GAS-FILLED SURGE ARRESTERS FOR NEMP PROTECTION

Gas-filled arresters have the same rugged metal and ceramic construction as standard lightning arresters, but their internal composition is radically different to achieve the very fast operation required for NEMP.

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INTRODUCTION

Standard types of gas-filled arresters generally used for the protection of electronic equipment against lightning and similar voltage surges are inadequate for protection against Nuclear Electromagnetic Pulses (NEMP). A standard arrester will normally strike at a few hundred volts when the rise time of the voltage pulse is in the microsecond range, which is typical for lightning interference. With a pulse rising in 1 nanosecond, as with NEMP, the strike voltage can rise to several kilovolts and the arrester will then provide very poor protection.

It has therefore been necessary to develop a new range of gas-filled arresters to meet the NEMP threat. These have the same rugged metal and ceramic construction as standard lightning arresters, and have the same ability to pass high peak (20kA) and ac (20A) currents, but their internal construction is radically different to achieve the very fast operation required for NEMP.

NEMP PROTECTION

A nuclear electromagnetic pulse will flood the surface of the earth with a pulse of energy rising in a few nanoseconds and persisting for some hundreds of nanoseconds. The energy density at the earth's surface will typically be around 1 joule per square meter. This energy can couple into electronic equipment through aerials, power supply lines, and unscreened orifices, and produce catastrophic damage and upset to electronic components, particularly semiconductors. Some integrated circuits can be damaged by as little as one microjoule of energy; a substantial attenuation of the incoming energy is required. It is normal to provide most of the damping by screening techniques, such as the use of Faraday Cages, but a surge protective device will be required to remove the residual energy, particularly where screening cannot be complete, such as at an aerial inlet to the equipment.

IMPROVED GAS-DISCHARGE ARRESTERS FOR NEMP

The gas-discharge arrester comprises two electrodes contained within a ceramic envelope to which the elec-

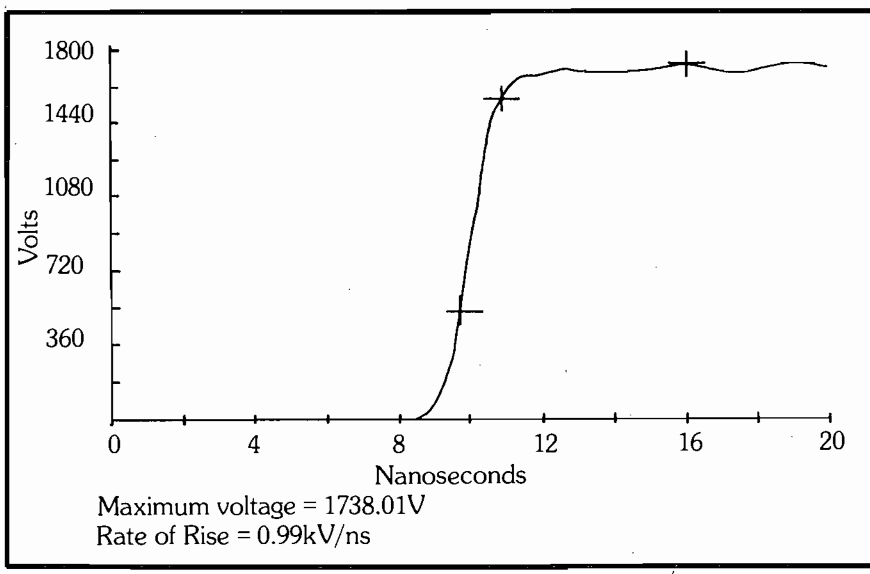

Figure 1. Typical Open-Circuit EMP Trace.

