Book 5

SPECIALIZED TELEVISION ENGINEERING

TELEVISION TECHNICAL ASSIGNMENT

CAPACITY

721D

TELEVISION TECHNICAL ASSIGNMENT

CAPACITY

FOREWORD

This is the first of two assignments on "Capacity." Capacity is one of the three basic components of all electrical and radio circuits, the others being inductance and resistance. Capacity is *always* present in *every* radio circuit or component, between the elements of every vacuum tube, between the body of a technician and the radio apparatus he operates. In fact, it is of such importance in so many desired applications—and so much of a nuisance where its presence is unwanted but unavoidable—that *every* radio and television engineer and technician requires an expert knowledge of its effects. To understand the effects of capacity and *how to control them* requires a good mental picture of capacity as well as a knowledge of the necessary formulas and how to use them.

This assignment takes up the study of the basic principles of capacity and attempts to build up a mental picture of the operation of a condenser, first, by means of a mechanical analogy, then by electronic theory. The effect of capacity on the phase relation of current and voltage in a circuit is discussed, as well as capacitive reactance which varies inversely with frequency in contrast to inductive reactance which varies directly with frequency.

One of the most embarrassing of the undesired effects of capacity occurs in the design of vacuum tubes for ultra-high frequency operation. As the frequency is raised, the capacitive reactance between the internal tube elements decreases, until with the ordinary power tube operated, for example, at 72 megacycles in a television transmitter or at 98 Mc/s in an FM broadcasting transmitter, the tube becomes effectively a short circuit instead of a power amplifying device. The capacity may be decreased and the reactance increased, by decreasing the area of the tube elements—grid and plate. This then necessitates reducing the power into the tube to keep from burning up the elements. If, then, several tubes are connected in parallel to increase the power output, the capacities of the tubes add (as shown in this assignment) and the engineer is right back where he started.

Tube inter-element capacities and stray circuit capacities make difficult the design of television video amplifiers as they tend to limit the gain at the high frequencies. This requires the use of special tubes, reduction in overall gain and elaborate compensating circuits—all because of a few micromicrofarads of capacity which in many applications would be entirely neglibible.

The effects of capacity and the factors which affect the capacity of a device, circuit component, etc., are explained in this assignment. A thorough understanding of this assignment is essential before proceeding to the next which takes up the direct applications of capacity in radio and television circuits.

E. H. Rietzke,
President.

- TABLE OF CONTENTS -

TECHNICAL ASSIGNMENT

CAPACITY

CAPACITY

Capacity is the principal property of the electrical condenser. A condenser may be defined as any apparatus in which energy or power can be stored in the form of an electro-static field. In turn an electro-static field may be defined as the stationary electric field existing between two unlike electric charges, positive and negative.

It is much easier to arrive at a thorough understanding of the operation of a condenser than to understand the effects of inductance in a circuit. This is due to the fact that exact mechanical analogies may be used to explain most of the effects of capacity. That is not true of inductance.

MECHANICAL ANALOGY: The term "capacity" immediately brings to mind the idea of volume or amount. For example, the capacity of a water tank is the amount of water the tank will hold, measured in gallons, cubic feet, or whatever unit it is desired to use. The capacity of an air tank is the number of cubic feet of air that can be forced into the tank with any given applied pressure. This example of the air tank compares almost exactly with the effects of a condenser and for that reason will be used to explain the elementary condenser operation. Air is compressible and so is an electric charge; their effects under pressure are almost identical. If too much air is forced into a tank, the pressure inside the tank will become so great as to burst the walls of the tank and release the pressure; if too large an electric charge is forced into a condenser, the voltage or pressure between the plates of the condenser will build up to such an extent as to break down the insulation between the plates and discharge the condenser.

In Figure 1 two containers are connected together by a pipe with a valve between. With the valve closed container B is exhausted of all air. Container A is pumped up to an air pressure of 100 pounds per square inch. A certain

DEFINITE NUMBER OF CUBIC FEET OF AIR, THE AMOUNT DEPENDING DIRECTLY UPON THE DIMENSIONS (CAPACITY) OF THE CONTAINER, MUST BE PUMPED INTO THE CONTAINER TO RAISE THE PRESSURE TO 100 POUNDS PER SQUARE INCH. IF THE PUMP IS CAPABLE OF SUPPLYING A PRESSURE EXACTLY EQUAL TO 100 POUNDS PER SQUARE INCH, AS SOON AS SUFFICIENT AIR HAS BEEN FORCED INTO THE TANK TO CAUSE THE INTERNAL PRESSURE TO EXACTLY EQUAL THE MAXIMUM PRESSURE OF THE PUMP, EVEN THOUGH THE PUMP IS LEFT RUNNING, NO MORE AIR WILL BE FORCED INTO THE TANK. THERE IS NOW SUFFICIENT AIR STORED IN TANK A TO CAUSE A PRESSURE OF 100 LBS/SQ.IN.ON ALL WALLS OF THE TANK. THE AIR IN B IS ZERO. THE PRESSURE THEREFORE BEING ZERO ALSO.

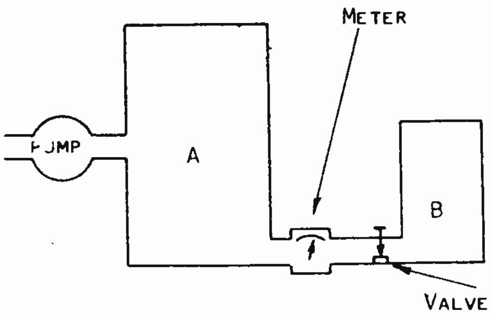


FIG. 1.

IF THE VALVE IS OPENED SUDDENLY THERE WILL EXIST THE CONDITION OF A CONTAINER HOLDING AIR AT HIGH PRESSURE CONNECTED DIRECTLY TO A CONTAINER AT ZERO PRESSURE. THE AIR WILL FLOW THROUGH THE VALVE INTO TANK B UNTIL THE PRESSURE OF B EQUALS THE PRESSURE OF A. IF THE PUMP IS STILL RUNNING IT WILL SUPPLY THE DEFICIENCY IN A CAUSED BY THE AIR LEAVING TO GO TO B, AND THE PRESSURE OF A WILL BE MAINTAINED AT 100 LBS/SQ.IN.

SINCE CONTAINER B IS MUCH SMALLER THAN A, A SMALLER ACTUAL VOLUME OF AIR WILL BE REQUIRED TO RAISE ITS PRESSURE TO 100 LBS/SQ.IN. THAN MUST BE CONTAINED IN A TO PRODUCE THAT PRESSURE. THE "CAPACITY" OF THE SMALL TANK IS LESS THAN THAT OF THE LARGE TANK.

WHEN THE VALVE IS FIRST OPENED THE DIFFERENCE IN PRESSURE BETWEEN A AND B IS 100 LBS/SQ.IN. THE PRESSURE IN B BEING ZERO, THERE IS AT THAT INSTANT NO OPPOSITION TO AIR FLOW INTO B, (ASSUMING THAT THE CONNECTING PIPE IS SUFFICIENTLY LARGE THAT THE FRICTION OF THE AIR ON THE WALLS OF THE PIPE MAY BE NEGLECTED). SINCE THERE IS NO OPPOSITION, THE INSTANTANEOUS RUSH OF AIR INTO B WILL BE large and the meter, which indicates cubic feet per second, will register a large air-flow. However, as the air flows into B a pressure is built up, the pressure increasing as the number of cubic feet of air in B increases. As this back pressure builds up it offers more and more opposition to the flow of air from A to B, until when the pressures of A and B are equal no air will flow through the connecting pipe. Thus the air-flow meter will deflect to maximum the instant the valve is opened, and will then gradually drop to zero as the pressures became equal.

<u>Operation of a Condenser</u>: Referring to Figure 2, it will be seen that an exactly similar condition exists if an electrical condenser is connected across a steady source of voltage.

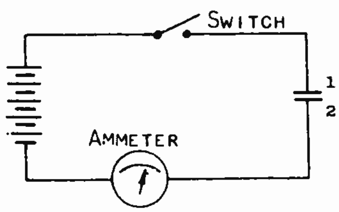


Fig. 2.

In this case the battery acts as container A and the chemical action of the battery, which moves a sufficient number of electrons from the positive terminal to the negative terminal of the battery to cause a difference of potential, (pressure), of 100 volts, is analogous to the pump. When the deficiency of electrons on the positive terminal and the excess on the negative terminal are such as to cause a difference of potential of 100 volts, the chemical action causes no further movement of electrons. If, however, some of this pressure is neutralized the chemical action will again commence.

The condenser takes the place of container B, and in its normal state no difference of potential exists between the plates.

The switch replaces the valve, and the ammeter, which measures ELECTRONS PER SECOND moving past a given point, is analogous to the air-flow meter which measures cubic feet of air per second flowing through it. The moving element has been changed from cubic feet of air to electrons. The air PRESSURE has been changed to the electrical pressure or difference of potential caused by

THE EXCESS OF ELECTRONS ON THE NEGATIVE TERMINAL TRYING TO NEUTRALIZE THE DEFICIENCY OF ELECTRONS ON THE POSITIVE TERMINAL.

AS THE SWITCH IS CLOSED THE POSITIVE TERMINAL OF THE BATTERY WILL ATTRACT ELECTRONS TO IT FROM THE CONDENSER PLATE AND THE NEGATIVE TERMINAL WILL REPEL ELECTRONS TOWARD THE OTHER PLATE OF THE CONDENSER. AS ELECTRONS MOVE AWAY FROM PLATE NUMBER 1, THAT PLATE ASSUMES A POSITIVE CHARGE. AS AN EXCESS OF ELECTRONS IS FORCED TO PLATE NUMBER 2 THAT PLATE ASSUMES A NEGATIVE CHARGE. THE MOVEMENT OF ELECTRONS WILL CONTINUE UNTIL THE DIFFERENCE OF POTENTIAL BETWEEN THE PLATES EQUALS THE APPLIED VOLTAGE OF THE BATTERY, 100 VOLTS.

