The Handiman's Guide to CAPACITORS

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Capacitors comprise the largest variety of electronic components. There are many types of capacitors, great variations in their performance, many methods of packaging and marking, and dozens of major manufacturers, not to mention new types constantly being introduced with specific applications and performances. As a result, capacitors often cause lots of problems for homebrewers. Hopefully this article will take some of the mystery out of the myriad of capacitors available, plus present some of the classic "do's and don'ts."

PRINCIPAL CAPACITOR TYPES

There are many capacitor types, which usually refers to the material used for the electrodes, dielectric, and the packaging or sealing method. Here are some of the major capacitor types used by QRPers:

DISK CERAMIC CAPACITORS

Disk Ceramics consist of two metallic plates separated by a ceramic dielectric, whose area and spacing determines the capacitance. These caps are low cost and suitable for many applications. Their main disadvantage is high capacitance changes with temperature (high temperature coefficient), except for the "NP0" varieties that are temperature stable. These caps are the most commonly used for general purpose circuits, but the non-NP0 types should be avoided in frequency determining circuits.

MONOLITHIC CERAMIC CAPACITORS

Alternating layers of electrodes and ceramic dielectric allow higher capacitances in physically smaller packages. Their characteristics are very similar to disk ceramics. They are encapsulated in epoxy to withstand insertion, soldering and solvent cleaning by the automatic PCB assembly machines. Introduced for mass production, they are inexpensive and available from surplus dealers.

POLYESTER FILM CAPACITORS

Polyester Films use layers of metal and polyester (Mylar®) dielectric to make a wide range of capacitances in relatively small packages at low voltages. These have become the standard caps for DC applications. The "rolled" film layers cause high dissipation and capacitance vs. temperature problems, and should be used carefully in high frequency or high current applications.
POLYPROPELENE FILM CAPACITORS

Polypropylene Films use layers of metal and polypropylene dielectric films virtually identical to Polyester Film caps. The polypropylene, however, is a dielectric offering a higher breakdown voltage than polyester, and thus more suitable for high voltage applications, such as switching power supplies. They also have low loss factors and good capacitance stability making them a good choice for high frequency applications, including oscillators and other frequency sensitive circuits. The main disadvantages are a slightly higher cost, and larger physical sizes over other film dielectric capacitors.

SILVER MICA CAPACITORS

This is a type of capacitor known as metalized film capacitor, in that the electrodes are a metal deposited by a sputtering process onto the dielectric film. Silver Mica's use a mica film dielectric with a thin layer of deposited silver forming the electrodes. These are very stable capacitors for high frequency circuits and the preferred choice for VFO and oscillator circuits. The main disadvantage are their higher cost, low operating voltages, and sometimes hard to find from hobby vendors.

POLYCARBONATE FILM CAPACITORS

These capacitors have become the standard for high stability MIL-SPEC film dielectrics. Their very low dissipation and extreme temperature stability make them almost the ideal capacitor --at a price! They are very expensive capacitors and not available from the hobby vendors, but listed here in the event you have the opportunity to appropriate some!

ELECTROLYTIC CAPACITORS

Aluminum Electrolytics are the most common, inexpensive electrolytic available from all hobby vendors. They are made similar to the polyester films, using aluminum foil electrodes and a dielectric material rolled into layers to increase the effective plate area to form high capacitances in small packages. The aluminum foil is “wetted” with a chemical agent to assist in conduction and increases the dielectric properties when a DC voltage is applied. This wetting agent can dry out after long periods of no use, or exceeding the rated voltage, causing a breakdown of the dielectric and component failure (usually a short circuit between the terminals). This is why electrolytics are often found shorted in older equipment that has not been powered for years. This is seldom a problem with equipment that is periodically powered up. These inexpensive aluminum electrolytic caps are suitable in all QRP applications.

