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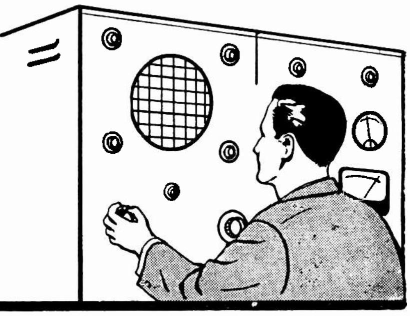

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Voltage-Variable Capacitors

Part 1

By the Engineering Department, Aerovox Corporation

The voltage-variable capacitor may roughly be regarded as the capacitive counterpart of the saturable reactor. This view, while a simplified one, is suitable for all practical purposes. In each unit, an applied d-c component is used to vary reactance, and this reactance, in turn, varies alternating current flowing through a load. In the saturable reactor (exemplified by the magnetic amplifier), the control component is direct current; whereas in the voltage-variable capacitor (exemplified by the dielectric, or capacitive, amplifier), it is d-c voltage. Since the saturable reactor is electromagnetic and current-actuated, it requires finite d-c control power. But the voltage-variable capacitor is electrostatic and voltage-actuated and thus theoretically requires no control power. (Any current drawn from the control voltage source is due to leakage in the capacitor.) It follows as a necessary corollary, then, that the saturable reactor is a low-impedance device, whereas the voltage-variable capacitor is a high-impedance device. Thus, considering one practical application of the two devices, amplification, it is readily seen that the magnetic amplifier has low input impedance, requires driving power, and is limited in high-frequency response; while the capacitive amplifier has high input impedance, requires no driving power, and is capable of a very high frequency operation.

Because dc-variable reactors are inherently reliable devices, are relatively simple in structure and opera-

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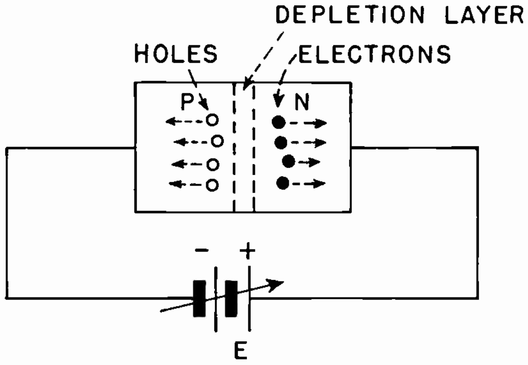
tion, and posses unlimited life, they have long attracted attention as substitutes for electron tubes. The magnetic amplifier was well established in certain areas of application for some time before practical voltage-variable capacitors were developed. However, the latter have been adapted with surprising speed to those radio-frequency applications in which they are more closely competitive with vacuum tubes and transistors than are electromagnetic devices, and in which their subminiature size is an important recommendation.

Nonlinear Capacitor Operation

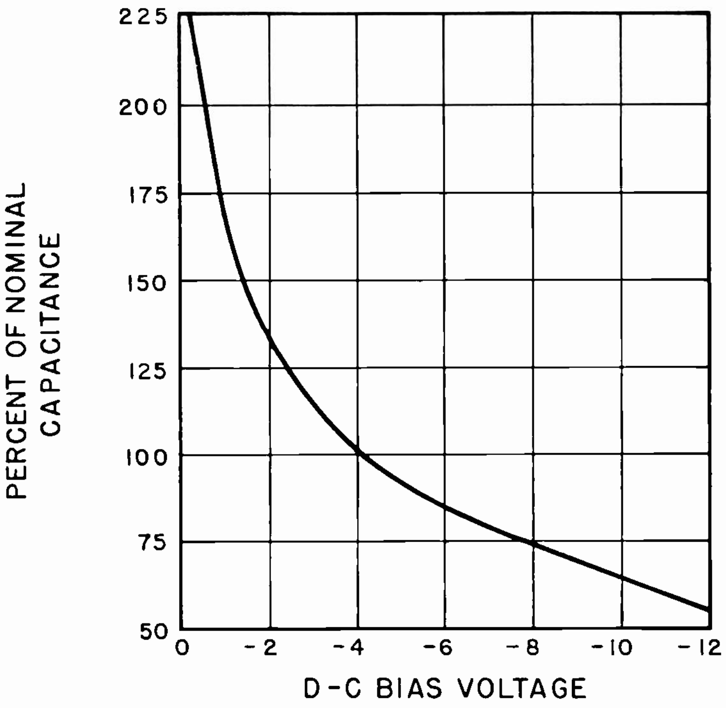
In voltage-variable capacitors, the dielectric constant, k, varies with the magnitude of an applied d-c voltage. The first practical nonlinear capacitors of this type were two-plate devices with a thin dielectric layer of a high dielectric constant ceramic such as barium titanate, strontium titanate, calcium titanate, or barium titanate strontium titanate compositions. Some of these units yielded large capacitance change coefficients, $\mu\mu F/\mu\mu F/V$, and were employed experimentally with good success in place of tubes in a-f and r-f amplifiers, frequency multipliers, afc circuits, fm oscillators, voltage-tuned tanks, and flip-flop circuits.[1, 2, 3, 4, 5, 6.]

