A Capacitance Based Measurement System for Produced Fluids in A Pivotted or Horizontal Centrifuge

by
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ABSTRACT

At present, virtually all centrifuges used to study capillary pressure and relative permeability in porous materials utilize visual techniques, either manual or automatic, to measure the amount of fluid produced. These techniques require a line-of-sight between a stroboscopic light and the observer/recorder. Recent work on high permeability and porosity samples suggests that a pivotted-head rotor would be beneficial during the low-speed portion of the experiment. A pivotted rotor precludes a line-of-sight, making the visual techniques inoperable. A method to measure the amount of fluids by detecting the capacitance of the receiver cup has been developed. The technique is based on the fact that there is a difference in the dielectric constant of brine and oil or gas. Therefore different mixtures of these fluids have different capacitances. This paper provides a detailed description of the system which includes the following components: an electronic circuit to convert the capacitance signal to a frequency signal; an infra-red opto-coupled circuit by which the frequency signal is passed from the center of the rotating shaft to a fixed receiver on the centrifuge cover; and an electronic circuit to convert the frequency signal into a voltage signal for recording purposes. This system removes the necessity for slip-rings or other electro-couplings, making retrofitting of existing centrifuges straightforward. Calibration results are reported for both stationary and spinning cases to demonstrate the functionallity of the system. The calibration for the spinning case was performed on a pivotted rotor centrifuge. The results show that a common calibration curve (for both the stationary and the spinning case) is possible over a large portion of the volume range. This system is ideally suited for capturing time-dependent data used for relative permeability experiments, and for a truly automatic, expert-system based capillary pressure apparatus, in either a pivotted or a horizontal configuration.

INTRODUCTION

Core analysts perform many tests to determine rock/fluid interactions within the rock matrix in order to characterize the nature of the reservoir formation. These tests include experiments to determine porosity, permeability, and saturation. The test of concern in this paper is the determination of capillary pressure by means of the centrifuge technique.

For the purpose of description, a primary drainage experiment will be considered, with oil displacing water in a core sample. The core sample, originally fully saturated with water, is mounted in a retainer bucket. When the centrifuge is spun, centrifugal force causes the heavier component (water) to drain from the sample and collect in a receiver cup. The volume of water is determined by looking through slits in the retainer bucket and noting the level of the water collected. The observer uses a stroboscopic light which is synchronized to rotor speed to both apparently stop the motion of the rotor and to illuminate the slit. Recently, several techniques to automate the reading procedure have been published (e.g. 0'Meara and Lease, 1983, King *et al*, 1990, Munkvold and Torsæter, 1990, Hirasaki *et al*, 1992, Nikakhtar *et al*, 1994, Kantzas *et al*, 1995). All of these methods make use of a stroboscopic system.

Synchronizing the strobe flash is difficult in some instances, particularly at low and at high speeds. Clear images of the buckets, for both visual and automatic systems, are compromized by the fact that the rotor speed always fluctuates to some degree. This can lead to blurry images and inaccurate data. Furthermore, recent work has been performed on pivotted rotors (see Chen and Ruth, 1994). Such rotors are not ameanable to stroboscopic systems because there is no line-of-sight between the strobe, the slit, and the observer — as the bucket pivots the relative positions of these three things change.

The present paper describes a capacitance technique for measuring the liquid level in a rotating centrifuge liquid collector. This new technique completely automates the data collection procedure and overcomes the problems associated with the stroboscopic system. The capacitance technique does not depend on a physical connection between the spinning rotor and the outside world. Rather, an infrared opto-coupler is used to transmit the liquid level signal. The opto-coupler is not affected by changing rotor speed. The capitance technique, in conjunction with the opto-coupler, provides a very promising method for level measurement in a rotating environment.

The design of the capacitance system is based on the equation for capacitance developed between a number of plates:

$$C = \alpha\, K\, \frac{A}{D}\, (N-1)\,. \tag{1}$$

Here C is the capacitance, K is the overall dielectric constant for the fluids (in the present case oil and water) filling the space between the plates, A is the area of the plates, D is the distance between the plates, and N is the number of plates. The dielectric constants of the two fluids must be different in order for the system to work. Because oils have dielectric constants in the range of 2.2 to 2.8 while water has a dielectric constant of about 35, this condition is met. As the relative amounts of the two fluids varies, the overall dielectric constant will vary. Therefore a measurement of the capacitance of the system can be interpreted as a change in the relative amounts of the two fluids present, hence the amount of production of one of the fluids from the sample.

