	*Emergency comms priority*
		✓		*70.4125*	*Digital modes*
		✓		*70.4250*	*FM simplex - used by GB2RS*
		✓		*70.4375*	*Digital modes*
		✓		*70.4500*	*FM calling*
		✓		*70.4625*	*Digital modes*
		✓		*70.4875*	*Digital modes*
70.500					

Notes:
1. 70.085MHz ± 0.005 designated for PSK31 use in the UK.

Figure 1. If and when radio regulatory authorities eventually decide to allocate the 4-m to radio amateurs then the IARU recommendations will be followed, with strong guidance available from the UK example.

What's in it for me

While the radio amateur fraternity is poised to grab their share of the spectrum around 70 MHz, it should be noted that the 68-88 MHz band has other, equally interesting users and applications including Government, MoD and PMR (private mobile radio) communications (not encrypted in many cases), security services, telemetry and the odd TV station. Unless you live in a really remote place, even a simple antenna in your loft will bring in a surprising number of stations using the 4-m band. Tune and Explore!

Design considerations

From the very start of this project, the design was to remain as simple as possible. This decision has important consequences as well as a background we'd like to share with you. Sure, a receiver for the 68-88 MHz band could be a double-conversion superheterodyne design employing a 10.7-MHz filter, a 10-turn pot for the tuning and a final intermediate frequency (IF) bandwidth of 15 kHz to suit NBFM (narrow-band frequency modulated) signals picked up at a sensitivity of 1 µV or so, not forgetting a squelch to make sure the receiver is quiet when nothing is received. Great shopping list, but such a receiver will be expensive as well as difficult to adjust by beginners. Next, please!

The good news is that an attractive alternative is available in the form of the TDA7000 chip from Philips that's been around for more than 10 years now, which is quite remarkable for a consumer-market chip. This 'evergreen', then, contains a complete radio receiver with a very low IF of just 70 kHz. Okay, so image frequencies occur just 2 x 70 kHz = 140 kHz away from the desired signals, but that need not be a problem because on the positive side we do not have to worry too much about the input filtering. Also, the IF filter responsible for

COMPONENTS LIST

Resistors:
R1=100kΩ
R2=150kΩ
R3=100Ω
R4=22kΩ
R5=330kΩ
P1=50kΩ logarithmic potentiometer
P2=50kΩ linear potentiometer

Capacitors:
C1=39pF
C2=27pF
C3,C6,C14=10nF
C4,C11,C13,C19,C23,C24,C25,C26,
C29=100nF
C5,C12=1nF, lead pitch 5mm
C7=100nF, lead pitch 5mm
C8=220pF
C9,C18=330pF
C10=10pF
C15,C17=3nF3, lead pitch 5mm
C16=180pF
C20=22pF PTFE trimmer
C21=150pF

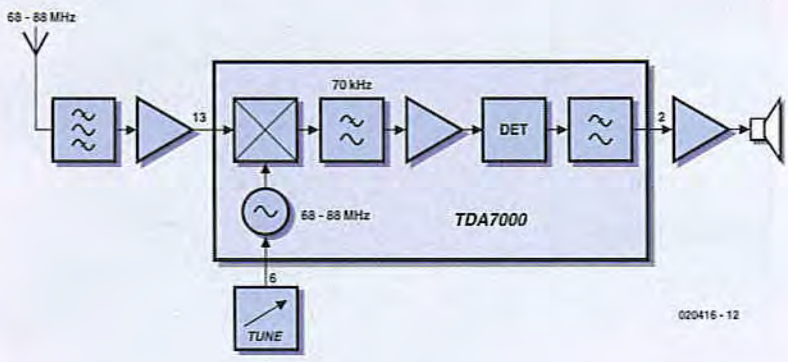


Figure 2. Block diagram of the single-conversion receiver. Note the low intermediate frequency of just 70 kHz which in our case has a number of advantages!

the selectivity may be realised as a simple R-C network, obviating the need for expensive and esoteric quartz or ceramic filters.

