SPECIALIZED
TELEVISION ENGINEERING

TELEVISION TECHNICAL ASSIGNMENT

CONDENSERS USED IN RADIO

722D

TELEVISION TECHNICAL ASSIGNMENT

CONDENSERS USED IN RADIO

FOREWORD

This assignment is devoted to the practical applications of capacities in radio and television. Condensers are used primarily as tuned circuit elements, as elements in filtering networks, as blocking condensers to pass radio, video or audio frequency energy while serving as a block against d.c. voltages, and as by-pass capacity to shunt radio and audio frequency voltages around direct current circuits.

Plates 1, 2 and 3 illustrate just a few of the many types of condensers used in radio and television. It is essential that the engineer and technician be thoroughly familiar with the major types available and the applications, uses and limitations of each. It would illustrate a great degree of engineering ignorance to specify a $100 precision condenser for a job which could satisfactorily be done with a $0.35 condenser, or vice-versa. For some applications a small inexpensive electrolytic condenser of large capacity can be used while in other cases the electrolytic type, because it is a polarized device, cannot be used. In certain frequency ranges a given type of condenser may be highly satisfactory while the same condenser, because of excessive losses, or inductive affects, may be entirely unsatisfactory if operated at much higher frequencies. Due to the extremely wide range of frequency response of video amplifiers, many unusual capacity combinations will be encountered. Very often a large by-pass condenser will be parallel by a very small mica condenser. Tube capacity change of a fraction of a micromicrofarad can noticeably affect the frequency response of a video amplifier.

The engineer must know how to calculate the tuning range of a variable condenser with a given coil, and to calculate required values of padder and trimmer capacities.

He must understand the effects on circuit tuning when variable condensers having differently shaped plates are used.

He must understand condenser ratings and the basis on which a condenser is rated. Of importance are the power loss, resistance, leakage and phase angle of a condenser. Of particular importance is the subject of "stray capacity"; this is a limiting factor in the operation of many radio frequency circuits, as well as in audio and video (picture) amplifiers. In video amplifier design he must know how to measure the small capacities involved in tubes and circuits and how to calculate and build the necessary compensating inductance to offset the undesired capacities.

All of these topics, and others, are discussed in this assignment. Do your very best on this one.

E. H. Rietzke,
President.

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TECHNICAL ASSIGNMENT

CONDENSERS USED IN RADIO

RATING--LOSSES--STRAY CAPACITIES

TYPE 722 PRECISION CONDENSER

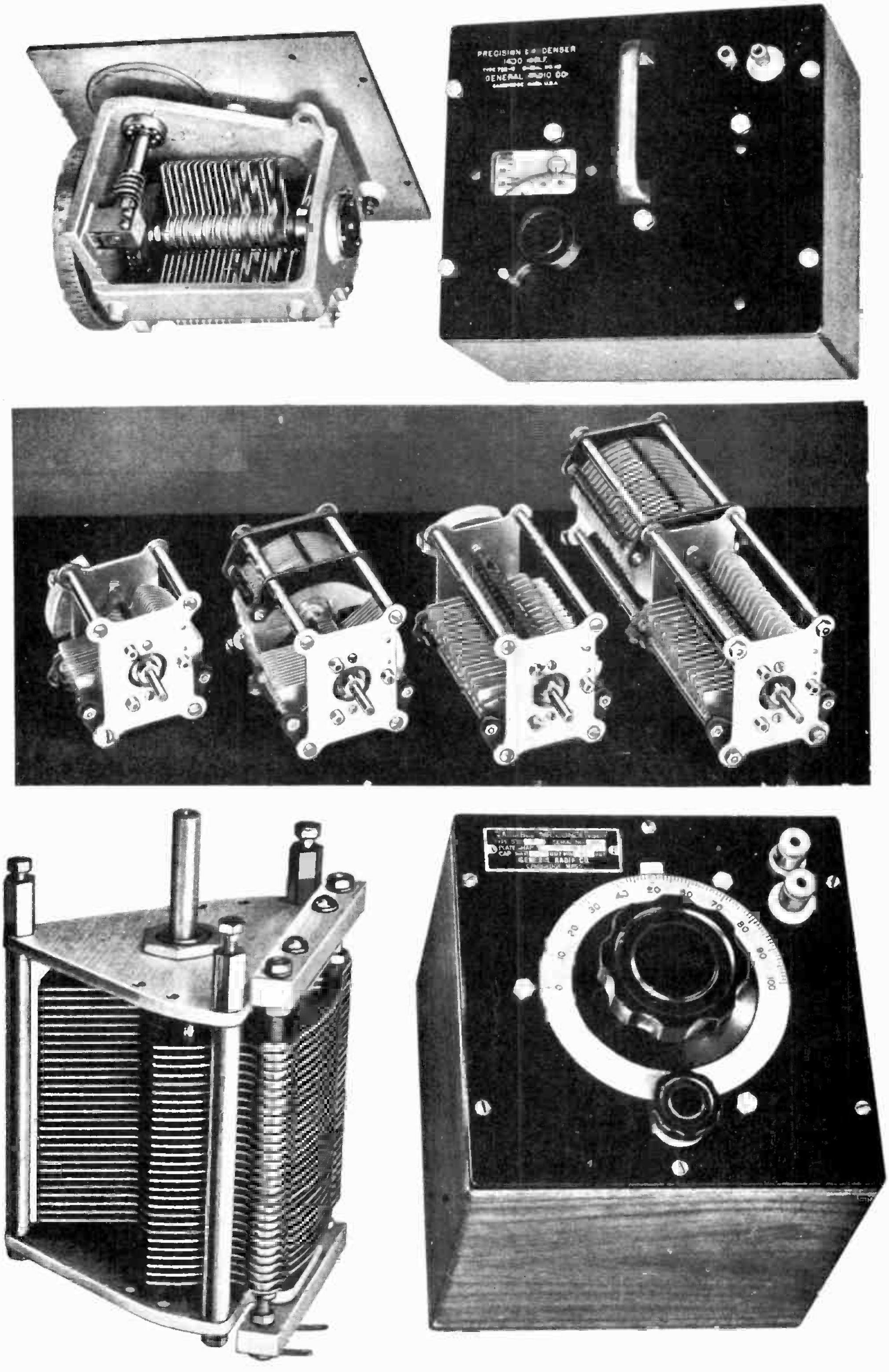
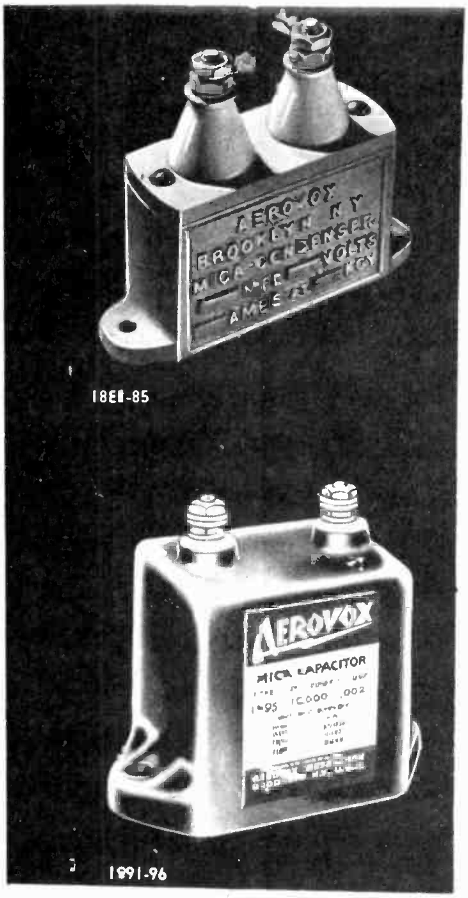
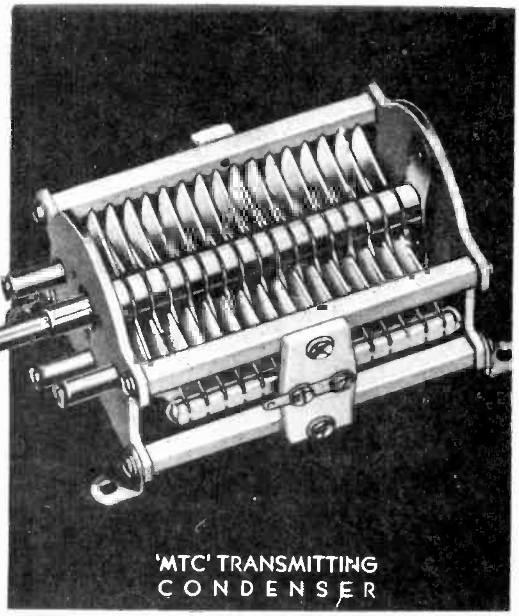
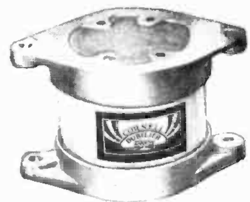


PLATE 1.




'MTC' TRANSMITTING CONDENSER

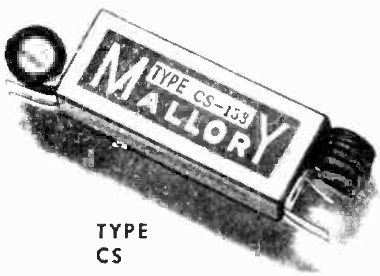

TYPE 40


TYPES 50 to 59

TYPE TX


TYPE TA
Dykanol filled heavy duty transmitting filter condensers that are an answer to high voltage filter problems. High tension insulators; hermetically sealed containers.

PLATE 2.



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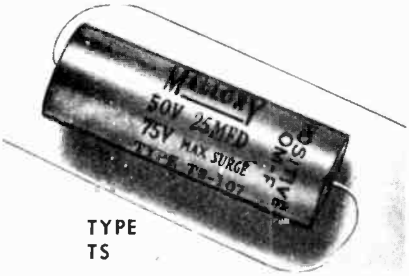

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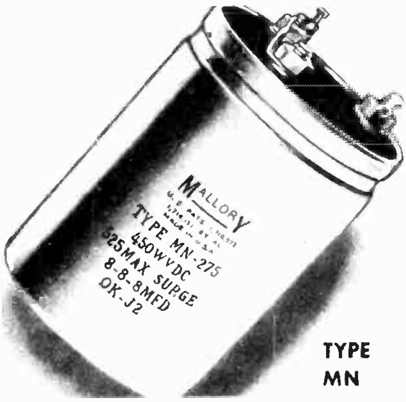

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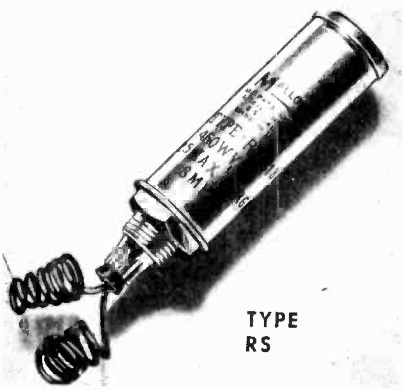

TYPE
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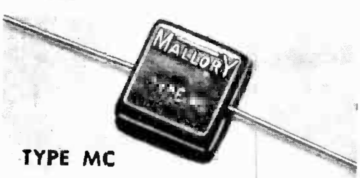
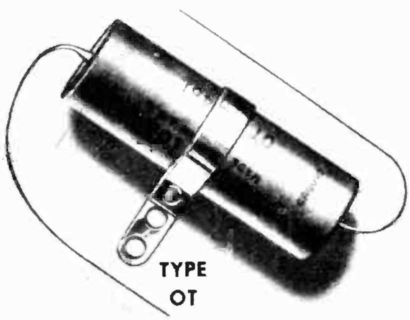


TYPE MC

TYPE EY
SCREW
MOUNTED

TYPE EX
RING
MOUNTED

TYPE
OW



TYPE
OT

TYPE
UB

PLATE 3.