TANTALUM CAPACITORS

Tantalum's are a most unusual process that yields a high reliable electrolytic with a long life. Tantalum pentoxide powder is mixed with a manganese dioxide electrolyte and formed into a "pellet," forming both the dielectric and the positive electrode plate. Graphite or silver plating forms the negative plate. This "pellet" forms a very large effective plate area, and thus very high capacitances in very small packages. Both wet and dry electrolytes are used, and called wet or dry tantalums. There are few QRP applications where tantalum's would be a must, but if you have them -- use them! The chief disadvantages are higher cost due to the complicated manufacturing process, and ensuring you never reverse the polarity. A small positive voltage on the negative terminal can fuse the "pellet."
PRINCIPAL PACKAGING STYLES

In addition to the capacitor types (ceramic, metalized films, etc.), the packaging style is also important, and often required when ordering. The major capacitor packaging styles are shown below, which can also be used as an aid in identifying unknown capacitors.

CAPACITORS WITH RADIAL LEADS

<table>
<thead>
<tr>
<th>Style</th>
<th>Illustration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disk Ceramic</td>
<td><img src="image" alt="Disk Ceramic" /></td>
<td>CK62</td>
</tr>
<tr>
<td>Resin Dipped Monolithics and Metalized Films</td>
<td><img src="image" alt="Resin Dipped Monolithics and Metalized Films" /></td>
<td>M15-M50, M60</td>
</tr>
<tr>
<td>Resin or Epoxy Molded Monolithics</td>
<td><img src="image" alt="Resin or Epoxy Molded Monolithics" /></td>
<td>CK05, CK06</td>
</tr>
</tbody>
</table>

Molded Monolithic and Metalized Films, Dipped Tubular (“Gum drops”), Standoffs

Conformal Coating is stated on modern data sheets, rather than specifying the actual encapsulation material. This means an epoxy or resin agent is used suitable for automatic insertion, wave soldering and industrial cleaners. Conformal coatings are more durable than coatings used on older capacitors.

CAPACITORS WITH AXIAL LEADS

<table>
<thead>
<tr>
<th>Style</th>
<th>Illustration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin Dipped Monolithic</td>
<td><img src="image" alt="Resin Dipped Monolithic" /></td>
<td>Type P or CK12</td>
</tr>
<tr>
<td>Epoxy or Resin Filled Sleeve</td>
<td><img src="image" alt="Epoxy or Resin Filled Sleeve" /></td>
<td>CS13</td>
</tr>
<tr>
<td>Resin Molded Monolithic</td>
<td><img src="image" alt="Resin Molded Monolithic" /></td>
<td>CL23 or CKR11</td>
</tr>
</tbody>
</table>

ORDERING/SPECIFYING CAPACITORS

When ordering capacitors, obviously the first concern is the capacitance, voltage rating and capacitor type needed. However, the temperature coefficient (TC) should be considered in frequency sensitive circuits (oscillators, VFO’s, etc.) and the dissipation factor (DF) or Ω when efficient energy transfer is needed (interstage coupling, active filters, etc.) or high peak-to-peak voltages (transmitter output filter caps).

TEMPERATURE COEFFICIENT

The temperature coefficient (TC) is the change in capacitance vs. a change in temperature. The ideal capacitor should have very little capacitance change with temperature, but as the charts show below, some capacitor types are far from ideal!

![Capacitance Change vs. Temperature](image)

25°C = 77°F = room temperature, where most electronic components, including capacitors, are specified.
The most common ceramic/monolithic ceramics are X7R, Z5U and Y5V. The Z5U and Y5V have a large temperature coefficient (and a large dissipation factor -- see below) and should not be used in frequency critical circuits or for coupling between stages. They are suitable for other general purpose applications and for DC and bypassing caps.

X7R's are the next best with moderate capacitance change vs. temperature and suitable as a general purpose capacitor, and can be used in oscillator circuits where moderate drift is acceptable.

NP0 (or C0G) are those ceramics made with a temperature stable dielectric which exhibits very little capacitance change with temperature. NP0's (N-P-zero) are recommended for oscillators and frequency sensitive circuits.

FILM CAPACITORS, such as the polyester and polypropylene, have much better capacitance stability vs. temperature than the general purpose ceramics, as also shown in the charts. Polyester caps are quite stable until about 120°F.

