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PART 4. CAVITY RESONATORS

By the Engineering Department, Aerovox Corporation

A cavity resonator or *resonant cavity*, such as employed at microwave frequencies, is a closed metallic chamber in which oscillating electromagnetic fields may be set up. The resonant cavity also is termed a *rhumbatron*. This device is a special form of linear circuit which has pronounced advantages at extremely high frequencies.

As a high-Q resonant circuit, the v. h. f. cavity resonator offers the advantages of a large ratio of overall dimensions to wavelength, it usually is simple in construction, and it is superior to other forms of microwave tuned circuits. The cavity resonator is encountered as the frequency determining element in oscillator, amplifier, and detector circuits and often is employed for frequency checking in a manner similar to the lower-frequency use of absorption wavemeters. At the centimeter wavelengths, the cavity resonator is the only practical form of tuned circuit.

Operation of a cavity resonator is analagous to the booming response of a closed room or barrel into which sound of appropriate frequency is introduced. Microwave energy is introduced into a cavity resonator by means of radiation from an antenna probe inserted into the chamber, by means of a loop similarly inserted, by wave guide coupling, or by direct passage of an electron beam through the chamber. Energy may be coupled out of the cavity by the same methods.

Electric and magnetic fields oscillate within a cavity resonator (with little loss of energy from reflections between the walls) in a specific mode, or set of modes governed as in wave guides by the method of excitation and the configuration of the cavity. The resonant frequency of the cavity for a given shape and mode of oscillation depends entirely upon the size of the cavity.

DESCRIPTION

Cavity resonators resemble metal cans or boxes. There are simple and complex shapes recommended for various applications. It is convenient to regard the cavity resonator as being evolved from a simple lumped inductance-capacitance circuit composed of two parallel capacitor discs connected together by a short, straight wire inductor. (See Figure 1). In Figure 1-A is shown this rudimentary L-C circuit, while 1-B shows the corresponding circuit with lumped constants. The frequency of the combination is determined in the usual fashion by the capacitance of the discs and the inductance of the wire.

If a second straight wire is connected between the discs, it will be effectively in parallel with the first wire and will reduce the circuit inductance for that reason. The frequency will be increased proportionately. This addition of the second wire is illustrated by 1-C, and the cor-

