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# Testing Power Converters Using a Liquid-Rheostat Dummy Load

**Described here is an electrochemical cell that can be a very effective dummy load for testing power converters. It has great practical benefits, such as simple and low-cost construction, reasonable power dissipation, negligible leakage inductance, and very low achievable resistances. These properties make it very useful for testing low voltage converters.**

As part of a power electronics design project involving a 3.6-V dc-dc converter, it became necessary to test and accurately characterize the planar transformer shown in *Fig. 1*. Transformer operating parameters are listed in the Table. To test this transformer, the dummy-load resistance used had to go as low as 0.2 Ω with the lowest possible series inductance, a fairly challenging requirement [2].

This planar transformer needed to be tested over its full range of current and voltage at an operating frequency of 200 kHz. The simplest way to test the transformer was to drive the primary with ac voltage, with a load resistance directly across the terminals of the secondary. This dummy load resistance had to meet the criteria described in the Table.

First, it was required to have a variable resistance range from 4 Ω down to 0.2 Ω. Ideally, the load should be a pure resistance to enable output-power calculations.

A pure resistance requires minimal reactive impedance, which means the reactive impedance at 200 kHz should be less than 5% of the lowest resistance (5% of 0.2 Ω = 0.04 Ω, which corresponds to 32 nH). Hence, the parasitic series inductance should be less than 32 nH.

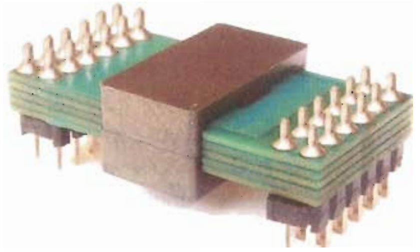

Fig. 1. The planar transformer to be tested is rated at 200 W with an output of 2.4 Vdc at 85 A.

| TRANSFORMER PARAMETERS | |
|---|---|
| Turns ratio | 1:1 |
| Core | E18 |
| Core material | 3F3 |
| Maximum input/output voltage | 4 V (peak) |
| Maximum input/output current | 20 A (peak) |
| Operating frequency | 200 kHz |
| Maximum output load resistance | 10 Ω |
| Minimum output load resistance | 0.2 Ω |
| Maximum load power dissipation | 40 W |

Second, it was required to dissipate up to 40 W continuously, but this power dissipation could not adversely affect the load or change its resistance. Besides meeting these specifications there were time and cost constraints associated with building this dummy load.

## ASSESSING THE OPTIONS

The first option was to use multiple low-inductance, high-power resistors in parallel to achieve the required power dissipation and low resistance. This would have required normal sourcing and delivery times, as well as the associated costs.

Provision would also have to have been made for switching resistors in and out to vary load resistance. These resistors would have to be mounted on a heat sink with series switches using extremely low-inductance connections. This task is time consuming, and such a low-parasitic series inductance would be difficult to achieve.

A second option for loading the transformer includes designing and building a full rectifier circuit for the secondary and then using a dc load. In this setup, the load current from the transformer is not linear, making it difficult to accurately measure the output power from the transformer before the rectifier circuit. It would also not be possible to compare practical results with theoretical calculations based on pure sine waves.

## A LIQUID RHEOSTAT ALTERNATIVE

The alternative is to use an electrochemical cell dummy load. This is possible because the transformer's output voltage is at a high frequency (200 kHz). This is also referred to as liquid rheostat [1, 6, 8, 9], dummy load resistor [4], and water resistance load system [5].

There are instances of radio amateurs using "salt-water loads" as an RF dummy load in the high-frequency radio band of 3 to 30 MHz [3], however no documented evidence was found at switchmode frequencies of 1 kHz to 1 Mhz. When using an electrochemical cell at high frequency its operation is similar to a dielectric heater [7], where dielectric material is placed between two plates and an RF voltage is used to heat the dielectric material between the two plates.

Fig. 2. Electrochemical dummy load cell consists of two parallel plates or electrodes placed in a jar containing an electrolyte.