ASSUMING THAT THE CONNECTING LEADS, ETC., ARE SUCH THAT THE CIRCUIT RESISTANCE IS NEGLIGIBLE, THEN THE ONLY OPPOSITION TO THE ELECTRON FLOW IS THE PRESSURE BUILT UP ACROSS THE CONDENSER. WHEN THE SWITCH IS FIRST CLOSED THERE IS NO DIFFERENCE OF POTENTIAL ACROSS THE CONDENSER, THEREFORE NO OPPOSITION, AND THE ELECTRON MOVEMENT WILL BE LARGE. AS THE ELECTRONS LEAVE ONE PLATE AND BECOME IN EXCESS ON THE OTHER, A PRESSURE IS BUILT UP ACROSS THE CONDENSER WHICH OPPOSES THE ELECTRON MOVEMENT, AND THE GREATER THIS PRESSURE, THE GREATER THE OPPOSITION. AT THE INSTANT THE CONDENSER VOLTAGE IS EQUAL TO THE APPLIED VOLTAGE THE ELECTRON MOVEMENT CEASES.

THIS EFFECT WILL BE INDICATED BY THE AMMETER IN THE FOLLOWING MANNER: THE AMMETER WHICH MEASURES THE ELECTRONS PER SECOND MOVING THROUGH THE CIRCUIT WILL INDICATE THE GREATEST MOVEMENT AT THE INSTANT OF LEAST OPPOSITION. THAT INSTANT IS AT THE CLOSING OF THE SWITCH, THEREFORE WHEN THE SWITCH IS CLOSED THE INDICATOR OF THE AMMETER WILL INSTANTLY JUMP TO A MAXIMUM READING AND GRADUALLY FALL OFF, REACHING ZERO AS THE CONDENSER VOLTAGE EQUALS THE APPLIED VOLTAGE.

FROM THEN ON, SO LONG AS THE VOLTAGE OF THE BATTERY REMAINS CONSTANT. NO MORE CURRENT WILL FLOW THROUGH THE CIRCUIT. IF, HOWEVER, THE BATTERY VOLTAGE IS INCREASED, CURRENT WILL AGAIN FLOW IN THE SAME DIRECTION AS BEFORE, IN ORDER THAT THE CONDENSER VOLTAGE MAY BE MAINTAINED EQUAL TO THE BATTERY VOLTAGE.

IF THE BATTERY VOLTAGE IS DECREASED CURRENT WILL FLOW IN THE CIRCUIT BUT IN THE OPPOSITE DIRECTION DISCHARGING THE CONDENSER, THAT IS, NEUTRALIZING THE DIFFERENCE OF POTENTIAL ACROSS THE CONDENSER IN ORDER THAT THE CONDENSER VOLTAGE MAY STILL EQUAL THE APPLIED VOLTAGE.

ASSUMING THAT THE RESISTANCE OF THE CIRCUIT IS NEGLIGIBLE, AND REMEMBERING THAT THE ELECTRON FLOW IS ALWAYS OF SUCH AMPLITUDE AND IN SUCH A DIRECTION AS TO TEND TO KEEP THE CONDENSER VOLTAGE AT EVERY INSTANT EQUAL TO THE APPLIED VOLTAGE, IT WILL BE SEEN THAT IF THE APPLIED VOLTAGE IS INCREASED VERY RAPIDLY THE ELECTRON FLOW, TENDING TO BUILD UP THE CONDENSER VOLTAGE JUST AS RAPIDLY, MUST BE LARGE. IF THE APPLIED VOLTAGE IS INCREASED SLOWLY THE ELECTRONS WILL NOT BE REQUIRED TO MOVE THROUGH THE CIRCUIT SO RAPIDLY TO KEEP THE COUNTER EMF, (CONDENSER VOLTAGE), EQUAL TO THE APPLIED EMF, THEREFORE THE AMMETER WILL NOT INDICATE AS LARGE A CURRENT FLOW ON THE SLOW VOLTAGE INCREASE AS ON THE RAPID VOLTAGE INCREASE.

IF IN BOTH CASES THE VOLTAGE IS INCREASED THE SAME AMOUNT, THE SAME ACTUAL NUMBER OF ELECTRONS MUST BE TRANSFERRED FROM ONE PLATE OF THE CONDENSER TO THE OTHER. ON THE SLOW INCREASE, HOWEVER, THE SAME NUMBER OF ELECTRONS REQUIRES A LONGER TIME TO PASS A GIVEN POINT, THE RATE OF FLOW IS THEREFORE LESS AND THE AMMETER WILL INDICATE A SMALLER FLOW OF CURRENT FOR A LONGER PERIOD OF TIME.

THE SAME PRINCIPLES APPLY TO THE CONDENSER DISCHARGING ON A DECREASE OF THE APPLIED VOLTAGE. THE MORE RAPIDLY THE APPLIED VOLTAGE DROPS OFF, THE MORE RAPIDLY THE ELECTRONS MUST FLOW THROUGH THE CIRCUIT IN SUCH A DIRECTION AS TO DECREASE THE CONDENSER CHARGE. THE RATE OF FLOW IS ALWAYS SUCH AS TO KEEP THE CEMF EXACTLY EQUAL TO THE APPLIED VOLTAGE. (THIS STATEMENT IS TRUE ONLY IN THE CASE WHERE THE CONDENSER HAS A CIRCUIT THROUGH WHICH IT CAN DISCHARGE RAPIDLY AS IN THE TYPE OF CIRCUIT BEING DISCUSSED. LATER IT WILL BE SEEN THAT THERE ARE CIRCUITS IN WHICH THIS FREE DISCHARGE ACTION CANNOT TAKE PLACE AND DIFFERENT CONDITIONS WILL BE ESTABLISHED. FOR EASE OF EXPLANATION IN THIS LESSON,

ALL CHARGING AND DISCHARGING CIRCUITS WILL BE CONSIDERED SUCH THAT THE CHARGE AND DISCHARGE IS GOVERNED ONLY BY THE ACTUAL APPLIED EMF AND COUNTER EMF AS SHOWN.)

THE IMPORTANT FACT TO REMEMBER IN THE STUDY OF CONDENSER ACTION IS THAT FOR A GIVEN CONDENSER THE CURRENT FLOW, EITHER ON CHARGE OR DISCHARGE, WILL BE GREATEST AT THE INSTANT THE VOLTAGE IS VARYING THE MOST RAPIDLY.

THE ANGLE OF LEAD: APPLYING THIS FACT TO AN ALTERNATING CURRENT CIRCUIT: THE VOLTAGE SUPPLIED BY THE ALTERNATOR IS CONTINUOUSLY VARYING EXCEPT AT THE INSTANTS OF MAXIMUM VOLTAGE WHICH OCCUR TWICE EACH CYCLE, AT 90 DEGREES AND 270 DEGREES. AT THOSE INSTANTS THERE WILL BE NO CURRENT FLOW IN A PURE CAPACITY CIRCUIT. AS WITH INDUCTANCE IT IS NOT POSSIBLE TO TOTALLY ELIMINATE RESISTANCE, BUT THE CONDITION MAY BE ASSUMED FOR THE STUDY OF THE EFFECTS OF CAPACITY ALONE.

THE VOLTAGE VARIATIONS, WHEN IN THE FORM OF A SINE CURVE, ARE THE MOST RAPID WHEN THE VOLTAGE IS PASSING THROUGH ZERO. FROM THE PRECEDING STATEMENTS ON CONDENSER ACTION IT IS EVIDENT THAT THE CURRENT FLOW MUST BE GREATEST AT THAT INSTANT. IN A PURE CAPACITY CIRCUIT WHEN THE VOLTAGE VARIATION IS IN THE FORM OF A SINE CURVE, THE CURRENT FLOW WILL BE MAXIMUM WHEN THE VOLTAGE IS PASSING THROUGH ZERO AND WILL BE ZERO WHEN THE VOLTAGE IS AT A MAXIMUM VALUE.

THE CURVES OF FIGURE 3(C) CLEARLY DEMONSTRATE THE CURRENT-VOLTAGE RELATION. SINCE THE EFFECTS OF CAPACITY ARE MANIFEST WHEN VOLTAGE VARIATIONS ARE TAKING PLACE, THE STUDY OF THE CURVES WILL BE BASED ON THE CURVE OF APPLIED VOLTAGE E. CURVE E IS DIVIDED INTO 4 CHANGES AND THE VOLTAGES AND CURRENTS IN THE CIRCUIT WILL BE STUDIED FOR EACH OF THE FOUR CHANGES OF APPLIED VOLTAGE. ASSUME THAT THE SWITCH IS CLOSED EXACTLY AT THE INSTANT THE VOLTAGE IS LEAVING ZERO AT ITS ZERO PHASE ANGLE AS SHOWN IN FIGURE 3(C).

AT THAT INSTANT, AS THE VOLTAGE IS JUST LEAVING ZERO, IT IS CHANGING THE MOST RAPIDLY. AT THAT INSTANT THE CONDENSER IS TOTALLY DISCHARGED AND THE

CONDENSER VOLTAGE, SHOWN ON CURVE CEMF, IS ZERO. THE CURRENT WILL THEN RISE INSTANTLY TO ITS MAXIMUM VALUE. AS THE APPLIED VOLTAGE CONTINUES TO RISE THE CURRENT CONTINUES TO FLOW IN SUCH A DIRECTION AS TO CHARGE THE CONDENSER, THAT IS, TO BUILD UP A COUNTER EMF EQUAL AND OPPOSITE TO THE APPLIED VOLTAGE. THE DIRECTION OF CURRENT FLOW IS SHOWN BY THE ARROWS, 1, ON FIGURE 3(A).