CONDENSERS USED IN RADIO

RATING--LOSSES--STRAY CAPACITIES.

CONDENSERS MAY BE SEPARATED INTO TWO GENERAL CLASSIFICATIONS, VARIABLE AND FIXED. BOTH TYPES HAVE A WIDE VARIETY OF USES AND BOTH ARE AVAILABLE IN MANY DIFFERENT VALUES OF CAPACITY, OPERATING VOLTAGE, AND PHYSICAL DIMENSIONS TO MEET THE REQUIREMENTS OF THE VARIOUS CIRCUITS AND PURPOSES FOR WHICH THEY MAY BE USED.

PLATES 1, 2 AND 3 ILLUSTRATE A NUMBER OF TYPES OF CONDENSERS FOR A NUMBER OF PURPOSES. THE ILLUSTRATIONS ARE USED BY COURTESY AEROVOX CORPORATION, CORNELL DUBILIER CORPORATION, GENERAL RADIO COMPANY, HAMMARLUND MFG. COMPANY, AND P. R. MALLORY AND CO. IT IS BELIEVED THAT THE INFORMATION LISTED ON THE CONDENSERS WILL MAKE THESE PLATES SELF-EXPLANATORY WHEN REFERRED TO IN CONNECTION WITH THIS ASSIGNMENT.

VARIABLE CONDENSERS: VARIABLE CONDENSERS MAY BE DIVIDED INTO TWO GENERAL DIVISIONS, "RECEIVING" AND "TRANSMITTING". THE PRINCIPAL DIFFERENCE BETWEEN RECEIVING AND TRANSMITTING CONDENSERS IS IN THEIR PHYSICAL DIMENSIONS. IN A TRANSMITTER THE CONDENSER IS SUBJECTED TO MUCH HIGHER VOLTAGES THAN WHEN USED IN RECEIVER CIRCUITS. IN A RECEIVER THE RADIO FREQUENCY CIRCUITS IN WHICH VARIABLE CONDENSERS ARE USED CARRY ONLY VERY SMALL CURRENTS--MICROAMPERES AND MILLIAMPERES--AND THE REACTIVE VOLTAGE IX_C ACROSS THE CONDENSER IS NEGLIGIBLE. THE HIGHEST TUBE PLATE POTENTIAL NORMALLY USED IN A RECEIVER R.F. OR I.F. CIRCUIT IS 250 VOLTS AND USUALLY DOES NOT EXCEED 150 VOLTS, AND THE VARIABLE CONDENSER IS SELDOM SUBJECTED TO THE D.C. PLATE POTENTIAL. THUS IN THE CASE OF A VARIABLE CONDENSER FOR USE IN A RECEIVER, THE DIELECTRIC IS AIR AND THE SPACING BETWEEN PLATES IS USUALLY NOT GREATER THAN 1/16TH INCH, AND IS OFTEN LESS, BECAUSE THERE IS NO DANGER OF VOLTAGE BREAKDOWN OF THE AIR BETWEEN THE PLATES.

THE PRINCIPAL CONSIDERATION IN THE DESIGN OF SUCH A CONDENSER IS THAT OF

MECHANICAL CONSTRUCTION. IF THE SPACING BETWEEN PLATES IS MADE TOO SMALL, IT BECOMES MECHANICALLY DIFFICULT TO PROPERLY LINE UP THE PLATES IN ASSEMBLY, AND TO BE ASSURED THAT AFTER MONTHS OR YEARS OF SERVICE THE TWO SETS OF PLATES WILL NOT TOUCH AND SHORT-CIRCUIT THE CONDENSER. WITH THE PLATES QUITE CLOSE TOGETHER IT IS POSSIBLE, WITH COMPARATIVELY SMALL PLATE AREA AND A LIMITED NUMBER OF PLATES, TO OBTAIN REASONABLY LARGE VALUES OF CAPACITY WITH CONDENSERS OF QUITE SMALL PHYSICAL DIMENSIONS.

FOR TRANSMITTING VARIABLE CONDENSERS THE OPERATING CONDITIONS ARE GREATLY DIFFERENT. CONSIDER THE PLATE TANK CIRCUIT OF A MEDIUM POWER TRANSMITTER OPERATING AT A FREQUENCY OF 2000 KC/S, THE VARIABLE CONDENSER CAPACITY SET AT 100 $\mu\mu F$ AND 10 AMPERES OF CURRENT IN THE CIRCUIT. THE CAPACITY REACTANCE OF THE CONDENSER AT THIS FREQUENCY IS:

$$X_C = \frac{1}{2\pi FC} = \frac{1}{6.28 \times 2 \times 10^6 \times 10^{-10}} = \frac{10^6}{1256} = 796\ \Omega$$

THE R.F. CURRENT IN THE CIRCUIT IS 10 AMPERES SO THAT THE R.M.S. VOLTAGE ACROSS THE CONDENSER, $IX_C = 7960$ VOLTS. THE PEAK VOLTAGE IS 1.41 TIMES GREATER OR 11,224 VOLTS.

THE VOLTAGE REQUIRED TO JUMP AN AIR GAP OF ONE INCH IS APPROXIMATELY 28,000 VOLTS. THUS TO TAKE CARE OF SURGES AND CIRCUIT CURRENTS WHICH MAY UNDER SOME ADJUSTMENTS CONSIDERABLY EXCEED THE ASSUMED VALUE OF 10 AMPERES, THE SPACING BETWEEN THE CONDENSER PLATES SHOULD BE NOT LESS THAN 1/2 INCH. SINCE THE CONDENSER IS VARIABLE, THE SAME FREQUENCY MAY BE OBTAINED IN ADJUSTMENT WITH MORE INDUCTANCE AND LESS CAPACITY. AS THE CAPACITY IS DECREASED, THE FREQUENCY BEING UNCHANGED, THE CAPACITY REACTANCE X_C IS INCREASED SO THAT WITH THE SAME CIRCUIT CURRENT THE VOLTAGE ACROSS THE CONDENSER WILL BE INCREASED. THIS IS THE REASON WHY IN TRANSMITTER TUNED CIRCUIT ADJUSTMENTS A LARGE L/C RATIO WITH A GIVEN CIRCUIT CURRENT WILL OFTEN CAUSE ARCING BETWEEN PLATES OF THE VARIABLE CONDENSER, WHILE THE SAME CONDENSER WILL OPERATE SATISFACTORILY WITH A SMALLER

L/C RATIO, THAT IS, WITH LARGER C AND SMALLER L FOR THE SAME RESONANT FREQUENCY.

IN EVEN COMPARATIVELY LOW POWER TRANSMITTERS THE RADIO FREQUENCY VOLTAGES MAY REACH QUITE LARGE VALUES SO THAT TRANSMITTING VARIABLE CONDENSERS ARE NORMALLY BUILT WITH THE SPACING BETWEEN PLATES OF 3/16TH INCH OR MORE. FOR HIGH POWER OPERATION THE PLATE SPACING MAY BE AS GREAT AS SEVERAL INCHES. SINCE INCREASING THE DISTANCE BETWEEN CONDENSER PLATES DECREASES THE CAPACITY, FOR A GIVEN CAPACITY AS THE SPACING IS INCREASED THE PLATE AREA MUST ALSO BE INCREASED. THUS WITH LARGER PLATES AND GREATER SPACING, THE PHYSICAL DIMENSIONS OF TRANSMITTING VARIABLE CONDENSERS WILL BE CONSIDERABLY GREATER THAN THOSE OF RECEIVING CONDENSERS, EVEN THOUGH THE CAPACITY USED IN A TRANSMITTER CIRCUIT FOR A GIVEN FREQUENCY IS USUALLY SMALLER THAN IN THE EQUIVALENT RECEIVER CIRCUIT.

THE CAPACITY OF A VARIABLE CONDENSER WILL BE VARIABLE OVER VERY DEFINITE LIMITS, THESE LIMITS OF COURSE DETERMINING THE TUNING RANGE OF A CIRCUIT IN WHICH THE INDUCTANCE IS FIXED. THE MAXIMUM CAPACITY IS OBTAINED WHEN THE TOTAL AREA OF THE VARIABLE PLATES IS WITHIN THE LIMITS OF THE FIXED PLATES. WITH VARIABLE CAPACITY AND FIXED INDUCTANCE, THE LOWEST FREQUENCY TO WHICH THE CIRCUIT WILL RESONATE IS DETERMINED BY THE MAXIMUM CAPACITY. HOWEVER WITH A COIL OF DIMENSIONS AS DETERMINED FOR THE LOWEST FREQUENCY, THE ACTUAL TUNING RANGE OF THE CIRCUIT IS DETERMINED BY THE MINIMUM VALUE OF CAPACITY THAT CAN BE OBTAINED. NO VARIABLE CONDENSER HAS ZERO CAPACITY AT ITS MINIMUM SETTING BECAUSE EVEN THOUGH THE VARIABLE PLATES DO NOT EXTEND WITHIN THE LIMITS OF THE FIXED PLATES, THERE IS STILL CONSIDERABLE CAPACITY BETWEEN THE EDGES OF THE TWO SETS OF PLATES. (THE MINIMUM CAPACITY IS USUALLY MADE APPROXIMATELY 10 PERCENT OF THE MAXIMUM.)

THE PERCENTAGE CHANGE IN CIRCUIT WAVELENGTH OR FREQUENCY THAT CAN BE EFFECTED WITH A GIVEN COIL AND A GIVEN VARIABLE CONDENSER IS DETERMINED BY THE AVAILABLE PERCENTAGE CHANGE IN CAPACITY.

CONDENSERS USED IN RADIO

$$\lambda = 1884\sqrt{LC} \qquad F = \frac{1}{2\pi\sqrt{LC}}$$

WAVELENGTH VARIES AS THE SQUARE-ROOT OF THE VARIATION OF CAPACITY AND FREQUENCY VARIES INVERSELY AS THE SQUARE-ROOT OF THE CAPACITY VARIATION. IF, WITH A GIVEN COIL AND CONDENSER COMBINATION, THE MAXIMUM CAPACITY IS 270 μμF AND THE MINIMUM CAPACITY IS 30 μμF, AND THE MINIMUM FREQUENCY OBTAINABLE IS 600 KC/S, THEN WITH A CAPACITY VARIATION OF 270/30 OR 9/1, THE FREQUENCY, VARYING INVERSELY AS $\sqrt{9/1}$ OR AS 3/1, CAN BE INCREASED TO 600 x 3 OR 1800 KC/S BY VARYING THE CONDENSER FROM MAXIMUM TO MINIMUM CAPACITY SETTING. IN TERMS OF WAVELENGTH, THE SAME CIRCUIT WILL HAVE A MAXIMUM λ OF 500 METERS AND A MINIMUM λ OF 500/3 OR 166.6 METERS.