OVERVIEW OF THE SYSTEM

Figure 1 provides an overview of the main system components. Within the liquid collector of the capillary pressure cell, a capacitance cell is constructed. The on-board circuit converts the capacitance signal into a frequency signal. The emitter of the opto-coupler therefore flashes at a frequency proportional to the measured capacitance. The detector senses this frequency and generates a signal which is passed to the external circuit. The external circuit converts the signal to a voltage which is the input to a data acquisition device. The opto-coupler allows the signal to be passed out of the system without the use of mechanical connections such as slip-rings. This allows retrofitting of systems to be done with relative ease. Although simple in principle, the electronics to make this system functional are quite sophisticated.

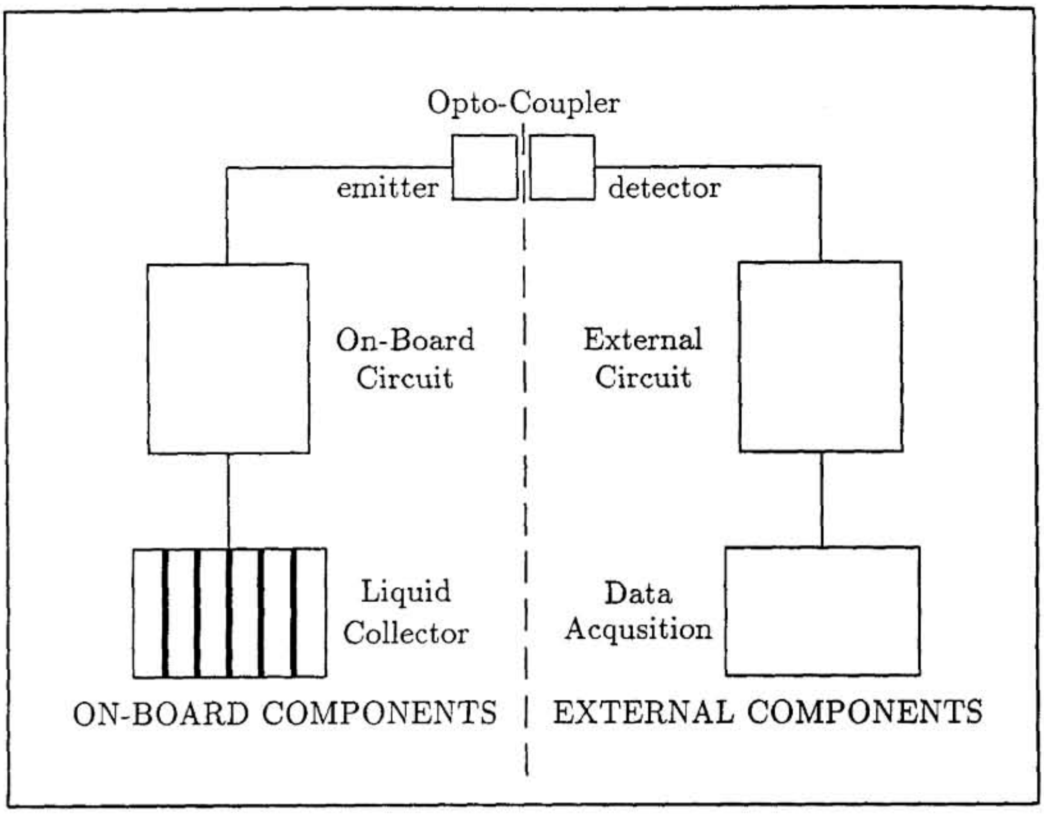

Figure 1 The System Components

THE CAPILLARY PRESSURE CELL

Before the liquid level can be measured, the displaced water must be collected. Figure 2 shows the capillary pressure cell. It is made in two halves: the top half, wherein is placed the core sample immersed in oil, and the bottom half which constitutes the capacitance cell. The bottom of the top half has drainage holes which allow oil and water to pass between the two halves. The top of the upper half is sealed with a cap and o-ring. The cap has an access hole to allow for precision filling of the chamber. Wire leads pass signals from the capacitance plates to contact plates mounted on the top of the bottom half. Signal rods conduct the signal to the top of the sample chamber where contact is made with wires from the on-board circuitry. The two halves of the cell are attached with bolts and sealed with an o-ring.