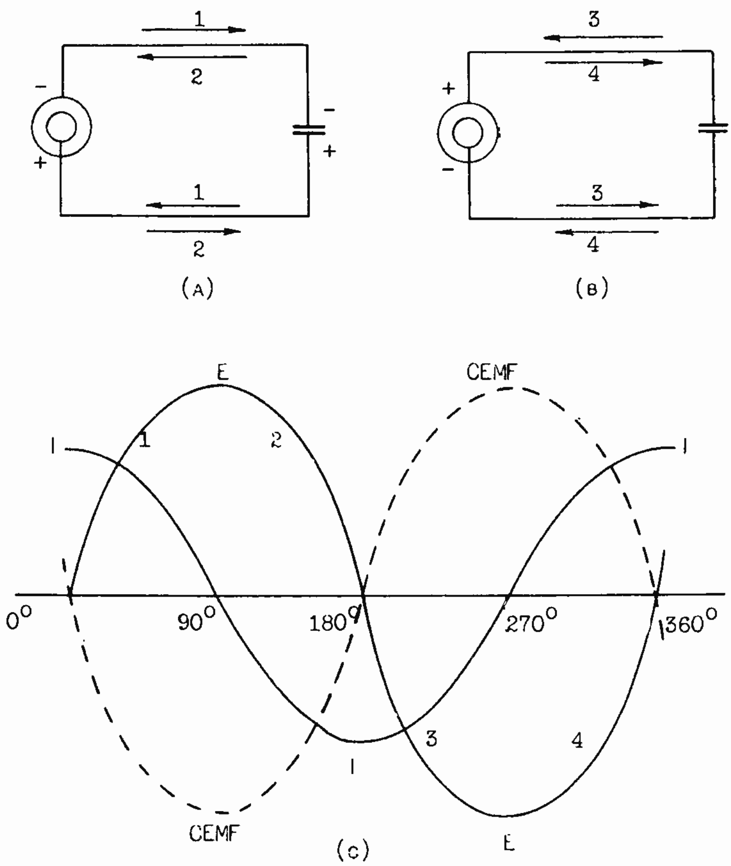


FIG. 3.

AGAIN REFERRING TO 3(C), AS THE APPLIED VOLTAGE RISES, THE CEMF RISES IN EXACT OPPOSITION AND EXACTLY EQUAL BOTH IN AMPLITUDE AND IN THE SHAPE OF THE CURVE; ALSO, AS THE APPLIED VOLTAGE RISES THE CURRENT GRADUALLY DROPS OFF, UNTIL AT 90 DEGREES THE CURRENT BECOMES ZERO. THIS AGREES WITH THE THEORY AS PREVIOUSLY EXPLAINED BECAUSE AS THE VOLTAGE INCREASES ITS RATE OF INCREASE DECREASES. (DUE TO THE SHAPE OF THE SINE CURVE.) IN A CAPACITY CIRCUIT THE CURRENT FLOW DEPENDS, NOT UPON THE AMPLITUDE OF THE VOLTAGE, BUT UPON THE AMOUNT OF THE VOLTAGE VARIATION. AT THE 90 DEGREE INSTANT THE CONDENSER IS FULLY CHARGED, THE APPLIED VOLTAGE AND CEMF ARE AT MAXIMUM VALUES AND THE CURRENT FLOW IS ZERO.

Consider change number two. The applied voltage is still of the same polarity but is now DECREASING IN AMPLITUDE. As the applied voltage falls off the current will flow in such a direction as to keep the CEMF equal to the applied voltage. Therefore the condenser must now be discharging, that is, the electrons must be moving in such a direction as to tend to neutralize the condenser voltage. This is shown by arrows 2 in Figure 3(A); also by the current curve from 90° to 180° on 3(C). When the voltage first begins to decrease, the decrease is very slow, therefore the current flow in the direction of discharge is small. However as the voltage approaches zero its decrease becomes more and more rapid, the current flow consequently increasing and the CEMF thereby falling off faster and faster, until at the instant the voltage reaches exactly zero, 180°, the CEMF will also be zero and the current flow will be at its maximum value. The condenser at this instant is TOTALLY DISCHARGED. If the applied voltage remained at zero the current would instantly fall to zero. That however is not the case. As the voltage reaches zero it instantly reverses and begins to rise in the opposite direction.

Change three. The voltage is now rising in the direction opposite to its rise in change one. As the applied voltage has reversed the CEMF must also reverse. In order for the CEMF to reverse the condenser must charge in a direction opposite to its first charge. This means that the electrons must move from one plate to the other in the opposite direction to their movement in change onl. This causes a continuation of the electron movement in the same direction as the flow in change two, (discharge). Reference to Figures 3(A) and 3(B) and the current curve of 3(C) will demonstrate this fact. Arrows 2 and 3 are in the same direction. The current flow as shown in change three is in the same direction as in change two, the difference being that in change two the current is rising in amplitude as the condenser discharges while in change three it is decreasing in amplitude as the condenser charges.

At the 270° instant the condenser is again fully charged, the applied E and the CEMF are at maximum values, and the current is zero.

In change four the condenser again discharges, the current reversing when the applied voltage falls off causing the CEMF to fall off also. At 360° the condition of the circuit is the same as at 0°, one complete cycle having been completed.

It will be seen that the current in this purely capacitive circuit reaches its maximum value at the instant the voltage begins to rise above zero. The current is therefore 90° AHEAD OF THE VOLTAGE and is said to LEAD THE VOLTAGE by 90°. The effect of capacity in the circuit is exactly opposite to the effect of inductance.

CAPACITY OF A CONDENSER: Referring again to the air container: The number of cubic feet of air required to raise the pressure in the tank any given amount depends directly upon the dimensions of the tank, a large tank requiring more air input for a given pressure increase than a small tank. If the pressures of both are increased by the same amount in the same time, the air flow into the large tank must be at a greater rate than into the small tank.

The same principle applies in the case of a condenser. A certain number of electrons must be moved from one plate of a condenser to the other in order to raise the voltage across the condenser any given amount, the number of electrons depending directly upon the CAPACITY of the condenser. In a condenser of large capacity more electrons must be moved to secure any given voltage difference between plates than in a condenser of smaller capacity. Therefore if the voltage across two condensers is raised the same amount in the same time, a greater number of electrons must be moved from plate to plate in the larger condenser than in the smaller condenser. The time element being the same in both cases, it is evident that the RATE OF FLOW must be greater into the larger condenser. Since an ammeter measures RATE OF FLOW of electrons, the current in

THE CIRCUIT OF THE LARGER CONDENSER WILL BE GREATER THAN IN THE CIRCUIT OF THE SMALLER CONDENSER.

AS THE ONLY OPPOSITION TO CURRENT FLOW IS OFFERED BY THE CAPACITY OF THE CIRCUIT, (THE RESISTANCE IS ASSUMED TO BE NEGLIGIBLE), IT WILL BE SEEN THAT THE SMALLER THE CONDENSER, AT A GIVEN FREQUENCY AND VOLTAGE, THE SMALLER THE CURRENT FLOW AND THEREFORE THE GREATER THE OPPOSITION. THE OPPOSITION THAT CAPACITY OFFERS TO CURRENT FLOW IS CALLED THE CAPACITY REACTANCE, (X_C), AND IS MEASURED IN OHMS. THE CAPACITY REACTANCE IS EQUAL TO E/I.

THE CAPACITY OF A CONDENSER IS NOT A FUNCTION OF THE BREAK-DOWN VOLTAGE OF THE CONDENSER. A CONDENSER, MECHANICALLY LARGE, DOES NOT NECESSARILY HAVE A LARGE CAPACITY. THE CAPACITY IS DETERMINED BY THE NUMBER OF ELECTRONS WHICH MUST BE MOVED FROM ONE PLATE TO THE OTHER PLATE, (OR BETWEEN SETS OF PLATES), TO RAISE THE VOLTAGE A GIVEN AMOUNT.

<u>A CONDENSER HAS A CAPACITY OF ONE FARAD WHEN ONE AMPERE FLOWING FOR ONE SECOND RAISES THE CONDENSER VOLTAGE ONE VOLT</u>. THIS IS MUCH TOO LARGE A UNIT FOR PRACTICAL WORK SO THE MICROFARAD, μF, (MILLIONTH OF A FARAD), IS COMMONLY USED. EVEN THIS UNIT IS EXCESSIVELY LARGE AT HIGH RADIO FREQUENCIES SO AT THOSE FREQUENCIES THE CAPACITY OF A CONDENSER IS COMMONLY EXPRESSED IN MICRO-MICROFARADS, $\mu\mu F$, (MILLIONTH OF A MICROFARAD).

THE CAPACITY OF A CONDENSER IS DETERMINED BY THREE FACTORS, THE AREA OF THE PLATES, (A LARGE AREA MAY BE OBTAINED EITHER BY TWO LARGE PLATES OR BY TWO GROUPS OF PLATES IN PARALLEL, THEIR AREAS ADDING), THE DISTANCE BETWEEN THE PLATES, AND THE MATERIAL, (DIELECTRIC), BETWEEN THE PLATES.

