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DC - 1 MHz Wattmeter Based on RMS Voltage Measurements

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***Abstract* - A wideband wattmeter for measuring active power over a frequency range of dc to 1 MHz is described. The wattmeter is based on the three voltmeter method in which three rms voltage measurements are used to calculate power.**

I. INTRODUCTION.

The three voltmeter method for measuring power was described by Ayrton nearly 100 years ago. More recently, various implementations of the technique have been described [1,2]. The applied power is derived from a set of three rms voltage measurements using the law of cosines.

II. WATTMETER DESIGN

A wideband wattmeter has been developed based on this principle that consists of a commercial digital voltmeter (DVM), a four-terminal resistor, two inductive voltage dividers, an isolation transformer, and associated control circuitry. This wattmeter was designed to be used with a source of synthetic power to test wattmeters over a wide range of power, power factor, and frequency. A simplified circuit diagram of the test system is shown in Fig. 1.

A test voltage V is applied to the voltage terminals of the wattmeter under test (MUT) and to inductive voltage divider T_1, which is used in conjunction with the buffer amplifier A_1 to scale V to V_1 (approximately 5 Vrms). The test current I is applied to the four-terminal resistor R in series with the current terminals of the test wattmeter. The voltage developed across R is converted to a ground-referenced voltage V_2 (also approximately 5 Vrms) using the two-stage transformer T_2 and buffer amplifier A_2. Amplifiers A_1 and A_2 are special composite, non-inverting amplifiers needed to minimize the loading errors of T_1 and T_2. They introduce errors of less than 5 parts in 10^6 in the 50 Hz to 1 kHz range [3]. Difference voltage $V_D = V_1 - V_2$ is converted to a ground-referenced voltage V_3 using a center-tapped inductive voltage divider T_3, thereby avoiding the need for any active circuitry to perform the difference function. A high precision, wideband DVM is used to measure the three ground-referenced voltages V_1, V_2, and V_3. These voltages are related to the phase angle θ between V_1 and V_2 by the *Law of Cosines*:

$$V_D^2 = V_1^2 + V_2^2 + V_1 V_2 \cos\theta$$

which may be expressed as:

$$V_1 V_2 \cos\theta = V_D^2 - V_1^2 - V_2^2 .$$

The magnitude of the difference voltage V_D can be described in terms of the three measured voltages and the ratio of T_3 (0.5) by the following equation:

$$V_D = [2(V_1^2 - V_2^2 - 2V_3^2)]^{1/2} .$$

The power applied to the test wattmeter is given by:

$$P = VI\cos\theta = (r_1 r_2 V_1 V_2 \cos\theta)/R$$

where r_1 is the step-down ratio of T_1 and r_2 is the step-up ratio of T_2.

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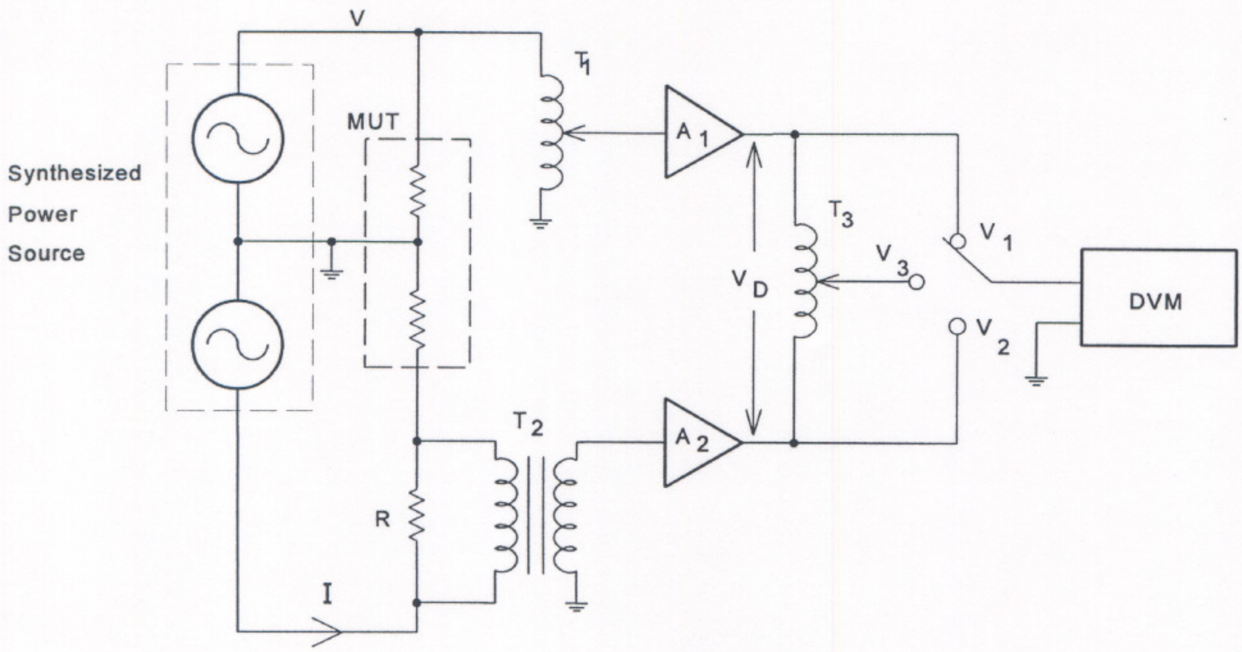

Fig. 1. Simplified diagram of the wattmeter based on rms voltage measurements.

III. CONCLUSION

The final paper will describe the implementation of this wattmeter in a system to calibrate test wattmeters that operate at 120 V and 5 A, at any power factor, over a wide frequency range with a low audio-frequency active power uncertainty of 30 parts in 10^6 (1-σ).

Standards to support precision power measurements presently are limited to the audio frequency range [4]. The wattmeter described here was developed to support the calibration of commercial power analyzers capable of measuring power components out to 1 MHz. Complete performance results as well as results of comparisons with other power measurement standards will be given in the final paper.

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