VHF millivoltmeter

Nick Wheeler's vhf millivoltmeter is useful to 150MHz, but more importantly, he achieves less than 2pF input capacitance through using surface-mount parts and a GaAs fet front end.

There's often a need to measure low-level rf signals If these are in a low-impedance part of the system and at a level of tens of millivolts, you can do this with an oscilloscope and a divide-by-ten probe. But the sensitive ranges of most oscilloscopes usually have a limited bandwidth – typically a fifth of the nominal instrument rating.

High-impedance test points on a circuit will be seriously loaded or detuned by the 20pF or so of the oscilloscope probe in its ×10 mode, and may be disabled completely if you use the probe in the ×1 mode.

This article describes a vhf millivoltmeter whose response extends to over 150MHz. Its input is less than 2pF in parallel with 100kΩ and the first scale indication is 2mV rms Radio frequency signals can be rich in harmonics and this is a peak-reading instrument The sensitivity quoted assumes a sinusoidal signal.

Indication is via a 50μA moving-coil meter You will find that an analogue indication is essential for most applications. The rf part is in a screened probe head and there is only a dc input in the connecting lead to the box housing the meter and mains psu.

Implementation

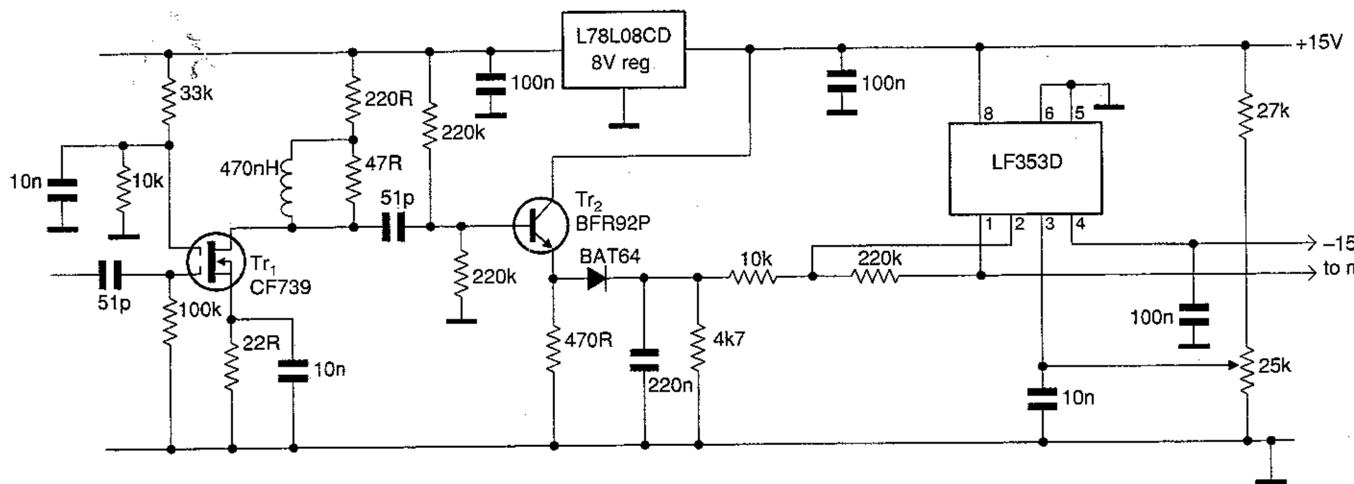
This instrument uses surface mount technology I believe that it would be virtually impossible to realise it by any other means.

All the active parts are accommodated on a double sided pcb measuring 9 by 1.5cm I think that I could have shrunk the design further, so that it would have fitted inside a piece of 15mm domestic copper water piping, but I decided to settle for 22mm

I have laid out the circuit diagram, Fig. 1, so that the placement of the parts corresponds roughly with the layout of the top surface of the pcb, Fig. 2 Most of the other side of the pcb is a copper ground plane, removed only where it would increase stray capacitance

Input device Tr_1 is the useful Siemens *CF 739* (RS 288-345). This is a dual-gate fet, characterised up to 2GHz The circuit is a conventional shunt-peaked video amplifier The 0.47μH peaking inductor is damped by 47Ω This was determined experimentally as giving the best approximation to a flat response. This is followed by a *BFR 92P* emitter follower, Tr_2 (RS 287-910). The emitter is a low-impedance point which can be probed with an oscilloscope for the purpose of getting the peaking right.

You will notice that the coupling capacitors are 51pF. Although much



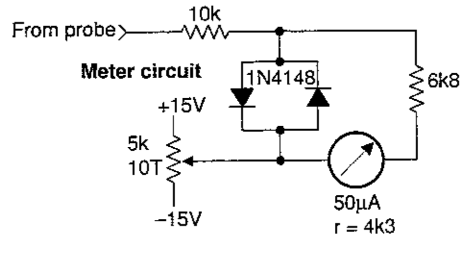


Fig. 1. Full circuit of the vhf millivoltmeter, demonstrating its simplicity. All earths are via pins to the backplane.

Fig. 2. Both sides of the circuit layout for the vhf millivoltmeter. Note that the component side is as it appears on the board. Flip it left to right before making a transparency.

greater values are available in the same package size, I have made them this value to roll off the response below 100kHz – particularly to avoid the effects of mains and other low-frequency pickup. Measurements can be made at 450kHz.

The diode is a *BAT 64*, a Schottky part (RS 287-229). Transistor Tr_2's emitter rests at about 3.5V in the absence of a signal and the forward voltage across the diode is just over 0.2V.

Successive positive-going half-cycles of any signal charge the 220nF capacitor to the positive peak excursion of the emitter of Tr_2, less the diode drop which remains essentially constant over the range of currents involved. The diode prevents this charge from draining away except though the 4.7kΩ resistor in parallel with the 10kΩ input resistor to the *353* op-amp.