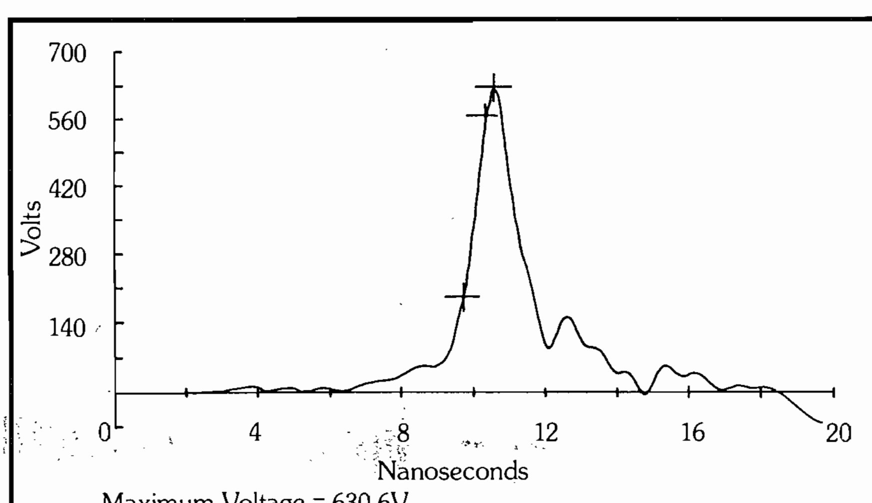

Figure 2. Response of Surge Arrester to EMP.

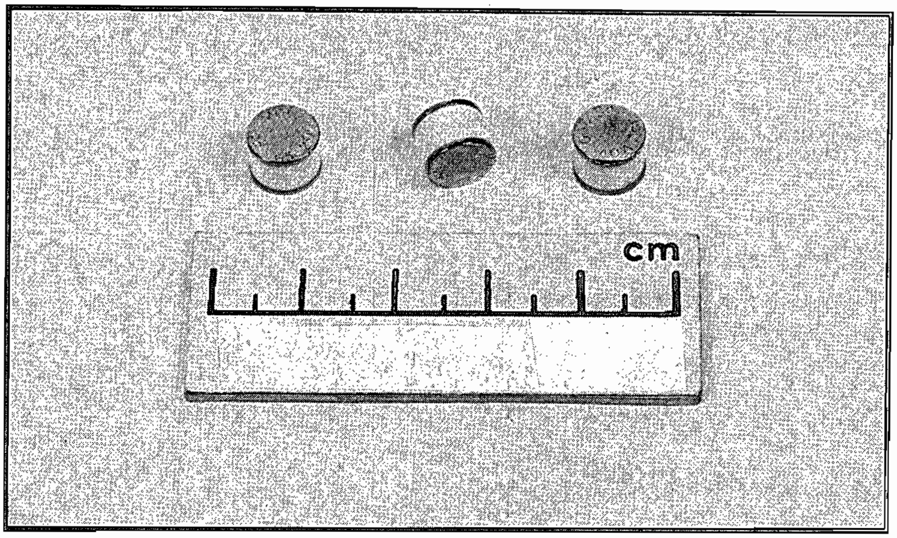

Figure 3. NEMP Diode Arrester.

trodes are sealed. The electrodes are spaced apart by a few tenths of a mm and the envelope contains a gas such as argon and hydrogen at a pressure below atmospheric. A mechanism is normally incorporated to generate a few free electrons, perhaps with the decay of a radioactive isotope such as tritium.

When a voltage is applied, the free electrons are accelerated by the electric field towards the positive electrode and they collide with neutral gas atoms, producing further electrons and positively charged atoms in a process known as ionization. These positive ions move toward the negative electrode and collide with this electrode to produce further electrons by the process of secondary emission. The whole process then becomes self-sustaining; i.e., the arrester breaks down. When the voltage pulse ceases, the charged particles recombine and the device once again becomes electrically insulating.

The speed of operation of the device depends upon the rapid generation of an initial supply of free electrons (the "statistical" lag), and the rapid movement of charged particles across the device to produce full breakdown (the "formative" lag).

By careful design, it has been possible to develop new types of gas-filled arresters where these two processes have been vastly speeded up, so that NEMP arresters break down in less than 1 nanosecond compared to the hundreds of nanoseconds of the standard types of lightning arrester. Figure 1 shows a typical open-circuit EMP trace on an oscillogram, and Figure 2 shows the effects of an arrester. An example of an NEMP diode arrester is shown in Figure 3.