THE CHARGE IN A CONDENSER IS IN THE FORM OF AN ELECTROSTATIC FIELD; THAT IS, A STATIONARY ELECTRIC FIELD, BUILT UP IN THE DIELECTRIC BETWEEN THE PLATES OF THE CONDENSER. AN ELECTRIC FIELD IS A STRAIN IN THE MEDIUM BETWEEN A POSITIVE CHARGE, (DEFICIENCY OF ELECTRONS), AND A NEGATIVE CHARGE, (EXCESS OF ELECTRONS). AS A DIFFERENCE OF POTENTIAL IS APPLIED ACROSS THE CONDENSER THE ELEC-

TRONS ARE DRAWN AWAY FROM ONE PLATE MAKING THAT PLATE POSITIVE, AND DEPOSITED IN EXCESS ON THE OTHER PLATE MAKING THE SECOND PLATE NEGATIVE. WITH THE PLATES RELATIVELY CLOSE TOGETHER THERE WILL BE AN ATTRACTION BETWEEN THE TWO OPPOSITE CHARGES CREATING A STRAIN IN THE MEDIUM BETWEEN THE PLATES IN WHICH THERE IS A TENDENCY FOR CURRENT FLOW TO NEUTRALIZE THE DIFFERENCE OF POTENTIAL. IF THE PLATES, SEPARATED A GIVEN DISTANCE, ARE OF SMALL AREA, THE MEDIUM IN WHICH THE FIELD WILL BE BUILT UP, BEING CONFINED PRACTICALLY WITHIN THE LIMITS OF THE PLATES WILL BE SMALL, AND A FEW ELECTRONS IN EXCESS ON ONE PLATE AND THE SAME NUMBER DEFICIENT ON THE OTHER WILL CREATE A DIFFERENCE OF POTENTIAL EQUAL TO THE APPLIED VOLTAGE. ONLY THOSE FEW ELECTRONS CAN BE MOVED FROM ONE PLATE TO THE OTHER WITH THE GIVEN APPLIED VOLTAGE, THE CAPACITY OF THE CONDENSER WILL THEREFORE BE SMALL.

IF THE AREA OF THE TWO PLATES IS INCREASED, THE SAME TRANSPOSITION OF ELECTRONS WILL NOT CREATE THE SAME DIFFERENCE OF POTENTIAL BETWEEN THE PLATES AND THE SAME STRAIN PER CUBIC UNIT IN THE MEDIUM. THE SURFACE OF THE PLATES BEING LARGER THE SAME SMALL NUMBER OF ATOMS WHICH WERE DEFICIENT OR IN EXCESS OF ELECTRONS WILL BE MORE WIDELY SEPARATED AND THE ELECTRIC FIELD, WHICH BEFORE WAS CONCENTRATED AND THEREFORE STRONG, WILL NOW BE WEAK; THE DIFFERENCE OF POTENTIAL BETWEEN THE PLATES WILL NOT EQUAL THE SAME APPLIED VOLTAGE. SINCE THE MOVEMENT OF ELECTRONS WILL CONTINUE UNTIL THE CEMF EQUALS THE APPLIED VOLTAGE, WITH THE LARGER PLATES THE ELECTRON TRANSPOSITION WILL CONTINUE UNTIL THE STRAIN IN THE MEDIUM, PER CUBIC UNIT, IS EQUAL TO THE INTENSITY OF THE ELECTROSTATIC FIELD IN THE CONDENSER OF SMALLER PLATES AND UNTIL THE CEMF EQUALS THE APPLIED VOLTAGE. THIS MEANS THAT A LARGER CHARGING CURRENT WILL BE NECESSARY TO CHARGE THE CONDENSER HAVING LARGE PLATES IN THE SAME TIME THAT WAS REQUIRED TO CHARGE THE CONDENSER OF SMALLER PLATE SURFACE AREA TO THE SAME VOLTAGE. THE CAPACITY OF A CONDENSER IS THEREFORE INCREASED BY AN INCREASE IN THE AREA OF THE PLATES.

THE DISTANCE BETWEEN THE PLATES ALSO HAS MUCH TO DO WITH THE CAPACITY OF A CONDENSER. IF TWO PLATES OF GIVEN AREA ARE PLACED A CERTAIN DISTANCE APART AND A DIFFERENCE OF POTENTIAL APPLIED ACROSS THEM, A CHARGE WILL BUILD UP BETWEEN THE PLATES. THE ELECTRONS ON BOTH PLATES ARE ACTED ON BY TWO FORCES. CONSIDER THE PLATE CONNECTED TO THE POSITIVE TERMINAL OF THE SOURCE OF EMF; THE ELECTRONS ARE ATTRACTED AWAY FROM THIS PLATE BY THE ACTION OF THE GENERATOR; AT THE SAME TIME THEY ARE UNDER THE REPELLING FORCE OF THE NEGATIVE CHARGE THAT IS BUILDING UP ON THE OPPOSITE PLATE. THE ELECTRONS ON THE OPPOSITE PLATE, (THE NEGATIVE PLATE), ARE ALSO SUBJECTED TO TWO FORCES, THE REPELLING FORCE OF THE NEGATIVE TERMINAL OF THE GENERATOR AND THE ATTRACTIVE FORCE OF THE OPPOSITE PLATE WHICH IS ASSUMING A POSITIVE CHARGE.

WITH THE EFFECTS OF BOTH THE ALTERNATOR AND THE MUTUAL ATTRACTION OF THE CHARGES OF THE TWO PLATES, MORE ELECTRONS ARE CAUSED TO MOVE FROM ONE PLATE TO THE OTHER THROUGH THE CIRCUIT THAN WOULD BE THE CASE IF THE EFFECT OF THE ATTRACTION BETWEEN PLATES WERE NOT PRESENT.

THE CLOSER TOGETHER THE TWO PLATES ARE BROUGHT THE GREATER THE CHARGING CURRENT FLOWING IN THE CIRCUIT AND THEREFORE THE GREATER THE CAPACITY. IN A CONDENSER COMPOSED OF TWO PLATES OF EQUAL AREA THE CAPACITY VARIES INVERSELY AS THE DISTANCE BETWEEN THE PLATES. IF THE DISTANCE BETWEEN THE PLATES IS DECREASED TO ONE-HALF, THE CAPACITY WILL BE DOUBLED, ETC. IN A MULTIPLATE CONDENSER THE EFFECT IS THAT OF A NUMBER OF TWO PLATE CONDENSERS IN PARALLEL. THE CAPACITY OF A MULTI-PLATE CONDENSER CAN BE CALCULATED BY THE USE OF THE FOLLOWING EQUATION:

$$C = .0885 \frac{K(N-1)S}{R}$$

WHERE
- K = DIELECTRIC PERMEABILITY (EXPLAINED BELOW)
- S = AREA OF ONE PLATE IN SQUARE CENTIMETERS (ALL PLATES SIMILAR)
- N = NUMBER OF PLATES
- R = SEPARATION BETWEEN PLATES IN CENTIMETERS
- C = $\mu\mu F$

<u>DIELECTRIC PERMEABILITY:</u> THE FACTOR K WHICH ENTERS INTO THE DETERMINATION OF THE CAPACITY OF A CONDENSER IS THE PERMEABILITY OF THE DIELECTRIC, THE MEDIUM BETWEEN THE PLATES IN WHICH THE ELECTRIC FIELD IS BUILT UP. IN THE ORDINARY VARIABLE CONDENSER THE DIELECTRIC IS MOSTLY AIR, AND THE PERMEABILITY OF DRY AIR IS TAKEN AS THE UNIT VALUE OF ELECTRIC PERMEABILITY. THE ELECTRIC PERMEABILITY OF A DIELECTRIC IS DEFINED AS THE EASE WITH WHICH AN ELECTRIC FIELD MAY BE SET UP IN THAT DIELECTRIC. IT HAS NOTHING TO DO WITH THE DIELECTRIC <u>STRENGTH</u> OF THE MEDIUM, THAT IS, ITS BREAKDOWN VOLTAGE. AN INSULATING MATERIAL THAT WILL STAND A HIGHER APPLIED VOLTAGE BEFORE BREAKING DOWN THAN SOME OTHER SUBSTANCE DOES NOT ALWAYS HAVE A HIGHER ELECTRIC PERMEABILITY. MANY INSULATING MATERIALS, GLASS, MICA, BAKELITE, RUBBER, WAX, ETC., HAVE A GREATER ELECTRIC PERMEABILITY THAN AIR. FOR A GIVEN APPLIED VOLTAGE A GREATER DISPLACEMENT OF ELECTRONS WILL TAKE PLACE IN THOSE DIELECTRICS THAN IN AIR, A GREATER ATTRACTION WILL THEREFORE EXIST BETWEEN THE OPPOSITE CHARGES ON THE CONDENSER PLATES, AND IT WILL BE EASIER TO SET UP AN ELECTRIC FIELD THAN WHEN THE DIELECTRIC IS AIR. THE OPPOSITION TO THE CHARGE WILL BE LESS UNDER THESE CONDITIONS AND A GIVEN APPLIED VOLTAGE WILL CAUSE A GREATER TRANSPOSITION OF ELECTRONS THAN IS POSSIBLE WITH THE SAME PLATES SEPARATED BY AIR ONLY. THIS MEANS THAT THE CAPACITY OF THE CONDENSER WILL BE INCREASED WHEN THE PERMEABILITY OF THE DIELECTRIC IS INCREASED, ALL OTHER CONDITIONS REMAINING UNCHANGED.

THE DIELECTRIC PERMEABILITY OF A SUBSTANCE, OFTEN CALLED THE DIELECTRIC "CONSTANT", IS NOT A CONSTANT. IT VARIES WITH FREQUENCY, MOISTURE, TEMPERATURE, VOLTAGE, ETC. THEREFORE EXCEPT IN THE CASE OF AN AIR CONDENSER EMPLOYING <u>VERY LITTLE</u> INSULATING MATERIAL, THE CAPACITY MAY BE CONSIDERABLY DIFFERENT AT A HIGH RADIO FREQUENCY FROM THAT MEASURED AT LOW FREQUENCY. THE DIELECTRIC PERMEABILITIES OF A FEW SUBSTANCES USED AS INSULATORS IN CONDENSERS ARE SHOWN BELOW:

SUBSTANCE	FREQUENCY IN KILOCYCLES	DIELECTRIC PERMEABILITY
FUSED QUARTZ	18,000 100	3.4 4.2
GLASS	30	5.1-7.9
HARD RUBBER	210 18,000	3.0 2.9
MICA, INDIA	100-1000	7.07-7.9
MYCALEX	100	8.0
BEESWAX	18,000	3.9
MAPLE WOOD	500	4.4

CONDENSER CONSTRUCTION: ALL OF THE ABOVE METHODS OF OBTAINING LARGE CAPACITY ARE MADE USE OF IN THE COMMERCIAL DESIGN OF FIXED CONDENSERS. IN LOW VOLTAGE CONDENSERS A LARGE CAPACITY IS OBTAINED BY BUILDING UP THE CONDENSER WITH LONG STRIPS OF WAXED PAPER ALTERNATED WITH STRIPS OF THIN METAL FOIL. SINCE THE PAPER IS THIN THE SEPARATION BETWEEN THE PLATES IS SMALL AND THE COMPARATIVELY HIGH DIELECTRIC PERMEABILITY OF THE WAXED PAPER COMBINES TO PROVIDE A LARGE VALUE OF CAPACITY. FOR COMPACTNESS THE CONBINATION OF ALTERNATE STRIPS OF PAPER AND METAL FOIL IS ROLLED UP TIGHTLY, PLACED IN A METAL CONTAINER, AND MELTED WAX THEN POURED IN TO INSURE AGAINST CHANGE AND TO INCREASE THE INSULATING QUALITIES.