### LIQUID RHEOSTAT DUMMY LOAD CELL

Essentially, the test electrochemical dummy load cell is two parallel plates or electrodes placed in an electrolyte as shown in *Fig. 2*. It is assumed that at frequencies of 1 kHz and higher, the cell does not have much electrolysis happening since electrolysis requires a dc current. The resistance will then be roughly proportional to the standard formula for a resistive material,

$$R = \frac{\rho \times L}{A}$$

where:
R = Resistance in ohms
⊠ = Resistivity in ohm-cm
L = Length of conductor in cm
A = Area of conductor in cm2

This can be rearranged to find the resistance of the electrochemical cell giving:

$$R = \frac{d}{\delta \times A}$$

Where:
R = Resistance in ohms
d = Distance between two plates in cm
$\delta$ = Conductivity of electrolyte in mhos
A = Area of conductor in $cm^2$

The test-cell size and setup was initially simply estimated and then improved empirically by testing and readjusting the physical size. The final version consisted of copper sheets as the electrode plates, with a physical area of 10 $cm^2$, and they were separated by a distance of 5 mm. A glass jar was used as the container for convenience sake, which was first filled with pure water for use as a suitable electrolyte.

### TEST SETUP

The test setup used is shown in *Fig. 3*. An Apex PA19 power amplifier was used as driving source to produce the ac power at 200 kHz. This amplifier then drove a 10:1 ETD transformer to step the voltage down and the current up to the correct levels required to test the planar transformer. The transformer was loaded on the secondary with the electrochemical dummy load.

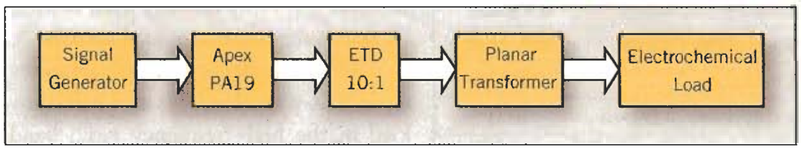

Fig. 3. Test setup consists of a signal generator driving a power amplifier with an ETD transformer whose output provides the input to the planar transformer with an electrochemical load.

Pure water was first used as the electrolyte in the initial setup, as this provides the highest initial resistance. Salt, acid, or alkali can be added to the water to decrease the cell's resistance, a technique that will increase conductivity.

This was done in an empirical manner, increasing the saline concentration or acid strength until the required resistance was obtained. Concentrated acid or alkali should always be added to water and not other way around.

Common examples of electrolyte include sodium chloride (NaCl) solution, diluted hydrochloric acid (HCl), or sodium hydroxide (NaOH) solution, also known as caustic soda. However, it is advisable that the chemistry of electrode plate metals and electrolyte is studied to avoid a reaction between them.

Copper is fairly suitable as an electrode material in this application. HCl acid offers an advantage over NaOH as an electrolyte, as it cleans the copper surface. Copper oxide forms on any copper surface that is exposed to air. HCl acid will react with this oxide to form Copper Chloride: $CuO + HC1 = CuCl_2 + H_20$. This effectively removes the oxide ensuring maximum conductivity between the electrodes.

The lowest resistance required for this application was 0.2 $\Omega$. This was achieved when the plate dimensions given above were fully submerged in a weak HCL acid solution (molar concentration unmeasured).

However, obtaining the correct resistance for different applications can be achieved experimentally by testing various electrode plate sizes, decreasing plate separation, and increasing acid concentration (i.e. conductivity) until the maximum desired current is drawn when the plates are fully submerged. Power dissipation can be increased by increasing the volume of the electrolyte.

### EXPERIMENTAL RESULTS

Voltage across—and the current into—the dummy load cell were measured directly at the cell-plate terminals (*Figs. 4 to 7*). In the waveforms, it becomes evident that there is no measurable phase-lag or non-linearity between voltage and current. It can also be seen from the non-sinusoidal waveforms in *Figs. 6* and *7* that the current is directly proportional to the voltage, which suggests that the load looks like a pure linear resistance.

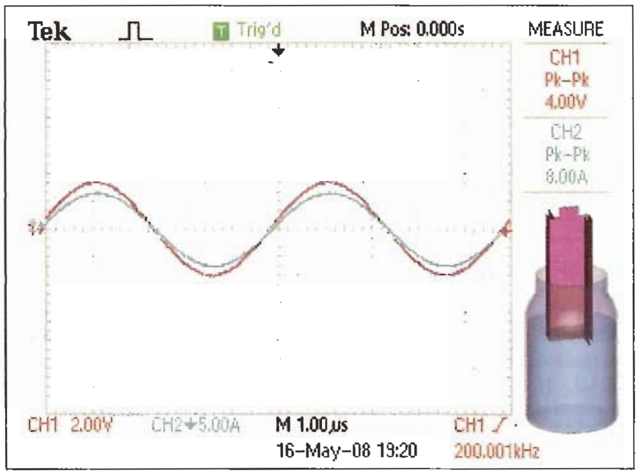

Fig. 4. Sinusoidal output voltage with one-third of the plate submerged.