DISSIPATION FACTOR (DF)

The Dissipation Factor (DF) is the ratio of the energy dissipated (lost) to the energy stored in the capacitor. The DF is frequency sensitive and specified at a certain frequency, such as 1KHz (for ceramics). The Quality Factor (Q) is the ratio of the energy stored vs. the energy dissipated - or the opposite of the dissipation factor. Film capacitors are usually specified by their “Q” factor.

Capacitors used for coupling small signals between stages, in active filters, the shunt caps on crystal filter, or in the transmitter output filter, should use low DF caps. Most all polyfilm caps and some monolithic ceramics meet this requirement. Old ceramic caps in your transmitter output filter should be replaced with a low DF capacitor type, as a high DF cap here can absorb a surprising amount of your output power, and us QRPers need to get as much of that power to the antenna we can!

THE BOTTOM LINE

Ceramics that are not NP0 make good general purpose capacitors for bypass caps, etc. but should not be used for interstage coupling or in oscillators. When ordering new caps, I would recommend purchasing the monolithic ceramics for their lower cost.

NP0 Ceramics (especially the mono’s) are a good choice for oscillator circuits.

Film Dielectrics are a good choice for a general purpose capacitor with low dissipation factors and good temperature characteristics. With their reasonably low cost, and about the same as ceramics, they would be today’s preferred choice when purchasing new capacitors due to the low cost and better performance characteristics.

When ordering caps, look at the specifications carefully for TC and DF, along with the information and charts in this article, to make the best choice, performance vs. cost.
REFERENCE INFORMATION

The information on the following two pages is meant to be a general reference guide to assist in identifying capacitors, specifications and standard values.

1. EIA IDENTIFICATION MARKINGS FOR CERAMICS

EIA TEMPERATURE CHARACTERISTIC CODES

Z 5 U

Capacitance Change over the Temperature Range

A = ±1.0%  P = ±10%
B = ±1.5%  R = ±15%
C = ±2.2%  S = ±20%
D = ±3.3%  T = ±33%, ±22%
E = ±4.7%  U = ±56%, ±22%
F = ±7.5%  V = ±82%, ±22%

Minimum Temperature
X = -55°C
Y = -30°C
Z = +10°C

Maximum Temperature
2 = +45°C
4 = +65°C
5 = +85°C
6 = +105°C
7 = +125°C

Example: Z5U = Capacitance change is -56% to +22% over the temperature range +10°C to +85°C

Tolerance Codes:
*C = ±25%
*D = ±50%
*F = ±1% (±1%)
*G = ±2% (±2%)

Example: 224J = 220000pF
= .22uF, 5% Tol.

<10pF, tolerance in pF (codes C-G)
>10pF, tolerance in % (codes F-Z)

2. DIRECT VALUE MARKING

Some manufacturer's mark the capacitance value directly on the case, along with other information. Ceramics will use the EIA codes (Z5U, X7R, etc.) while non-ceramics will use the industry codes (NPO, N150, etc.) for the temperature coefficient.

3. INDUSTRY MARKINGS FOR MONOLITHIC & FILM CAPACITORS

Non-ceramic capacitors use the EIA markings for the capacitance value and tolerance. However, these dielectrics, such as polyester or polypropylene, have a linear change in capacitance per °C and thus the temperature coefficients are expressed in parts-per-million (ppm)/°C or in %/°C. A few of the common industry (non-ceramic) and EIA (ceramic) markings are shown in the following table.
4. COLOR CODING SCHEMES

Capacitor color coding schemes have all but disappeared except on some foreign made ceramics and dipped tantalums. The prevalent schemes are shown below.