Block diagram

Even if you are not a radio boffin, the block diagram of the proposed receiver in **Figure 2** should be largely self-explanatory. The TDA7000 contains a muting circuit which is activated at a level of about 6 µV. As we will want to use a whip antenna as the bare minimum, an RF preamplifier will have to be inserted between the antenna and the input of the TDA7000. Everything from the output of the RF preamp right up to the input of the audio amplifier is contained in the TDA7000. If you want to know everything about the chip, get a copy of the datasheet (see Web pointers).

Inside the receiver

Figure 3 pictures the circuit diagram of our little receiver. MOSFET T1 at the antenna input provides a gain of about 18 dB across the band, driving the TDA7000 RF input via coupling capacitor C5. The receiver's input impedance is 50 Ω to match most types of coax cable available these days. A number of capacitors strewn around the TDA7000 ensure an IF bandwidth of about 70 kHz. The VFO (variable frequency oscillator) inside the chip is tuned by a varicap (D1) which gets its bias voltage from tuning pot P2. IC2, a 78L05, supplies the regulated 5 volts for the receiver chip, the preamp and, importantly, the tuning pot.

The circuit configuration around the TDA7000 follows information from Philips on making the chip better compatible with NBFM signals. After all, the TDA7000 was originally designed for reception of VHF FM broadcast stations, which at 100+ kHz deviation are much wider than the 'thin' PMR signals (3 kHz) we're interested in. None the less, as the IC will produce a rather low nett output signal, some extra amplification is furnished in the audio section by adding an electrolytic capacitor between pins 1 and 8 of the LM386 AF power amp (another evergreen).
Hang on, where are the adjustments and the dreaded home-made coils in this receiver? Well there's only trimmer C20 to adjust the tuning to 68-88 MHz. The receiver employs off the shelf miniature chokes only, so there are 0 (say, zero) coils to wind.

Build it!

At this point, you should have enough confidence and 'inside knowledge' about the receiver to start building it, if necessary with the help of a friend with RF experience. If you do not have the means to make your own board, you can easily order a ready-made one through our Readers Services. The board, pictured in **Figure 4** together with its external elements, is single-sided with a large copper plane at the solder side to assist in RF stability, screening and decoupling. There are many small ceramic capacitors on the board which need to be positively identified before they are soldered in place. The same goes for the three miniature chokes, the coloured bands on them indicating the value in microhenries. The TDA7000 should be soldered directly on to the board.
The 4-legged MOSFET T1 is mounted at the solder side of the board, perched directly onto four solder pads. The close-up photograph in **Figure 5** should help to get our message across.

We would suggest using a small diecast case from Hammond to house the receiver and the battery. The case is then drilled to secure the volume pot, tuning pot and the loudspeaker. Battery powering is not a must however, and you may decide to power the receiver from an existing DC source like a cheap mains adapter. This will require one additional hole to be drilled and filed for the mains adaptor socket.

Caveats and limitations

Due to the simplicity of the design, some inherent limitations should be

C22=100pF
C27=2nF2
C28=10µF 16V radial
C30,C31=100µF 16V radial

Inductors:
L1=100nH (brown, black, silver)
L2=330nH (orange, orange, silver)
L3=180nH (brown, grey, silver)

Semiconductors:
D1=BB911
T1=BF981
IC1=TDA7000
IC2=78L05
IC3=LM386 N4

Miscellaneous:
8 ohm, 1 watt miniature loudspeaker
Diecast case: e.g., Hammond type 1590B
9V battery (PP3 / 6F22) with clip-on leads
PCB, order code 020416-1 (see Readers Services page or www.elektor-electronics.co.uk)

taken into account. First, the receiver will be found rather susceptible to cross modulation, breakthrough and general interference from nearby FM broadcast transmitters. This not at all surprising in view of the nearby frequencies (89-107 MHz) and power levels in the kilowatts range. Good shielding, coax cable and a tuned antenna for 4 m (see 'Antenna' inset) should remove most of the interference. Second, a small problem with spurious oscillation was discovered when the receiver's RF input is not terminated