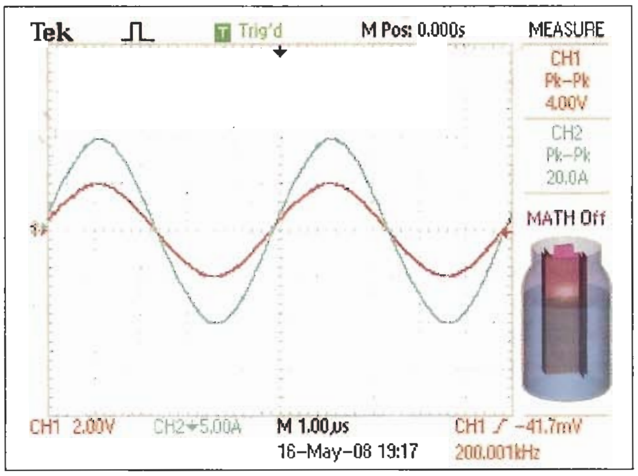

Fig. 5. Sinusoidal output voltage two-thirds of the plates submerged.

Hence, the load is suitable for use with square waves and quasi square waves generated by power electronic converters. Power in and power output of the transformer could be measured by multiplying input voltage by input current and averaging them on an oscilloscope, or by doing sinusoidal calculations. Power output can also be calculated using the $I_{rms}$ reading from the oscilloscope, and the resistance of the cell.

The dummy load cell handled the power dissipation well and there was no significant temperature rise of the water after 60 mins of testing. The resistance of the cell was found to stay relatively constant across the test frequency range of 50 to 400 kHz.

There was also no visible electrolysis in the cell in terms of gas bubbles or plate erosion, even at 1 kHz. This absence of electrolysis also means that the resistance of the cell will stay constant since no chemical change will occur in the cell during operation.

Load current could be varied in a linear manner, simply by lifting the plates in or out of the electrolyte. The current was directly proportional to the depth of plates submerged. This is illustrated with a sine wave in *Fig. 4* and *Fig. 5*, and a quasi-square wave in *Fig. 6* and *Fig. 7*, with one-third of the plate submerged and two-thirds of the plate submerged, respectively.

The dummy load cell was very time efficient and cost effective to construct, with readily available materials. The electrochemical cell or liquid rheostat performed exceptionally well as a dummy load for ac voltages at frequencies typically encountered in power electronics. The load current could be varied in linear fashion by simply lowering or raising the plates into the electrolyte.

The load was found to be a pure linear resistance with no measurable inductance, making it simpler to calculate the power delivered, which can be done using the oscilloscope's $I_{rms}$ reading. Several power converters produce a high frequency (1 kHz to 1 MHz) ac voltage at an unknown point in the conversion chain, and this liquid rheostat could be useful in testing the performance of the converter at that point.

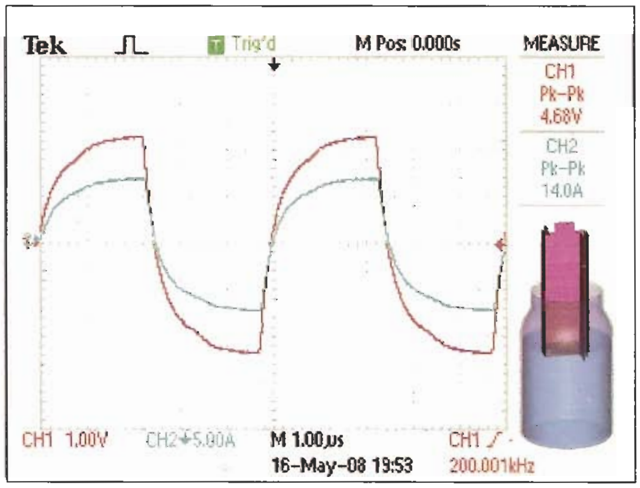

Fig 6. Quasi-square wave voltage output with one-third of the plate submerged.

