rectifiers, have a 4 mA and 12.5 kV capability. Due to the high-frequency operation mode, the capacitance required to filter the output is much reduced. With loads as low as 10 kΩ, 1 µF gives a smooth response. The voltage drop across the variable resistor $R_V$ is used for current feedback. This resistor is a series of wirewound 10 kΩ resistors, one of which is a multiturn potentiometer to allow for small adjustments. A standard resistor connected in series with the transference cell supplies a voltage drop, which is read in a DVM, providing an accurate current measurement.

Figure 3 shows the control circuit diagram: A waveform generator, the RS305–804 (equivalent to 8038CC), is used to produce a stable sinewave output of 5 kHz, 1 V peak-to-peak. This signal is fed to an electronic attenuator, the MC3340, goes through an isolation stage and is then supplied to the power amplifier. A power driver, the ICL 8063† is used to drive the pair of output transistors, a 2N3055 and a 2N3789. The output of the power amplifier is fed to the step-up ferrite transformer, which supplies the high voltage side of the apparatus. The current feedback, after a buffer stage, is compared with a reference voltage derived from the temperature-compensated Zener 1N827. The amplified error signal controls the output of the sinewave going through the electronic attenuator.

3 Limiting factors and performance
As far as output capability is concerned, the current and voltage ratings can be changed using rectifiers, capacitors and transformers of suitable ratings. The output capability of the power amplifier used in the apparatus is about 50 W.

Some components in the circuit play an important role in keeping a highly stable current. The critical elements with respect to temperature and time drifts are the voltage reference Zener, the differential amplifier and associated resistors, and the current feedback resistors and buffer amplifier. The voltage reference diode, the 1N827, has a temperature coefficient of 0.001%°C. The current feedback and differential amplifier resistors are of the wirewound type having a temperature coefficient of 0.002%°C. The differential and buffer amplifiers use the low-cost 741, whose offset characteristics are reasonable for the purpose. Some improvement may be expected using very low-drift amplifiers such as the AD510 or AD517.

The system has been operating satisfactorily for several months, presenting a warming-up time of about 15 min and a current change of less than 0.1%, when the load changes from 1 MΩ to 10 kΩ. In experiments lasting up to 12 h, the maximum overall drift observed did not exceed 0.015%. The regulator described presents a low-cost solution, the total cost of components being around £100, for a high-voltage current regulator. With small modifications this type of circuit can satisfy different requirements.

References
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† Intersil, Inc., Cupertino, California.
For these reasons it is assumed that all particles impinging on the first MCP in the interchannel space are not detected.

Let us consider now the case when an infinitely thin annular flux of radius $R_0$ is registered. The ideal detector output would be

$$ I(R) = A \delta(R - R_0) $$

where $A$ is a constant and $\delta$ is the delta-function. The MCP has a definite structure but if the radius $R$ is large enough ($R \gg \phi$) the distribution of distances between the circumference of this radius and the centres of the channels crossing it may be regarded as uniform. If an infinite number of channels crosses such a circumference then for an infinite number of detected particles

$$ I(R) = C \left( 1 - ((R - R_0)/a)^2 \right)^{1/2}, \quad |R - R_0| < r $$

$$ = 0, \quad |R - R_0| \geq r $$

where $C$ is a constant. The mathematical expectation of $R$ equals $R_0$ and $\sigma$ is the standard deviation $\sigma = 0.5 \, r$. If the numbers of channels and detected particles are limited the mathematical expectation of $R$ will differ from $R_0$ by a standard deviation

$$ \sigma = \sigma_0 \left( 1/N_p + 1/N_c \right)^{1/2} $$

where $N_p$ is the number of detected particles and $N_c$ the number of channels crossing circumference of radius $R_0$.

In real measurements (Wijnaendts van Resandt, Champion and Los 1976) the variation range of $R$ is divided into intervals. For simplicity they are assumed to be equal. The value of $I(R)$ will differ from $C$ by a standard deviation $\sigma_0 = 0.5 \, r$. If the numbers of channels and detected particles are limited the mathematical expectation of $R$ will differ from $R_0$ by a standard deviation

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A water-wave height probe with
calibration stabilised for changes
in water conductivity

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Abstract A twin-wire wave height probe with calibration
stabilised for changes in water conductivity has been
produced. A conductivity cell driven by a constant current
signal is used to monitor the water conductivity. Use of
the cell voltage as a signal source for the wave height probe
eliminates the need for frequent probe calibration.
Experimental verification proves the system to be extremely
accurate.

1 Introduction
Wave height probes are frequently used to measure the surface
condition in water channels, towing tanks and wave tanks. A
number of probe designs are reported in the literature (Fryer
and Thomas 1975, Sancholuz 1978). Of these the twin-wire
resistance probe has found favour because of its ease of
manufacture and good dynamic performance. Its application
is, however, generally limited to fresh-water tanks where the
water conductivity is quite low. In practice two parallel
vertical wires are partly immersed in water and supplied with
a constant voltage. If the depth of immersion is sufficiently
large, the end effect will be negligible and the electrical
conductance between the wires will be proportional to the
depth of immersion and the water conductivity. Provided that
the conductivity does not change, the electrical current
flowing between the wires will be a measure of the water
surface elevation. Problems such as nonlinearity from long
supply cables have been solved by suitable feedback methods
(Fryer and Thomas 1975). Polarisation around the wires is
avoided by driving the probes with an ac signal, and unwanted
common-mode signals are eliminated by driving the two wires
with anti-phase signals and measuring the differential current
between them.

One problem which still exists is the sensitivity of the probe
to changes in water conductivity. The amplitude of the driving
voltage is normally kept constant and changes in conductivity,
due to impurities or temperature variations, then alter the
probe current and upset the depth calibration. Frequent
 calibration of these probes is consequently required.

The solution to this problem lies in altering the driving
voltage so that it varies in inverse proportion to the water
conductivity. This is easily achieved by fitting a separate, fully
submerged conductivity cell in the water tank and driving it
with a constant-current ac signal. A change in water con-
ductivity results in an inverse change in the voltage across the
cell. This cell voltage, via a suitable high-input-impedance
buffer, is used to drive the wave height probe. This may be
illustrated as follows:

If $V_p$ is the wave probe voltage, $I_p$ the wave probe current,
$V_c$ the conductivity cell voltage, $I_c$ the conductivity cell current,
$k$ the water conductivity and $h$ the depth of wave probe
immersion.