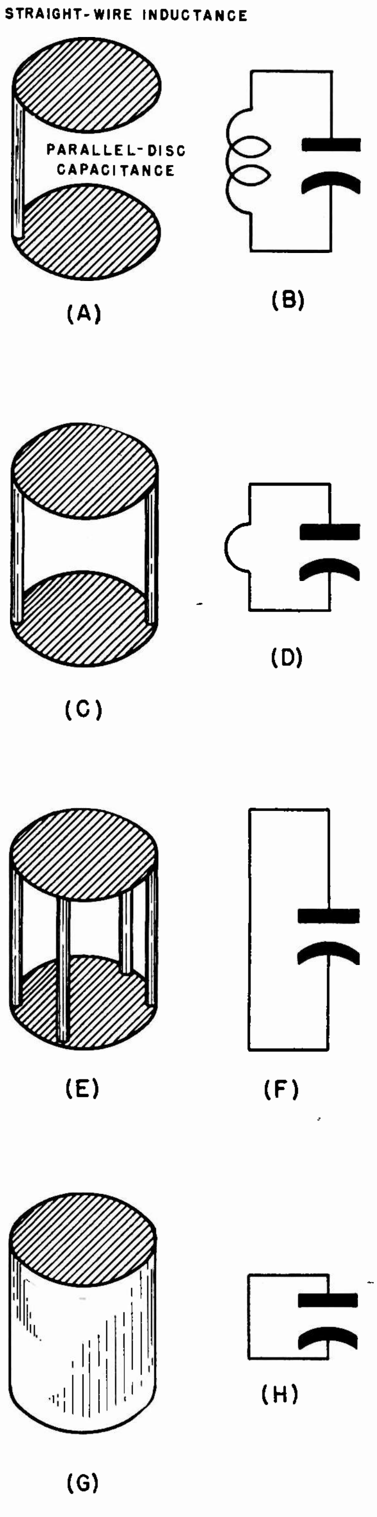


FIG. 1

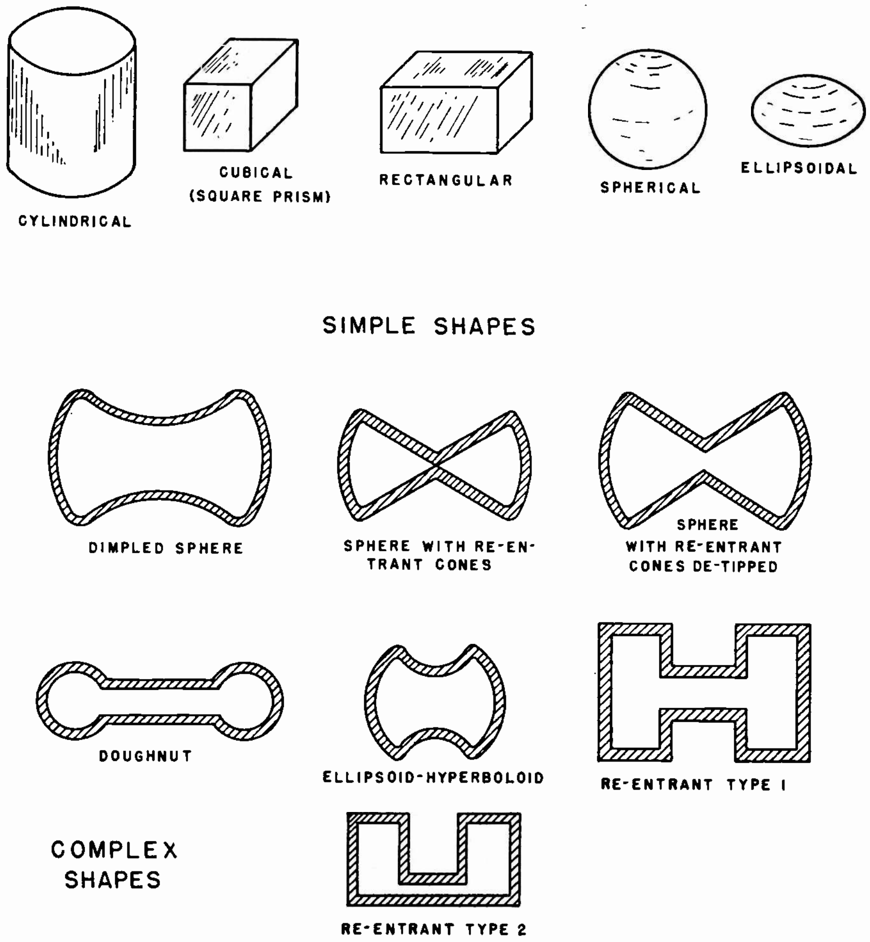


FIG. 2

responding change in the equivalent lumped-constant circuit by 1-D.

Several such wires might be connected between the discs, as shown at 1-E, the total inductance being reduced proportionately with each addition and the resonant frequency increased still further. An infinite number of such wires, closely adjacent to each other, would be equivalent to a solid wall connecting the two capacitor discs and giving the lowest possible inductance and highest frequency values for the particular disc separation. (See Figures 1-G and 1-H). If microwave energy then is introduced into this can-shaped cavity in such a way as to excite a fundamental mode of oscillation, the cavity will resonate at a frequency determined by its shape and dimensions.

In the manner of reflection of electromagnetic waves back and forth by its inner walls, and in its ability to operate at one or more modes, the cavity resonator is similar to the wave guide. In fact, a rectangular cavity may be regarded as a wave guide with closed ends. Some authors have shown the cavity resonator to be analogous to the concentric line, the energy being supported by reflected waves between the walls rather than by currents flowing in a central conductor.

