Recent Electronic Voltmeter Practice - Referring to the Marconi TF2603

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a comprehensive 1500 page volume covering technology of the period)

1. As an illustration of recent practice in the electronic voltmeter field (including the use of semiconductors instead of thermionic valves), the main features of the Marconi TF 2603 R.F. Electronic Millivoltmeter are described below.

This instrument is a fully transistorized millivoltmeter, designed for A.C. voltage measurement from 300 microV to 3V through the frequency range 50 kc/s-1,500 Mc/s. The 0.5in. diameter probe uses a pair of fast germanium diodes in a full-wave circuit whose response is close to true r.m.s. with inputs of less than 40 mV and peak-to-peak in the 0.5 to 3V region. Meter scales are virtually linear and approximately 5in. long, being calibrated in the r.m.s. value of a sine wave. Accessories available include a 100:1 attenuator which allows voltage measurements up to 300 V. As an alternative to the normal mains supply, the instrument may be operated from an external battery connected to the rear terminals.

The TF 2603 falls into the category of rectifier-amplifier-indicator instruments. The probe utilises a pair of germanium diodes in a full-wave detector circuit, whose D.C. output passes through a balanced attenuator to an electromechanical chopper. The resultant square wave is amplified and rectified, and the D.C. thus produced operates the meter. Use of semiconductor devices throughout ensures reliability and freedom from microphony.

2. Probe design. The metal body of the probe has a diameter of only 0.5in. and is 3.75in. long, excluding the pick-up spike. It contains two germanium gold-bonded diodes in a full-wave circuit, which, in measuring complex voltages, has smaller inherent error than the half-wave alternative. This is especially true in dealing with signals containing asymmetrical waveforms and/or noise. The probe contains a heater to minimise changes of sensitivity with ambient temperature variations. Without a heater the probe output would fall as ambient temperature decreases, the slope becoming steeper just below 20 deg. C. The prime object of the heater is to maintain the diodes at a temperature well above 20 deg C through the ambient temperature range likely to be encountered. A thermostat mounted in the main body of the instrument ensures that the heater current is switched on only at ambient temperatures below 33 deg C, thus preventing the probe temperature becoming so high that it is uncomfortable to handle.

The frequency response of the probe is flat between 200 kc/s and 50 Mc/s, and the specification at other frequencies is as follows: 50 kc/s to 200 kc/s = + 0/ - 0.5 dB; 50 Mc/s to 200 Mc/s = $\pm$0. 4 dB; 200 Mc/s to 900 Mc/s = $\pm$1dB; 900 Mc/s to 1,500 Mc/s = ±2.0 dB. In fact, most probes are within the 2 dB limits up to 3,000 Mc/s.

The fall-off at 50 kc/s (typically 0.1 dB) is caused by the deliberate restriction of the value of the input and reservoir capacitors; this allows connection of the probe to D.C. voltages of up to 300 V without damage to the diodes by excess pulse energy.

The frequency response figures given above assume that the probe spike is directly contacting the live point under test, and that the earth connection between the probe case and circuit earth has negligible inductance and resistance. Provided that the probe spike is directly contacting the live point, a 6-in. length of 14/0.0076 wire, or its equivalent can be used up to 20 Mc/s. A clip is provided for the attachment of such an earth wire. A telescopic earth spike designed to accommodate differences between live and earth planes is also supplied. It is suitable for use up to 100 Mc/s, or up to 300 Mc/s provided an additional error of up to 2.5 per cent can be tolerated. Above 100 Mc/s the probe case must directly contact a substantial earth point of the system under test.

The probe circuit responds closely to true r.m.s. when the input is less than 30 mV. In the 0.5-3 V region, it behaves as a peak-to-peak device, while the remaining ranges fall in between these two conditions.

The D.C. output from the probe varies from approximately 2.5 microV (300 microV input) to 8.2 V (3.16 V input), and the main instrument must provide high D.C. amplification with low noise. Its input/output characteristics are the inverse of that of the probe; *e.g.* on the 10 mV range, where the probe has a square law characteristic, the amplifier has an inverse square law to achieve a linear meter scale. The input impedance is typically 210k ohms in parallel with 2pF for an input of 1V at 1Mc/s

3. Amplifier design. Many precautions are taken to minimise noise; the most important are as follows:

(1) The probe output circuit, D.C. attenuator and chopper input connections are all balanced above earth. This arrangement affords many advantages, the chief being that low frequency (1/f) noise voltages existing at the base of the first transistor are less likely to be chopped at a 100 c/s rate and passed through the narrow-band amplifier than would be the case in an unbalanced system.

(2) The 100 c/s chopper is of the electromechanical variety, which is vastly superior to the transistor type (whose breakthrough spikes and offset voltages are prohibitively large in low-voltage, high impedance circuits). The balanced attenuator, together with succeeding circuits, has to present a high value load (several megohms) to the probe in order to achieve the maximum possible efficiency. A photo-chopper using cadmium sulphide or cadmium selenide photo-resistors would also be noisier than the electromechanical version, though the margin is smaller. *(The use of FETs in later versions proved very effective! -ed)*

(3) A high value of resistance is required at the input of the high impedance amplifier, but without the concomitant noise penalty. This is achieved by using a resistance of comparatively low value which determines noise voltage, and then, by means of positive feedback, bootstrapping it to a much higher effective value.

(4) The first four transistors are low-noise types run at a low collector current and with small voltages between collector and base.

(5) A 100 c/s band-pass filter of the multi-stage C-R type restricts bandwidth so that noise handled by the output stages is of a low order.

