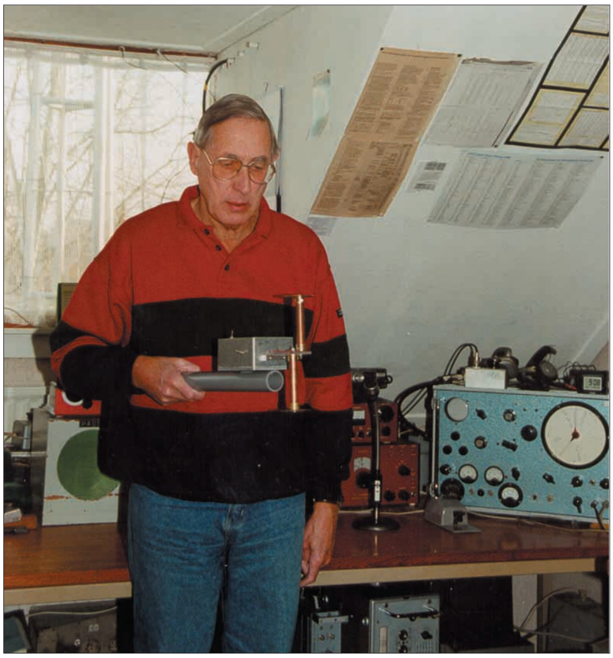
Build an E-Field Meter

By Dick Rollema, PA0SE*



The author measuring the E-field in his shack.

WHEN EXPERIMENTING with antennas, an E-field meter is a handy device to determine strength and direction of the electric field around them.

FAR FIELD AND NEAR FIELD

COMMERCIAL field strength meters usually employ a screened loop as an antenna. There is a simple formula for the voltage e_{ant} induced in a single turn loop when positioned for maximum signal in a field of E V/m:

$$e_{ant} = 2\pi EA/\lambda$$

in which A = area of loop in m² and λ = wavelength in m.

For performing experiments on antennas I constructed a field strength meter with a single turn loop, tuneable to all amateur bands

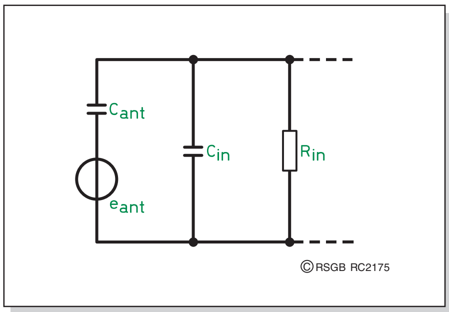


Fig 1: Equivalent circuit of a short dipole and the input capacitance and resistance of the E-field measuring circuit. C_{ant} and C_{in} are both of the order of a few picofarad.

10 - 160m. The simple equation for the voltage induced in the loop made it easy to calibrate the instrument in V/m by injecting a known voltage in the loop from a signal generator. The instrument is usable down to about 0.1V/m, which is sufficient for the intended application.

However, the voltage in the loop is mainly induced by the *magnetic* component of the electromagnetic field. But the magnetic field component H in A/m and the electric field component in V/m have a fixed relation given by E/H = 120π ohms = 377 ohms. This makes it possible to calibrate an instrument that acts on the magnetic component of the field in terms of the electric component.

But the equation E/H = 377Ω is only valid in the so called far field of the antenna. Close to the antenna exists the near field. The boundary between near and far field is fuzzy but generally accepted as $D = 2L^2/\lambda$, in which L is the largest dimension of the physical antenna, expressed in the same units of measurements as the wavelength λ. Others state that the boundary is 5 wavelengths away from the antenna. In the near field no simple relation exits between the E- and the H-field components. So if we want to know the E-field near the antenna this has to be measured directly.