IN HIGHER VOLTAGE CONDENSERS THE PAPER STRIPS ARE REPLACED WITH STRIPS OF MICA THUS OBTAINING A SLIGHTLY HIGHER DIELECTRIC PERMEABILITY AND MUCH BETTER INSULATING QUALITIES.

IN VARIABLE CONDENSERS IT IS HARDLY PRACTICAL TO USE INSULATION OTHER THAN AIR BETWEEN THE PLATES. IN VARIABLE RECEIVING CONDENSERS, FOR COMPACTNESS AND TO OBTAIN REASONABLY LARGE VALUES OF CAPACITY, THE SEPARATION BETWEEN PLATES IS USUALLY SMALL. THE USE OF VARIABLE CONDENSERS HAVING PLATES EXTREMELY CLOSE TO TOGETHER HOWEVER SHOULD BE AVOIDED; FIRST, BECAUSE OF THE PROBABILITY OF ME-

CHANICAL TROUBLES DUE TO THE PLATES BENDING, GETTING OUT OF LINE SLIGHTLY AND SHORT-CIRCUITING; AND SECOND, BECAUSE, WHEN THE SPACING IS VERY SMALL A SMALL CHANGE IN THE SEPARATION BETWEEN PLATES MAKES A LARGE CHANGE IN CAPACITY, AND WHEN THE PLATES ARE NORMALLY SO CLOSE TOGETHER ANY SLIGHT IRREGULARITY WILL CAUSE A LARGE PERCENTAGE CHANGE IN THE CAPACITY OF THE CONDENSER. IT IS USUALLY BETTER TO SACRIFICE A CERTAIN AMOUNT OF COMPACTNESS IN ORDER TO OBTAIN STURDY CONSTRUCTION AND BETTER CONSTANCY OF CALIBRATION.

IN VARIABLE TRANSMITTING CONDENSERS, FOR HIGH POWER WORK PARTICULARLY, COMPACTNESS IS A SECONDARY CONSIDERATION. THE PRIMARY CONSIDERATION IS A HIGH BREAKDOWN VOLTAGE. THE BREAKDOWN VOLTAGE OF DRY AIR IS ABOUT TWENTY-EIGHT THOUSAND VOLTS PER INCH DEPENDING ON THE CHARACTER OF THE OPPOSING SURFACES. IF VERY HIGH VOLTAGES ARE TO BE HANDLED IT SOMETIMES BECOMES NECESSARY TO SEPARATE THE CONDENSER PLATES BY SEVERAL INCHES. THIS WIDE SEPARATION OF THE PLATES HAS THE EFFECT OF DECREASING THE CAPACITY, SO THAT IN ORDER TO OBTAIN THE DESIRED CAPACITY THE WIDE SPACING MUST BE COMPENSATED FOR BY INCREASING THE AREA OF THE PLATES. THUS VARIABLE CONDENSERS OF VERY LARGE PHYSICAL DIMENSIONS AS USED IN MODERN HIGH POWER TUBE TRANSMITTERS OFTEN HAVE CAPACITIES LESS THAN THOSE OF THE CONDENSERS USED IN SMALL RECEIVERS.

WHEN THE CONDENSER VOLTAGE APPROACHES THE POINT WHERE IONIZATION OF THE SURROUNDING AIR BEGINS, PRECAUTIONS MUST BE TAKEN AGAINST THAT CONDITION BECAUSE POWER IS REQUIRED FOR IONIZATION, AND THE POWER EXPENDED IS MANIFEST IN THE FORM OF LOSSES IN THE CONDENSER. IONIZATION OCCURS MOST READILY AT POINTS OF HIGH FIELD CONCENTRATION AND IN PARTICULAR AT CONDUCTOR SHARP POINTS AND EDGES. THEREFORE THE EDGES OF THE PLATES OF A HIGH VOLTAGE VARIABLE CONDENSER SHOULD BE ROUNDED TO MINIMIZE IONIZATION LOSSES. IN A RADIO FREQUENCY CIRCUIT QUITE HIGH PEAK VOLTAGES MAY OCCUR, EVEN WITH COMPARATIVELY LOW POWER, SO THIS FACTOR OF DESIGN MUST NOT BE NEGLECTED.

<u>SELECTING A CONDENSER</u>: IN SELECTING A CONDENSER, PARTICULARLY FOR A HIGH

FREQUENCY CIRCUIT, GREAT CARE SHOULD BE TAKEN TO AVOID UNNECESSARY LOSSES. THE LOSSES IN A CONDENSER ARE MOSTLY IN THE DIELECTRIC. AS THE CONDENSER IS RAPIDLY CHARGED AND DISCHARGED AND THE POLARITY OF THE PLATES REVERSED, THE ELECTRONS IN THE DIELECTRIC ARE RAPIDLY DISPLACED FROM ONE SIDE OF THEIR RESPECTIVE ATOMS TO THE OTHER SIDE. MOST OF THE ELECTRONS DO NOT ACTUALLY LEAVE THE ATOMS BUT THEIR ORBITS ARE CHANGED OR DISTORTED WITH EVERY CHANGE IN THE APPLIED VOLTAGE. THE RAPID DISPLACEMENT OF ELECTRONS, EVEN THOUGH THE ACTUAL CURRENT LEAKAGE THROUGH THE DIELECTRIC IS NEGLIGIBLE, PRODUCES HEAT. THE HEAT DOES NO USEFUL WORK AND THE POWER EXPENDED IN CAUSING THE HEAT IS THEREFORE LOST. THIS MEANS A LOSS OF POWER IN THE CIRCUIT IN WHICH THE CONDENSER IS USED. THE MORE RAPID THE DISPLACEMENT OF ELECTRONS FROM ONE SIDE TO THE OTHER IN THE ATOMS, THE GREATER THE HEAT PRODUCED. OFTEN WHEN USING FIXED CONDENSERS, THE CASES OF WHICH ARE FILLED WITH WAX, IF THE CONDENSER IS OVERLOADED THE CONDENSER WILL BECOME SO HOT THAT THE WAX WILL MELT OUT. A CONSIDERABLE AMOUNT OF POWER OR ENERGY IS REQUIRED TO RAISE THE TEMPERATURE OF THE WAX TO THE MELTING POINT AND THAT AMOUNT OF POWER IS TAKEN FROM THE CIRCUIT AND WASTED.

IN RECEIVING CONDENSERS IT IS PARTICULARLY IMPORTANT THAT THE LOSSES BE KEPT TO A MINIMUM. IF A RECEIVER IS EXPECTED TO HAVE SUFFICIENT GAIN TO REPRODUCE WEAK DISTANT SIGNALS, EVERY POSSIBLE AMOUNT OF THE AVAILABLE ENERGY MUST DO USEFUL WORK. IF ANY APPRECIABLE AMOUNT OF THE RECEIVED ENERGY, WHICH IS SMALL TO BEGIN WITH, IS WASTED, A MARKED DECREASE IN SIGNAL STRENGTH WILL BE NOTED. ALSO THE GAIN PER STAGE OF THE R. F. AND I. F. AMPLIFIERS GOES DOWN RAPIDLY WITH INCREASED LOSSES.

MOST INSULATORS WHICH ARE GOOD FROM THE VOLTAGE BREAKDOWN VIEWPOINT INTRODUCE COMPARATIVELY LARGE DIELECTRIC LOSSES IN THE CONDENSER WHEN PLACED DIRECTLY IN THE ELECTRO-STATIC FIELD. A GOOD VARIABLE CONDENSER, FOR THAT REASON, SHOULD EMPLOY THE MINIMUM OF INSULATING MATERIAL CONSISTENT WITH GOOD MECHANICAL CONSTRUCTION, AND THE INSULATING MATERIAL SHOULD NEVER EXTEND BETWEEN THE

CONDENSER PLATES.

IT HAS BEEN SHOWN THAT IN CHARGING A CONDENSER ELECTRONS MUST BE MOVED FROM ONE PLATE OF THE CONDENSER TO THE OTHER PLATE. POWER IS REQUIRED TO MOVE THOSE ELECTRONS AND TO OVERCOME THE CEMF THAT IS BUILT UP IN THE CONDENSER. IF, HOWEVER, THERE WERE NO RESISTANCE OR DIELECTRIC LOSSES DURING THE CHARGE, ALL OF THE ENERGY USED UP IN THE CHARGING PROCESS WOULD BE STORED IN THE FORM OF AN ELECTRO-STATIC FIELD BETWEEN THE PLATES OF THE CONDENSER. THEN, IF THE CIRCUIT WERE OPENED AT THE INSTANT OF FULL CHARGE, THE CHARGE WOULD REMAIN IN THE CONDENSER; FOREVER, IF THERE WERE NO LEAKS, OR LOSSES. THE LATTER CONDITION IS OF COURSE IMPOSSIBLE TO ATTAIN; HOWEVER IN A GOOD HIGH VOLTAGE CONDENSER A LARGE CHARGE MAY BE BUILT UP THAT MAY TAKE SEVERAL HOURS TO LEAK OFF.

