LF/HF TEST PROBE

For most electronic test and measurement applications, a modern digital multimeter represents excellent value for money. However, in spite of the high input resistance, the accuracy of a DMM degrades rapidly when the frequency of the measured voltage rises above 400 Hz or so. This article describes the basics of designing a passive test probe to overcome this limitation and extend the usable frequency range of a DMM to about 100 MHz.

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The accuracy of digital multimeters is in general, sufficient for all practical purposes. Although there are low-priced models that give usable results above the maximum input frequency of 400 Hz (stated by the manufacturer). DMMs with a guaranteed frequency range of 20 kHz, 50 kHz or even 100 kHz are rare and quite expensive.

An ideal passive signal rectifier flips each negative half-cycle of a sinusoidal voltage in between two positive half-cycles. The result is a direct voltage of which the peak value is roughly equal to that of the alternating voltage—irrespective of its frequency.

The inertia of a moving-coil meter in an analogue voltmeter provides an certain degree of integration of the measured alternating voltage. The result is a built-in averaging function that smooths the ripple on the direct voltage supplied by the rectifier. Since a DVM is an all-electronic instrument, a capacitor is required at the output of the rectifier to provide the required smoothing and ensure correct measurement results.

All diodes have a certain threshold voltage below which they do not conduct. For the application we are dealing with here, the threshold voltage and the reverse leakage current must be as small as possible. Small-signal germanium diodes of the point-contact type have the lowest threshold voltage followed by Schottky diodes, normal germanium diodes and silicon diodes, in that order. The forward voltage drop is not a static characteristic but depends to some extent on the current passed by the diode, or, in other words, the load resistance at the output of the rectifier. Obviously, the high input resistance of the DMM (typ 10 MΩ or more) is advantageous here, since apart from presenting a small load to the rectifier diode it also allows a small capacitor to be used for the previously mentioned averaging function. As a consequence, the smoothing capacitor may be a high-grade type, e.g., a polystyrene capacitor, avoiding large leakage currents typically introduced by, for instance, electrolytic capacitors.

Simple: the single-phase rectifier

A rectifier circuit in its simplest form is shown in Fig 1. It consists of a diode, *D*, a buffer capacitor, *C*, and a resistor, *R*. The input resistance, R_i, of the measuring instrument exists in parallel with *R*. When *R* is omitted, R_i alone determines the time constant of the *R-C* network. Since the diode passes the positive half cycles only, the capacitor is charged to the peak value of the alternating input voltage minus the forward drop across the diode. The *R-C* time constant determines the lower frequency limit and must, therefore, be large relative to the period of the input signal with the lowest expected input frequency. The time constant must, however, not be made too large to avoid an excessively slow meter response. The capacitor values shown in Figs 2, 3 and 4 may be used for easy reference and as starting points for your experiments.

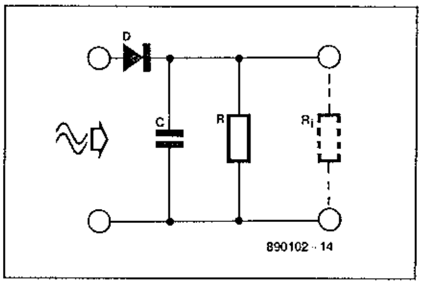

Fig. 1. The single-phase rectifier measures the peak value of the alternating voltage.

Provided a suitable diode is used, the single-phase rectifier will give good results. The use of a point-contact germanium diode results in a virtually linear frequency response up to about 10 MHz. Above this frequency, the response degrades slowly to about –3 dB at 100 MHz. The output voltage is 100 mV to 200 mV smaller than the peak value of the measured alternating voltage (the peak value equals 1.414 times the effective or root-mean-square value).

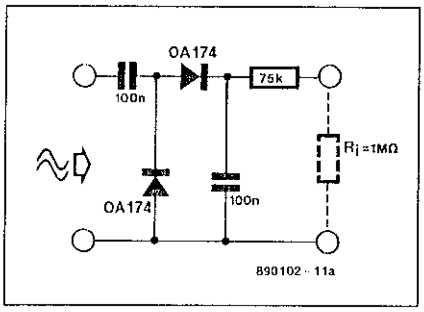

Fig. 2. The Villard circuit is a voltage doubler, i.e., it measures the peak-to-peak value of the alternating voltage. The circuit shown here is dimensioned for a frequency range of 10 kHz to about 1 MHz.