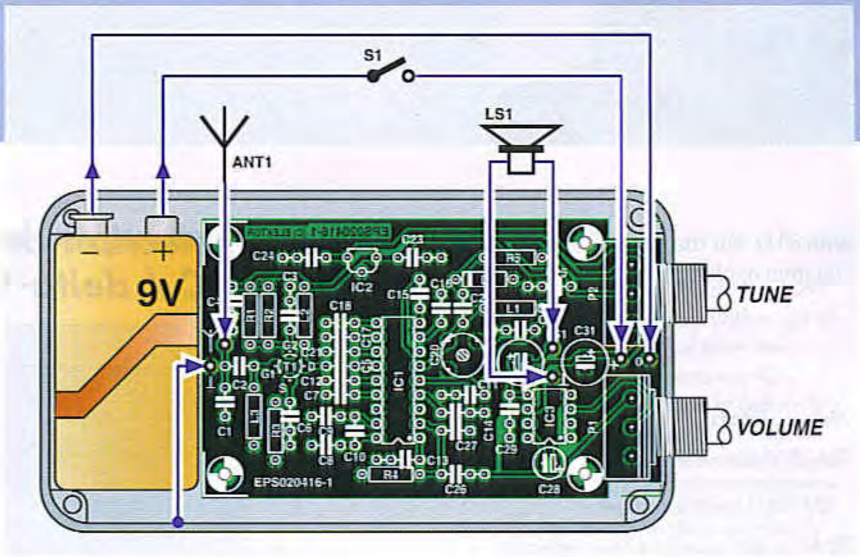


Figure 4. A drawing to show how the board is connected to its external elements. The copper track layout may be found elsewhere in this issue.