While these nonlinear ceramic capacitors were essentially low-power devices and accordingly noncompetitive with the magnetic amplifier outside of the r-f field, dielectric amplifiers were known to deliver enough output power to drive the loudspeakers of small table model radios. The greatest shortcoming of the ceramic voltage-variable capacitor is the sensitivity of its dielectric constant to both temperature and frequency change. (The k-value peaks at a temperature termed the Curie point, which is near 120°C for the commonly used pure barium titanate capacitors. A wide variety of ceramic compositions including mixtures of compounds are used in practical capacitor applications for the control of Curie temperature that they afford.) Hence, elaborate control of temperature and power supply frequency is necessary for stability, full gain, linearity, and low distortion. A further disadvantage is the tendency of barium titanate to fatigue, with an attendant deterioration in performance, in such applications as high-speed switching. These disadvantages undoubtedly impeded exploitation of the ceramic voltage-variable



PRINCIPLE OF SEMICONDUCTOR CAPACITOR

FIG. 1



CAPACITANCE - VOLTAGE CHARACTERISTIC
OF A TYPICAL FAMILY OF SILICON CAPACITORS

FIG. 2

capacitor. Nevertheless, the basic principles and circuits for obtaining power gain by capacitance variation, developed in connection with this device, provided groundwork for later, more stable voltage variable capacitors.

Semiconductor Voltage-Variable Capacitor

The semiconductor voltage-variable capacitor has overcome most of the limitations of the ceramic unit. It is only very slightly temperature-sensitive, much smaller in size, and capable of high power dissipation, while at the same time being more rugged, operable from lower d-c control voltages and free from fatigue effects.

Capacitance is one of the parameters of a semiconductor junction, and for some time has been known to be voltage dependent. The capacitance of a small flat-plate selenium rectifier cell, for example, may be between 0.01 and 0.25 μF, depending upon applied voltage, while for a point-contact germanium diode, the capacitance is often 1.0$\mu\mu$F or less. The modern voltage-variable capacitor is a specially processed, tiny P-N junction diode. The junction capacitance is varied by means of a d-c bias voltage; and since, for this purpose, the junction is reverse-biased (in the direction of high diode resistance) and leakage current is extremely low, the device is essentially voltage-operated. The semiconductor capacitor goes under the names of silicon capacitor, voltage-variable capacitance diode, varactor, paramp diode, and a variety of trade names such as Varicap and Semicap.

To understand the nature of capacitance in a P-N junction, it is necessary to recall that the P-layer has a deficiency of electrons (presence of holes) and the N-layer has an excess of electrons. The P-layer then is electrically positive and the N-layer negative. When the junction is reverse-biased by an applied d-c voltage (i.e., the P-layer connected to dc-minus, and N-layer to dc-plus), the positive bias attracts electrons from the N-layer, and the negative bias attracts holes from the P-layer. This action pulls electrons and holes away from the junction between the P- and N-layers, leaving a depletion layer, one in which there are no mobile current carriers, at this junction. The absence of mobile current carriers makes the depletion layer a dielectric. Thus, a capacitor is formed when the positive P-region faces the negative N-region across a thin dielectric (the depletion layer). The thickness of the depletion layer increases as the reverse bias voltage is increased, thus decreasing the capacitance. (See Figure 1.) In this way, the capacitance may be varying the bias voltage. At zero bias, the junction capacitance is highest and is due to the thin natural depletion layer. (C varies approximately as $1/\sqrt{E}$.) Capacitances as high as 1800 pF at -4v. are provided in commercial silicon capacitors. The figure of merit at 50 Mc extends from about 20 to 125, depending upon the nominal capacitance and manufacturing source.

Figure 2 shows the voltage-capacitance characteristic for a typical family of silicon capacitors from one manufacturing source. (The table in Figure 3 lists the principal characteristics of twenty-three commercially available semiconductor voltage-variable capacitors.)