(6) The phase-sensitive detector not only discriminates against noise but retains polarity sense. This is convenient when setting the meter electrical zero, which therefore coincides with the scale zero; thus, on the most sensitive range, noise produces no standing dither about the mechanical zero mark.

(7) The meter damping is chosen to give a small effective bandwidth while still achieving a reasonable pointer speed. Further damping is switched in on the most sensitive range (1 mV f.s.d.) where pointer fluctuations due to noise are typically ±2 per cent of f.s.d. about reading which are below half scale.

There are only two front panel controls; the range switch and balance control. The latter has no effect on the 30 mV range and above, and very little on the 10 mV range. Its purpose is to balance out the few microvolts D.C., which may exist at the chopper input due to the thermal e.m.f.'s developed within the probe attenuator or chopper. These are most significant on the 1 mV range, and to a lesser extent on the 3 mV range. Therefore, when measuring voltages below 10 mV, it is necessary to switch temporarily to the 1 mV range, ensure that R.F. input to the probe is zero, and adjust the balance control to zero the meter pointer.

The range control not only switches the balanced attenuator, but also the amount of negative feedback applied to the amplifier system. By this means, the sensitivity is varied while maintaining a high degree of negative feedback appropriate to the range concerned; i.e. the feedback ratio is not determined once and for all by the requirements of the most sensitive range. This system ensures that maximum long-term reliability is achieved.

A further aid to stability is contained in the phase-lock system. In order to allow battery operation of the instrument, the chopper is driven by a 100 c/s oscillator. Consequently, the chopper is chosen to be of the mechanically resonant type because of its comparatively small drive requirements. Unfortunately, variations of ambient temperature cause small changes of resonant frequency in the high-Q mechanical system; this results in an unwanted phase shift between the chopper drive and its output signal, the oscillator frequency remaining constant. Without correction, this could give rise to an error in meter reading up to 1 per cent, as the chopper drive is in phase with the switching voltage at the phase-sensitive detector. To prevent this happening, a sample of the chopped signal is taken from an early part of the filter, is amplified, shaped and used to lock the multivibrator oscillator. In other words, the high-Q mechanical system of the chopper determines the instant of switching at the oscillator, and hence any variation of (mechanical) resonant frequency will pull the oscillator with it, thus preventing any phase-shift and consequent error.

Scale linearizing is achieved by means of a silicon diode shaping system, which in effect shunts the meter by a progressively greater amount as full scale deflection is approached. The range switch adjusts the system so that it has less effect with higher R.F. input voltages, where the probe is more linear; it is switched out altogether on the 1 and 3 V ranges.

The meter voltage scales are virtually linear and adjacent to a dB scale, 0 dB coinciding with full scale deflection. The 1 mV scale is shorter, has square law characteristics and does not correlate with the dB scale. On this last range, the linearizing system is switched out to avoid exaggeration of noise fluctuations at the lower end of the scale.

4. Applications of R.F. millivoltmeter.

The TF 2603 can perform a great variety of tasks, many of them attainable only by this type of instrument. The following applications are typical:

(1) Measurement of low-level signals in semiconductor circuits, especially transistors and tunnel diodes.

(2) Measurement of transistor parameters, for instance f_T in the 500 -1,500 Mc/s region.

(3) Voltage measurement on strip-line circuits.

(4) Measurements on battery-operated equipments at locations remote from mains supply.

(5) Accurate voltage measurement in conditions where difficulty arises from circuit earth loops, errors being eliminated by using battery operation.

(6) Measurement of noise, facilitated by the r.m.s. response up to 30 mV, or up to 3 V, if the 100:1 divider is used.

(7) Distortion measurements over a wide frequency in the form of percentage distortion relative to total signal, i.e. $100 V1/V2$, where V1 = voltage due to harmonics and V2 = voltage due to harmonics plus fundamental. V1 is measured by using the r.m.s. region of the millivoltmeter, which is connected to the output terminals of a network capable of sufficiently suppressing the fundamental.

(8) Impedance measurements at low-voltage levels, using the millivoltmeter in conjunction with a Q meter; this is a common requirement with transistor circuits. To make direct measurements of Q at low levels, the AC method should be used to avoid error due to the shunting effect of the millivoltmeter probe. If required, a much higher resistance can be obtained by also using the multiplier, if the voltage across the Q-meter capacitor is 30 mV or more.

(9) Detecting high-frequency parasitic oscillations.

Despite all pre-cautions regarding layout, feedback and inclusion of 'stopper' resistors, a wide-band video multistage amplifier may develop spurious oscillations whose frequency may lie anywhere between 1 and 1,000 Mc/s. To carry out a search with tuned receivers is tedious, but a loop connected to the millivoltmeter probe and held near each part of the circuit in turn can ascertain if unwanted oscillations are present and remedial action taken.

(10) The tuning of narrow-band amplifiers, filters and other networks, where a multiplicity of tuned circuits require adjustment, is made easy by use of the more sensitive ranges of the millivoltmeter. The probe spike can be held close to circuit conductors and the preceding circuit tuned for a maximum voltage reading; because of the loose coupling used, removal of the probe will have negligible effect, and little, if any, tuning correction will be necessary.

(11) Testing of filter frequency response, particularly in the stop band, can be achieved without excessive voltage requirements from the signal generator. For example, 50 dB attenuation can be measured using a generator capable of delivering 0. 1 V to the filter input terminals.

(12) R.F. bridge null detection. In wide-band R.F. bridge measurements, the millivoltmeter can be used as a sensitive null detector in place of several radio receivers, provided sufficient source voltage is available. If necessary, a simple resonant step-up circuit can be inserted between the bridge and the millivoltmeter.