TYPES OF CAVITY RESONATORS

Figure 2 shows the common shapes of cavity resonators. In the first group are the simple cylinder, or can; cube, or square prism or box; rectangular, or "closed wave guide"; spherical, or ball; and ellipsoidal, or egg. In the second group are cross sections of the more complex shapes, such as the dimpled spheres, doughnut, ellipsoid hyperboloid, and re-entrant types. Re-

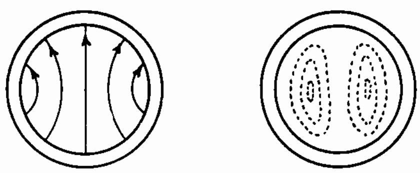
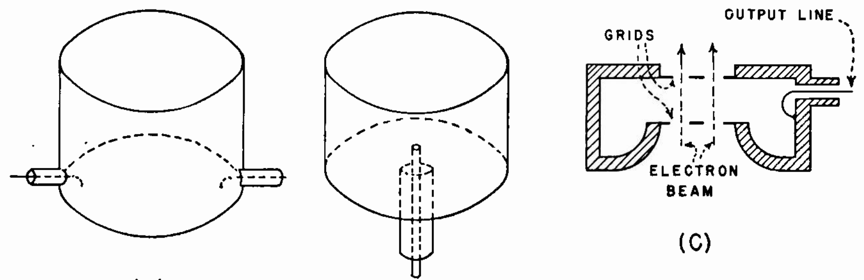


FIG.3

entrant type 2 corresponds to the upper half of re-entrant type 1.

Commercial cavity resonators are made entirely of metal. Copper is favored, although silver plating has been employed. As in the case of wave guides, inner wall surfaces are highly polished. It has been proposed that, since in high-Q cavity resonators skin currents where present do not penetrate deeply into the walls, cavities might be made of molded dielectric material and highly plated by means of one of the methods now available for plating metals on nonmetals.



(A) (B) (C)

FIG. 4

RESONANT FREQUENCY AND MODES

Formulae are available for calculating the resonant frequencies of simple, symmetrical cavity resonators, such as those shown in the first group in Figure 2, for fundamental modes. These frequencies are governed by cavity shape. For example, wavelengths in centimeters for several of the simple shapes are: cylinder, 2.61 X radius; cube, 2.83 X one side; sphere, 2.28 X radius. The dimensions also are in centimeters. These wavelengths, which are for fundamental modes, may be converted into megacycles by dividing into 300.

Methods of calculating the resonant frequency of a cavity resonator of complex shape are much more complicated. In microwave practice, it has been the rule, in order to avoid laborious computations which might lead only to approximations, to make a cavity of the desired shape and proportions and to measure its wavelength carefully. The ratio of measured wavelength to desired wavelength then gives the factor whereby each of the dimensions of the cavity must be multiplied in order to produce a second cavity having the desired resonant wavelength.

As in a simple wave guide, the mode of operation of a cavity resonator is influenced by the manner in which excitation is accomplished and energy is removed from the cavity. Here again the term "mode" refers to the arrangement of electric and magnetic fields within the chamber, as well as (in the case of the cavity) to frequency of oscillation. Numerous higher-order modes, corresponding to higher resonant frequencies than that of the fundamental mode, may exist in resonant cavities, sometimes simultaneously with each other or with the fundamental. In general, higher order modes are more closely grouped than the fundamental and the first high-order mode. Although the Q of the cavity resonator is much higher for some of the higher modes of oscillation, fundamental operation is preferred because of the close spacing of the high-order modes. Distributions of the electric and magnetic fields in the fundamental oscillation mode of a simple spherical cavity are shown in Figure 3.

COUPLING METHODS

Microwave energy may be introduced into and coupled out of cavity resonators inductively, capacitively, by means of radiation, or by electron beams. Figure 4 illustrates these methods.

The use of small loops introduced into the cavity by means of concentric lines is shown at 4-A. This method excites a magnetic field. 4-B shows insertion of a small antenna probe into the cavity to set up an electric field, a component of which is in the direction of the electric field of the desired mode. 4-C shows a special type of cavity having grids in its opposite walls for the passage of an electron beam. This type is employed in the Klystron tube. Another method, not illustrated consists of conducting energy in and out of the cavity by means of wave guides. The exciting guide is so positioned that it sets up fields of the desired mode within the chamber.