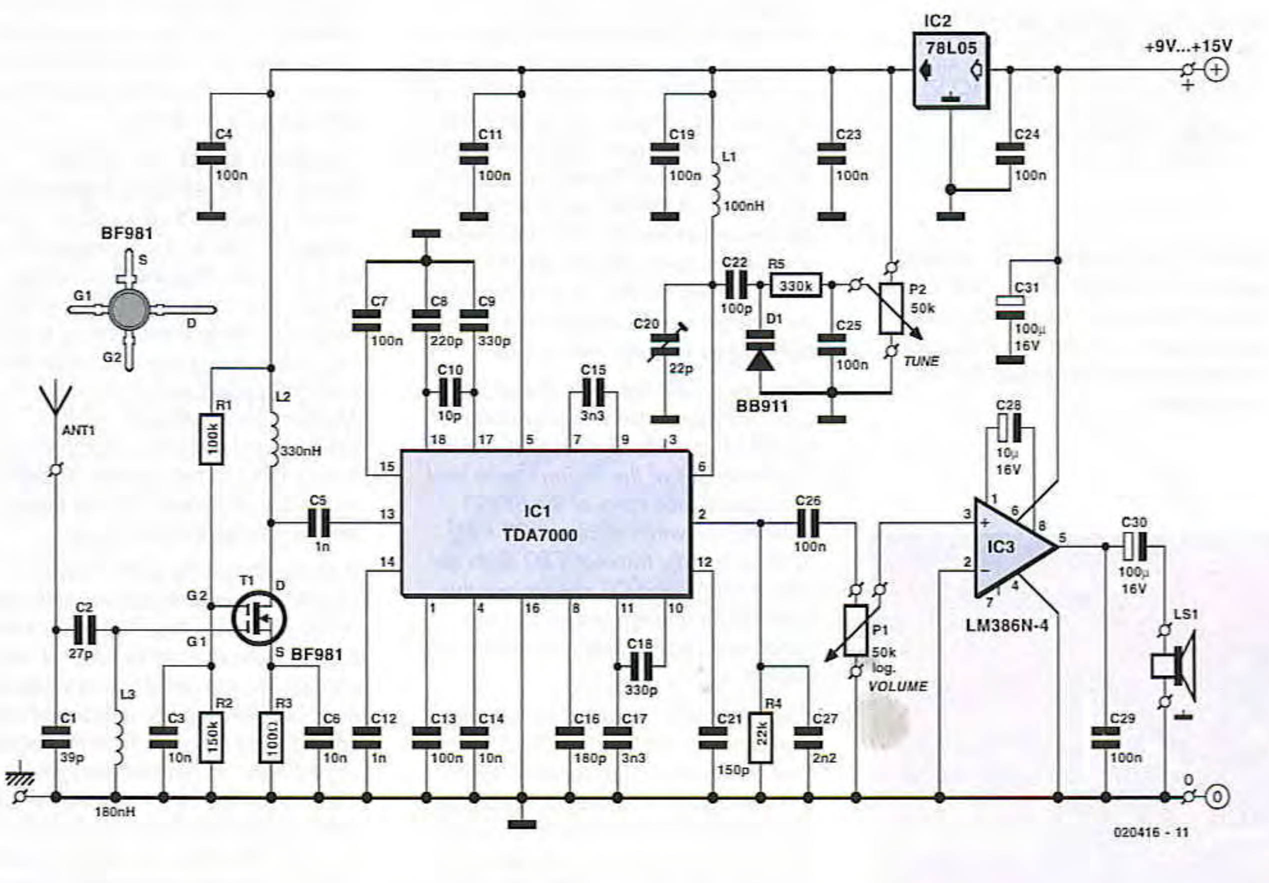


Figure 3. The circuit diagram of the VHF-Low Explorer has few surprises and proves the simplicity of the design.

About the author

Gert Baars (42) has been active in electronics from a young age. In 1988 he graduated in electronics at the Polytechnic of Alkmaar in the Netherlands. Gert's main interest is RF electronics, but also software and digital hardware. He has had over 20 projects published in this magazine since 1997, including the successful Airband Receiver, the 20-m Band Receiver and the DDS RF Signal Generator. In the future, Gert hopes to write about Atmel micros in control of RF equipment, and possibly the design of a UHF sweep generator. He invites comments and suggestions by email, g.baars13@chello.nl.

with 50 Ω. For the rest, nothing to stop you from exploring the 4-metres band.

(020416-1)

Web pointers

TDA7000 datasheet:
www.semiconductors.philips.com/pip/TDA7000.html#datasheet

70 MHz info page and news reflector:
www.70mhz.org

International Amateur Radio Union (IARU):
www.iaru.org

Radio Society of Great Britain (RSGB):
www.rsgb.org

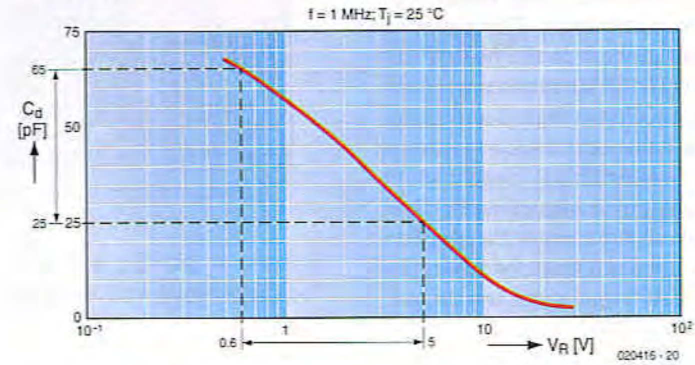
4-m band in Ireland:
www.qsl.net/ei7gl/vhfpage.htm#70mhz

70 MHz Yagi antennas (DK7ZB):
www.qsl.net/dk7zb/start1.htm

7-element Yagi for 70 MHz (M1CCZ):
www.qsl.net/zr6dxb/PROJECTS/4mBeam/4MBeam.htm

Figure 5. This is as close as we could get a lens to the MOSFET at the solder side of the board. Use the MOSFET pinout drawing in the circuit diagram to get the device positioned the right way around.

Varicap selection or the delta-C / delta-V issue



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For some strange reason varicaps (or variable capacitance diodes) have always been rather elusive components. Try this: design, engineer and publish a design at instant T and you'll find that the varicap you've specified after hours of careful researching has disappeared from the market at [T+1 day]. Here at Elektor we're optimists by nature but because we anticipate supply problems with the BB911 varicap specified for this present receiver, we thought we'd give you a few clues to help you find equivalent types.

The component values in the circuit diagram guarantee a tuning range of 68-88 MHz, with trimmer C20 defining the edges of the tuning range and the capacitance ratio of the BB911 defining the width of about 20 MHz. In other words, trimmer C20 shifts the tuning range and D1 determines the width of the tuning range. The two parameters have some interaction, of course.