The capacitance cell is made up of five uniformly sized copper plates. These plates are coated with $m - coat$ strain gauge protective coating. This material is a polyurethane which seals the plates from the water, preventing both shorting between the plates and production of hydrogen by electrolysis. The plates are evenly spaced within the cell.

ON-BOARD CIRCUITRY

A detailed circuit diagram for the on-board electronics is illustrated in Plate 1 (at the end of the paper). The main conponents are a timer, a frequency divider, a pulse shaper, a transistor, and the infrared emitter. The timer used was a Type N555N with a frequency

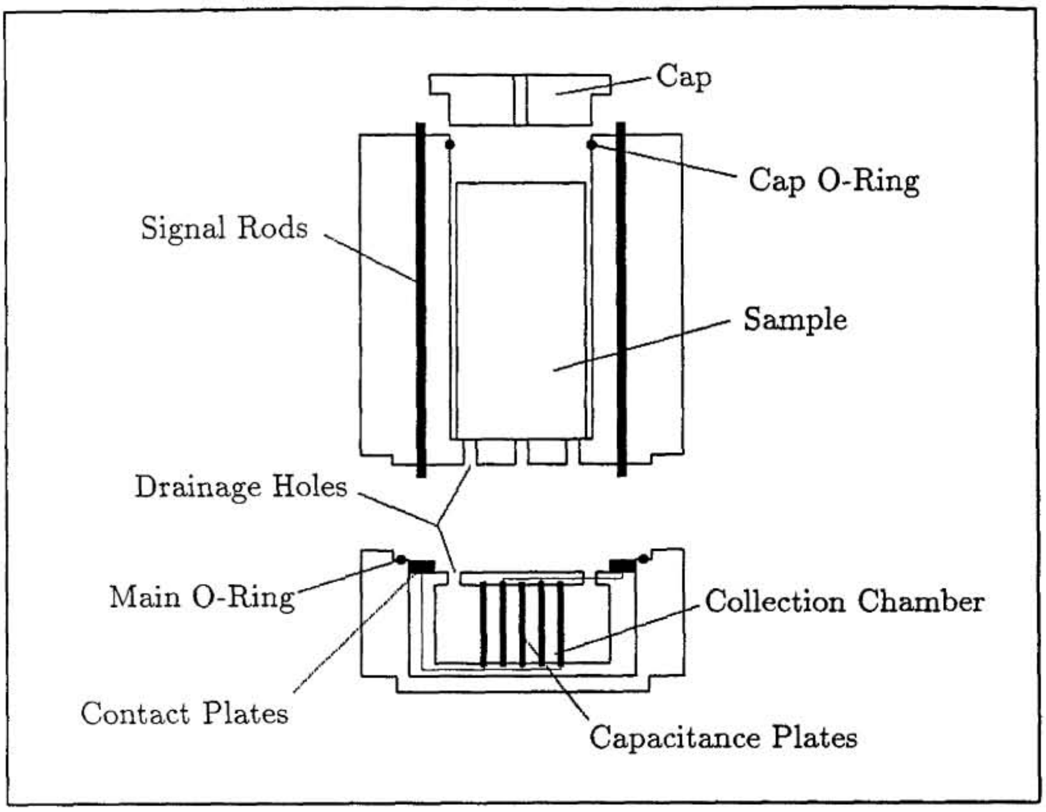

Figure 2 The Capillary Pressure Cell

range of up to 2 MHz. The circuit is powered by four AA batteries with a supplied voltage of 6 VDC. When the circuit is powered, the capacitance cell begins to charge at a rate determined by the RC constant of the circuit. The timer has a flip-flop that is reset when the charge reaches a value of two-thirds of the supply voltage. The charge then falls. At a value of one-third of the supply voltage, the flip-flop is set and the cell begins to charge again. This leads to a frequency signal from the timer that is proportional to the RC of the circuit. The resulting signal has a DC offset and operates at a frequency that is too high for the opto-coupler. The 47 μF capacitor removes the DC offset and produces a pure, non-linearly ramping frequency, fluctuating about zero volts.