A CONSIDERATION OF THESE FIGURES WILL SHOW THAT, SINCE A COIL MUST BE SELECTED SUCH THAT WITH THE MAXIMUM CAPACITY A SPECIFIED MINIMUM FREQUENCY CAN BE OBTAINED, THE ACTUAL TUNING RANGE OF THE CIRCUIT IS DETERMINED BY THE MINIMUM CAPACITY. IN THIS CIRCUIT ADDING 10 TO THE 270 μμF MAXIMUM WOULD ONLY INCREASE THE CAPACITY RATIO TO 280/30 OR 9.33 AND THE λ RANGE TO $\sqrt{9.33}$ OR 3.05, AN INCREASE OF 1.63 PERCENT. IF THE MAXIMUM IS LEFT AT 270 μμF AND THE MINIMUM DECREASED TO 20 μμF, THE CAPACITY VARIATION WILL BE 270/20 OR 13.5 AND THE λ RANGE $\sqrt{13.5}$ OR 3.67, AN INCREASE OF 22 PERCENT.

IN MANY OF THE OLDER BROADCAST RECEIVERS, TUNING TO 550 KC/S—THE LOWER FREQUENCY END OF THE BAND—WAS SATISFACTORY, BUT DUE TO THE HIGH MINIMUM CAPACITY CAUSED BY FAULTY CONDENSER DESIGN AND STRAY CAPACITIES OF TUBE, SOCKET AND WIRING, THE HIGHER FREQUENCY OF 1500 COULD NOT BE REACHED. IN MOST PRESENT-DAY RECEIVERS THE BROADCAST BAND TUNING EXTENDS FROM ABOUT 530 KC/S TO ABOVE 1600 KC/S.

VARIABLE CONDENSERS ARE MADE WITH PLATES OF VARIOUS SHAPES FOR VARIOUS PURPOSES. WHERE IT IS DESIRED THAT THE VARIATION OF CAPACITY PER DEGREE OF DIAL SETTING BE THE SAME OVER THE ENTIRE DIAL FROM MINIMUM TO MAXIMUM CAPACITY, THE CONDENSER IS CALLED A "STRAIGHT LINE CAPACITY" CONDENSER AND THE PLATES ARE

SEMI-CIRCULAR. SUCH A CONDENSER MAY BE USED FOR MEASUREMENTS OF CAPACITY AND FOR ANY PURPOSE WHERE SUCH A CHARACTERISTIC IS DESIRED. IF SUCH A CONDENSER IS USED IN A WAVEMETER OR FREQUENCY METER, SINCE THE VARIATION OF λ AND F ARE FUNCTIONS OF THE $\sqrt{C}$, IF EITHER λ OR F IS PLOTTED ON A GRAPH AGAINST CONDENSER DIAL SETTINGS A CURVE WILL RESULT, WHILE THE CAPACITY OF SUCH A CONDENSER IS PLOTTED A STRAIGHT LINE SHOULD RESULT, (EXCEPT WITHIN A VERY FEW DIAL DIVISIONS OF THE MINIMUM CAPACITY SETTING AND SOMETIMES RIGHT NEAR MAXIMUM WHERE THE PLOTTED LINE USUALLY DEVIATES FROM THE STRAIGHT LINE). SEE FIGURE 1. IT SHOULD BE OBSERVED THAT WHILE THE GRAPHS OF BOTH λ AND F ARE CURVES FOR STRAIGHT LINE C, λ INCREASES WITH INCREASE OF C WHILE F DECREASES WITH INCREASE OF C. THIS IS IN ACCORDANCE WITH THE EQUATIONS.

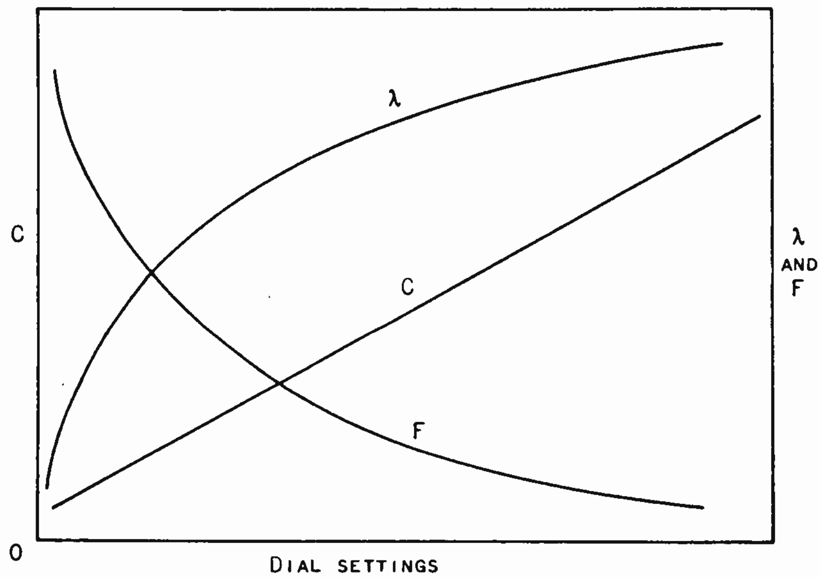


FIG. 1.

FOR FREQUENCY METERS AND FOR RADIO RECEIVERS IT IS USUALLY DESIRABLE THAT THE FREQUENCY CHANGE PER DIAL DIVISION BE THE SAME AT ALL POINTS ON THE DIAL. TO OBTAIN SUCH A GRAPH THE CONDENSER PLATES SHOULD BE SO SHAPED THAT THE CAPACITY VARIES INVERSELY AS F^2. SUCH A CONDENSER IS CALLED A "STRAIGHT LINE FREQUENCY" CONDENSER.

IF IT IS DESIRED THAT THE WAVELENGTH OF THE TUNED CIRCUIT PLOTTED AGAINST

DIAL SETTINGS VARY IN THE FORM OF A STRAIGHT LINE THEN, SINCE λ VARIES DIRECTLY AS $\sqrt{C}$, THE CONDENSER PLATES MUST BE SO SHAPED THAT C VARIES AS λ^2. SUCH A CONDENSER IS CALLED A "STRAIGHT LINE WAVELENGTH" CONDENSER. IN THE CASE OF EITHER THE STRAIGHT LINE λ OR STRAIGHT LINE F CONDENSER, THE CAPACITY PLOTTED AGAINST DIAL SETTINGS WILL RESULT IN A CURVE.

FIGURE 2 ILLUSTRATES THE SHAPE OF PLATES REQUIRED FOR EACH OF THE THREE TYPES OF CONDENSERS DISCUSSED. THE DOT ON EACH PLATE REPRESENTS THE SHAFT AND THE POINT ABOUT WHICH THE PLATE ROTATES.

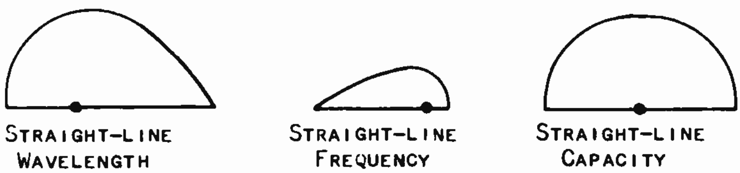


FIG. 2.

SPLIT CAPACITIES: IN CERTAIN RADIO FREQUENCY CIRCUITS, SUCH AS THE INPUT AND OUTPUT CIRCUITS OF A PUSH-PULL STAGE, IT IS DESIRABLE TO HAVE THE CAPACITY OF THE CONDENSER SYMMETRICAL AT TWO POINTS WITH RESPECT TO GROUND. SUCH A CIRCUIT ARRANGEMENT IS SHOWN IN FIGURE 3. IT IS ALSO USUALLY DESIRABLE TO HAVE THE MOVABLE PLATES OF THE CONDENSER AT GROUND POTENTIAL SO THAT THE CIRCUIT IS NOT DETUNED BY BODY CAPACITY TO GROUND WHEN THE HAND IS PLACED ON THE DIAL, WHICH OF COURSE IS MOUNTED ON THE SHAFT CONNECTING TO THE MOVABLE PLATES. (IT IS CONSIDERED STANDARD PRACTICE IN ALL CIRCUITS EMPLOYING VARIABLE CONDENSERS, EITHER SPLIT OR SINGLE SECTION, TO CONNECT THE MOVABLE PLATES AT GROUND POTENTIAL.)

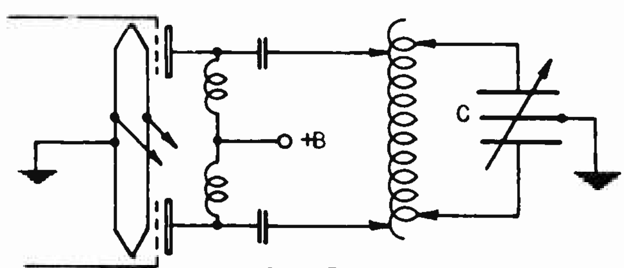


FIG. 3.

IN THE CONDENSER SHOWN AS C IN FIGURE 3 THE FIXED PLATE ASSEMBLY IS SPLIT WITH INSULATORS INTO TWO SECTIONS AND THE MOVABLE PLATES FOR BOTH SECTIONS ARE MOUNTED ON A COMMON METAL SHAFT. THE TWO CONDENSERS OPERATE AS ONE, EACH OF

THE SETS OF FIXED PLATES BEING AT HIGH POTENTIAL, AND THE TOTAL CIRCUIT CAPACITY IS EQUAL TO ONE-HALF THE CAPACITY OF A SINGLE SECTION BECAUSE THE TWO SECTIONS ARE IDENTICAL AND IN SERIES.

IN THE CIRCUIT SHOWN IN FIGURE 3 WHERE BOTH SIDES OF THE CIRCUIT MUST BE SYMMETRICAL WITH RESPECT TO GROUND, THE CAPACITIES OF THE TWO SECTIONS SHOULD BE EQUAL. IN CERTAIN TYPES OF CIRCUITS, SUCH AS ONE USED IN A CERTAIN PRECISION TYPE OF HETERODYNE FREQUENCY METER, A SYMMETRICAL ARRANGEMENT IS NOT DESIRED. IN THAT CIRCUIT THE CONDENSER IS ARRANGED EXACTLY AS IN FIGURE 3 EXCEPT THAT THE CAPACITY OF ONE SECTION IS THREE TIMES AS GREAT AS THAT OF THE OTHER SECTION AT MAXIMUM AND GOES THROUGH A MUCH SMALLER PERCENTAGE CHANGE OVER THE VARIABLE LIMITS. AT ANY SETTING THE TOTAL CAPACITY OF THE CIRCUIT IS COMPUTED ON THE BASIS OF THE TWO CAPACITIES IN SERIES.

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

FOR EXAMPLE, ASSUME THAT C_1 IN FIGURE 4 HAS MAXIMUM OF 500 $\mu\mu F$ AND MINIMUM OF 50 $\mu\mu F$, AND THAT C_2 HAS MAXIMUM OF 1500 $\mu\mu F$ AND MINIMUM OF 500 $\mu\mu F$. THE TWO ARE GANGED TOGETHER SO THAT THEIR MAXIMUM OR MINIMUM CAPACITIES ARE OBTAINED SIMULTANEOUSLY. AT THE MAXIMUM CAPACITY SETTING THE TOTAL CIRCUIT CAPACITY IS,

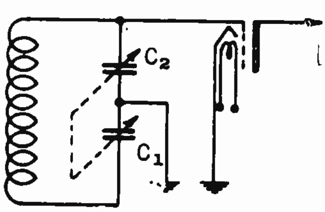


FIG. 4.

$$C = \frac{1}{\frac{1}{500} + \frac{1}{1500}} = 375 \ \mu\mu F.$$

AT THE MINIMUM CAPACITY SETTING,

$$C = \frac{1}{\frac{1}{50} + \frac{1}{500}} = 45 \ \mu\mu F.$$

THE TOTAL CIRCUIT CAPACITY VARIATION OVER THE TUNING RANGE IS FROM 375 TO 45, A RANGE OF 8.3 : 1. THE VARIATION OF FREQUENCY IS $\sqrt{8.3}$: 1 OR 2.9 : 1. IT SHOULD BE OBSERVED THAT A GOOD CAPACITY AND FREQUENCY VARIATION IS OBTAINED.