IN THE THEORETICALLY PERFECT CONDENSER ALL OF THE POWER REQUIRED FOR BUILDING UP THE CHARGE WILL BE STORED IN THE CONDENSER, A DIFFERENCE OF POTENTIAL WILL EXIST BETWEEN THE TWO PLATES, AND THE CONDENSER MAY THEN BE CONSIDERED A SOURCE OF EMF. IF THE CHARGED CONDENSER IS SHORT-CIRCUITED BY A CONDUCTOR IT WILL DISCHARGE THROUGH THE CONDUCTOR EXPENDING ITS POWER IN HEAT IN THE CONDUCTOR. IF THIS PERFECT CONDENSER IS PLACED IN AN A. C. CIRCUIT, THE POWER TAKEN FROM THE ALTERNATOR DURING THE CHARGE WILL BE RETURNED TO THE ALTERNATOR CIRCUIT DURING THE DISCHARGE, AND NO POWER WILL BE EXPENDED IN THE CONDENSER ITSELF. SINCE NO PIECE OF ELECTRICAL APPARATUS CAN BE MADE PERFECTLY NO-LOSS SUCH A CONDITION CANNOT BE COMPLETELY OBTAINED. HOWEVER, IN A WELL DESIGNED RADIO FREQUENCY CIRCUIT USING A GOOD CONDENSER, THE LOSSES IN THE CONDENSER MAY BE CONSIDERED AS A VERY SMALL PROPORTION OF THE TOTAL LOSSES EXCEPT AT EXTREMELY HIGH FREQUENCIES--THAT IS, FREQUENCIES ABOVE 15 MEGACYCLES.

<u>CAPACITY REACTANCE</u>: IT HAS BEEN SHOWN THAT FOR A CONDENSER OF A GIVEN CAPACITY ONLY ENOUGH ELECTRONS CAN FLOW THROUGH THE CIRCUIT TO KEEP THE CEMF EQUAL TO THE APPLIED VOLTAGE; ALSO THAT THE SMALLER THE CAPACITY THE SMALLER THAT NUMBER OF ELECTRONS WILL BE. A CONDENSER THEREFORE INTRODUCES OPPOSITION,

CAPACITY REACTANCE, X_C, INTO THE CIRCUIT. THE REACTANCE IS EQUAL TO E/I AND INCREASES DIRECTLY AS THE CAPACITY DECREASES AND VICE VERSA; I.E., X_C VARIES INVERSELY AS THE CAPACITY.

THE CAPACITY REACTANCE ALSO VARIES WITH THE APPLIED FREQUENCY. WITH A GIVEN CAPACITY AND A GIVEN APPLIED VOLTAGE, A CERTAIN DEFINITE NUMBER OF ELECTRONS MUST BE MOVED THROUGH THE CIRCUIT. THESE ELECTRONS MUST MOVE THROUGH THE CIRCUIT AT SUCH A RATE AS TO KEEP CEMF EQUAL TO E. THIS MEANS THAT WHEN A GIVEN APPLIED VOLTAGE VARIES RAPIDLY, (AS AT HIGH FREQUENCIES), THE ELECTRONS THAT MOVE THROUGH THE CIRCUIT TO COMPLETE A GIVEN CHARGE MUST, AS THE FREQUENCY IS INCREASED, MOVE AT A HIGHER VELOCITY THAN WHEN THE CONDENSER IS CHARGED AND DISCHARGED SLOWLY. PROVIDING THE PEAK VOLTAGE IS THE SAME FOR BOTH CONDITIONS, THE ACTUAL NUMBER OF ELECTRONS MOVED <u>PER CHARGE</u> IS THE SAME, BUT AT THE HIGHER FREQUENCY THERE ARE MORE CHARGES PER SECOND. THE RATE OF FLOW OF THE ELECTRONS IS THEREFORE GREATER, AND SINCE AN AMMETER REGISTERS RATE OF FLOW OF ELECTRONS, IT IS APPARENT THAT THE CURRENT FLOW HAS BEEN INCREASED BY THE INCREASE OF FREQUENCY. IF THE CURRENT FLOW IS INCREASED THE OPPOSITION, CAPACITY REACTANCE, MUST BE DECREASED. IT MAY BE STATED THAT THE CAPACITY REACTANCE VARIES INVERSELY AS THE FREQUENCY, INCREASING DIRECTLY AS THE FREQUENCY DECREASES, AND VICE VERSA.

FROM THE PRECEDING PARAGRAPHS IT IS EVIDENT THAT THE CAPACITY REACTANCE VARIES INVERSELY AS BOTH THE CAPACITY AND THE FREQUENCY, AN INCREASE OF EITHER CAPACITY OR FREQUENCY DECREASING THE CAPACITY REACTANCE OF THE CIRCUIT. SINCE THE REACTANCE IS A FUNCTION OF BOTH CAPACITY AND FREQUENCY THERE WILL BE AN EQUATION STATING THE CAPACITY REACTANCE IN TERMS OF FREQUENCY AND CAPACITY. THAT EQUATION IS:

$$X_C = \frac{1}{2\pi FC}$$

WHERE C = CAPACITY IN FARADS
F = FREQUENCY IN CYCLES
2π = 6.28, A CONSTANT
X_C = THE CAPACITY REACTANCE IN OHMS

WHEN CALCULATING THE CAPACITY REACTANCE AT RADIO FREQUENCIES WHERE THE

FREQUENCY IS STATED IN KILOCYCLES, IT IS IMPORTANT TO REMEMBER THAT THE FREQUENCY IN KILOCYCLES MUST BE CONVERTED TO CYCLES. THIS IS DONE BY MULTIPLYING BY ONE THOUSAND OR 10^3. THUS 200 KC/S WILL BECOME 200,000 CYCLES, OR 2×10^5 CYCLES.

IN RADIO FREQUENCY WORK THE CAPACITY VALUES ARE USUALLY GIVEN IN EITHER MICROFARADS OR MICROMICROFARADS. THESE VALUES MUST BE CONVERTED TO FARADS. IN LESSON ONE IS A CONVERSION TABLE FOR SUCH TERMS. TO CHANGE FROM MICROFARADS TO FARADS THE VALUE SHOULD BE MULTIPLIED BY 10^{-6}. TO CHANGE FROM MICROMICROFARADS TO FARADS MULTIPLY BY 10^{-12}. FOR EXAMPLE,

$.0005\ \mu F$ BECOMES $.0005 \times 10^{-6} = 5 \times 10^{-4} \times 10^{-6} = 5 \times 10^{-10}$ FARADS

$400\ \mu\mu F$ BECOMES $400 \times 10^{-12} = 4 \times 10^{2} \times 10^{-12} = 4 \times 10^{-10}$ FARADS

A CONDENSER OF 400 $\mu\mu F$ CAPACITY IS PLACED IN A CIRCUIT OPERATING AT A FREQUENCY OF 600 KC/S. CALCULATE THE OPPOSITION TO CURRENT FLOW OFFERED BY THIS CONDENSER, THAT IS, THE CAPACITY REACTANCE. THIS IS DONE AS FOLLOWS:

$$X_C = \frac{1}{2\pi FC}$$

$F = 600$ KC/S $= 600{,}000$ CYCLES $= 6 \times 10^5$ CYCLES.

$C = 400\ \mu\mu F = 400 \times 10^{-12}\ F = 4 \times 10^{-10}$ FARADS.

$2\pi = 6.28 = 628 \times 10^{-2}$

SUBSTITUTING GIVEN VALUES FOR THE SYMBOLS IN THE EQUATION, IT BECOMES,

$$X_C = \frac{1}{628 \times 10^{-2} \times 6 \times 10^{5} \times 4 \times 10^{-10}} = \frac{1}{628 \times 6 \times 4 \times 10^{-7}}$$

$$X_C = \frac{10^7}{628 \times 6 \times 4} = \frac{10^7}{15072} = 663 \text{ OHMS.}$$

BY THE USE OF WHOLE NUMBERS TIMES TEN TO THE REQUIRED POSITIVE OR NEGATIVE POWER INSTEAD OF LARGE NUMBERS AND DECIMALS, THIS TYPE OF PROBLEM IS GREATLY SIMPLIFIED.

THE DERIVATION OF THE EQUATION FOR X_C WILL BE OF INTEREST.

THE TWO BASIC EQUATIONS FOR THE CHARGE IN A CONDENSER ARE:

$Q = EC$, WHERE Q = AMOUNT OF CHARGE IN COULOMBS.

E = VOLTAGE OF CONDENSER WHEN CHARGED.

C = CAPACITY IN FARADS.

AND Q = AVERAGE I x TIME OF CHARGE.

THAT IS, THE AMOUNT OF THE CHARGE IN COULOMBS IS EQUAL TO THE AVERAGE CURRENT FLOW IN AMPERES DURING THE CHARGE TIMES THE DURATION OF THE CHARGE IN SECONDS.