A Texas Instrument SN74LS92N frequency divider is used to half the frequency of the signal. This device works by dissipating every second pulse. Again the circuit includes a 47 μF capacitor, this time to filter out any noise.

The pulse shaper is another N555N timer. In this chip, as the leading edge of the pulse enters the timer, the flip-flop is set high. The output stays high until the falling trailing edge is detected, which resets the flip-flop low. The 0-200 $k\Omega$ potentiometer is used to set the trigger level of the flip-flop.

The transistor (Type 2N3904M736) is required to produce the TTL signal level required by the infrared emitter. The infrared light region was chosen for the opto-coupler so that ambient light from fluorescent and incandescent bulbs would not interfere with the signal. The emitter is an Optek Technology OP133W. This emitter has a very wide beam pattern which can tolerate relatively large rotor and spindle vibrations. The opto-coupler will maintain signal integrity with up to a 1.5 mm misalignment between emitter and detector.

EXTERNAL CIRCUITRY

The external circuit is powered by a ± 5 VDC power supply which itself is powered directly from the 110 VAC building main. A detailed circuit diagram is provided in Plate 2. The light pulse train is detected by a Type OP805SL phototransistor which is located 0.5 to 1.0 mm above the emitter. The location is controlled precisely using a two-axis micrometer head system. When there is no incoming light pulse, the charge on the 21 mF capacitor remains at -5 V. When the detector senses a light pulse, the phototransistor switches and allows the capacitor to charge to +5 V. When the light pulse ends, the phototransistor switches again and allows the negative charge to build. The speed at which the switching occurs is so fast that the capacitor does not have time to fully saturate. The result is that the output of the detector is not a square wave, like the emitter, but rather a sawtooth wave.

As the water level increases, the frequency drops and the capacitor charge time increases. This guarantees that if the signal is measureable when the collector cup is empty, then the signal will reamin measureable throughout the entire level range.

The first operational amplifier is used to amplify the AC signal by approximately a factor of 15. The amplifier is a Type LM324. The signal passes from the operational amplifier to a Teledyne TC9400C voltage conversion chip. This chip senses each zero crossing of the signal, and in concert with the capacitors and resistors of the circuit, generates a DC voltage level almost linaearly proportional to the input frequency. However, this voltage was found to have a small AC ripple.

An LM324 operational amplifier is used to reduce the ripple. A final operational amplifier is used to both zero the voltage at the beginning of each experiment and to change the sign of the voltage. (The signal from the ripple eliminator decreases as water level increases.) The signal is then ready to be recorded on a voltmeter, or feed to an A/D board to allow automatic data collection using a computer.

RESULTS

Figure 3 shows the results of a calibration curve run with the collection cup stationary. The data were obtained by placing measured amounts of water into the cup and recording the signal produced. Although the signal is not linear, it is obvious that a calibration curve can be easily generated. Figure 4 shows results of a different calibration run performed in both stationary and spinning modes. For the spinning case, the centrifuge was stopped between each liquid level and a measuring increment of fluid was placed in the cup. At low volumes there is a discrepancy between the two calibration curves. At the speed used, the bucket is not horizontal and probably had a slightly different tilt angle for each test (because this angle depends on the weight of the bucket hence the amount of fluid in the bucket). This could lead to a systematic error in the reading when only a small amount of water is present, and all of the plates are not in the same degree of contact with the water. This error would presumably become less important as the amount of water increases and the variations become smaller relative to the total signal. The discrepancy between the