Electronic products placed on the market from 1 January 1996 must carry a CE mark and should comply to the immunity standards laid down in the applicable European Directives. For consumer equipment this means the equipment should be immune to disturbance by electromagnetic sources like nearby radio transmitters producing a field strength up to 3V/m. When in the Netherlands the owner of a piece of electronic equipment suffers from an EMC problem caused by a nearby radio amateur he can call in the Rijksdienst voor Radiocommunicatie, RDR, comparable to the RA in the UK. The RDR measures the field strength caused by the amateur radio transmitter around the affected equipment. When the E-field is less than 3V/m for equipment with a CE-mark or less than 1V/m for equipment without such a mark (bought before 1 January 1996) no action on the part of the radio amateur is required. When the affected equipment is found to be immune up to a field strength of 3V/m or 1V/m respectively then the amateur either must reduce his transmitter power or take measures at his cost to improve the immunity of the affected equipment. It is convenient if the amateur concerned can determine beforehand what will be expected from him before the RDR is called in. So he must be able himself to measure the E-field.

DESIGN

E-FIELD METERS use as an antenna a short rod instead of a loop. The voltage induced in such an antenna is independent of frequency provided:

(a) The antenna is short with respect to the wavelength, say one tenth of a wavelength or less.

(b) The antenna does not have to supply power to the measuring circuit. In other words, the input impedance of the circuit must be very high so as not to load the antenna.

The equivalent circuit of a very short (in

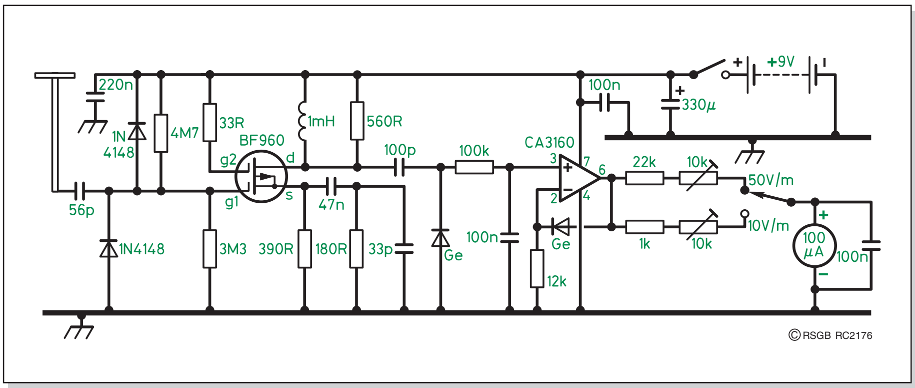


Fig 2: Circuit diagram of the E-field meter designed by ZL2BBJ.

*V d Marckstraat 5, 2352 RA Leiderdorp, Netherlands. E-mail: d.w.rollema@gironet.nl