If you are only interested in, say, the 4-m amateur band (70.0-70.5 MHz) then a narrow tuning range is sufficient and you will have no trouble getting just about any old VHF varicap to work in the receiver, simply by adjusting C20 to a 'known-good' signal in the band (ask for assistance from a local licensed radio amateur).

If, on the other hand, you want everything from low-band TV (68 MHz) to police, MoD and government PMR (in some cases just below 87 MHz) then some thought should be given to the selection of the varicap.

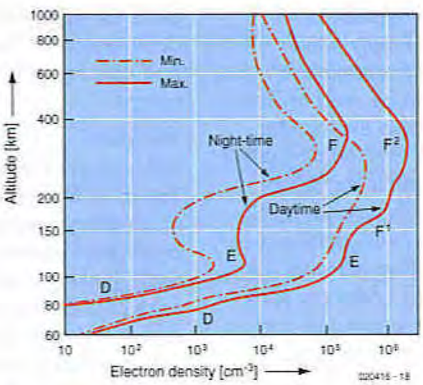
The Philips BB911 was chosen because of its relatively large capacitance range of 25 pF to 65 pF for a corresponding tuning voltage of 0.6 V to 5 V — see ***Figure A*** *(courtesy Philips Semiconductors). That's right, the capacitance presented by a varicap is inversely proportional to the voltage applied across the device! Mathematically, though, [delta-C / delta-V] is a dimensionless device constant which, in the case of the BB911, works out at about 9 for the linear part of its capacitance range.*

If you can't get the BB911locally there's no reason to abandon the project or send Blue Murder emails to the Editor because there are lots of alternatives. Do not be afraid to experiment. In many cases, unlabelled varicaps picked up at radio rallies or salvaged from an FM radio may be used, provided you know they are for VHF. Connecting a few varicaps in parallel ('stacking') is perfectly legitimate in order to arrive at the desired ΔV/ΔC value and hence the receiver's tuning span.

Features at a glance

- Single conversion receiver
- Frequency range 68-88 MHz (VHF-Low band)
- Free-running VFO
- TDA7000 FM Radio Circuit modified for NBFM
- MOSFET preamplifier
- Single-board construction
- On-board audio amplifier
- 1.7 µV sensitivity for 12 dB SINAD (3 kHz deviation)
- Power supply 9-18 VDC, 20 mA (muted)

Propagation — the total surprise factor



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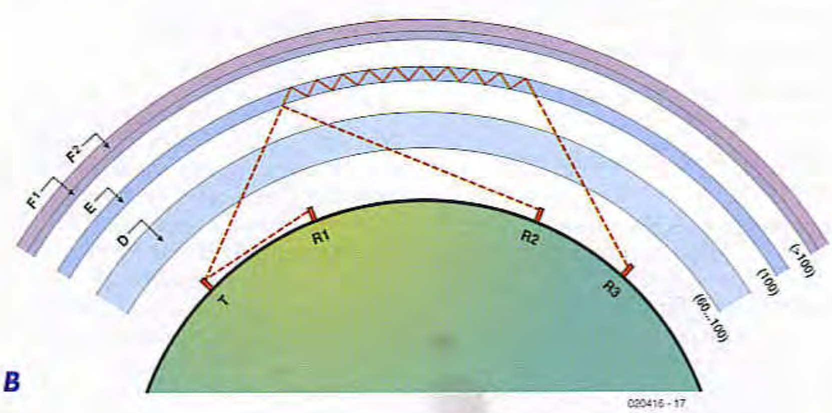
The propagation of radio waves is a fascinating phenomenon because most of it is guesswork and sheer surprise. That is not to say the subject has not been studied extensively by researchers and radio amateurs — far from it, a number of underlying principles have been described in scientific terms as early as the 1920s by Nobel Laureate Sir Edward V. Appleton (1892-1965). Appleton discovered that radio waves, depending in their frequency, were subject to refraction, reflection and (partial) absorption by certain regions of the earth's atmosphere. These regions are marked by different electron densities and occur at heights of 60-400 km above the earth. The basic distribution is shown in ***Figure A****. You will search in vain for the A, B and C regions. This is because Appleton first discovered the region around 100 km height and called it 'electron' region. The D and F (actually F1 & F2) regions were discovered later when the name E region was already established. Today, researchers employ extremely sophisticated radio equipment as well as observations from radio amateurs in an attempt to prove the existence of more 'layers' in the atmosphere.*

Because it is easily ionised, the E region is favourable for reflection and refraction of signals in the 70 MHz and VHF bands in general. Apart from rather unexpected behaviour, usually during periods of high air pressure, the E region is also predictable in that the electron density drops considerably at sunset due to a lesser degree of ionisation. As an aside, the E region reflects medium-wave band signals at night time when the absorption by the D region largely disappears.