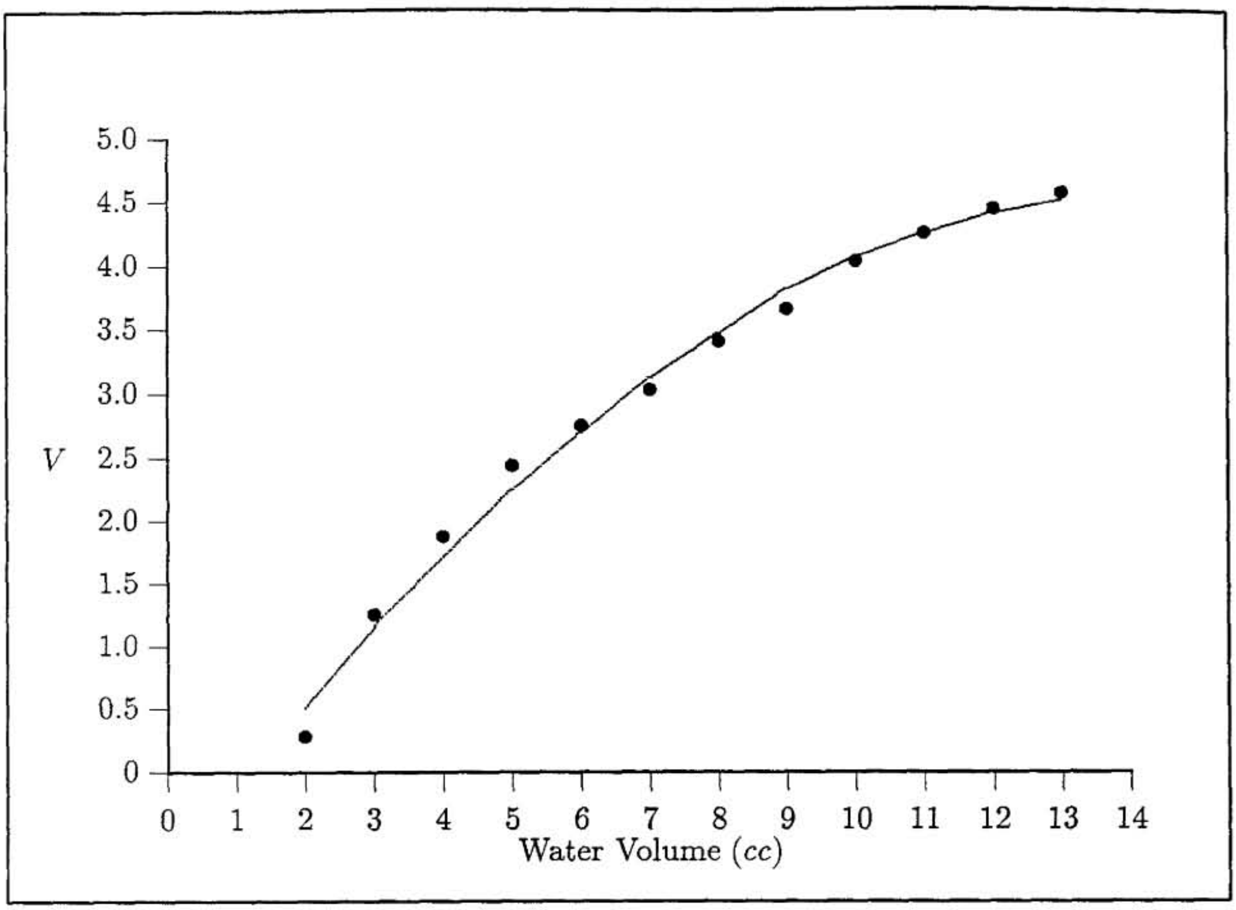

Figure 3 First Calibration Curve

two series of tests disappears at higher fluid levels. In the region between 15 and 22 *cc* of production, the points agree very well and the curve is essentially linear. This range of 7 *cc* is adequate for most experiments and a system could be designed to operate in this region. These calibration runs were performed to demonstrate that the system works in principle. Currently, the system is being developed into a fully functional capillary pressure apparatus. One concern that should be mentioned is that the system calibration will be unique for each fluid pair used.

CONCLUSIONS

The following conclusions are draw from the work completed to date:

1. It has been demonstrated that a capacitance technique can be used to measure produced liquid volumes in a spinning centrifuge.
2. The final system will require calibration for each fluid pair used.

ACKNOWLEDGEMENTS

The authors would like to thank ESSO Resources and the National Research Council of Canada for their financial support of this project.