THE TOTAL FREQUENCY VARIATION IS 2.9 : 1. HOWEVER THE GRID AND FILAMENT OF THE TUBE ARE CONNECTED ACROSS ONLY C_2, THE CAPACITY OF WHICH VARIES FROM 1500 µµF TO 500 µµF, OR OVER A CAPACITY RANGE OF 3 : 1. THIS IS ALMOST EXACTLY THE SAME AS THE CIRCUIT FREQUENCY RANGE (2.9 : 1) <u>BUT IN THE REVERSE DIRECTION</u>. THAT IS, AS C_2 IS INCREASING, F IS DECREASING. $X_C = \frac{1}{2\pi FC}$. IF F IS MADE TO VARY INVERSELY AS C AND BY THE SAME AMOUNT, X_C REMAINS CONSTANT. WITH THE FIGURES SHOWN ABOVE THIS IS ESSENTIALLY TRUE. IF THE R.F. CURRENT IN THE CIRCUIT IS FAIRLY UNIFORM OVER THE FREQUENCY BAND, THE VOLTAGE ACROSS C_2, ($E_{C_2} = IX_{C_2}$), IS ESSENTIALLY CONSTANT. SINCE E_{C_2} IS THE EXCITATION VOLTAGE FOR THE TUBE, IF THIS CIRCUIT IS USED TO TUNE AN R.F. OSCILLATOR, THE OSCILLATOR EXCITATION AND OUTPUT CAN BE MAINTAINED QUITE UNIFORM OVER A CONSIDERABLE RANGE OF FREQUENCIES.

A MORE COMMON APPLICATION OF THE USE OF SERIES CAPACITIES IS FOUND IN EVERY SUPERHETERODYNE RECEIVER IN WHICH AT LEAST TWO AND USUALLY THREE CIRCUITS MUST BE TUNED BY A SINGLE DIAL. FOR ECONOMIC REASONS AND FOR SIMPLICITY OF CONSTRUCTION IT WOULD BE DESIRABLE TO USE A SIMPLE THREE SECTION VARIABLE CONDENSER IN WHICH ALL THREE SECTIONS ARE IDENTICAL. THIS CAN BE DONE BY THE USE OF A SOMEWHAT ELABORATE FIXED CONDENSER PADDING COMBINATION IN THE OSCILLATOR CIRCUIT. THAT TYPE OF CIRCUIT WILL NOT BE DISCUSSED AT THIS POINT. THE ALTERNATIVE IS TO USE SLIGHTLY DIFFERENTLY SHAPED PLATES IN THE VARIABLE CONDENSER SECTION WHICH TUNES THE OSCILLATOR.

AS WILL BE SEEN, THE OSCILLATOR CIRCUIT, WHILE IT TUNES OVER THE SAME NUMBER OF KILOCYCLES AS THE R.F. AMPLIFIER AND THE FIRST DETECTOR, DOES SO IN A SOMEWHAT DIFFERENT FREQUENCY BAND AND HENCE THE RATIO OF MAXIMUM TO MINIMUM FREQUENCY IS DIFFERENT. IT WILL BE SHOWN THAT THIS INTRODUCES DIFFICULTY IN MAKING THE TUNED CIRCUITS "TRACK"; THAT IS, THE OSCILLATOR AND R.F. AMPLIFIER CIRCUITS MAY BE SEPARATED BY THE SAME INTERMEDIATE FREQUENCY AT THE MAXIMUM AND MINIMUM CONDENSER SETTINGS, BUT BY DIFFERENT FREQUENCIES AT THE INTERMEDIATE CONDENSER SETTINGS. TO COMPENSATE FOR THIS DIFFICULTY, THE OSCILLATOR CONDENser plates are shaped a little differently than those of the R.F. condenser section.

An example of the calculations, in their most simple form, for the R.F. and oscillator variable condenser requirements, the oscillator "padding" condenser, and the circuit inductances will be shown below. It is assumed that the oscillator and R.F. variable condensers have the same maximum and minimum values of C_1 but slightly different plate shape.

Assume that the R.F. amplifier and the first detector grid circuit are to cover a frequency range of 550 – 1650 KC/s, and that the intermediate frequency is to be 450 KC/s, the oscillator frequency to be that much higher than the signal frequency at all dial settings. The oscillator frequency range is then (550 + 450) to (1650 + 450) or 1000 KC/s to 2100 KC/s.

The signal frequency range, 1650 – 550 KC/s, is a ratio of 3 : 1. Since the tuning capacity is inversely proportional to F^2, the variable condenser must have a capacity ratio of 1 : 9. If the variable condenser C_V has maximum capacity of 360 μμF, minimum capacity must be 40 μμF. To cover the specified frequency band with such a condenser the coil must have inductance of 233 μH. (Calculated by means of LC Tables. The equation is, $F = \frac{1}{2\pi\sqrt{LC}}$, L and C in units.) The tuned circuit is shown schematically in Figure 5. This is a simple tuned circuit coupled to the antenna and to the grid of the first tube which may be either an R.F. amplifier or a first detector stage. There is no particular tuning problem involved. The small trimmer condenser across C_V is simply for fine adjustments of minimum or maximum.

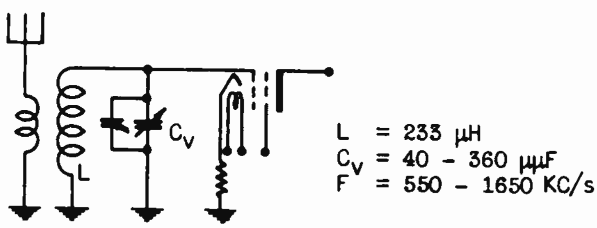


Fig. 5.

Consider the oscillator circuit. First, the frequency range is higher—

1000 TO 2100 KC/S AS COMPARED WITH THE SIGNAL FREQUENCY RANGE OF 550 TO 1650 KC/S. THE FACT THAT THE FREQUENCIES INVOLVED ARE HIGHER OFFERS NO COMPLICATIONS BECAUSE THAT COULD BE COMPENSATED FOR BY THE USE OF A SMALLER COIL. HOWEVER THE TUNING RATIO--THE RATIO BETWEEN THE HIGHEST AND LOWEST FREQUENCY--IS DIFFERENT. THE FREQUENCY RATIO IS NOW 2100 : 1000 = 2.1 : 1 AND THE CORRESPONDING CAPACITY RATIO IS $2.1^2 : 1 = 4.41 : 1$. BUT THE VARIABLE CONDENSER SECTION IT IS DESIRED TO USE HAS A CAPACITY RANGE OF 360 – 40 µµF AND A CAPACITY RATIO OF 9 : 1. THIS IS TAKEN CARE OF BY THE USE OF A "PADDING" CONDENSER C_x AS SHOWN IN FIGURE 6.

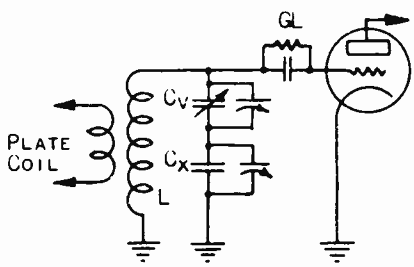


FIG. 6.

A PRELIMINARY CALCULATION FOR C_x CAN BE MADE ON THE ASSUMPTION THAT C_x IS LARGE COMPARED WITH THE MINIMUM VALUE OF C_v SO THAT AT A MINIMUM SETTING OF C_v THE TOTAL CIRCUIT CAPACITY C IS NOT GREATLY DECREASED BY THE ADDITION OF C_x IN SERIES. ASSUME THAT WITH C_v AT MINIMUM OF 40 µµF THE CONNECTION OF C_x IN SERIES DECREASES C BY 10 PERCENT OR TO 36 µµF. IT HAS BEEN SHOWN THAT AT MAXIMUM SETTING OF C_v, C MUST BE 4.41 TIMES THE VALUE AT MINIMUM, OR $4.41 \times 36 = 159$ µµF. THE PROPER VALUE OF C_x TO OBTAIN THIS CONDITION IS CALCULATED FROM THE BASIC EQUATION AS FOLLOWS:

$$C = \frac{1}{\frac{1}{C_v} + \frac{1}{C_x}} \qquad \text{AND } C_x = \frac{1}{\frac{1}{C} - \frac{1}{C_v}}$$

$$C_x = \frac{1}{\frac{1}{159} - \frac{1}{360}} = 284 \ \mu\mu F.$$

AT MINIMUM,

$$C = \frac{1}{\frac{1}{C_v} + \frac{1}{C_x}} = \frac{1}{\frac{1}{40} + \frac{1}{284}} = 35 \ \mu\mu F$$

THIS IS ONLY 1 µµF FROM THE ASSUMED VALUE AND CAN EASILY BE TAKEN CARE OF BY THE TRIMMER CONDENSERS.

FROM LC TABLES IT IS FOUND THAT INDUCTANCE OF 160 µH IS REQUIRED WITH CA-

PACITY OF 36 μμF FOR THE HIGH OSCILLATOR FREQUENCY OF 2100 KC/S.

IT SHOULD BE UNDERSTOOD THAT THE ABOVE FIGURES ARE ONLY CLOSE APPROXIMATIONS WHICH HAVE NOT TAKEN INTO CONSIDERATION THE STRAY CAPACITY OF TUBE, SOCKET, WIRING, ETC. IN THE ACTUAL DESIGN OF A RECEIVER THE STRAY CAPACITIES MUST BE CAREFULLY CONSIDERED. ALSO IT MUST BE UNDERSTOOD THAT IT IS IMPRACTICAL TO DESIGN CIRCUITS AND CAPACITIES WHICH IN PRODUCTION WILL BE ACCURATE TO WITHIN FRACTIONS OF A MICROMICROFARAD. THAT IS THE REASON WHY A TRIMMER CONDENSER IS CONNECTED ACROSS EACH MAJOR CONDENSER TO ALLOW FOR SMALL DISCREPANCIES IN CONDENSER CAPACITIES, STRAY CAPACITIES, ETC., WHICH CANNOT BE ACCURATELY CALCULATED. THUS EVEN AFTER THE CIRCUIT CONSTANTS ARE CAREFULLY CALCULATED AND PRODUCTION STANDARDIZED TO A HIGH DEGREE OF ACCURACY. **THE ALIGNMENT PROCESS IS ONE** OF THE MOST IMPORTANT JOBS AND CALLS FOR A HIGH DEGREE OF SKILL AND CARE.