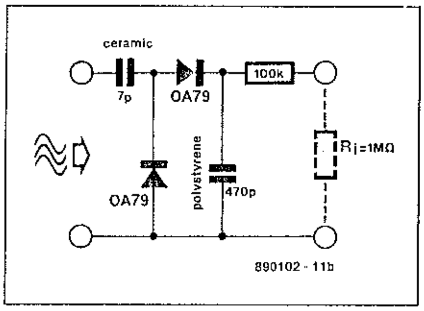

Fig. 3. RF version of Villard rectifier with point-contact germanium diodes.

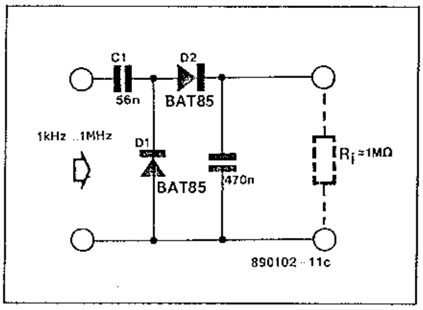

Fig. 4. Villard circuit with Schottky diodes for optimum linearity.

In the small-signal range, Schottky diodes such as the Type BAT85 are better than germanium types because they have a smaller reverse leakage current than point-contact germanium types. The one disadvantage of a Schottky diode, namely its slightly higher forward voltage drop (150 mV typ.), is made good by the better defined conduction voltage (the V-I curve shows a sharper rise than a germanium diode). In practice, the DVM reading for signals smaller than 1 V_{rms} is always a little lower than the actual effective value.

The Villard rectifier

The circuits in Figs 2, 3 and 4 all contain two capacitors and two diodes. These parts provide voltage doubling. If ideal diodes were used (i.e., diodes with a threshold voltage of nought) the voltage across the output capacitor would be exactly two times that across R in Fig 1. This voltage represents the peak-to-peak value of the input voltage, or

$$U_{PP} = U_{rms} \times 2 \times 1.4141$$

The operation of the Villard rectifier is best explained by assuming a point in time where a negative half cycle of the input voltage arrives at the input of the circuit in Fig. 4. Diode D_1 conducts, and capacitor C_1 is charged to the peak value of the half cycle. When the positive cycle starts, the voltage at C_1 is added to the peak value of it. This is because diode D_1 blocks, but D_2 conducts, so that C_2 is charged to the peak value plus the voltage across C_1. Thus the voltage across C_2 represents virtually the peak-to-peak value of the input voltage:

$$U_{C2} = (U_p + U_{C1}) = U_{PP}$$

Capacitor C_2 and the resistance R_i of the DMM form the previously mentioned time constant.

The Villard/Delon rectifier not only supplies a higher output voltage than a single-phase rectifier, it is also more sensitive. Furthermore, its input resistance is roughly equal to that of the DMM at the output. Initially, the measured voltage is only briefly loaded as the capacitors are charged. After a few cycles of the input signal, the charge current virtually disappears, and the input signal is loaded only by R_i and the reverse leakage currents of the diodes.

Basically, the circuits in Figs 2, 3 and 4 differ only in regard of the time constant, and, therefore, the frequency range. The circuits in Figs. 2 and 3 contain a series resistor at the output to protect the diodes against output short-circuits. In view of the high value of R_i (>1 MΩ) these resistors do not significantly affect the time constant.

The circuit in Fig 2 is dimensioned for audio signal measurements and provides a linear peak-to-peak voltage reading for signals between 20 Hz and about 1 MHz, provided the DMM input resistance is not smaller than 10 MΩ. When a DMM with R_i = 1 MΩ is used, the capacitor values must be increased to 820 nF. The curves shown in Fig 5 were recorded with a 1 MΩ DMM and 100 nF capacitors.

The circuit in Fig. 3 is basically the same but adapted to give a frequency range of 300 kHz to about 300 MHz, depending on the type of diode used. The 7 pF capacitor at the input allows the rectifier to be coupled lightly to the circuit under test, avoiding excessive loading of tuned circuits while these are adjusted.

Finally, the circuit in Fig 4 is set up for a frequency range extending from audio to about 1 MHz. Its remarkably straight response curve is shown in Fig. 6. The sensitivity is also remarkable: the rectifier 'starts' at signal levels as low as 35 mV_{rms} or about 100 mV_{PP}, while at higher input levels (up to 2.5 V_{PP}) the direct output voltage is equal to the peak-to-peak value of the input voltage minus a constant difference of 0.1 V.