THE RATINGS OF NEMP ARRESTERS

It is important to realize that it is unwise to provide protection of equipment just for NEMP interference. An NEMP pulse may last for only a few hundred nanoseconds, and may, after screening, produce currents of only a few hundred amperes at particular points in a device. An NEMP arrester incorporated into equipment will, however, strike with other types of interference, including lightning, where the current pulses may be hundreds of microseconds long, or power crosses, where the discharges may last for seconds. The NEMP arrester must, therefore, be designed with these points in mind. Thus, the improvements which have been incorporated into the NEMP gas-discharge arrester have not detracted from its performance with other types of interference. The arrester in Figure 3, for example, is suitable for peak currents of up to 5000 amps with an 8/20 microsecond waveform, or 1000 amps with a 1500 microsecond pulse. It will also conduct ac currents for several seconds.

NEMP ARRESTER MOUNTS

Following the fast voltage breakdown of an NEMP arrester, the rise of current will be equally rapid, reaching 10^{11} amperes per second. In these circumstances, the method of connection of the NEMP arrester to the circuit is of great importance. Wire connections of even a few nanohenries inductance will produce unacceptable voltage rises.

A variety of NEMP arrester mounts have therefore been developed to minimize the inductive effects. Figure

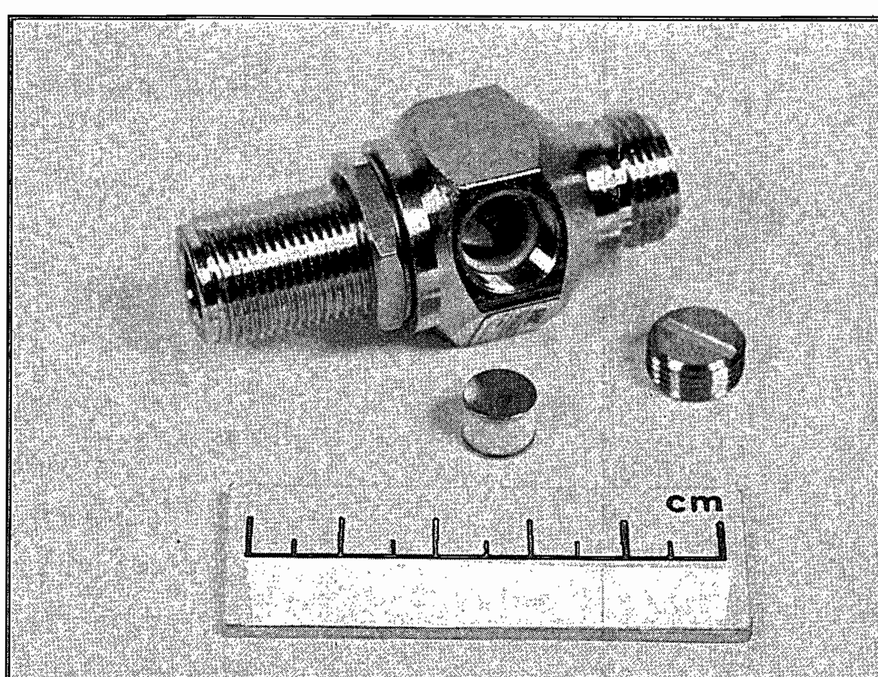

Figure 4. Bulkhead Mount.