SINCE THE RIGHT HAND EXPRESSION IN EACH EQUATION IS EQUAL TO Q THE EQUATION MAY BE REWRITTEN,

$$EC = \text{Ave } I \cdot T$$

DURING EACH COMPLETE CYCLE THERE ARE FOUR COMPLETE CHANGES, TWO CHARGES AND TWO DISCHARGES. THE TIME OF EACH CYCLE IS $1/F$ SECOND. THE TIME OF ONE CHANGE IS THEN $1/4\ F$ SECOND. SUBSTITUTING THE VALUE OF T, ($1/4\ F$), FOR T,

$$EC = \text{Ave } I \cdot 1/4\ F = \frac{\text{Ave } I}{4F}$$

$$\text{Average } I = .636 \cdot I, \text{ therefore,}$$

$$EC = \frac{.636 \cdot I}{4F} \qquad \left(\frac{.636}{4} = \frac{1}{6.28}\right)$$

CANCELLING, $$EC = \frac{I}{6.28F} = \frac{I}{2\pi F}$$

DIVIDING THROUGH BY C,

$$E = \frac{I}{2\pi FC}$$

BUT $$E = IX_C$$

THEREFORE $$IX_C = \frac{I}{2\pi FC}$$

DIVIDING THROUGH BY I,

$$X_C = \frac{1}{2\pi FC}$$

IT HAS BEEN SHOWN THAT IN A PURE CAPACITY CIRCUIT THE CURRENT LEADS THE VOLTAGE BY EXACTLY 90^0. THIS WILL MAKE THE EFFECTS OF CAPACITY ON THE CURRENT 90^0 OUT OF PHASE WITH THE EFFECTS OF RESISTANCE, AND IN A SERIES CIRCUIT COMPOSED OF BOTH CAPACITY AND RESISTANCE THE CURRENT WILL LEAD THE VOLTAGE BY SOME ANGLE BETWEEN ZERO AND NINETY DEGREES, THE EXACT ANGLE DEPENDING UPON THE RATIO

OF X_C TO R. THE TANGENT OF $\theta = X_C/R$. THIS CONDITION IS IDENTICAL TO THAT OF THE INDUCTIVE CIRCUIT EXCEPT THAT IN THE CAPACITIVE CIRCUIT θ REPRESENTS AN ANGLE OF LEAD WHILE IN THE INDUCTIVE CIRCUIT θ REPRESENTS AN ANGLE OF LAG.

CONDENSERS IN SERIES AND IN PARALLEL: IF TWO OR MORE CONDENSFRS ARE CONNECTED IN PARALLEL THE EFFECT IS JUST AS IF THE PLATE AREA OF A CONDENSER HAD BEEN INCREASED. THUS THE TOTAL CAPACITY OF CONDENSERS IN PARALLEL IS EQUAL TO THE SUM OF THE INDIVIDUAL CAPACITIES.

FOR EXAMPLE, IF THREE CONDENSERS ARE CONNECTED IN PARALLEL, ONE HAVING A CAPACITY OF 300 μμF, ONE OF 600 μμF, AND ONE OF 2000 μμF, THE TOTAL CAPACITY IS EQUAL TO 300 + 600 + 2000 OR 2900 μμF. (SEE FIGURE 4.)

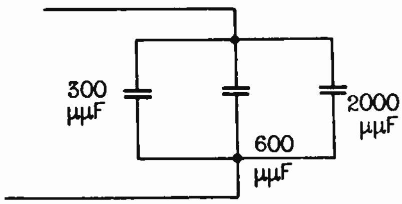


FIG. 4.

IF THE CONDENSERS ARE CONNECTED IN SERIES THE EFFECT IS TO INCREASE THE DISTANCE BETWEEN THE OUTSIDE PLATES. IF THE DISTANCE BETWEEN THE PLATES IS INCREASED THE CAPACITY DECREASES IN PROPORTION. THEREFORE, IF TWO CONDENSERS OF EQUAL CAPACITY ARE PLACED IN SERIES THE EFFECT IS THAT OF DOUBLING THE DISTANCE BETWEEN THE PLATES AND THE TOTAL CAPACITY IS EQUAL TO ONE-HALF OF THE CAPACITY OF ONE CONDENSER. IF THREE EQUAL CAPACIIIES ARE CONNECTED IN SERIES THE RESULTING CAPACITY IS ONE-THIRD OF THE CAPACITY OF ONE, ETC.

FOR EXAMPLE, IF TWO 600 μμF CONDENSERS ARE CONNECTED IN SERIES, C = 600/2 = 300 μμF. IF THREE 600 μμF CONDENSERS ARE CONNECTED IN SERIES, C = 600/3 = 200 μμF. IF SIX .0006 μF CONDENSERS ARE CONNECTED IN SERIES, C = .0006/6 = .0001 μF.

IF THE SERIES CAPACITIES ARE NOT OF EQUAL VALUE THE EQUATION BECOMES:

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \text{ ETC.}}$$

THIS MAY BE STATED AS FOLLOWS: THE TOTAL CAPACITY OF CONDENSERS IN SERIES

IS EQUAL TO THE RECIPROCAL OF THE SUM OF THE RECIPROCALS OF THE INDIVIDUAL CAPACITIES.

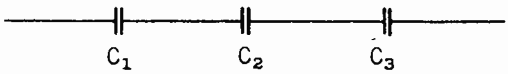


FIG. 5.

THE TOTAL CAPACITY OF SEVERAL CAPACITIES IN SERIES IS ALWAYS LESS THAN THE CAPACITY OF THE SMALLEST.

FOR EXAMPLE, IF THREE CONDENSERS, ONE OF 200 µµF, ONE OF 800 µµF, AND ONE OF 1000 µµF, ARE CONNECTED IN SERIES THE TOTAL CAPACITY OF THE COMBINATION WILL BE SOMETHING LESS THAN 200 µµF. THIS IS CLEARLY SHOWN AS FOLLOWS:

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

$$C = \frac{1}{\frac{1}{200} + \frac{1}{800} + \frac{1}{1000}}$$

$$C = \frac{1}{.005 + .00125 + .001} = 138\ \mu\mu F.$$

CONSIDER THE CASE OF A SMALL CONDENSER CONNECTED IN SERIES WITH A MUCH LARGER CONDENSER. FOR EXAMPLE, $C_1 = 20$ µµF, $C_2 = .002$ µF = 2000 µµF.

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}} = \frac{1}{\frac{1}{20} + \frac{1}{2000}}$$

$$C = \frac{1}{.05 + .0005} = 19.8\ \mu\mu F.$$

THIS COULD ALSO BE HANDLED BY THE PRODUCT/SUM METHOD:

$$C = \frac{C_1 C_2}{C_1 + C_2} = \frac{20 \times 2000}{20 + 2000}$$

$$C = \frac{40,000}{2020} = 19.8\ \mu\mu F$$

THE SMALLEST CONDENSER OF A GROUP IN SERIES ALWAYS HAS THE GREATEST EFFECT ON THE CAPACITY OF THE COMBINATION. IF A LARGE CAPACITY IS PLACED IN SERIES WITH A COMPARATIVELY SMALL ONE, THE EFFECT OF THE LARGER CONDENSER ON THE TOTAL CAPACITY USUALLY MAY BE CONSIDERED NEGLIGIBLE, AS IS CLEARLY SHOWN IN THE PROBLEM ABOVE. THIS FACT IS OFTEN MADE USE OF IN HIGH POWER VACUUM TUBE CIRCUITS where it is desired to use a variable condenser of small capacity, as in a balance or neutralizing circuit, and where the accidental short-circuiting of the variable condenser might cause damage due to shorting to ground of the high voltage D.C. power supply. To effectively prevent such an occurance, a fixed condenser of fairly large capacity and high voltage breakdown factor is placed in series with the small variable condenser. If the fixed condenser has a capacity ten or more times greater than that of the variable condenser. Its effect on the total capacity may be practically neglected. Its high voltage breakdown point however protects the D.C. supply in case the variable condenser is accidentally short-circuited during adjustment.

In high power radio transmitters it is often desired to use a certain standard type of condenser in a circuit in which the current flow is very much greater than the maximum current rating of that type of condenser.

<u>For example</u>: Assume a radio frequency circuit in which, at maximum output. the current as indicated by the radio frequency ammeter will be 40 amperes; it is desired to use a certain type of condenser which, at the frequency at which the transmitter is to operate, is rated at 15 amperes. The circuit specifications call for a .002 μF capacity; the condensers it is desired to use are rated at .002 μF.

In order to safely carry 40 amperes three condensers rated at 15 amperes must be connected in parallel. (See Figure 6.) Since the maximum permissible current is 40 amperes, the three condensers should not overheat. But—with three .002 μF condensers in parallel the capacity is .002 x 3 or .006 μF, three times the specified capacity of the circuit.

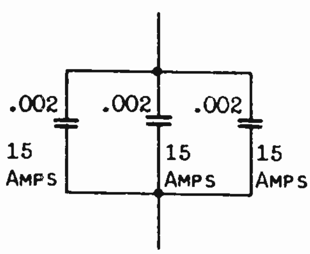


Fig. 6.

In order to bring the circuit capacity back to the specified value, .002 μF, it will be necessary to place three of these combinations in series. (See Figure 7.) By placing the

THREE EQUAL VALUES OF CAPACITY IN PARALLEL THE CAPACITY IS INCREASED TO THREE TIMES THE ORIGINAL VALUE. THEN BY PLACING THREE COMBINATIONS OF CAPACITY IN SERIES THE RESULTING COMBINED CAPACITY WILL BE DECREASED TO ONE-THIRD THAT OF A SINGLE PARALLEL COMBINATION. THE TOTAL CAPACITY OF THE NINE CONDENSERS IS THUS EQUAL TO THE CAPACITY OF A SINGLE CONDENSER BUT THE CURRENT CARRYING CAPACITY IS THREE TIMES AS GREAT.

ANOTHER ADVANTAGE OF SUCH A COMBINATION IS THE FACT THAT WITH THREE EQUAL CAPACITIES IN SERIES THE VOLTAGE DROP ACROSS EACH CONDENSER IS ONLY ONE-THIRD OF THE TOTAL VOLTAGE ACROSS THE COMBINATION. THUS, IF THE CONDENSER COMBINATION AS SHOWN IN FIGURE 7 HAS A TOTAL EFFECTIVE VOLTAGE ACROSS IT OF 6300 VOLTS, THE EFFECTIVE VOLTAGE ACROSS EACH CONDENSER IS ONLY 6300/3 OR 2100 VOLTS. BY BUILDING UP SUCH A COMBINATION OF CAPACITIES A TYPE OF CONDENSER HAVING A MUCH LOWER BREAKDOWN VOLTAGE CAN BE USED THAN WOULD BE POSSIBLE IF A SINGLE CONDENSER OF THE SAME CAPACITY AS THE COMBINATION HAD BEEN USED.