Practical notes

The combination of a DMM and a passive LF/HF probe may in many cases replace a much more expensive high-grade LF/HF millivoltmeter, and in addition prove useful for audio purposes, including filter adjustments, frequency response recordings and frequency response corrections (tape recorder calibration, adjustments on equalizers, etc.). The passive probe also allows loudspeaker enthusiasts to record, with the aid of a simple signal generator, the frequency response and steepness of cross-over filters. Provided a linear microphone is available (e.g. an electret reference microphone), it is possible to perform frequency response tests on loudspeakers.

In the RF range, a probe of the type described here enables small signals to be traced and measured. Critical adjustments on filters and oscillators no longer present problems caused by overloading and detuning effects.

The germanium diodes used in the circuits in Figs. 2 and 3 are obsolete types which may, however, be around somewhere in your junk-box. Recuperating an old TV set may also provide you with twenty-odd OA-type diodes of different power ratings. Use the ones that are physically the smallest since these, in general, have the lowest stray capacitance (a rectifier diode from somewhere around the TV's power supply is obviously not worth trying in a probe).

Alternative types with the prefix AA are still current components and may be used instead of the OA174. Arranged in order of decreasing sensitivity, these include: AA113, AA112, AA119, AA118, AA138 and AA137.

For AF applications, the difficult-to-obtain germanium diodes may be replaced by germanium transistors with an 'AC' prefix (AC151, AC152 and similar types). Simply cut off the emitter terminal. The collector becomes the anode, and the base the cathode, of your (admittedly relatively large) germanium diode. ■

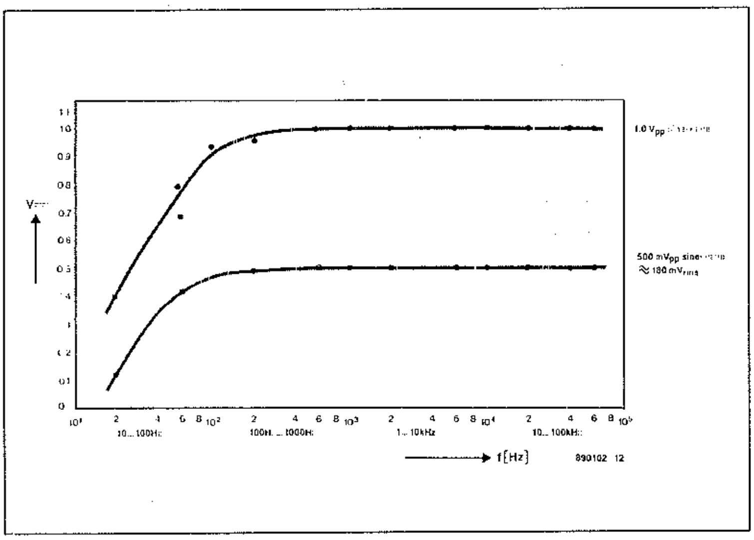

Fig 5. Frequency response of the circuit in Fig. 2 at two typical AF voltage levels and a terminating resistance of 1 MΩ. The roll-off frequency will be a factor of 10 lower when a 10-MΩ DMM is used.

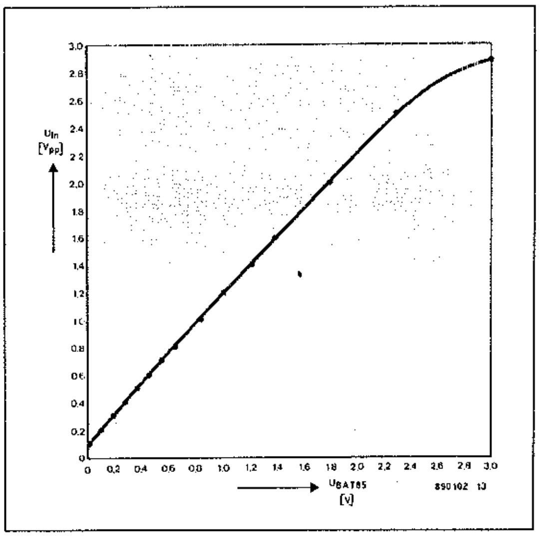

Fig. 6. Correlation between input voltage and output voltage for the circuit in Fig. 4. Excellent linearity is achieved by the use of a Schottky diode.