Sporadic E (Es) is what we are after for our 70-MHz receiver, and the reason should be obvious if you look at ***Figure B****. Normally, the range of a transmitter T using the VHF-Low band is governed by line of sight, so it will reach receiver R1 as the farthest location. However, with a bit of help from Es the signal may be reflected and reach receiver R2 which, seen from T, is way below the horizon. In extreme case the signal may even 'bounce' within the E layer and reach receiver R3.*

Es is due to the formation of 'clouds' of densely ionised regions in the atmosphere at a height of 100-125 km. Es typically occurs during summer months, but exceptions have been noted. Given a sufficient degree of ionisation (sometimes helped by sunspot outburst), radio contacts via sporadic E have been made over distances of 2000 miles and more. A good way to check for Es activity is to use your receiver to monitor the signal strength of one of the many beacons in the 70-MHz radio amateur band, or TV stations near the low end of the band. Many years ago, thanks to a peak in sunspot activity coupled with massive Es cloud activity across the Atlantic Ocean, police cars from Boston and New York could be heard loud and clear in Europe, some signals even making it across police repeaters on this side of the ocean. Starski & Hutch Ten-four!



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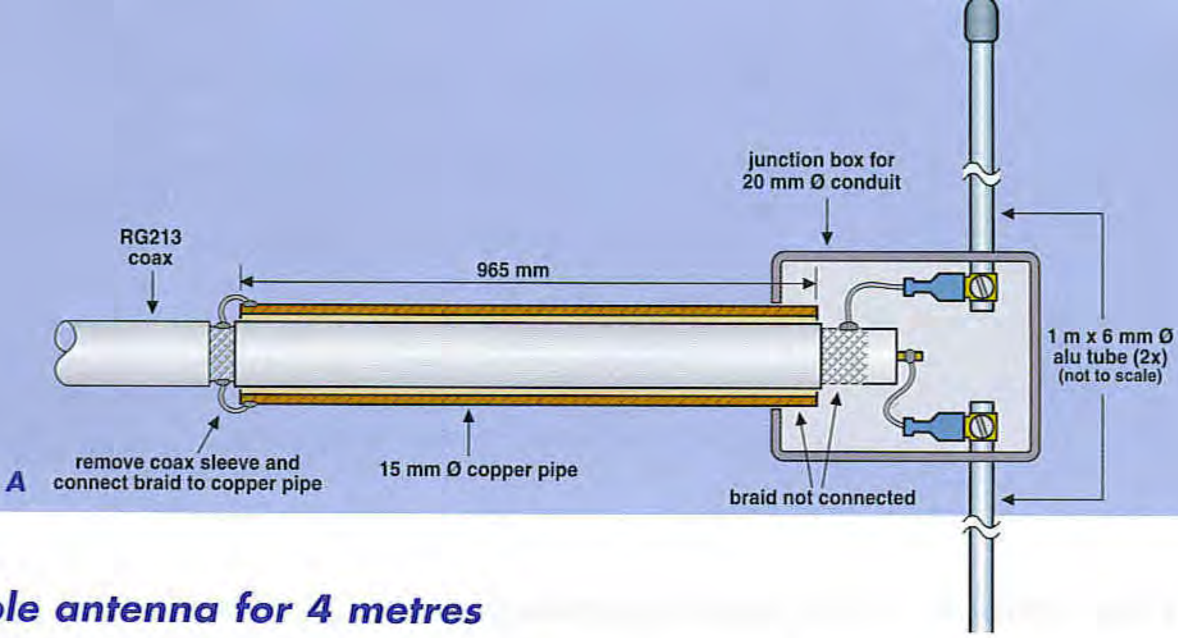


A dipole antenna for 4 metres

No receiver is complete without a matching antenna. Commercial offerings for the 4-m band being few and far between (or scrapped by PMR fleet owners), we decided to present a design for a low-budget get-u-going dipole. Not sophisticated, want a directional antenna? Then try the links at the end of this article. Too difficult? It doesn't get much simpler than this, so give this antenna design a try and you'll be pleasantly surprised. The antenna is great for initial experiments even when installed on your attic.

