LARGE REFERENCE CAPACITANCES
FOR A RANGE UP TO 1000 Hz

T. M. Gushchina

Capacitances with nominal values above 1 μF are normally measured with an error of the order of 0.1-2%. This precision is about an order below that attained in technically developed countries (USA, Britain) and does not meet all the requirements of our industry.

Research in a number of radioelectronic enterprises and in metrological institutes has shown that the production of large-value specimens and boxes of capacitances (up to 100 μF) can be attained with metal-film styroflex capacitors MPGOT. Below we describe the results of work in producing reference capacitors (up to 100 μF) and methods for their certification with a metrological precision in the frequency range up to 10^3 Hz.

The data thus obtained have shown that the instability of 10 μF MPGOT capacitors for one year amounted to 0.1%, and that of MPGP capacitors with nominal values of 1-10 μF did not exceed 0.05%. The instability of MPGT and MPGOT capacitors with nominal values of 1-2 and 1-10 μF (which approached the nominal value within 0.1-0.2%) did not exceed 0.03% per year after one and a half to two years stabilization under laboratory conditions.

Styroflex capacitors of the hermetically sealed type have a small and stable loss angle. In foreign advertisements it is given as \( \tan \delta = (1-2.5) \cdot 10^{-4} \), which apparently is the lower limit for capacitors with nominal values below 2 μF [1].

Our own standard for \( \tan \delta \) of film hermetically sealed capacitors (MPGP and MPGOT) amounts to \((10-15) \cdot 10^{-4}\) and is overestimated. Tests made at the VNIM (All-Union Scientific-Research Institute of Metrology) and the VNIIGK (All-Union Scientific-Research Institute of the State Committee of Standards, Measures, and Measuring Instruments) have shown that \( \tan \delta \) does not exceed \((5-8) \cdot 10^{-4}\) for 10 μF capacitors at 1 kHz. The loss-angle tangent of separate 2 μF sections from which the large-value (up to 10 μF) capacitors are assembled amounts to \((2-3) \cdot 10^{-4}\).

The rise in \( \tan \delta \) with an increasing nominal value of capacitors is due to the effect of wiring. The loss-angle instability of the above capacitors does not exceed \(2 \cdot 10^{-4}\) per year. The frequency characteristics of capacitors also depend on the assembly of their separate sections in their casings. The temperature coefficient of capacitance in polystyrene capacitors is a little worse than in mica capacitors and amounts to \(-100-200) \cdot 10^{-6}\).

In producing reference specimens of large values it is necessary to provide them with a rational circuit and assembly in order to ensure minimum residual parameters and a small loss angle, as well as a structural shape suitable for the technique of transferring accurate and precise parameter values.

The experimental data thus obtained, as well as the experience of previous work in metrological institutes, have made it possible to produce fixed-value capacitances from 1 to 100 μF in a set with nominal values of \((1, 2, 3, 4) \cdot 10^n\), where \(n = 0\). Standard capacitors of 1, 2, 3, 4, 10, and 20 μF are assembled from existing MPGOT capacitors specially selected, adjusted downwards and tested for at least one year. Reference capacitors of 30 and 40 μF are made for quicker assembly, from separate sections which consist of tightly-wound styroflex films with sprayed contacts at either end. The capacitance of each section amounts to \(\sim 2 \mu F\).

For obtaining capacitances of 30 and 40 μF the sections are assembled in separate units of 5-6 sections in a row, soldered at their ends to four copper-silver wires and provided with a leadout for each unit. The separate units are then interconnected by copper buses, with the units placed in such a position that the buses have a minimum length. Thus, it is possible to obtain for the common buses a minimum inductance of \(\sim (5 \cdot 10^{-3} \mu H)\) and for the leadouts from the unit to the bus of \(20 \cdot 10^{-3} \mu H\). The units thus assembled are placed in vinyl casings which are made airtight by sealing the lead-out wires with epoxy resin. The over-all size of the finished specimen fits the dimensions of standard KSD capacitors developed for values of 0.1-1 μF.
A uniform structural shape of reference capacitors is not only convenient, but also necessary for their certification by existing calibrating methods [2, 3] and their application in standard equipment [4]. According to the adopted construction hermetically sealed units are placed in a metal screen and a lagging external plexiglas easing. A set of capacitors with nominal values of 1, 2, 3, 4, 10, 20, 30, and 40 μF serves to obtain any value of 1 to 100 μF. The design of capacitors facilitates their parallel connection by placing one on top of the other.

Reference capacitor box MBE-2, Class 0.1, whose capacitance is variable in steps, was also produced in addition to the fixed reference capacitors. In producing the capacitance box we took into consideration the experience gained by our industry and foreign firms, and the results of testing separate capacitors and capacitance boxes in order to obtain a rational choice and location of box components, the selection of adding values, switches, screening systems, assembly components, etc. The boxes were made up of metal-film hermetically sealed 1-100 μF capacitors MPGOT (with a polystyrene dielectric) and 0.01-1 μF capacitors SGO (with a mica dielectric). From the possible ways of adding separate units in a decade we chose the method of 1+2+3+4, which is standard for sets of reference capacitors and is convenient to certify.

The schematic of capacitance box MBE-2 is shown in Fig. 1. It will be seen from this figure that the capacitors (or groups of them) are located in such a manner that the larger-value groups are closer to the box lead-out conductors. The box is provided with external and internal screens and a facility of joining or disconnecting them, thus forming two or three-terminal connections with virtually constant parameters.

The equivalent schematic of a box decade is shown in Fig. 2.

By assuming for computation purposes inductance $l$ of lead-out wires in each unit to be the same, we find for each unit that

$$C_{10C} = C_{10} [1 + \omega^2 (l_1 + l_2 + l_3 + l_4 + l) C_{10}], \quad C_{30C} = C_{30} [1 + \omega^2 (l_1 + l_2 + l_3 + l) C_{30}],$$

$$C_{20C} = C_{20} [1 + \omega^2 (l_1 + l_2 + l_3 + l) C_{20}], \quad C_{40C} = C_{40} [1 + \omega^2 (l_1 + l) C_{40}].$$

The sum of these values (computed sum) amounts to

$$C_{100C} = C_{10} + C_{30} + C_{20} + C_{40} + \omega^2 \left[ (\sum l_i + l) C_{10} + (\sum l_i + l) C_{20} + (\sum l_i + l) C_{30} + (l_1 + l) C_{40} \right].$$

For the purpose of measuring the total capacitance of all the capacitor units of a decade connected simultaneously we find that

$$C_{100M} = C_{10} + C_{30} + C_{20} + C_{40} + \omega^2 \left[ (\sum l_i + l) C_{10} + (\sum l_i + l) C_{20} + (\sum l_i + l) C_{30} + (l_1 + l) C_{40} \right] +$$

$$+ 2\omega^2 (C_{10C} + C_{30C} + C_{20C} + C_{40C}) l.\]$$

The difference in these values (by neglecting the small quantities of a higher order) is

$$C_{100S} - C_{10} = 4\omega^2 l_2 C_{10} + 22\omega^2 l_2 C_{10}^2 + 70\omega^2 l_1 C_{10}^2$$