CURRENT COLOR SCHEMES (STILL IN USE)

DIPPED TANTALUM CAPACITOR

<table>
<thead>
<tr>
<th>1st Digit</th>
<th>2nd Digit</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>.01 Gray</td>
<td>.1 White</td>
<td>.1 Black</td>
</tr>
<tr>
<td>10 Brown</td>
<td>20V Blue</td>
<td>3V White</td>
</tr>
<tr>
<td>25V Gray</td>
<td>6.3 Yellow</td>
<td>10v Black</td>
</tr>
<tr>
<td>35v Pink</td>
<td>16v Green</td>
<td>1v Brown</td>
</tr>
</tbody>
</table>

MONOLITHIC CAPACITOR

Use Table 1

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Brown 100v</th>
<th>Red 200v</th>
<th>Yellow 400v</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tolerance</td>
<td>Black ±20%</td>
<td>White ±10%</td>
<td>Green ±5%</td>
</tr>
</tbody>
</table>

TUBULAR CERAMIC CAPACITOR

<table>
<thead>
<tr>
<th>Temperature Coefficient</th>
<th>1st Digit</th>
<th>Multiplier</th>
<th>% Tol.</th>
<th>T.C. ppm/°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>±1% Brown</td>
<td>.1</td>
<td>.1</td>
<td>1 ±20%</td>
<td>-0</td>
</tr>
<tr>
<td>±2% Red</td>
<td>.1</td>
<td>.1</td>
<td>1 ±10%</td>
<td>-30</td>
</tr>
<tr>
<td>±5% Green</td>
<td>.1</td>
<td>.1</td>
<td>1 ±5%</td>
<td>-80</td>
</tr>
<tr>
<td>±10% White</td>
<td>.1</td>
<td>.1</td>
<td>1 ±5%</td>
<td>-150</td>
</tr>
<tr>
<td>±20% Black</td>
<td>.1</td>
<td>.1</td>
<td>1 ±5%</td>
<td>-220</td>
</tr>
</tbody>
</table>

STANDARD CAPACITOR VALUES

These are the EIA standard capacitor values. These are the values available from most vendors. Non-polarized run from 1pF to 1uf, while electrolytics are available from 0.1uf and higher (not all electrolytic values listed here).

<table>
<thead>
<tr>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0pF</td>
<td>10pF</td>
<td>100pF</td>
<td>.01uF</td>
<td>.1uF</td>
<td>.1uF</td>
</tr>
<tr>
<td>1.2pF</td>
<td>12pF</td>
<td>120pF</td>
<td>.012uF</td>
<td>.12uF</td>
<td>.12uF</td>
</tr>
<tr>
<td>1.5pF</td>
<td>15pF</td>
<td>150pF</td>
<td>.015uF</td>
<td>.15uF</td>
<td>.15uF</td>
</tr>
<tr>
<td>1.8pF</td>
<td>18pF</td>
<td>180pF</td>
<td>.018uF</td>
<td>.18uF</td>
<td>.18uF</td>
</tr>
<tr>
<td>2.2pF</td>
<td>22pF</td>
<td>220pF</td>
<td>.022uF</td>
<td>.22uF</td>
<td>.22uF</td>
</tr>
<tr>
<td>2.7pF</td>
<td>27pF</td>
<td>270pF</td>
<td>.027uF</td>
<td>.27uF</td>
<td>.27uF</td>
</tr>
<tr>
<td>3.3pF</td>
<td>33pF</td>
<td>330pF</td>
<td>.033uF</td>
<td>.33uF</td>
<td>.33uF</td>
</tr>
<tr>
<td>3.9pF</td>
<td>39pF</td>
<td>390pF</td>
<td>.039uF</td>
<td>.39uF</td>
<td>.39uF</td>
</tr>
<tr>
<td>4.7pF</td>
<td>47pF</td>
<td>470pF</td>
<td>.047uF</td>
<td>.47uF</td>
<td>.47uF</td>
</tr>
<tr>
<td>5.6pF</td>
<td>56pF</td>
<td>560pF</td>
<td>.056uF</td>
<td>.56uF</td>
<td>.56uF</td>
</tr>
<tr>
<td>6.8pF</td>
<td>68pF</td>
<td>680pF</td>
<td>.068uF</td>
<td>.68uF</td>
<td>.68uF</td>
</tr>
</tbody>
</table>

The capacitor information in this article was extracted from the Data Book for Homebrewers and QRPers, which contains data and information sheets on most all discrete components, hardware, IC’s, etc. It is available for $20 each (which includes postage to US/VE addresses). Available from:

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