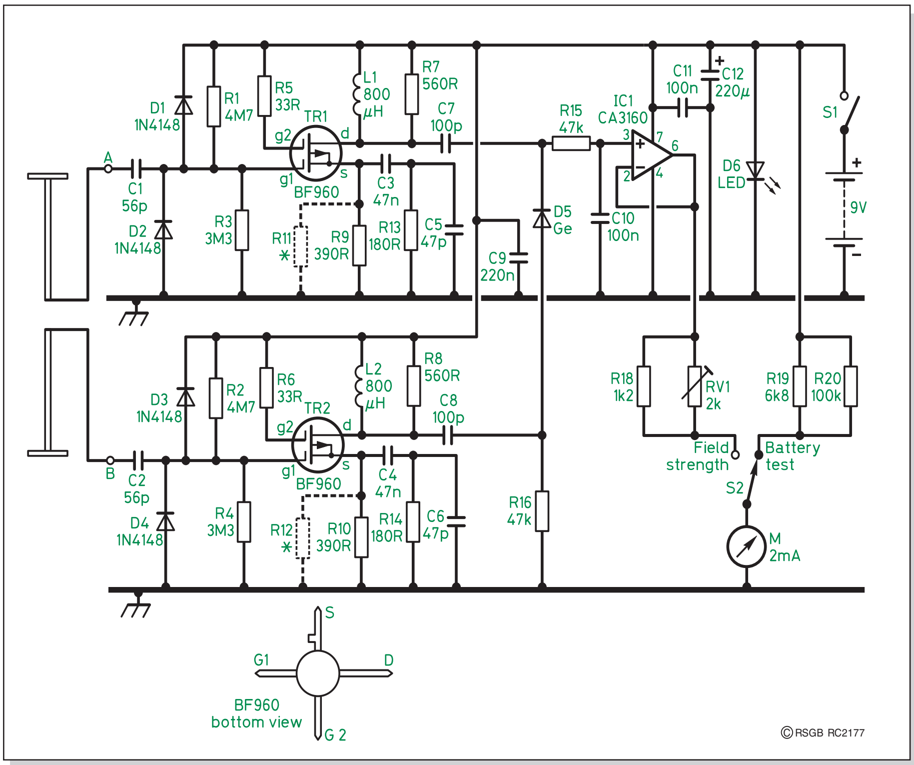


Fig 3: Circuit diagram of the PA0SE E-field meter.

wavelength) receiving dipole is shown in **Fig 1** and consists of a voltage source e_{ant}, representing the induced voltage, in series with a small capacitor C_{ant} of a few pF at the most. This capacitor forms a voltage divider with the input capacitance C_{in} of the measuring circuit. In order to get most of the induced voltage into the measuring circuit of the E-field meter, C_{ant} should be made as high as feasible by using a fat dipole. Also, C_{in} must be as low and the input resistance R_{in} as high as possible. Both conditions are easily satisfied by using a dual gate MOSFET at the input.

New Zealand amateur Andrew Corney, ZL2BBJ, designed an E-field meter of which the circuit diagram is given in **Fig 2** [1]. The antenna is a 75mm long piece of wire topped with a disc of printed circuit board 25mm diameter. The meter circuitry is mounted in a metal box that acts as a ground plane for the antenna. In order not to disturb the measurement the box is not held in the hand but mounted at the end of plastic tube, at least 1m long.

I preferred to use a short dipole, which needs no ground plane, so the only task of the metal box is to protect and screen the circuitry of the meter. And so the circuit of **Fig 3** emerged. The amplifier is now a balanced one using two dual gate MOSFETs. The difference voltage between the drains is rectified by D5, a germanium point contact diode. The DC voltage so obtained is fed to Op Amp IC1 that drives the meter. As an indicating instrument I used a small square one with 270° deflection. In its former life it had been given a scale in percent with FSD corresponding to 120%. I decided to make this 120% reading equivalent to a field strength of 12V/m, so the original scale could be used simply dividing the reading by ten. The meter deflection is linear down to about 1V/m, where the reading is about 20% low. I simply keep that in mind. Due to effects of the surroundings, the field strength usually varies considerably, even with a small change in measurement position, so there is no point in aiming at high precision. Nevertheless, perfectionists could draw a new scale to cope with the non-linearity at the bottom end. Ian White, G3SEK, has shown how to do that [2].

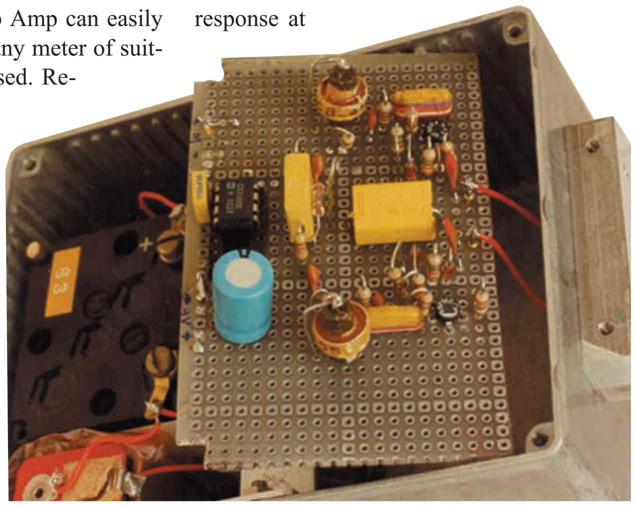
ZL2BBJ included a germanium diode in the feedback loop around the Op Amp to improve the linearity; an idea he had borrowed from a QRP wattmeter designed by Roy Lewallen, W2EL [3]. I found the diode made things worse rather than better, so I left it out. The moving coil meter I used is not very sensitive at 2mA FSD, but that does not matter at all because the Op Amp can easily supply the current. Almost any meter of suitable dimensions could be used. Resistors R18-R20 of course have to be matched to the meter sensitivity. To give some idea of what to expect, in my instrument a field strength of 10V/m produces 0.38V RF between A and B at the input of the meter and 1.16V DC at the output of the Op Amp.