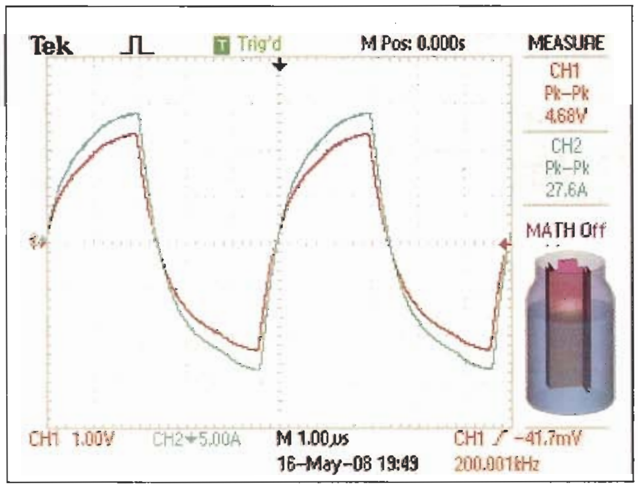

Fig. 7. Quasi-square wave voltage with two-thirds of the plate submerged.

## ABOUT CAPE PENINSULA UNIVERSITY OF TECHNOLOGY

Located in Cape Town, South Africa, Cape Peninsula University of Technology (CPUT) is the only university of technology in the Western Cape province, and is also the largest university in the province, with more than 29,000 students. Most of the courses offered by CPUT incorporate in-service training; the training consists of an internship, usually six months to a year.

The university's comprehensive co-operative education policy ensures the student is placed within a company approved by the university; this ensures that institutional academic learning is incorporated into work-based content. ⏻

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## TEST PERFORMED ON TRANSFORMER USING LIQUID RHEOSTAT

**TWO DIFFERENT WAVEFORMS** at 200 kHz were used for the testing of the transformer. Using an oscilloscope, the voltage and current waveforms observed on the windings of the transformer were recorded. The test setup for this is shown in Fig. A.

Fig. A. The connection of the various measuring probes onto the transformer.

| EFFICIENCY CALCULATIONS OF TRANSFORMER | | | | |
|---|---|---|---|---|
| | PRIMARY (VA) | SECONDARY (VA) | POWER DISSIPATED (W) | EFFICIENCY |
| Test 1 | 37.5 | 35 | 2.5 | |
| Probe Swop | 38 | 36.4 | 1.6 | |
| Average | **37.75** | **35.7** | **2.05** | **94.57** |
| | | | | |
| Test 2 | 35.9 | 35 | 0.9 | |
| Probe Swop | 36.7 | 33.7 | 3 | |
| Average | **36.3** | **34.35** | **1.95** | **94.63** |

First, a sine wave of 8 Vp-p was applied with the load set so that the transformer drew 20 A on the primary. The process was repeated with a square wave of 8.6 Vp-p and the load set so the Ipri is 35.8 A. The waveforms of both these tests are shown in Fig. B.

Using the data obtained from the oscilloscope, the power and efficiency of the transformer could be calculated. To eliminate any errors of accuracy of the probes, various VA measurements were taken while exchanging the voltage and current probes. The average of these measurements was then calculated to give an accurate value of the VA on the primary and secondary. The efficiency calculated from the measurements equalled roughly 95%, as shown in the Table.

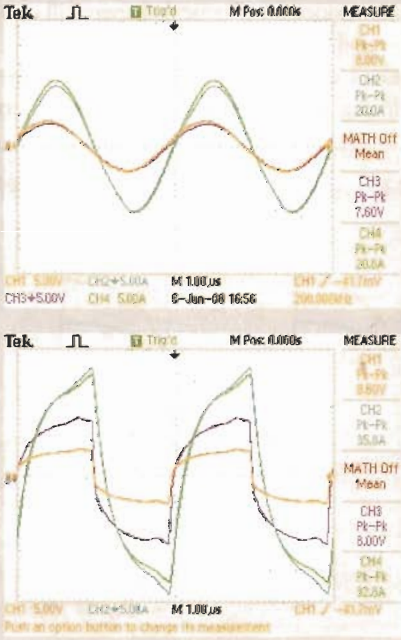

Fig. B. The test results of the transformer using the liquid rheostat.