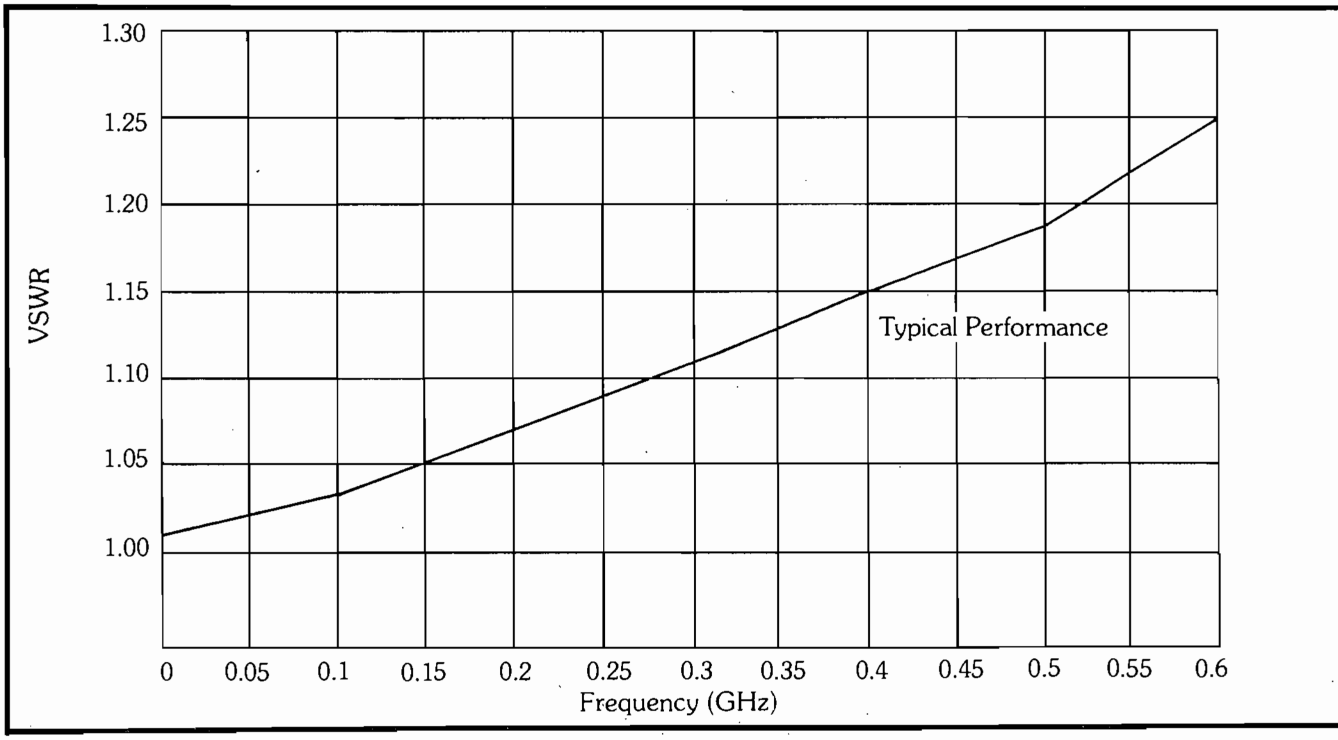

Figure 5. Standing Wave Ratio.

4 shows a bulkhead mount in which the arrester shown in Figure 3 is firmly clamped between inner and outer concentric lines, with minimal inductance of connections. The standing wave ratio of this mount as a function of frequency is shown in Figure 5. The small stray capacitance of the arrester (2pF) contributes to this wide frequency range of operation.

Alternatively, the stripline approach can be used (see Figure 6) with two connections in and two out, to reduce the inductive coupling between line and load.

Three-electrode NEMP arresters are available, such as that shown in Figure 7, and a suitable multi-arrester mount for this device is shown in Figure 8.

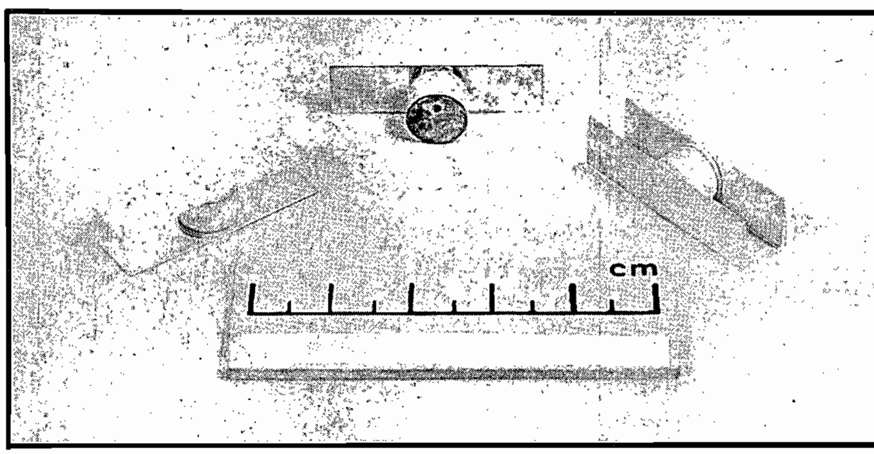

Figure 6. Stripline Approach.