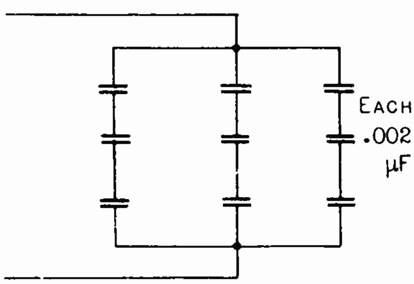


FIG. 7.

ASSUME THE CIRCUIT CONDITIONS AS THOSE FOR WHICH THE COMBINATION SHOWN IN FIGURE 7 WAS DESIGNED. IT IS DESIRED TO USE THE CAPACITY IN A CIRCUIT THROUGH WHICH 40 AMPERES WILL FLOW AT A FREQUENCY OF 200 KC/S. TO COMPUTE THE EFFECTIVE VOLTAGE ACROSS THE COMBINATION IT IS FIRST NECESSARY TO DETERMINE X_C.

$$X_C = \frac{1}{2\pi FC} = \frac{1}{6.28 \times 2 \times 10^5 \times .002 \times 10^{-6}} = \frac{10^6}{2512} = 398 \text{ OHMS}$$

THE EFFECTIVE VOLTAGE ACROSS THE CAPACITY COMBINATION WILL BE,

$$E = IX_C = 40 \times 398 = 15,920 \text{ VOLTS.}$$

THE PEAK VOLTAGE ACROSS THIS COMBINATION WILL BE $E_{EFF}/.707 = \frac{15,920}{.707} =$ 22,517 VOLTS. IF A SINGLE CONDENSER HAVING A CAPACITY OF .002 µF WERE PLACED IN THIS CIRCUIT IT WOULD BE REQUIRED TO NOT HEAT EXCESSIVELY AT AN EFFECTIVE current of 40 amperes and not to break down at peak voltages of 22,500 volts. This would be an extremely expensive condenser.

By using three capacities in series, condensers having a breakdown factor of 10,000 volts would provide an excellent margin of safety. By placing three capacities in parallel, condensers having a current rating of 15 amperes should not heat excessively in this circuit.

Such smaller sizes of condensers are much less expensive and if a single condenser proves defective and breaks down it is only necessary to replace the one defective unit. Capacity combinations of this sort are used in practically all high power transmitters, particularly in the intermediate frequency range.

When operating large capacity condensers in series at high voltage for D.C. filtering, it becomes necessary to use a resistance voltage divider to equalize the voltage across the condensers. The circuit arrangement is shown in Figure 8. This is done to minimize the effect of leakage if one condenser unit becomes defective. If the resistance network were not used, a leaky condenser which would not take a full charge would act as a partial short-circuit and throw practically the full voltage across the two good condensers, the voltage across each thus being increased by fifty percent. The equalizing network of three equal values of R minimizes the effect of leakage and divides the total voltage equally across the three condensers.

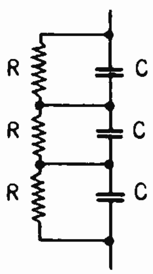


Fig. 8.

Total R should be sufficiently great to make the power loss negligible. A leakage current of 10 mils through R is ordinarily sufficient for quite high power filter circuits.

V-9174-33

TELEVISION TECHNICAL ASSIGNMENT

CAPACITY

EXAMINATION

1. (A) What is a condenser?

A condenser is any apparatus in which energy can be stored in the form of an electro-static field.

(B) What is meant by the capacity of a condenser?

The number of electrons which must be moved from one plate to the other to raise the voltage a given amount.

(C) What is meant by the charge in a condenser?

The total transfer of current from one plate to the other. The unit of measurement is a coulomb. The charge is the product of the average current in amperes times the duration in seconds.

(D) What will happen in the circuit if the applied voltage across a condenser is increased? Why? Decreased? Why?

Explain in detail.

When the voltage is increased current will flow in the same direction as on the initial charge so as to bring the CEMF of the condenser equal to the applied EMF.

When the applied voltage is decreased current will flow in the opposite direction of the initial charge so as to lower the CEMF to equal the applied EMF.

2. (A) Explain what takes place when a battery is connected in a series with a condenser?

The positive terminal of the battery will attract electrons from one plate and the negative terminal will repel electrons toward the other plate.

(B) If an ammeter is also connected in the circuit, what will be the indication on the ammeter when the circuit is closed? Why?

There will be a large flow of current at the instant the switch is closed. At this instant there is no CEMF and therefor no opposition to current flow.

3. In the circuit of Question 2: The voltage across the condenser is increased by 100 volts in one-tenth of a second such as by impressing a sawtooth voltage in series with the battery; it is then increased by 100 volts in one-hundredth of a second. Will the ammeter reading be the same for the two changes?

Explain in detail.

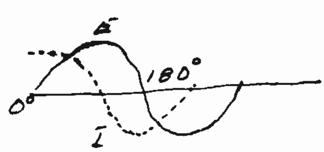
No, the reading will be greater in the second case because the same number of electrons have to flow in one tenth the time, and an ammeter indicates rate of current flow.

4. How does the explanation in Question 3 apply to an a.c. circuit? *Explain in detail.*

The voltage is continuously varying except at the points of maximum voltage in the cycle. At these points there will be no current flow.

5. What is the phase relation between current and voltage in a pure capacity circuit in which the voltage variations are in the form of a sine curve? Why?

The current leads the voltage by 90°. The current is at maximum value at the point where the voltage is varying the most - where it is changing polarity (at 0° and 180° - and minimum where the variation of voltage is the least - at its maximum value.



The sketch at left shows that for this to be true the current must lead the voltage by 90°

V-9174-33

CAPACITY

EXAMINATION, Page 3

6. What is meant by the "capacitive reactance" of a condenser? How is this reactance affected by variations of capacity and frequency? *Explain.*

The capacitive reactance of a condenser is its opposition to current flow and is measured in ohms. It varies inversely with the capacity and with the frequency. With increased frequency the same electron flow takes place in less time therefore the rate of flow is greater which means the reactance is less. Increasing capacity necessitates a greater flow of electrons in the same time, thereby also indicating less reactance.

7. What is the unit of capacity? What is the definition of the unit?

The unit of capacity is the Farad.

A condenser has a capacity of one farad if one ampere flowing for one second raises the condenser voltage one volt.

8. What will be the capacitive reactance of a .00015 µf by-pass condenser used in a television receiving set at a frequency of 400 kc/s? At 1,500 kc/s? At 100 mc? At 1,000 cycles?

Show all work. $X_c = \frac{1}{2\pi FC}$.

A. $X_c = \frac{1}{6.28 \times 4 \times 10^5 \times 1.5 \times 10^{-10}} = \frac{10^5}{37.68} = 2654\ \Omega$.

B. $X_c = \frac{1}{6.28 \times 1.5 \times 10^6 \times 1.5 \times 10^{-10}} = \frac{10^4}{14.13} = \cancel{707.4}\ 707.7\ \Omega$

C. $X_c = \frac{1}{6.28 \times 10^8 \times 1.5 \times 10^{-10}} = \frac{10^2}{9.42} = 10.62\ \Omega$

D. $X_c = \frac{1}{6.28 \times 10^3 \times 1.5 \times 10^{-10}} = \frac{10^7}{9.42} = 1,062,000\ \Omega$

8. *(Continued)*

9. Given a 25-plate condenser, the plates being separated by mica dielectric; the mica having a thickness of 20 mils. Each plate has a length of 3 inches and a width of 2 inches. Assume the dielectric constant of mica to be 5.8. Calculate the capacity of the condenser in μf. *Show your work.*

(1 mil = .001 inch)

$$C = .0885 \frac{K(N-1)S}{R} \ \mu\mu F$$

$$\text{Area} = S = 3 \times 2 \times 2.54^2 = 38.709 \text{ cm}^2$$

$$R = .020 \times 2.54 = .0508 \text{ cm.}$$

$$C = \frac{.0885 \times 5.8 \times 24 \times 38.709}{.0508} = 9384.8 \ \mu\mu F$$

$$= .0094 \ \mu F$$

10. A capacitance of 640 μμf is required for a television i.f. amplifier. Four condensers are available, the capacities of which are respectively, C_1 = 600 μμf, C_2 = .0004 μf, C_3 = .001 μf, C_4 = 800 μμf.

(A) What is the capacity of the four condensers connected in parallel? *Show your work.*

For parallel Connection

$$C = C_1 + C_2 + C_3 + C_4$$

$$= .0006\,\mu f + .0004\,\mu f + .001\,\mu f + .0008\,\mu f$$

$$= .0028\,\mu f \text{ or } 2800\,\mu\mu f$$

(B) What is the capacity of the four condensers connected in series? *Show your work.*

For Series Connection.

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}}$$

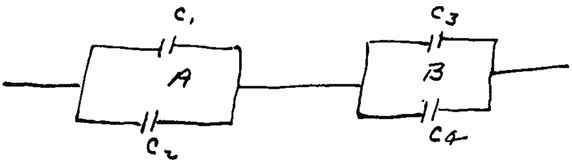
$$= \frac{1}{\frac{1}{600} + \frac{1}{400} + \frac{1}{1000} + \frac{1}{800}}$$

$$= \frac{1}{.00166 + .0025 + .001 + .00125}$$

$$= \frac{1}{.00641} = 156.0\,\mu\mu f$$

or .000156 μf

(C) Connect C_1 and C_2 in parallel, C_3 and C_4 in parallel. Then connect the two combinations in series. What is the total capacity of the combinations?



$$C_A = C_1 + C_2 = 600 + 400 = 1000 \text{ uuf}$$

$$C_B = C_3 + C_4 = 1000 + 800 = 1800 \text{ uuf}$$

$$C = \frac{C_A C_B}{C_A + C_B} = \frac{1000 \times 1800}{1000 + 1800} = \frac{1800000}{2800} = 642.8 \text{ uuf.}$$

(D) Which arrangement comes closest to the value desired?

The series-parallel combination.