The gain of the TR1 and TR2 must be the same, but this is often not the case due to spread in the characteristics of MOSFETs. If the gain is not equal then common mode voltages, picked up by the antenna as a whole (not balanced as in the dipole mode) would also give a deflection of the meter. The gain can be equalised by connecting a resistor in parallel with the resistor in the source circuit of the stage with the lower gain, so increasing the standing current and with it the transconductance of the MOSFET and at the same time decreasing the negative feedback at the source. These resistors are indicated as R11 and R12 in Fig 3. Only one of them has to be used, of course. The gain can be checked by connecting an RF signal source between common and first point A at the input and then point B, and noting the deflections of the meter, which should be equal in both cases. Even simpler is to connect A and B together and feed a common mode signal into them. Resistor R11 or R12 is then selected for minimum deflection of the meter.

Preset potentiometer RV1 is set when calibrating the E-field meter. R18 was first omitted. A first attempt to calibrate the instrument showed that RV1 had to be set to about 670Ω. The adjustment was rather critical and R18 was then added, producing a much smoother control.

ZL2BBJ provided his instrument with a second measuring range of 50V/m. I only use a single range of 12V/m because in my station this value is sufficient. Those who wish to provide a second range can easily do so by replacing S2 by a three way switch and adding a second preset potentiometer. The circuit has just sufficient headroom for ranges up to 50V/m.

The 33Ω resistors at gate 2 of TR1 and TR2 prevent parasitic oscillations at VHF. For L1 and L2 I used air core chokes because they were already available. But modern moulded ones with a value of 820µH or 1mH would be just as suitable. Capacitors C5 and C6 decrease the negative feedback at high frequencies in order to maintain a flat frequency response. ZL2BBJ used 33pF but I needed 47pF. The E-field meter now has a response that is flat within 10% from 280kHz to 50MHz. There is even a useful response at



The components are mounted on perforated board.