In effect, the diode is automatically forward biassed exactly the right amount to negate its small forward voltage drop. Another advantage of this arrangement is that Tr_2, which has a reverse V_{B-E} rating of only 2.5V, is not put at risk.

Only one of the two op-amps within the *353*'s SOIC package is used. I use a dual *353* as opposed to a single *351* as they are the same price.

Choosing the right amount of gain

The chosen gain, set by the 220kΩ feedback resistor, is a matter of compromise. Higher gain gives greater meter deflection for a given signal but makes zero-adjustment very tricky. The 25kΩ ten-turn trimmer potentiometer is used to give approximately zero volts out for no signal, but actual zeroing is by the ten-turn shaft-operated potentiometer in the meter/power-supply box.

The meter is protected from damage by the diode-resistor arrangement shown. The values are adjusted to give full-scale deflection for 50mV rms at 50MHz. The scale is compressed towards fsd, as the protective diodes are beginning to conduct.

A protective device which I have not included is the conventional arrangement of two diodes in inverse parallel shunting the input. Probably the best readily available part for this purpose is the double-diode *BAT 17-04* (RS 288-452). But even this excellent part has a shunt capacitance per diode of typically 0.75pF. The two would virtually double the input capacitance. The effect of this, taken together with the necessary current limiting resistor, would be severely to reduce the upper frequency limit. So I have left the *CF 739* at risk. They only cost £2 each anyhow.

You will notice that there is a regulator in the supply to Tr_1. This is the SOIC version of the *7808* part. Such regulators cost little more than the resistor/zener combination which would otherwise have been needed.

I will not detail the power supply, which is conventional, except to mention that the rails are stabilised using *7815* and *7915* parts.

Accuracy and application

One cannot hope for such an instrument to be accurate to better than 10%. Noise, stray fields and drift see to that. What it is useful for is determining whether circuits like IF amplifiers are operating in the right ball-park in regard to such matters as automatic-gain control action.

And, of course, the meter is useful for tuning because its small input capacitance does not detune circuits to which it is applied. In spite of the very small amounts of power involved and the tiny thermal capacity of the surface-mount parts, the instrument takes a few minutes to stabilise after being switched on.

Obviously, a sensitive instrument of this kind is prone to pickup. Operating with the input unconnected will result in full-scale swings of the meter pointer if you place your hand anywhere near the input. The lead to the point being tested must be as short as possible, and the earth used must be as near as possible to the test point.

In spite of the fact that this instrument will cope successfully with high-impedance signal sources, you should always go for the the lowest possible source impedance, the emitter of an emitter-follower rather than its base, for example.

Calibration

I calibrated my prototype at 50MHz in a properly terminated 50Ω coaxial system. Everything was placed on, and bonded to, a metal plate. A good 100MHz oscilloscope claiming ±3% accuracy was used. The 20dB pad enables small signals to be applied to the input while larger ones can be measured on the oscilloscope. The setup is shown in **Fig. 3**.

A 100MHz oscilloscope has some response up to about 150MHz. This means that the second and third harmonics of a 50MHz signal will, if they are significant, be perceptible. A signal that looks like a sinewave can therefore be assumed to have an rms value of about $1/2\sqrt{2}$ of its peak-to-peak value.

In summary

This circuit uses a combination of surface-mount technology and a uhf GaAs fet to provide a broadband amplifier with response extending well beyond 100MHz. Where this design differs from IC solutions like the *SL560* is in its high input impedance.

There are obviously many other applications for this approach. You will not get away with them, however, unless you use surface-mount devices to achieve the postage-stamp sized rf circuitry described here. ■

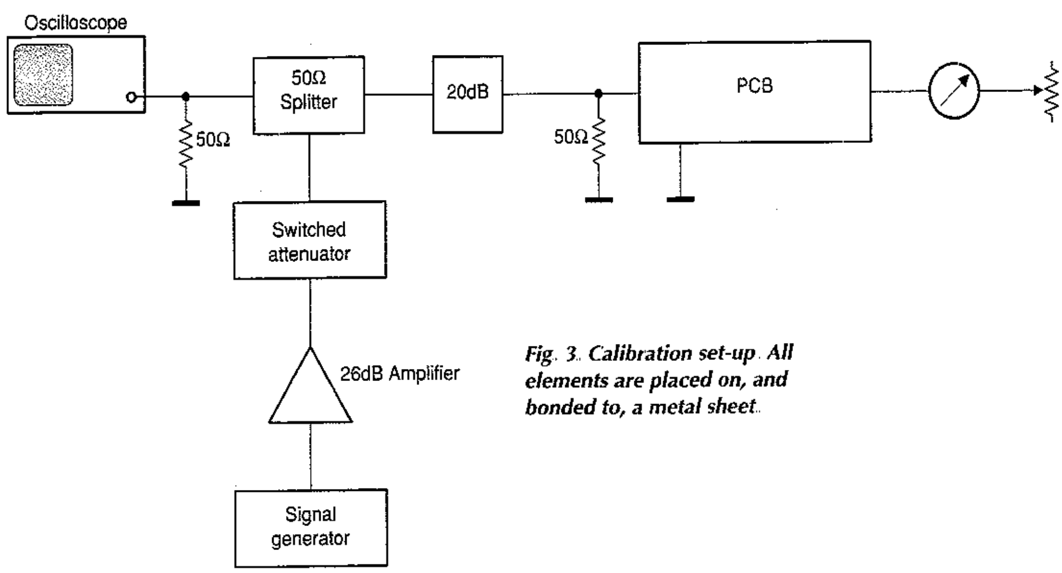


Fig. 3. Calibration set-up. All elements are placed on, and bonded to, a metal sheet.