CALCULATION SHOWS THAT THE CIRCUITS AS DESIGNED ABOVE "LINE UP" AT THE MAXIMUM AND MINIMUM POINTS. THAT IS, AT MAXIMUM VALUES OF C_V, I.F. = 1000 KC/S − 550 KC/S = 450 KC/S, AND AT MINIMUM VALUES OF C_V, I.F. = 2100 KC/S − 1650 KC/S = 450 KC/S. CONSIDER SOME INTERMEDIATE POINT. ASSUME THAT IN THE R.F. CIRCUIT THE VARIABLE CONDENSER IS ADJUSTED TO A CAPACITY OF 200 μμF. CALCULATION SHOWS THAT THIS CIRCUIT WILL NOW RESONATE AT A FREQUENCY OF 737.5 KC/S. THE OSCILLATOR FREQUENCY SHOULD THEN BE 737.5 + 450 = 1187.5 KC/S. THE OSCILLATOR CIRCUIT INDUCTANCE IS 160 μH. CALCULATIONS SHOW THAT WITH THIS VALUE OF L, AT 1187.5 KC/S CIRCUIT CAPACITY C SHOULD BE 112 μμF.

$$C = \frac{1}{\frac{1}{C_V} + \frac{1}{C_X}} \qquad \text{AND } C_V = \frac{1}{\frac{1}{C} - \frac{1}{C_X}}$$

$$C_V = \frac{1}{\frac{1}{112} - \frac{1}{284}} = 185\ \mu\mu F.$$

THIS SIMPLE CALCULATION CLEARLY DEMONSTRATES THAT THE OSCILLATOR VARIABLE CONDENSER MUST HAVE DIFFERENTLY SHAPED PLATES THAN THAT IN THE R.F. SIGNAL CIRCUIT. AT C_V = 200 μμF IN THE R.F. CIRCUIT, IN THE OSCILLATOR CIRCUIT C_V = 185

$\mu\mu F$ IN ORDER THAT THE TWO CIRCUITS MAY TRACK. BY MAKING SIMILAR CALCULATIONS AT SEVERAL VALUES OF R.F. CIRCUIT C_V, A CURVE MAY BE DRAWN SHOWING THE REQUIRED VALUES OF OSCILLATOR C_V FOR ALL VALUES OF R.F. CIRCUIT C_V. THE CONDENSER PLATES MUST THEN BE SHAPED TO PRODUCE THAT CAPACITY CURVE.

VARIABLE CONDENSERS ARE MADE IN MANY DIFFERENT VALUES OF CAPACITY FOR VARIOUS PURPOSES. RECEIVING CONDENSERS ARE COMMONLY MADE WITH CAPACITIES OF 100, 150, 250, 350, 500 $\mu\mu F$ FOR USE IN TUNED CIRCUITS. SMALL VARIABLE PADDING AND TRIMMER CONDENSERS, NEUTRALIZING CONDENSERS, ETC., COMMONLY HAVE CAPACITIES OF 15 TO 50 $\mu\mu F$. TRANSMITTING VARIABLE CONDENSERS HAVE CAPACITIES OF 50, 75, 100, 150, 250 $\mu\mu F$. LABORATORY CONDENSERS, CONDENSERS IN LONG WAVE RECEIVERS, AND IN LOW FREQUENCY FREQUENCY METERS COMMONLY HAVE CAPACITIES OF 1000, 1500, 2000, 3000 $\mu\mu F$. (ALL OF THE VALUES ABOVE ARE FOR MAXIMUM RATED CAPACITY.) IN ORDINARY COMMERCIAL VARIABLE CONDENSERS THERE IS CONSIDERABLE MANUFACTURING TOLERANCE SO THAT A CONDENSER RATED AT 500 $\mu\mu F$ MAY ACTUALLY HAVE A MAXIMUM CAPACITY OF 520 $\mu\mu F$. HIGH GRADE PRECISION CONDENSERS ARE USUALLY SUPPLIED BY THE MANUFACTURER WITH A CALIBRATION CURVE FOR THE INDIVIDUAL CONDENSER. ALL RADIO FREQUENCY LABORATORIES HAVE FACILITIES FOR CALIBRATING CONDENSERS SO IT IS NOT DIFFICULT TO GET AN ACCURATE CALIBRATION CURVE FOR ANY GOOD CONDENSER IF ONE IS REQUIRED FOR MEASUREMENT OR COMPARISON PURPOSES.

FIXED CONDENSERS: FIXED CONDENSERS ARE CONDENSERS IN WHICH THE CAPACITY IS FIXED. A FIXED CONDENSER MAY CONSIST OF TWO SETS OF PLATES WITH AIR DIELECTRIC SIMILAR TO THE VARIABLE CONDENSER EXCEPT THAT NO MEANS ARE PROVIDED FOR CHANGING THE RELATION BETWEEN THE TWO SETS OF PLATES. SUCH CONDENSERS ARE USED QUITE OFTEN IN COMPARATIVELY HIGH POWER TUBE TRANSMITTERS WHERE A COMPARATIVELY SMALL CAPACITY WITH A VERY HIGH BREAKDOWN VOLTAGE IS REQUIRED, AND WHERE AN EXACT VALUE OF CAPACITY MUST BE USED.

FIXED CONDENSERS ARE MORE COMMONLY MADE UP OF ALTERNATE LAYERS OF CONDUCTING PLATES SEPARATED BY AN INSULATING MATERIAL HAVING A HIGH BREAKDOWN VOLTAGE

AND A HIGH DIELECTRIC PERMEABILITY. THE HIGH BREAKDOWN VOLTAGE CHARACTERISTIC ALLOWS THE PLATES TO BE PLACED CLOSE TOGETHER, THIS COMBINING WITH THE HIGHER DIELECTRIC CONSTANT OF THE MICA OR OTHER INSULATING MATERIAL TO PERMIT A VERY MUCH LARGER CAPACITY TO BE OBTAINED WITH GIVEN PLATE AREA THAN COULD BE OBTAINED WITH THE SAME PLATE AREA AND BREAKDOWN VOLTAGE IN AN AIR DIELECTRIC CONDENSER.

FIXED CONDENSERS ARE MADE IN MANY SIZES AND FOR MANY PURPOSES. AS A WHOLE THE CAPACITY VALUES OF FIXED CONDENSERS RANGE MUCH HIGHER THAN THOSE OF VARIABLE CONDENSERS. THUS A FIXED CONDENSER OF .002 μF (2000 μμF) IS CONSIDERED AS HAVING A QUITE SMALL VALUE OF CAPACITY, WHILE IN A VARIABLE CONDENSER THIS WOULD APPROACH THE LARGEST SIZES BUILT. HOWEVER FIXED CONDENSERS ARE MANUFACTURED WITH CAPACITIES AS SMALL AS 2 μμF!

FIXED CONDENSERS FOR RADIO WORK MAY BE SEPARATED INTO THREE MAJOR CLASSIFICATIONS. FIRST, THOSE USED TO PASS RADIO FREQUENCY OR TO TUNE RADIO FREQUENCY CIRCUITS. DEPENDING ON THE FREQUENCY AT WHICH THE CIRCUIT IS TO BE OPERATED SUCH CONDENSERS RANGE IN STANDARD SIZES FROM .0001 μF TO ABOUT .004 μF. SECOND, THOSE USED IN BYPASS CIRCUITS FOR BOTH RADIO AND AUDIO FREQUENCIES. SUCH CONDENSERS WILL NORMALLY HAVE CAPACITIES OF FROM .01 μF TO ABOUT .5 μF, ALTHOUGH FOR CERTAIN TYPES OF CIRCUITS PASSING AUDIO FREQUENCIES, INDIVIDUAL CONDENSERS AS LARGE AS 4 μF MAY BE USED. THIRD, THOSE USED IN FILTER CIRCUITS IN COMBINATION WITH INDUCTIVE REACTANCE TO REMOVE HUM AND NOISE FREQUENCIES FROM POWER SUPPLIES. CONDENSERS FOR SUCH PURPOSE ARE NORMALLY MANUFACTURED IN 1 μF, 2 μF, AND 4 μF SIZES. (THIS DOES NOT INCLUDE ELECTROLYTIC CONDENSERS.)

<u>RATINGS OF CONDENSERS</u>: CONDENSERS FOR USE IN LOW FREQUENCY CIRCUITS AND FOR FILTERING DIRECT CURRENT CIRCUITS ARE NORMALLY RATED AT BOTH CAPACITY AND WORKING VOLTAGE. THUS A FILTER CONDENSER MAY BE RATED 4 μF - 5000 VOLTS AND SHOULD NOT BE USED IN A CIRCUIT IN WHICH THE VOLTAGE EXCEEDS THAT VALUE. WELL DESIGNED CONDENSERS ARE NORMALLY TESTED BY THE MANUFACTURER AT VOLTAGES OF FROM

50 TO 100 PERCENT ABOVE THE RATED VALUES SO THAT A GOOD CONDENSER CAN NORMALLY BE WORKED NEAR ITS RATED VALUE WITHOUT MUCH DANGER OF BREAKDOWN DUE TO SURGES AND RIPPLE VOLTAGES. IN THE DESIGN OF APPARATUS WHICH MUST OPERATE CONTINUOUSLY FOR MANY HOURS PER DAY, SUCH AS A BROADCAST TRANSMITTER, IT IS USUALLY LESS EXPENSIVE IN THE END TO SELECT CONDENSERS WITH A VOLTAGE RATING SOMEWHAT HIGHER THAN THAT AT WHICH THEY ARE TO BE OPERATED. WITH MODERN WELL DESIGNED FILTER CONDENSERS A SAFETY FACTOR OF 25 PERCENT SHOULD ASSURE SATISFACTORY OPERATION.

FIXED CONDENSERS FOR USE IN R.F. TANK CIRCUITS OF TRANSMITTERS, ANTENNA CIRCUITS, COUPLING, BLOCKING, AND BY-PASS APPLICATIONS IN WHICH THE CONDENSER CURRENTY MAY BE QUITE HIGH ARE RATED, IN ADDITION TO CAPACITY, AT THE CURRENT THEY CAN SAFELY CARRY AT SPECIFIED FREQUENCIES. SAMPLE RATINGS ARE GIVEN FOR MICA TYPE CONDENSERS:

CAP. µF	TYPE	TEST VOLTAGE EFFECTIVE	MAXIMUM CURRENT IN AMPERES 3000KC	1000KC	300KC	100 KC
.0006	A	30,000	30	20	12	4
.002	A	40,000	30	40	27	13
.004	A	25,000	35	45	32	20
.0001	B	10,000	6	3.5	1.5	.5
.0006	B	10,000	10	8	4	1.3
.02	B	3,000	20	30	22	15
.0001	C	3,000	2 AMP. AT 60 MC. (SPECIAL U.H.F. DESIGN)			

COURTESY CORNELL DUBILIER

THESE RATINGS ARE DETERMINED AS FOLLOWS: THE DIELECTRIC DETERMINES THE MAXIMUM VOLTAGE THAT CAN BE IMPRESSED ACROSS THE CONDENSER, WHEREAS THE METAL FOIL DETERMINES THE MAXIMUM CURRENT THAT CAN BE SAFELY PASSED. AT THE SAME TIME, THE RELATION BETWEEN THE ACTUAL CURRENT AND VOLTAGE IS GIVEN BY THE WELL-KNOWN FORMULA

$$E = \frac{I \times 10^6}{6.28 \times F \times C} = IX_C'$$

WHERE E IS THE R.M.S. VOLTAGE ACROSS THE CONDENSER, I IS THE R.M.S. CURRENT IN AMPERES, F IS THE FREQUENCY IN C.P.S., AND C IS THE CAPACITY IN MICROFARADS. AT VERY LOW FREQUENCIES $X_C = 10^6/6.28FC$ IS HIGH, SO THAT A VERY HIGH VOLTAGE IS REQUIRED ACROSS THE CONDENSER FOR EVEN A SMALL CURRENT, AND THE DIELECTRIC

LIMITS THE MAXIMUM VOLTAGE THAT CAN BE IMPRESSED, WHEREAS THE CURRENT FLOW IS SO SMALL AS NOT TO OVERHEAT THE METAL FOIL OR PLATES. HOWEVER, IN SOME CASES THE PLATES MUST BE ADEQUATE TO PASS LARGE CURRENTS, AND THE CONDENSER MAY BE LARGE IN CAPACITY. IF A SMALL CAPACITY IS DESIRED, SEVERAL LARGE CONDENSERS IN SERIES MUST BE USED. WHILE THE INDIVIDUAL CONDENSER RATINGS MAY NOT BE EXCEEDED, THE VOLTAGE BETWEEN TERMINALS OF THE ENTIRE CONDENSER MAY BE EXCESSIVE AND THE RATING ADJUSTED ACCORDINGLY.