TUNED CAVITIES

The resonant frequency of a cavity resonator may be adjusted over a small range by means of a movable metal piston, plunger, slug, or sphere, as shown in Figure 5. The frequency is lowest when the piston is at the center of the cavity, since in this position the electrostatic lines of force are shortened, effectively increasing the capacitance. The frequency is highest when the piston is at the top or bottom of the cavity, since in this position the magnetic lines of force are shortened, effectively lowering the inductance. At the center of the cavity, the electromagnetic field has its lowest intensity, hence its lines are unaffected by the piston. The opposite is true at the ends of the cavity — there, the electrostatic field has its lowest intensity, hence its lines of force are unaffected by the presence of the disc there.

Other forms of cavities, particularly the re-entrant type, are tuned occasionally by squeezing one of the side walls. One type of Klystron oscillator is adjusted in this manner.

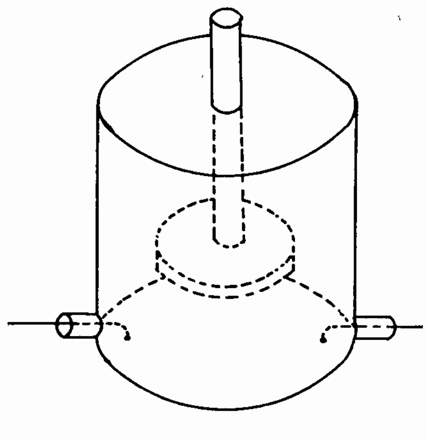


FIG. 5

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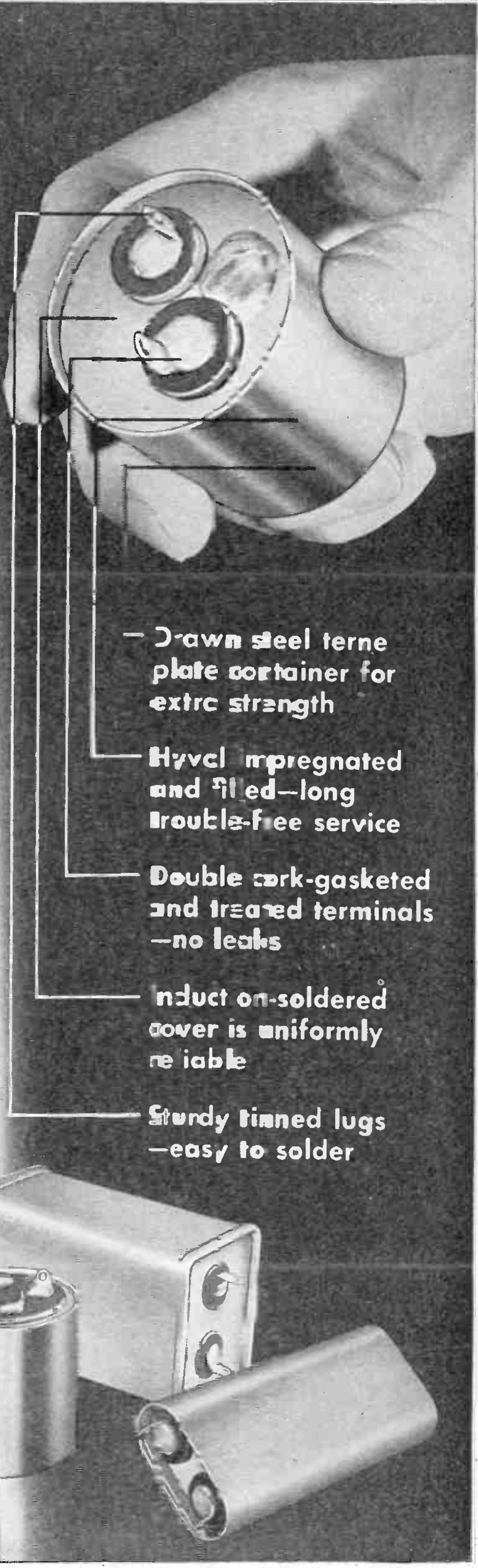

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