HIGH FREQUENCY CONCENTRIC NEMP ARRESTERS

The curve of Figure 5 shows that the stray capacitance of the arrester eventually produces an unacceptable increase in standing wave ratio. The solution to this problem is found in a new design of arrester which is of concentric construction. The inner and outer electrodes of the arrester are similar to a short length of transmission line, with hermetic seals at each end to contain the gas filling (see Figure 9). The stray capacitance of

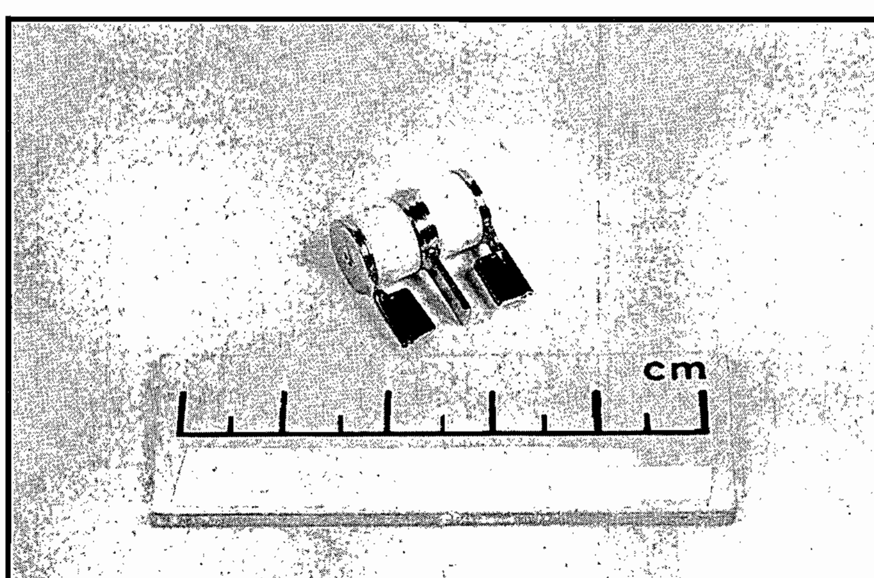

Figure 7. Three-electrode NEMP Arrester.

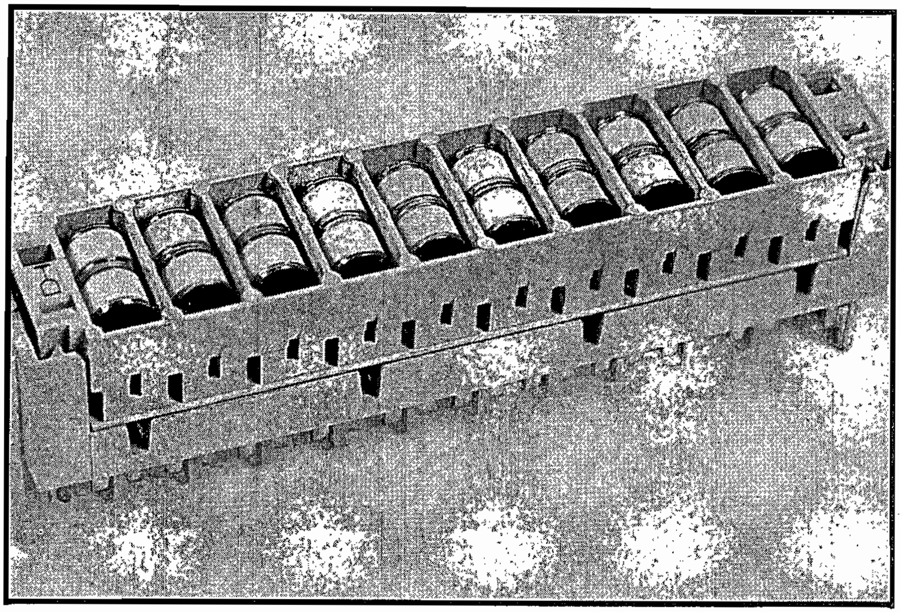

Figure 8. Multi-arrester Mount.

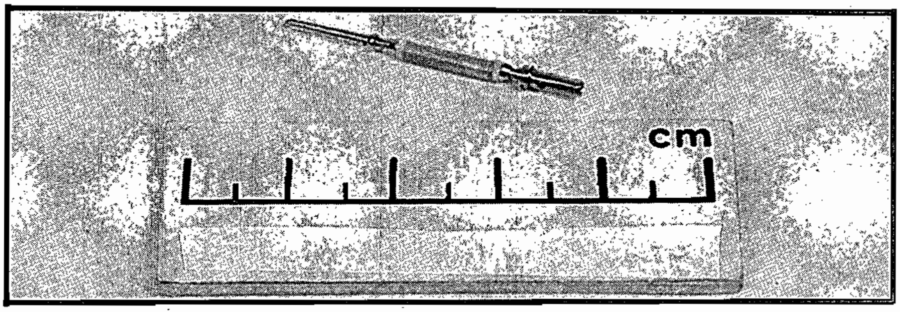

Figure 9. Concentric Arrester.