AT VERY HIGH FREQUENCIES THE REACTANCE IS SO LOW THAT EVEN A SMALL VOLTAGE MAY CAUSE SUFFICIENT CURRENT TO FLOW TO MELT THE FOIL. THEREFORE THE CURRENT IS THE LIMITING FACTOR RATHER THAN THE VOLTAGE. IN THE FREQUENCY RANGE BETWEEN 300 - 1,000 KC BOTH FACTORS MAY REACH LIMITING VALUES SO THAT THEIR PRODUCT OR KVA IS USED TO RATE THE CONDENSER.

AT HIGH FREQUENCIES ADDITIONAL LOSSES OCCUR OWING TO DIELECTRIC LOSSES, EDDY CURRENTS IN THE METAL FOIL, ETC. THESE PRODUCE HEATING EFFECTS WHICH TEND TO LOWER THE CURRENT RATING OF THE CONDENSER. EVIDENTLY LISTINGS IN A CATALOGUE MAY APPEAR QUITE ARBITRARY IN VOLTAGE AND CURRENT RATINGS OWING TO ALL THE FACTORS MENTIONED. NOTE THAT THESE RATINGS ARE LIMITING VALUES. IN OPERATION THE ACTUAL CURRENT AND VOLTAGE DROP ARE RELATED TO ONE ANOTHER BY THE REACTANCE AS STATED PREVIOUSLY.

MAXIMUM D.C. WORKING VOLTAGE SHOULD CORRESPOND TO THE TEST VOLTAGE EFFECTIVE AS GIVEN IN THE TABLE. VALUES CAN BE INTERPOLATED IN THE TABLE BETWEEN THE FPEQUENCIES GIVEN. FOR OTHER FREQUENCY RANGES AND SPECIAL APPLICATIONS THE MANUFACTURER SHOULD BE CONSULTED, SINCE SPECIAL DESIGN MAY BE INDICATED. THE STANDARD MICA CAPACITORS LISTED IN THE TABLE CAN WITHSTAND AMBIENT TEMPERATURES UP TO 60°C. ALSO NOTE THAT WHERE AUDIO OR R.F. RIPPLE IS SUPERIMPOSED ON A D.C. WORKING VOLTAGE, THE MAXIMUM VOLTAGE OF THE COMPLEX WAVE SHOULD NOT EXCEED THE TEST VOLTAGE RATING. TEST VOLTAGE EFFECTIVE IS .707 OF THE MAXIMUM SINE WAVE VALUE.

ELECTROLYTIC CONDENSERS: THE ELECTROLYTIC CONDENSER WAS DEVELOPED TO MEET THE DEMAND FOR COMPARATIVELY LOW VOLTAGE, SMALL BULK, INEXPENSIVE CONDENSERS OF VERY LARGE CAPACITY. ONE OUTSTANDING APPLICATION OF SUCH CONDENSERS IS IN THE RECTIFIER FILTER CIRCUITS OF A.C. OPERATED RECEIVERS.

ELECTROLYTIC CONDENSERS ARE DESIGNED IN STANDARD SIZES FOR D.C. OPERATING VOLTAGES UP TO 450 VOLTS. FOR SUCH A CONDENSER THE ALLOWABLE PEAK VOLTAGE DURING SURGE OR RIPPLE IS ABOUT 525 VOLTS. STANDARD CAPACITY SIZES ARE 4 μF, 8 μF, 16 μF AND 32 μF. ELECTROLYTIC CONDENSERS HAVE BEEN BUILT FOR SLIGHTLY HIGHER VOLTAGES BUT ABOUT 500 VOLTS SEEMS TO APPROACH THE UPPER PRACTICAL LIMIT. ELECTROLYTIC CONDENSERS CAN BE BUILT FOR VERY LARGE CAPACITIES--HUNDREDS OR THOUSANDS OF MICROFARADS--BUT THE VALUES LISTED ABOVE ARE STANDARD FOR MOST PURPOSES. AN ELECTROLYTIC CONDENSER HAS VERY SMALL DIMENSIONS FOR ITS CAPACITY RATING IN COMPARISON WITH OTHER TYPES. A 4 μF ELECTROLYTIC CONDENSER HAVING A RATED D.C. VOLTAGE OF 450 VOLTS CAN BE MADE TO OCCUPY A METAL CONTAINER LESS THAN ONE INCH IN DIAMETER AND TWO INCHES IN LENGTH. EQUALLY EFFICIENT TYPES ARE ALSO AVAILABLE IN SMALL CARDBOARD CONTAINERS FOR FLAT MOUNTING.

THE LARGE CAPACITY OF THE ELECTROLYTIC CONDENSER IS OBTAINED BY ELECTRO-CHEMICAL ACTION. TWO SETS OF ELECTRODES, THE ANODE CONSISTING OF CORRUGATED ALUMINUM PLATES (CORRUGATED TO INCREASE THE SURFACE AREA), AND THE CATHODE OF FLAT ALUMINUM PLATES (ONE CATHODE PLATE FOR EACH ANODE PLATE), ARE IMMERSED IN ELECTROLYTE. SEVERAL TYPES OF ELECTROLYTE MAY BE USED, ONE COMMONLY USED SOLUTION CONSISTING OF BORAX AND BORIC ACID IN WATER. AS A POSITIVE POTENTIAL IS APPLIED TO THE ANODE AND A NEGATIVE POTENTIAL TO THE CATHODE, ELECTRO-CHEMICAL ACTION STARTS AND A VERY THIN FILM OF ALUMINUM OXIDE IS FORMED ON THE ANODE. THE FILM MAY BE FROM ONE TO SEVERAL MOLECULES THICK. THIS THIN FILM FORMS THE DIELECTRIC OF THE CONDENSER, THE ANODE FORMING ONE CONDENSER PLATE AND THE ELECTROLYTE THE OTHER CONDENSER PLATE. THE CATHODE ELECTRODE IS USED SIMPLY TO MAKE ELECTRICAL CONTACT WITH THE ELECTROLYTE. A FILM OF OIL IS PLACED ON TOP

OF THE ELECTROLYTE TO PREVENT EVAPORATION.

THE CAPACITY OF THE CONDENSER IS AN INVERSE FUNCTION OF THE THICKNESS OF THE ANODE FILM WHICH IN TURN IS A FUNCTION OF THE FORMING VOLTAGE. THE FILM IS FORMED BY ELECTRO-CHEMICAL ACTION, AND FOR A GIVEN SOLUTION THE HIGHER THE FORMING VOLTAGE THE THICKER THE FILM THAT IS DEPOSITED ON THE ANODE, AND HENCE THE LOWER THE CAPACITY. A CONDENSER FORMED AT 100 VOLTS MAY HAVE A CAPACITY OF 40 μF, AND A SIMILAR CONDENSER FORMED AT 500 VOLTS MAY HAVE A CAPACITY OF 8 μF. ONE FORMED AT 200 VOLTS MAY HAVE A CAPACITY OF 20 μF. FOR ORDINARY FILTER CONDENSERS DESIGNED FOR 450 VOLT RATING, CAPACITY OF APPROXIMATELY 1 μF/SQUARE INCH OF FILM MAY BE CONSIDERED TYPICAL.

THE CONDENSER DESCRIBED ABOVE IS THE WET TYPE WHICH IS ENCLOSED IN A METAL CONTAINER. ELECTROLYTIC CONDENSERS ARE ALSO MANUFACTURED IN THE SO-CALLED "DRY" TYPE. IN THE DRY TYPE THE ELECTRODES CONSIST OF ALUMINUM ALLOY FOIL SEPARATED BY GAUZE WHICH IS SOAKED WITH ELECTROLYTE, A COMMON ELECTROLYTE BEING A SOLUTION OF BORIC ACID, GLYCERINE AND AMMONIA. THE STRIPS OF FOIL ARE ROLLED UP, SEALED TO PREVENT EVAPORATION, AND PLACED IN A CARDBOARD CONTAINER. IT IS OBSERVED THAT THE TERM "DRY" IS USED ONLY IN THE COMPARATIVE SENSE THAT THE ELECTROLYTE IS NOT KEPT IN AN ACTUAL LIQUID FORM. THE OPERATIONS OF THE TWO TYPES ARE IDENTICAL.

IT SHOULD BE NOTED THAT <u>THE ELECTROLYTIC CONDENSER IS A POLARIZED DEVICE AND MUST BE CONNECTED INTO THE CIRCUIT WITH THE CORRECT POLARITY</u>. IF THE POLARITY OF THE VOLTAGE IS REVERSED, A SHORT CIRCUIT WILL OCCUR BECAUSE THE ONLY OPPOSITION OFFERED WILL BE THE RESISTANCE OF THE ELECTROLYTE. THUS SUCH A CONDENSER SHOULD BE USED ONLY WHERE THE VARYING VOLTAGE IS SIMPLY AN ALTERNATING COMPONENT OF A D.C. VOLTAGE. THIS IS THE CONDITION IN RECTIFIER FILTER CIRCUITS AND IN THE PLATE OUTPUTS OF VACUUM TUBES.

THE D.C. LEAKAGE CURRENT IN THE ELECTROLYTIC CONDENSER IS LARGE COMPARED WITH THE LEAKAGE IN OTHER TYPES OF CONDENSERS, BEING IN THE ORDER OF .2 MIL PER microfarad in the ordinary commercial types. Such leakage is negligible in filter circuits and other circuits where such condensers are ordinarily used. The electrolytic condenser is rugged and has a number of years of useful life. It is self-healing if it flashes over on a voltage peak.

Where it is desired to use electrolytic condensers in a circuit in which the circuit voltage exceeds the rated operating voltage of the condenser, a series-parallel arrangement of condensers may be used, or larger condensers may be used in series to obtain the smaller required capacity at the higher operating voltage. For example, to obtain 8 μF capacity across a 1600 volt circuit, four 32 μF 450 volt condensers may be connected in series, the total capacity being 8 μF and the rated voltage 1800 volts.

<u>Power Loss, Resistance, Leakage, Phase Angle of Condensers</u>: The two principal sources of loss in condensers are leakage, (conductance between plates through the dielectric), and series resistance due to skin effect of plates and leads. Figure 7(a) illustrates the leakage resistance while 7(b) illustrates the effect of the series resistance.

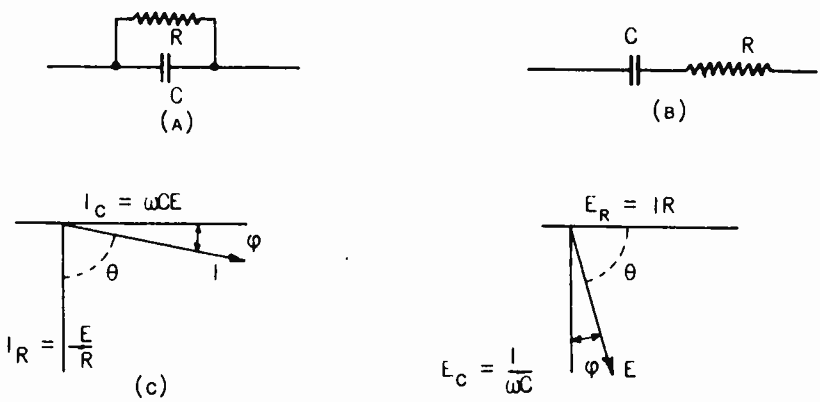


Fig. 7.