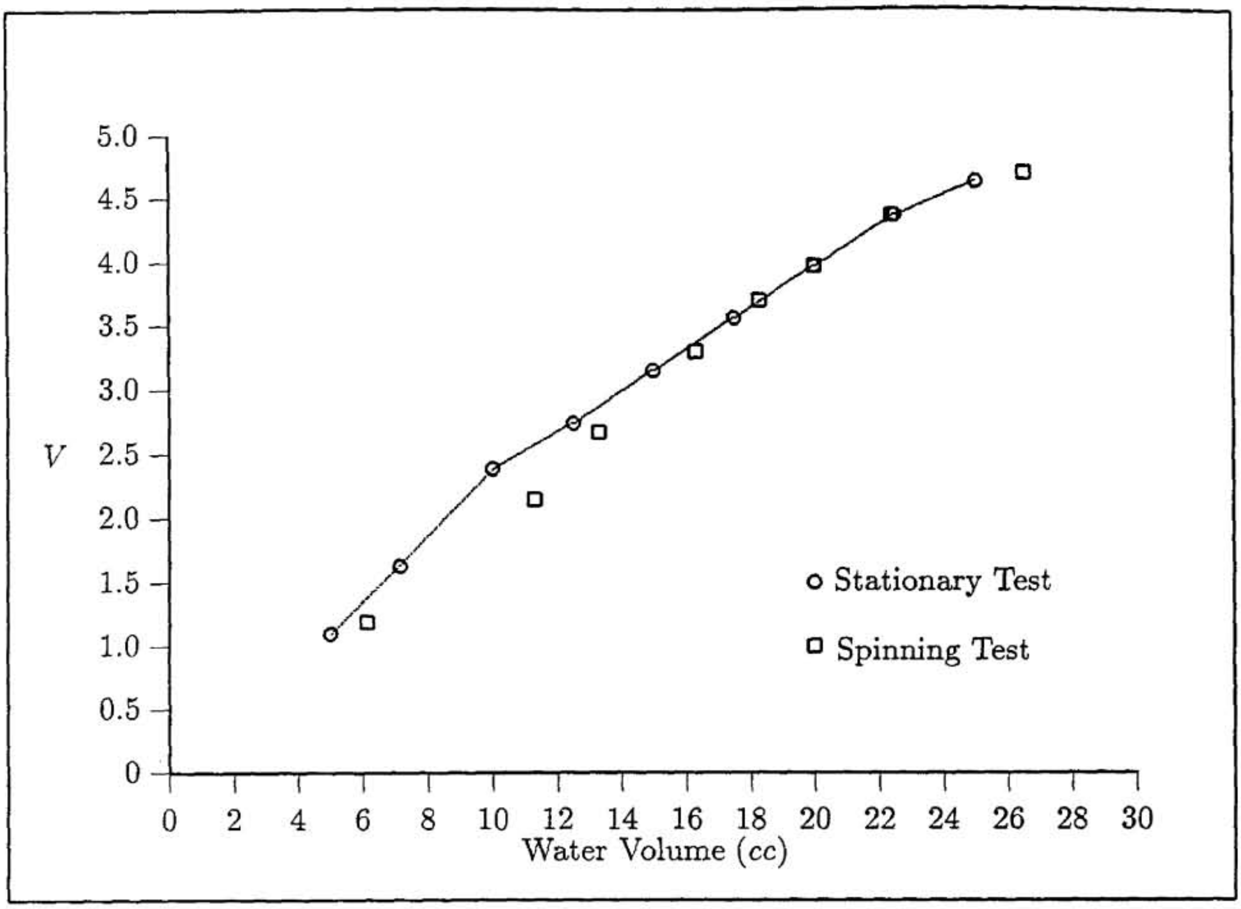

Figure 4 Second Calibration Curve

REFERENCES

Chen,Z.A. and D.W.Ruth, "Centrifuge Capillary Pressure Data Interpretation: Gravity Degradation Aspects Considerations," *SCA Annual Technical Conference,* (8th), Stavanger, Norway, September 12-14, [SCA 9425], 1994.

Hirasaki,G.J., J.A.Rohan and J.W.Dudley, "Modification of Centrifuge and Software for Determination of Relative Permeability Curves," *SPE Unsolicited Paper,* [SPE 25290], 1992.

Kantzas,A., B.Nikakhtar, D.Ruth and M.Pow, "Two Phase relative Permeabilities using the Ultracentrifuge," *JCPT,* Vol.34, No.7, (september), pp.56-63, 1995.

King,M.J., K.R.Narayanan and A.J.Falzone, "Advances in Centrifuge Methodology for Core Analysis," *SCA Annual Technical Conference,* (4th), Dallas, Texas, August 14-16, [SCA 9011], 1990.