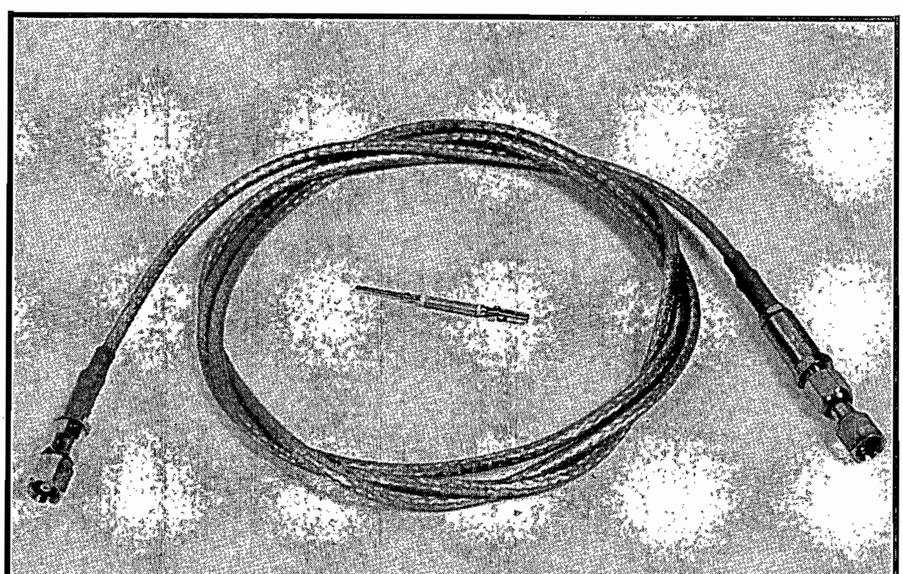

Figure 10. Use of Single Concentric Connector.

the arrester is now effectively balanced by its inductance, and careful design of the electrodes produces a characteristic impedance of 50 or 75 ohms. The signal path is now through the arrester (unlike the standard arrester which is in shunt with the signal path). The device will maintain its low standing wave ratio at frequencies in excess of 2 GHz.

The device can be used singly, as in the concentric connector shown in Figure 10, or in a multi-pin socket as in Figure 11.

OTHER PARAMETERS OF GAS-FILLED ARRESTERS AND COMPARISONS WITH SEMICONDUCTOR PROTECTIVE DEVICES

The striking voltage and peak current performance of the gas-filled arrester have been described, together with the low capacitance. Other relevant parameters are insulation resistance (10^9 ohms at 100 volts), arc voltage during current discharge (25V), and holdover voltage (i.e., maximum dc circuit voltage for recovery following a discharge) 100V.

The few hundred volts required to strike the gas-filled arrester during an NEMP pulse certainly exceeds the voltages achievable with semiconductor devices. However, the gas-filled arrester will pass peak currents many times greater than the semiconductor and at lower arc voltage, and the high stray capacitance of the semiconductor (200 to 1000pF) makes it quite unsuitable for high frequency circuits.

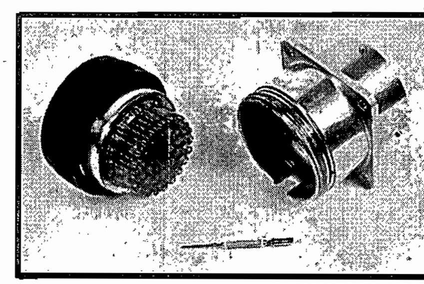

Figure 11. Use of Numerous Concentric Connector in Multi-pin Socket.

CONCLUSIONS

The gas-filled surge arrester has been improved in speed of operation to the point where it is eminently suitable for the protection of electronic circuits against NEMP interference. The very low stray capacitance of the gas arrester, particularly in its concentric form, makes it far superior to semiconductor devices in high frequency circuit operation. ■