As in all circuits the phase angle is a measure of the operating efficiency of a condenser as it expresses the power-factor of the condenser. However, in well designed condensers operated under normal conditions the phase angle is so near 90° that it is difficult to express and handle in terms of Tan θ as in other electric circuits. Thus the term "Phase Difference" is normally

USED, THIS TERM EXPRESSING THE ANGLE BY WHICH THE PHASE ANGLE DIFFERS FROM 90°. THUS INSTEAD OF STATING THAT THE PHASE ANGLE OF A CONDENSER IS $89^{\circ}15'$ IT IS CUSTOMARY TO SAY THAT THE PHASE DIFFERENCE OF THE CONDENSER, DUE TO LOSSES, IS 45'. THE PHASE DIFFERENCE IS EXPRESSED BY THE SYMBOL φ. (GREEK LETTER PHI).

THIS IS CLEARLY SHOWN IN FIGURES 7(C) AND 7(D). THE ANGLES IN BOTH CASES ARE TAKEN WITH RESPECT TO THE REACTIVE COMPONENTS OF CURRENT (7-C WHERE $I_C = \omega CE$) AND VOLTAGE (7-D WHERE $E_C = \frac{I}{\omega C}$). IT PARTICULARLY SHOULD BE NOTED IN THE FOLLOWING PARAGRAPH THAT THE POWER FACTOR OF THE CONDENSER WHICH IS AN EXPRESSION OF THE POWER LOSS IN THE CONDENSER, IS TAKEN AS THE TANGENT OF THE PHASE DIFFERENCE φ WHILE IN MOST ELECTRICAL CIRCUITS THE POWER FACTOR IS EQUAL TO THE COSINE OF THE PHASE ANGLE θ. AS SHOWN IN FIGURE 7-C AND 7-D, φ IS THE COMPLEMENTARY ANGLE OF θ AND IN CONDENSERS IS ALWAYS SMALL COMPARED WITH θ. AN INSPECTION OF A TABLE OF TANGENTS AND COSINES WILL SHOW THAT SO LONG AS φ IS SMALL (LESS THAN 5°), TAN φ IS ESSENTIALLY EQUAL TO COS θ.

THE POWER FACTOR OF A CONDENSER DUE TO ITS PARALLEL LOSSES, FIGURE 7(A), CAUSED BY DIELECTRIC LEAKAGE IS EQUAL TO, $\tan\varphi = \frac{1}{R\omega C}$, (R IN OHMS, $\omega = 2\pi f$ WITH F IN CYCLES PER SECOND, AND C IN FARADS). IT WILL BE SEEN THAT AS THE FREQUENCY IS INCREASED, TAN φ AND CORRESPONDINGLY THE PROPORTIONATE PARALLEL LOSSES IN THE CONDENSER DECREASE. AT RADIO FREQUENCIES THE POWER FACTOR DUE TO CONDUCTANCE, EXCEPT IN EXTREMELY POOR CONDENSERS, IS NEGLIGIBLE, WHILE AT POWER FREQUENCIES, SUCH AS 60 CYCLES, THIS IS THE PREDOMINATING CONDENSER LOSS.

THE POWER FACTOR OF A CONDENSER DUE TO SERIES LOSSES, (FIGURE 7-B), CAUSED BY THE RADIO FREQUENCY RESISTANCE OF PLATES AND LEADS AND MOSTLY DUE TO SKIN EFFECT, IS EQUAL TO:

$$\tan\varphi = R\omega C$$

φ OR Φ OR Φ = GREEK LETTER PHI (FEE)

(R IN OHMS, $\omega = 2\pi f$ WITH F IN CYCLES PER SECOND, AND C IN FARADS.)

IN THE CASE OF A CONDENSER OF .001 μF WITH A SERIES RESISTANCE OF 2 OHMS, OPERATED AT 1000 KC/S,

$$\text{Power Factor} = \tan\varphi = R\omega C = 2 \times 628 \times 10^{-2} \times 10^{6} \times 10^{-9}$$

$$= .01256 \text{ or } 1.256 \text{ percent.}$$

If this same condenser is operated at 5000 KC/s, even if its series resistance does not increase,

$$\text{Power Factor} = \tan\varphi = R\omega C = 2 \times 628 \times 10^{-2} \times 5 \times 10^{6} \times 10^{-9}$$

$$= .0628 \text{ or } 6.28 \text{ percent.}$$

This is a very serious power factor. It should also be noted that in practice an increase of frequency from 1000 to 5000 KC/s would considerably increase the series resistance. Paper condensers at radio frequencies often have series resistance of several ohms. These formulas apply equally to variable condensers, so that if a variable condenser is to be used at a high radio frequency it is essential that the plates be constructed of low loss material and that the plate assembly, connecting lugs, etc., be such that the radio frequency resistance is very low, because these factors, more than leakage across the insulation between plates, are what determine the power factor of the condenser at the higher frequencies.

The Power Loss of a condenser may be expressed by the equation,

$$P = \omega C E^2 \varphi$$

where $\varphi = R\omega C$ = Power Factor

and R = Series resistance.

(For simplicity in writing the equation power factor is here expressed by φ instead of by $\tan\varphi$.)

Enlarging, $P = \omega^2 C^2 R E^2$

The power losses in a given condenser are proportional to F^2 and E^2. Considering the condenser in the problem above, .001 µF with series resistance of 2 ohms operated at 1000 KC/s, in which case the power factor φ was found to be .01256. Assume that the effective voltage across the condenser at this frequency is 1000 volts. Then,

$$P = \omega C E^2 \varphi$$

$$P = 628 \times 10^{-2} \times 10^{6} \times 10^{-9} \times 10^{6} \times 1256 \times 10^{-5} = 78.8 \text{ watts}$$

Since the RMS voltage across the condenser at 1000 KC/s is only 1000 volts it may be assumed that the condenser is being used in a comparatively low power transmitter. Thus even at this frequency power of 78.8 watts is being dissipated in the condenser in heat and this power represents a total loss to the circuit. If it were attempted to use this condenser at a much higher frequency or at a higher voltage, in either case the power loss would increase as the square of the increase of F or E and the losses in the condenser would be considerably higher.

TIME CONSTANT OF A CONDENSER CIRCUIT: In discussing the charging and discharging action of a condenser it has been assumed that the only opposition to the charge is the CEMF, and that the condenser is allowed to discharge through a circuit in which the resistance is negligible. In many circuits in actual practice such conditions cannot be assumed. For example, in the case of the grid leak and condenser in a vacuum tube detector circuit, the condenser may be required to discharge through a grid leak resistance of up to 10 megohms. In the automatic volume control circuit of a receiver the bypass condensers may have to discharge through resistance networks of several hundred thousand ohms.

With a given voltage only a certain number of electrons can be moved through a given resistance in a given time. Thus a circuit consisting of capacity and resistance requires a definite time to charge and discharge, the time in seconds being a function of C and R. The larger either of these factors the longer the time required for discharge.

The time constant of a condenser circuit is taken as the time required for the condenser to acquire 63 percent of its final charge or, on discharge, for the condenser to lose 63 percent of its charge. The time constant of a condenser is expressed as follows:

$$\text{Time Constant} = CR$$

where C is in farads, R in ohms and the Time Constant in seconds. Thus a cir-

CUIT CONSISTING OF A .1 μF CONDENSER AND A RESISTANCE OF 400,000 OHMS WILL HAVE A TIME CONSTANT OF,

$$\text{Time Constant} = 10^{-7} \times 4 \times 10^{5} = 4 \times 10^{-2} = .04 \text{ second.}$$

IN THE CASE OF THE DETECTOR GRID LEAK AND CONDENSER, THE CONDENSER CHARGES AT RADIO FREQUENCY FROM THE VACUUM TUBE GRID CURRENT BUT CANNOT DISCHARGE BACK THROUGH THE SAME CIRCUIT. IT MUST DISCHARGE AT AUDIO FREQUENCY THROUGH THE GRID LEAK. IF THE CONDENSER IS LARGE AND A VERY HIGH RESISTANCE GRID LEAK IS USED, THE CONDENSER MAY NOT BE ABLE TO DISCHARGE RAPIDLY ENOUGH TO FOLLOW THE AUDIO FREQUENCY VARIATIONS AND WITH A STRONG SIGNAL THE TUBE WILL GRADUALLY BLOCK.

IN THE CASE OF AN AUTOMATIC VOLUME CONTROL CIRCUIT, IF THE CAPACITY AND RESISTANCE ARE NOT SUFFICIENTLY LARGE THE A.V.C. ACTION MAY BE SO RAPID AS TO FOLLOW THE ACTUAL MODULATION OF THE SIGNAL, WITH CONSEQUENT DISTORTION. IF CR IS TOO LARGE THE A.V.C. ACTION WILL BE SLUGGISH AND WILL FOLLOW ONLY VERY SLOW FADING. THUS THE VALUES OF C AND R IN ANY NETWORK MUST BE CAREFULLY SELECTED FOR THE PURPOSE FOR WHICH THE NETWORK IS TO BE USED.

STRAY CAPACITIES: IN LOW FREQUENCY POWER WORK IT IS CUSTOMARY TO THINK OF CAPACITY ALMOST ENTIRELY IN TERMS OF ACTUAL CONDENSERS. HOWEVER AT RADIO FREQUENCIES, AND OFTEN AT AUDIO FREQUENCIES, THE UNAVOIDACLE AND STRAY CAPACITIES MAY HAVE VERY SERIOUS EFFECTS. FOR EXAMPLE, THE CAPACITY BETWEEN WIRES IN A LONG DISTANCE TELEPHONE LINE IS SO GREAT, THAT UNLESS COMPENSATING CIRCUITS ARE USED THE HIGHER FREQUENCIES OF SPEECH AND MUSIC ARE GREATLY ATTENUATED BY THE CAPACITY BYPASSING EFFECT BETWEEN WIRES, THUS ALLOWING THE LOWER FREQUENCIES TO PREDOMINATE OUT OF PROPORTION TO THEIR ORIGINAL LEVELS.

THE DESIGN OF A GOOD HIGH GAIN AUDIO TRANSFORMER IS MADE DIFFICULT BY THE CAPACITY BETWEEN TURNS OF THE SECONDARY WINDING WHICH, COMBINED WITH THE INDUCTANCE OF THE WINDING, "PEAKS" SUCH A TRANSFORMER AT AN UNDESIRABLY LOW FREQUENCY.

At radio frequencies the condition is still more aggravated because at the higher frequencies smaller capacities have proportionately greater effects. Thus in the design of coils and circuits for radio frequency operation special forms of windings are usually employed to minimize the capacity effects. The capacity between elements in vacuum tubes for use at radio frequencies is so serious that it has necessitated the design of special types of tubes to minimize the effects of capacity. Where special tubes are not used elaborate capacity neutralizing circuits are employed.

In the design of a radio transmitter or receiver where coils are shielded to minimize inductive coupling, it is necessary to take into consideration the capacity between the coil and the shielding. Thus when a transmitter is tuned to a given frequency with the shields removed, slight readjustments are almost always necessary when the shielding is in place. Shielding over coils should never be placed any closer to the coil than is absolutely necessary.