* Company	Type	Capacitance (pf @ -4v)	Max. Working Voltage (vdc)	Q (50 Mc)
A	PC 113	22	80	50
	PC 114	47	80	50
	PC 115	10	100	100
	PC 122	47	100	75
	PC 124	15	50	125
	PC 126	15	100	100
	PC 128	33	50	125
	PC 129	33	80	50
	PC 133	22	25	50
	PC 141	6.5	100	125
B	1N950	35	130	39
	1N951	50	80	36
	1N952	70	60	30
	1N953	100	25	23
	1N954	35	25	20
	1N955	50	25	20
	1N956	70	25	20
C	SC 1	10	22	35
	SC 15	150	6	35
	SC 47	470	25	—
	SC 180	1800	18	—
	SCH 51	0.5	10	100
	SCH 52	1.0	7	100

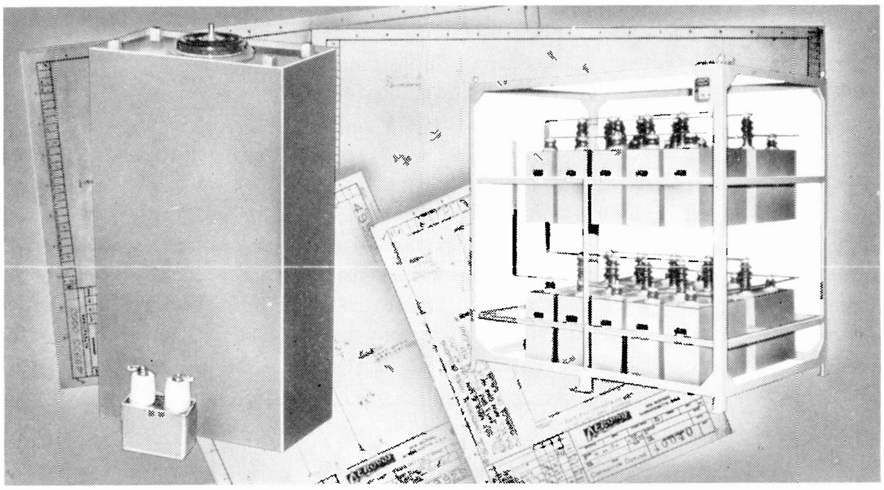
* Names available on request.

PRINCIPAL CHARACTERISTICS OF TYPICAL COMMERCIAL SEMICONDUCTOR CAPACITORS

FIG. 3

PRODUCT NEWS FROM

RELIABLE ENERGY STORAGE CAPACITORS... CUSTOM-DESIGNED BY EXPERIENCED AEROVOX ENGINEERS TO MEET YOUR SPECIFIC REQUIREMENTS



The Aerovox team of energy storage specialists welcomes even the most unusual design problems.

If you are planning to use energy storage capacitors, Aerovox offers you the engineering know-how and the advanced manufacturing techniques achieved through years of experience as a pioneer in the design and manufacture of capacitors. Our team approach to every customer requirement has proven highly successful in the custom design and production of a broad range of types and sizes to meet the most exacting specifications. From research and development, design engineering, manufacturing, and on through quality control to delivery, experts work as a team to supply your every need.*

Applications

High-current discharges, often occurring in fractions of a microsecond, and voltage reversals up to about 90% that may result from an oscillatory discharge, are the heavy-duty applications for which Aerovox energy storage capacitors are specifically designed. These units may be used individually or in large banks ranging up to a few million joules for a wide variety of applications, including thermo-nuclear research, generation of shock waves, exploding wires, metal forming, generation of intense magnetic fields, and numerous special research uses. Aerovox has also designed and built energy storage capacitors for airport runway lighting, photoflash, welding, sonar, radar, and other commercial, military, industrial, and R & D applications.

Construction

The dielectric of Aerovox high-quality energy storage capacitors consists of specially processed and controlled kraft paper impregnated with Aerovox Hyvol J® . . . a nonflammable dielectric with extended temperature range. The electrodes are high-purity aluminum foil. Other dielectric materials, such as plastic films, can be used where special characteristics are required. Other impregnants, such as mineral oil, can also be used where their specific characteristics are desired.

The larger capacitors are hermetically sealed in heavy-gauge welded cases. Smaller sizes may be furnished in cans with crimped and soldered seams. Where special requirements make it necessary, non-magnetic or non-metallic cases can be provided.

Technical Assistance

Contact your Aerovox Representative or write on your letterhead today for full information. For data on Aerovox energy storage capacitors, ask for a free copy of Catalog 151B1.

*Standard packaged capacitor banks also available.

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