Munkvold,F. and O.Torsæter, "Relative Permeability from Centrifuge and Unsteady State Experiments," *SPE Latin American Petroleum Engineering Conference,* Rio de Janerio, Brazil, October 14-19, [SPE 21103], 1990.

Nikakhtar,B., A.Kantzas, F.Wong and M.Pow, "Some Observations on the Capillary Pressure Hysteresis using the Ultracentrifuge," *SCA Annual Technical Conference,* (8th), Stavanger, Norway, September 12-14, [SCA 9423], 1994.

O'Meara,D.J.Jr. and W.O.Lease, "Multiphase Relative Permeability Measurements Using an Automated Centrifuge," *SPE Annual Technical Conference and Exhibition,* (58th), San Francisco, California, October 5-8, [SPE 12128], 1983.

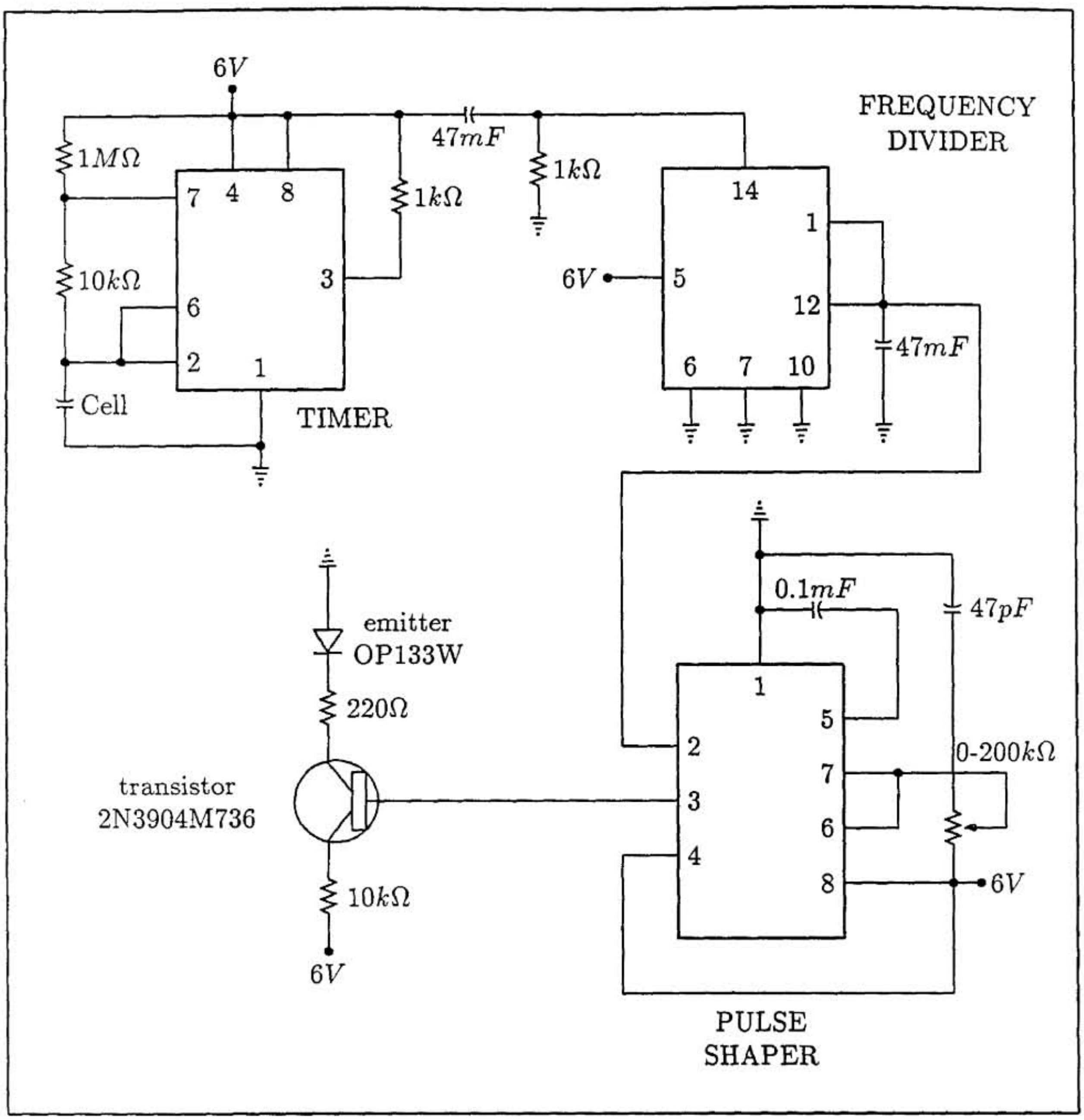

Plate 1 The On-Board Circuit

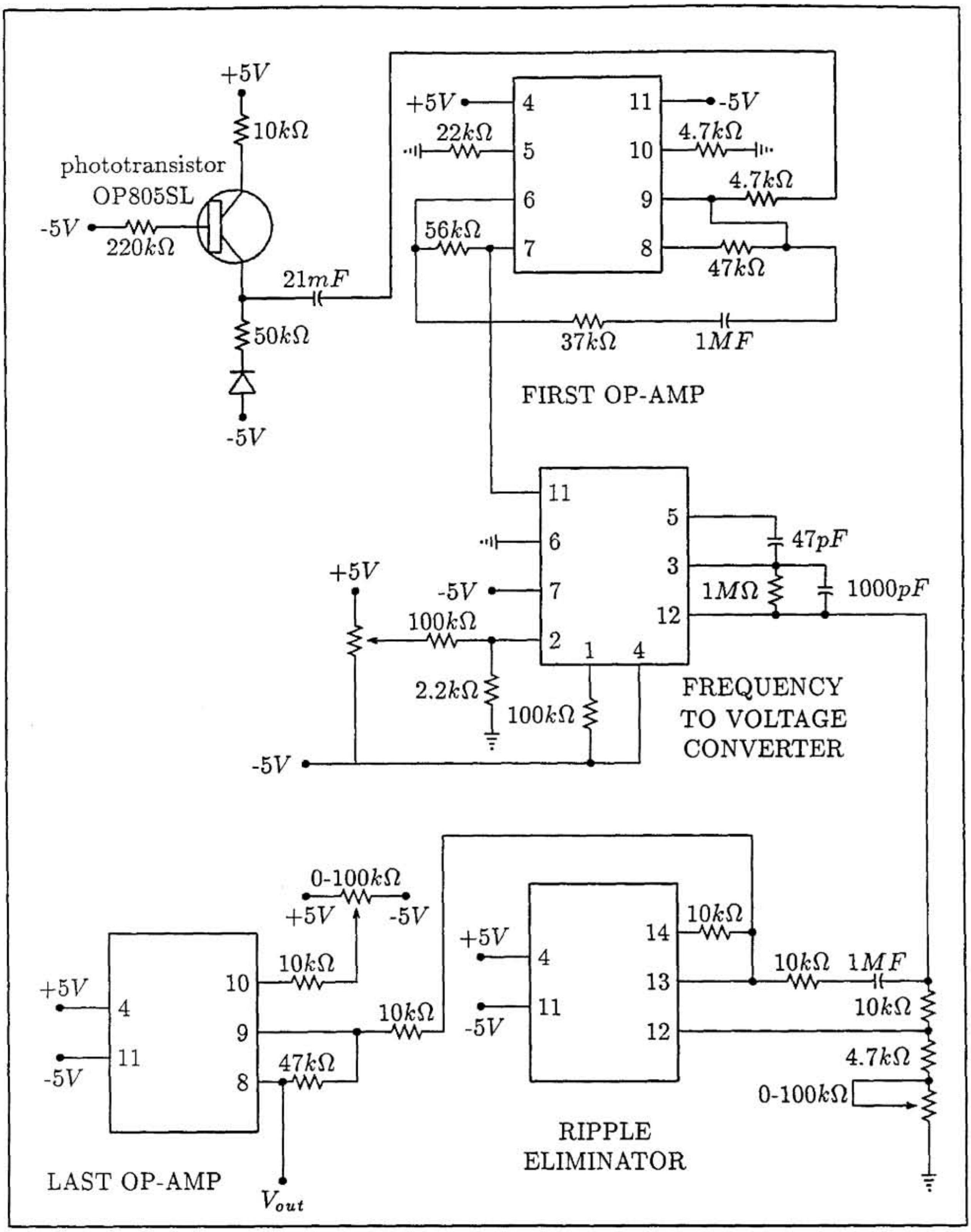

Plate 2 The External Circuit