Our ingredients and tools are:

- *a length of 50 Ω RG213 or RG8 coax cable (10.3 mm outside diameter)*
- *a piece of copper pipe, 15 mm outside diameter, length 965 mm*
- *two aluminium rods, 6 mm diameter, length 1 m*
- *two cable eyelets*
- *a round T-junction box for electrical conduit, 20 mm openings*
- *some not too thin wire*
- *a powerful soldering iron (> 50 watts)*
- *nylon or plastic bushes, 20 mm diameter*
- *permission from the missus*

The drawing in ***Figure A*** *is intended as a guide to constructing the antenna. The copper pipe acts as a balun (balanced to unbalanced transformer), not only matching the asymmetrical coax cable to the symmetrical dipole, but also stepping down the dipole impedance of about 72 Ω to the cable impedance of 50 Ω. RF buffs will like to refer to it as a bazooka or sleeve balun. Unless you have electrical connection materials to fit to the rod ends (like a 60-A electrical 'chocolate block' terminal strip), simply flatten and drill the ends of the aluminium rods to allow screws to be used for the connection with the cable eyelets. For extra rigidity, the rods are fed through bushes (drilled to accept them) where they enter the junction box, and the box itself may be filled with potting compound or hard setting silicone sealant. The other ends of the alu rods should be deburred, rounded off and sealed to prevent moisture ingress.*

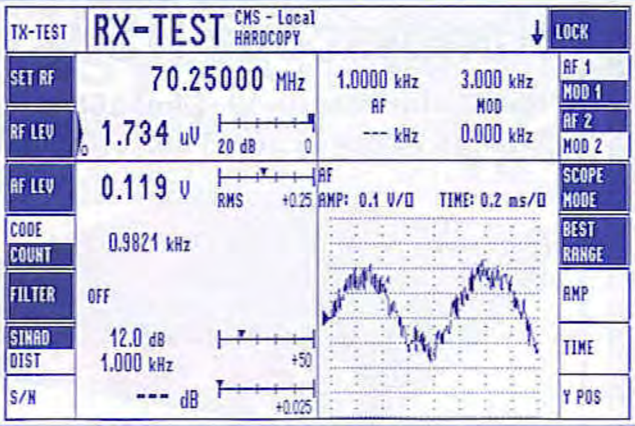
If the antenna is to be used out of doors, the junction of the copper pipe and the coax braid should be protected as well. This may be achieved by inserting the balun assembly in a length of 20-mm dia conduit and filling the lot with silicone sealant. All soldering to the coax cable should be done as quickly as possible to prevent deformation of the PTFE (Teflon) core and consequently creating 'impedance humps'.

Variations on the theme are possible, but be careful if you lack experience. You may, for instance, decide to use much thinner material for the dipole arms (for instance, lengths of welding rod), thinking it will make no difference as it is only the length that counts. Wrong, because your antenna will lose much of its broadband response and will present an acceptable VSWR at about 75 MHz ± 2 MHz only. A larger rod diameter increases the bandwidth so the antenna can be used for the entire VHF-Low band (68-88 MHz). That is why base antennas use for PMR services in the VHF bands are so thick!

On the rack!