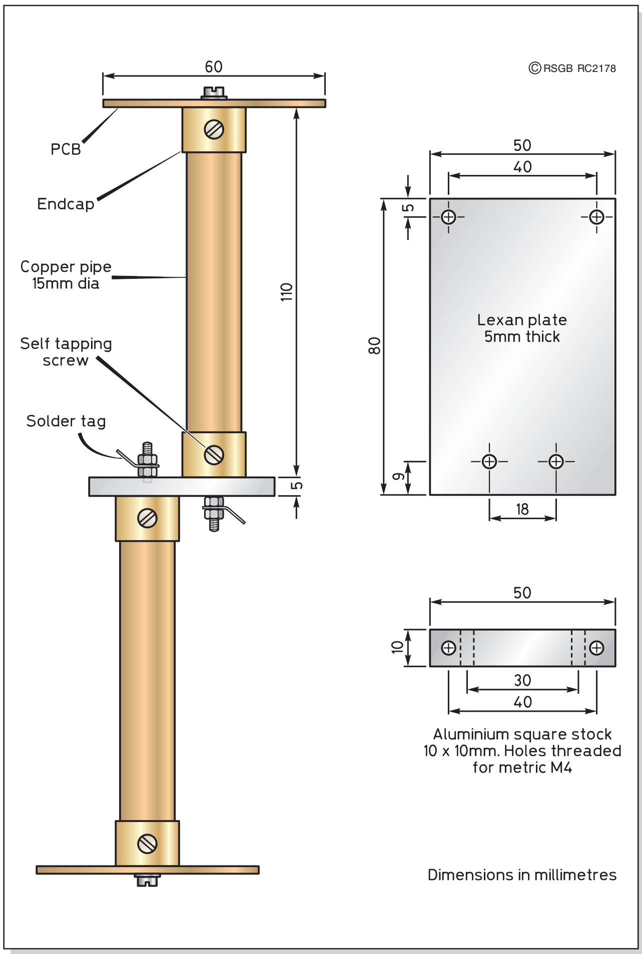


Fig 4: Antenna assembly of the PA0SE E-field meter.

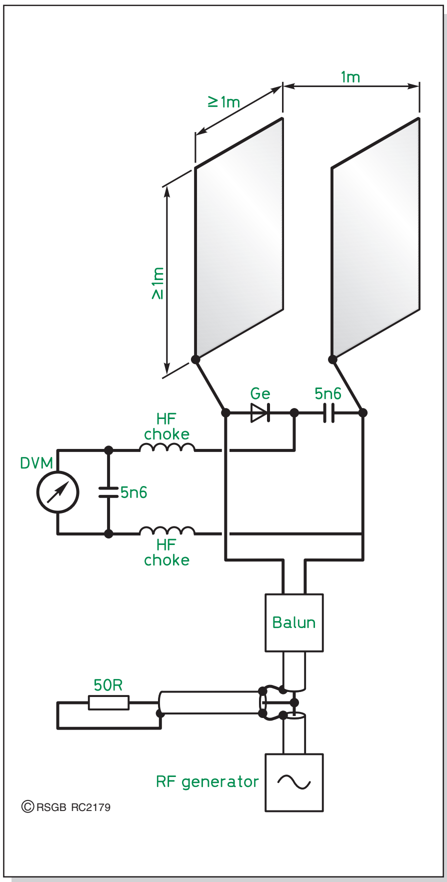


Fig 5: Set-up for calibration.

136kHz and 144MHz, but the calibration is no longer valid there of course (30% low on 136kHz).

I wanted a visual indication that the meter is switched on. A LED would require about 20mA, which is just as much as the whole of the measuring circuit takes. This I found unacceptable, because of the rather limited capacity of the PP9 type battery. I therefore used a flashing red LED. These can be bought as such, the flashing circuitry included in the mounting. The one I used was marked '12V', but it performs perfectly at 9V. I measured the average current at 2mA, which hardly adds to the total current taken by the circuit, and the flashing light shows even better than the steady one of a normal LED.

S2 permits the meter to read the battery voltage under load. I first put a variable resistor in series with the meter instead of R19 and R20 and made the meter read '100%' on its scale with a new battery. I then measured the resistance required with a digital multimeter and made up the same value by connecting fixed resistors from the standard range in parallel.

The short, fat dipole antenna is made of two 10cm long pieces of 15mm diameter copper water pipe. I later added discs of printed circuit board at the ends of the dipole, each one 6cm in diameter. The end loading almost doubled the sensitivity of the instrument!

CONSTRUCTION

CONSTRUCTION WAS very much determined by materials that were on hand. **Fig 4** and the photographs show the result. The meter is housed in a diecast box. The circuit common is not connected to the box, so is electrically floating.

I consider PCBs fine for mass production but a waist of time for one-off projects like the present one, so I used perforated board with metallised holes instead. Normal perforated board would be just as good. I did not make a drawing for the wiring but simply started plugging components into the board starting at the input end of the circuit. I took care however that the balanced amplifier became more or less symmetrically situated with respect to the centre line of the board. The common bus is a piece of heavy copper wire. For pre-set potentiometer RV1 I used a normal potentiometer, with the shaft shortened to about 4mm. With a hacksaw I made a slot for a screwdriver in the head of the shaft. The potentiometer is mounted on a bracket against a wall of the box. A hole in the wall gives access to the pot during calibration of the E-field meter.

I thought it advisable to keep the dipole some distance away from the box to avoid screening effects. The antenna is mounted on a piece of Lexan, a material which is mechanically very strong, but Perspex could be used as well. The Lexan plate is attached to the box by a piece of square aluminium stock with holes tapped for M3 screws, but other solutions suggest themselves. To keep construction simple, the two halves of the dipole are not in line. This has no effect on operation.

The end caps on the two copper pipes are normally soldered on, but I secured them by self tapping screws so the dipole can be taken apart easily if necessary.

COMPONENTS

Resistors	
R1, R2	4M7
R3, R4	3M3
R5, R6	33R
R7, R8	560R
R9, R10	390R
R11, R12	see text
R13, R14	180R
R15, R16	47k
R18	1k2
R19	6k8
R20	100k
RV1	2k pre-set
Capacitors	
C1, C2	56p
C3, C4	47n
C5, C6	47p (see text)
C7, C8	100p
C9	220n
C10	100n
C11	100n
C12	220µF, 16V
Inductors	
L1, L2	800µH RF-choke
Semiconductors	
D1, D2, D3, D4	1N4148
D5	germanium point contact diode, eg OA71
D6	flashing red LED, panel mounting
TR1, TR2	BF960
IC1	CA3140
Miscellaneous	
9V Battery	
M	2mA FSD
S1	SPST miniature toggle
S2	SPDT miniature toggle
Diecast aluminium box 120 x 94 x 61 mm	
Perforated board	
Printed circuit board, single or double sided, for antenna loading discs	
Copper pipe 15 mm diameter	
End caps for copper pipe	
Aluminium stock, square 10 x 10 mm	
Lexan plate, 5 mm thick	
PVC tube, 40 mm diameter	
Bolts, nuts, washers (M3 and M4)	
Self tapping screws	
Soldering tags	

I found that the meter reading is affected when the instrument is held close to the body. I therefore attached a 45cm long piece of 40mm diameter PVC tube to the lid of the box by two M4 screws.

CALIBRATION

TO CALIBRATE THE E-field meter the instrument has to be positioned in a field of known strength. One way to achieve this was suggested by ZL2BBJ [1]. Two metal plates with sides of at least 1 meter are placed parallel to each other at a distance of 1 meter. If a voltage of for instance 10V is applied between the plates, a field of 10V/m is formed between them. The E-field meter is positioned at the centre between the plates and positioned for maximum response. RV1 is then adjusted for a reading of 10V/m on the meter.

ZL2BBJ connected one plate to the voltage source (his transmitter, loaded by a dummy antenna) and the other to earth. I found that the deflection of the meter increased when moved from the centre towards the 'hot' plate and decreased when moved towards the earthed plate. This was unexpected, because the field between the plates is supposed to be uniform. I therefore changed to a symmetrical set-up, as shown in **Fig 5**. The reading now remained the same around the centre position. It only increased somewhat when the E-field meter came close to either of the plates. I assume this was caused by direct capacitive coupling between the plate and the half of the dipole nearest to it. The DVM reads the maximum value of the applied RF voltage minus the threshold voltage of the diode. I used a germanium one. For a field of 10V/m the DVM therefore should read $10\sqrt{2}$ - 0.3 = 13.8V. The 50Ω resistor provides a proper load for the signal source. To avoid disturbing effects from for instance the connecting wires, a low frequency band (80m or, better still, 160m) should be used for calibration. I made the two plates from hardboard, with sides of 107cm, covered on one side by aluminium foil, pinched from the kitchen. They are held at a distance of 1m by PVC tubes in the four corners and one near the middle.