While tidying up the design of the VHF-Low Explorer for publication in this issue, an opportunity arose to have our little receiver tested on a high-end instrument called the ***Rohde & Schwarz CMS 54 Radio Communications Service Monitor****. This instrument (pictured here) can perform automated measurements across the frequency range 0.4 MHz to 1 GHz which is not normally within the capacity of the RF test equipment available in the Elektor Electronics design laboratory. The offer came from Mr. Ed Warnier PA1EW who is totally conversant with this piece of kit, handling and operating it as if he were driving his car to the supermarket. Not only the test results obtained from the receiver are worth telling you about, but also the basics of some of the specific tests the instrument can perform, as they may be unknown to many readers entering the radio hobby.*

A few facts had to be established first. Our receiver is designed for narrowband FM (NBFM) reception between 68 MHz and 88 MHz, these values marking what is generally referred to as the VHF-Low communications band. As the receiver is of specific interest to radio amateurs, it was decided to tune it to ***70.250 MHz*** *being the centre of the 4-metre band as defined by the IARU. The receiver being VFO tuned*



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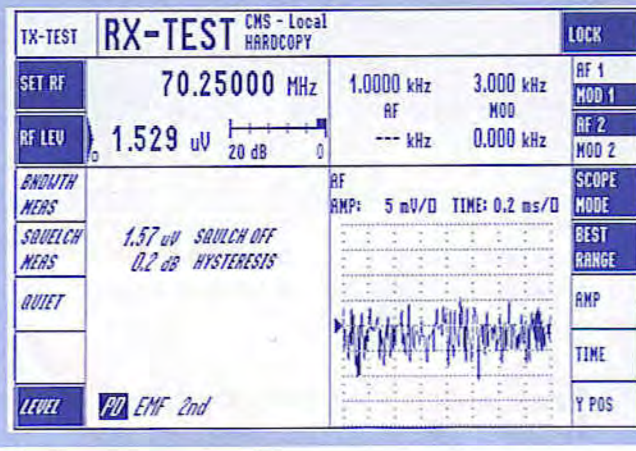

B

and lacking a frequency readout, reverse thinking quickly lead to the CMS 54 being set to 70.250 MHz and cheerfully tuning the receiver until the test signal was audible.

Hooray, it works!

Receiver sensitivity measurement

With the generator tuned to the receiver (or was it the other way around?) a great moment arrives — we're ready to decrease the RF output level on the generator until the receiver under investigation loses the signal. The VHF-Low Explorer not having an adjustable squelch or squelch defeat switch, the transition from 'very noisy signal' to 'muted' was found to be fairly abrupt (more about this further on).

Receiver sensitivity is defined as the RF signal level at which the receiver's audio output signal achieves a certain signal-to-noise ratio. For NBFM receivers, SINAD = 12 dB is considered the standard — meaning that the signal we would like to hear is 12 dB above the sum of noise and distortion (hence the acronym SINAD; an older measurement standard, S/N, employs noise only in the quotient). The RF signal level is usually given in microvolts pd (potential difference) although emf (electromotive force) is preferred by purists. The CMS 54, then, had its RF signal output connected to the receiver input (by a length of RG58 coax cable) and the audio input, to the receiver's audio output. After a manual adjustment of the volume control on the receiver, an automated measurement is started on the CMS 54 which steps down its RF signal level until it measures an audio signal of 12 dB SINAD. The RF signal level at which that happens is frozen and displayed — see **screendump A**. In our case, a sensitivity of about **1.7 microvolts for 12 dB SINAD** was obtained which is not bad at all given the simplicity of the design. The test was carried out using a test tone of 1 kHz and a deviation of 3 kHz. As you can see in the screendump, the CMS 54 also displays a real-time image of the receiver's output signal.

Absolute sensitivity and squelch action

Since the CMS 54 is capable of interpreting audio signals with such amazing precision it has no problems at all detecting when such a signal is passed or muted by the receiver. The latter action is taken care of by the squelch ('mute') function built into the TDA7000. An automated, stepped measurement was launched again, this time to establish the RF signal level at which the squelch closes. The result, about 1.6 microvolts, can be seen in **Screendump B**. Ed kindly informed us that a squelch hysteresis of just 0.2 dB is not favourable for NBFM listening, a value of 2-3 dB being the standard. A bit more hysteresis ensures that stations dropping into the noise do not cause the squelch to close abruptly. Rather, the receiver will 'follow' such flutter-infested signals which, although barely intelligible in the noise will not cause the squelch to 'chatter'.

The CMS 54 has a plethora of other functions for some really gruelling tests on radio communications equipment and in particular PMRs. We hope to be able to use it again some time in the future.