The first attempt at calibration took place in the shack, the two plates standing upright on the floor. The source was a Rohde & Schwarz power signal generator. I was concerned that the metal frame in the concrete floor might disturb the field between the plates. I therefore repeated the calibration outside, the plates standing on a plastic garden table. As a signal source I used a home-made QRP transmitter, tuned to 160m and fed from a 12V battery in series with a variable resistor to control the output. The result was the same as in the shack.

I also tried the set-up used by ZL2BBJ with one plate earthed (the balun was then omitted). It produced the same reading as the symmetrical set-up, provided the E-field meter was positioned at the centre between the plates, just as prescribed by ZL2BBJ.

PHOTOGRAPH: PA0SE

Set-up for calibration. Below can be seen the QRP-transmitter with balun and digital voltmeter on top.

REFERENCES

[1] 'Does Your Station Comply With RF Field Limit Standards?' by Andrew Corney, ZL2BBJ, *Break-In*, December 1995.
[2] 'In Practice', *RadCom* March 1996.
[3] 'A Simple and Accurate QRP Directional Wattmeter' by Roy Lewallen, W7EL, *QST* February 1990. ♦

technical **feedback**

SGC SG-2020 REVIEW

RADCOM, MARCH 1999

All radios with software 1.04 and above have a tune feature. Momentarily depress the PBT; a tone will be there for five seconds and thereafter when the PTT is depressed.

Also, CW can be operated with the PTT button.

P Cooper, SGC Inc.

POOR MAN'S CAESIUM CLOCK

RADCOM, JANUARY 1999

Apparently some crystal oscillators are slow to start. The common activity 10MHz crystals vary a bit, so it may be necessary to reduce the value of R10, but only by the amount necessary to ensure ready starting.

Dave McQue, G4NJU

TECHNICAL FEEDBACK

RADCOM, FEBRUARY 1999

There is an excellent article to add to G6XN's list: 'A Logarithmic Audio Speech Processor', by William E Sabin, *Communications Quarterly*, Winter 1997.

I am in the process of building one, as I could use the extra 6dB!

Wayne Cooper, AG4R

THE ART OF SHUNTING METERS

RADCOM, MARCH 1999

The third paragraph in column 2 should read: "From this it should be apparent that the current through the shunt (Ishunt) is equal to the total current (Itotal) minus the current through the meter (IFSD) or:"

Bruce Edwards, G3WCE

RATING OF MASTS AND AERIALS

RADCOM, AUGUST 1998

Following the request for information in '*Helplines*', I received three responses from members, all of whom live in Scotland. These replies indicate clearly that the 'rating' of masts only takes place in Scotland, and then only in certain local authority areas, notably Glasgow, Strathclyde, Central and Fife.

A legal opinion obtained in 1980/81 indicated an arguable case to take to the Courts, but that the costs of doing so (even in the unlikely event of success) would well outweigh any savings in rates payable. Whilst the Society met the expenses of obtaining the opinion, it was not felt prudent to pursue the matter and I believe that current funds will not stretch to a further attempt at litigation.

Geoff Bond, G4GJB

RSGB NFD 1998

RADCOM, NOVEMBER 1998

The photograph of some aerials and a rainbow, credited to myself, was actually taken by Derrick Webber, G3LHJ.

Andy Stafford, G4VPM

TECHNICAL TOPICS

RADCOM, MARCH 1999

The soldering hint by KE4TFE about putting a diode in series with the AC supply is a good one, but the suggestion that the power is reduced to a quarter of its normal rating is incorrect. The power is, in fact, halved.

Alan Betts, G0HIQ

QST have now corrected this.

Pat Hawker, G3VA

BACKPACKER TRANSCEIVER

RADCOM, SEP-DEC 1998

Not all 1N4007s are suitable as PIN diodes. Motorola are fine, but some unbranded devices I have come across meet the 1N4007 spec as a rectifier, but have much shorter recovery times. This means they won't act properly as PIN diodes.

Peter Chadwick, G3RZP