Capacity of circuits to ground is of importance. As has already been explained, the movable plates of variable condensers are grounded in order to eliminate body capacity in tuning. When measuring the constants of a coil or circuit the coil or circuit should be grounded if that is the way it will actually be used in practice. (This is almost always the condition in radio frequency circuits.) If that is not done the measurements will not represent actual working conditions.

CAPACITY SCREEN: A capacity screen is used between circuits to shield the circuits electrostatically, but at the same time to allow power transfer by electronic or inductive coupling. Such a device is the screen grid in the four element vacuum tube, the principle of which is shown in Figure 8. One of the most serious disadvantages of the three element vacuum tube is the interelement capacity between control grid and plate. In the screen grid tube a wire grid called a screen grid is placed BETWEEN the control grid and the plate and the

Screen grid connects directly, through a large bypass condenser, to the cathode. Electric lines of force extending from the control grid toward the plate terminate on the screen grid which, so far as the R.F. voltage is concerned, is at cathode or ground potential. Electric lines of force extending from the plate toward the control grid also terminate at the grounded screen grid; thus there is almost no electrostatic field set up between the control grid and plate because between the two there is a grounded electrostatic screen.

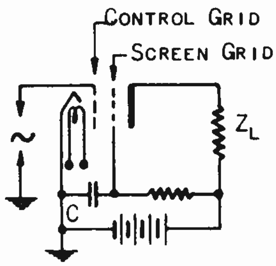


Fig. 8.

Another use for the electrostatic shield is between the coupling coils of two inductively coupled circuits, where it is desired that there be only inductive coupling and no capacitive coupling between the coils. The arrangement is shown in Figure 9. (This is also called a Faraday screen.) The screen conductors are open at one end and only one end is grounded. There are no closed electrical circuits and hence no appreciable eddy currents in the screen conductors and little power loss in the screen. On the other hand electric lines of force that would ordinarily extend between the two coils due to the capacity between them, terminate at the grounded screen, with the result that if the arrangement is well designed the capacity between coils is reduced to a negligible value without any appreciable effect on the inductive coupling.

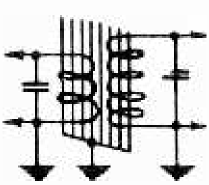


Fig. 9.

A few years ago a capacity screen between coils was seldom used except in laboratory precision measurements. Today such screens are extensively used in all types of radio apparatus, including high power broadcast transmitters, and between the coils in impedance matching transformers connected between broadcast receivers and the transmission lines of noise reduction antennas.

<u>Tests for Shorted and Open Condensers</u>: Testing a condenser for short-cir-

CUIT IS VERY SIMPLE. SUCH A TEST CAN BE MADE WITH A RESISTANCE BRIDGE OR AN OHMMETER. WHERE THERE IS REASON TO BELIEVE THAT ONE OF A BANK OF FIXED CONDENSERS IN AN R.F. CIRCUIT HAS BROKEN DOWN, THE DEFECTIVE CONDENSER CAN USUALLY BE LOCATED BY FEELING THE CASES. THE DEFECTIVE CONDENSER WILL HEAT UP MORE THAN THE GOOD CONDENSERS.

AN OPEN CIRCUIT INSIDE THE CONDENSER CASE IS MORE DIFFICULT TO LOCATE AND IT CAN ONLY BE DETERMINED BY ACTUAL TEST. THE TEST HOWEVER IS EXTREMELY SIMPLE. A CONDENSER WHICH HAS AN OPEN CIRCUIT WILL NOT TAKE A CHARGE. A D.C. VOLTMETER AND BATTERY CONNECTED IN SERIES ACROSS A GOOD CONDENSER WILL INDICATE A CHARGE. THAT IS, WHEN THE CONNECTION IS MADE THE METER, ACTING AS A MILLIAMMETER, INDICATES A HIGH CHARGING CURRENT WHICH GRADUALLY FALLS TO ZERO AS THE CONDENSER CHARGES. IF THE CONDENSER IS OPEN, THERE WILL BE NO DEFLECTION OF THE METER WHEN METER AND BATTERY ARE CONNECTED ACROSS THE CONDENSER. A D.C. VOLTMETER IS SUGGESTED IN PLACE OF A LOW READING D.C. MILLIAMMETER, BECAUSE WHERE THE CAPACITY IS LARGE THE INITIAL CURRENT PEAK WILL TEND TO BE HIGH. THE RESISTANCE OF THE VOLTMETER LIMITS THE CHARGING CURRENT TO A VALUE WHICH WILL NOT DAMAGE THE METER.

IMPEDANCE AND ANGLE OF LEAD: JUST AS IN AN INDUCTIVE CIRCUIT, $Z = \sqrt{R^2 + X^2}$, THE DIFFERENCE BEING THAT IN THE CAPACITIVE CIRCUIT REACTANCE IS X_C. THUS IN A CIRCUIT HAVING 60 OHMS OF RESISTANCE, AND CAPACITY SUCH THAT AT THE OPERATING FREQUENCY $X_C = 80$ OHMS,

$$Z = \sqrt{R^2 + X_C^2} = \sqrt{60^2 + 80^2} = 100 \text{ OHMS.}$$

$$\text{TAN } \theta = \frac{X}{R} = \frac{80}{60} = 1.333$$

$$\theta = \text{TAN}^{-1}\ 1.333 = 53^\circ 8' \text{ LEAD.}$$

MEASUREMENTS OF CAPACITY WILL BE DISCUSSED IN DETAIL IN A LATER ASSIGNMENT

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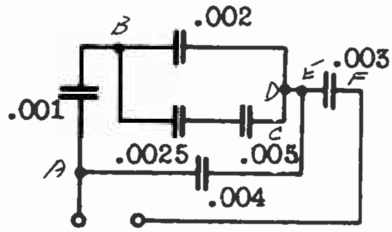
TELEVISION TECHNICAL ASSIGNMENT

CONDENSERS USED IN RADIO

EXAMINATION

1.



Values are all µf.

Find total C.

$C_{BC} = \frac{1}{\frac{1}{.0025} + \frac{1}{.005}} = \frac{.005}{3} = .00166\,\mu f$ $\quad C_{BD} = .002 + .00166 = .00366\,\mu f$

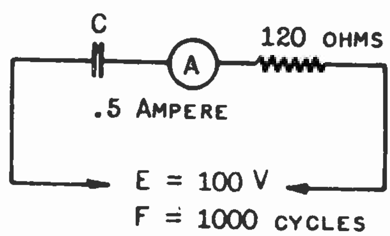
$C_{AD} = \frac{1}{\frac{1}{.001} + \frac{1}{.00366}} = \frac{.00366}{4.36} = .000785\,\mu f$

$C_{AE} = .004 + .00085 = .004785\,\mu f$

$C = C_{AF} = \frac{1}{\frac{1}{.003} + \frac{1}{.00485}} = \frac{.00001455}{.00785} = .00147\,\mu f$

$.001845\,\mu F$

2.



Solve for Z,

$Z = \frac{E}{I} = \frac{100}{.5} = 200$ ohms

Find C.

$X_c = \sqrt{Z^2 - R^2} = \sqrt{40000 - 14400} = \sqrt{25600} = 160\,\Omega$

$X_c = \frac{1}{2\pi FC} \quad C = \frac{1}{2\pi F X_c} = \frac{1}{6.28 \times 1000 \times 160} = 9.952 \times 10^{-7}$ farads.

$= 0.995\,\mu f$

3. A .005 µf condenser is used as a by-pass capacity across a circuit in a video amplifier, in which current components of 5,000 cycle and 1,000 kc/s are flowing at the time under consideration. What is the reactance of the condenser at each frequency?

$$X_c = \frac{1}{2\pi f C} = \frac{1}{6.28 \times 5000 \times .005 \times 10^{-6}} = \frac{10^3}{6.28 \times .025} = 6375\ \Omega$$

$$X_c = \frac{1}{2\pi f C} = \frac{1}{6.28 \times 10^6 \times .005 \times 10^{-6}} = \frac{1}{.0314} = 31.85\ \Omega$$

4. What is the impedance at 150 kc/s of a series circuit consisting of a .002 µf condenser and a resistance of 500 ohms?

$$X_c = \frac{1}{2\pi f C} = \frac{1}{6.28 \times 15 \times 10^4 \times .002 \times 10^{-6}} = \frac{10^2}{.1884} = 530.8\ \Omega$$

$$Z = \sqrt{R^2 + X^2} = \sqrt{250,000 + 281,730} = 729.2 \text{ ohms}$$

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CONDENSERS USED IN RADIO

5. A coupling circuit in a video amplifier is to have a time constant of .025 second. If a .05 μf condenser is employed, what value of resistance must be used?

Time constant = CR

$$R = \frac{\text{time constant}}{C} = \frac{.025}{.05 \times 10^{-6}} = .5 \times 10^{6}$$

or $\underline{500,000}$ ohms

6. A tuned circuit consists of inductance and a variable condenser, the minimum capacity of which is 25 μμf and the maximum/minimum capacity ratio is 4/1. The circuit tunes to 8,000 kc/s at the high frequency end. What is the maximum capacity of the condenser and what is the lowest frequency to which the circuit will tune?

Max. C = 25 × 4 = 100 uuf

Frequency ratio = $\sqrt{\text{Capacity ratio}} = \sqrt{4/1} = 2/1$

So lowest frequency = $\frac{8000}{2}$ = $\underline{4000}$ kcs

8. *(Continued)*

9. (A) The operating frequency of your television transmitter is 60 mc and you require a total tank capacity of 100 μμf. The tank current may be as high as 4 amperes.

(a) What is the least number of 100 μμf condensers that should be employed if each condenser is rated at 2 amperes r.m.s. at 60 mc and 100 volts peak?

$$X_C = \frac{1}{2\pi FC} = \frac{1}{6.28 \times 6.0 \times 10^7 \times 10^2 \times 10^{-12}} = 26.54\ \Omega$$

$$E = IX_c = 26.54 \times 2 = 53.08\ V.$$

Least number of condensers is four.

(b) How should they be connected?

Series - parallel.

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9. (Continued)

(B) Reference 9(A). The series resistance of each condenser at the operating frequency is .531 ohm.

(a) What is the power factor of the total tank capacity at the operating frequency?

$$PF = R\omega C = .531 \times 6.28 \times 6 \times 10^7 \times 10^2 \times 10^{-12}$$

$$= .531 \times 37.68 \times 10^{-3} = .020007 \text{ or } 2\%$$

(b) With 3.5 amperes in the tank circuit, what is the voltage across each condenser and power loss in the combination?

$$E = I X_c = 1.75 \times 26.54 = 46.445 \text{ Volts}$$

$$\text{Pwr loss} = \omega C E^2 \phi = 6.28 \times 6 \times 10^7 \times 10^{-10} \times 92.890^2 \times .02$$

$$= .6505 \text{ watts}$$

9. *(Continued)*

10. A tuned circuit consists of an inductance and a straight line capacity condenser having a maximum capacity of 230 μμf and a minimum of 40 μμf. The condenser dial is divided into 100 divisions. At 100 divisions C = 230 μμf and the circuit has a wavelength of 350 meters. What is the resonant frequency of the circuit when the condenser dial setting is 30 divisions?

μμf per division $= \frac{230-40}{100} = \frac{190}{100} = 1.9$

at 30 divisions $C = 40 + (1.9 \times 30 = \underline{\underline{97\ \mu\mu f}}$

350 meters = 854.3 kcs.

$F = \frac{1}{2\pi\sqrt{LC}}$ $\quad L = \frac{1}{(2\pi F)^2 97\times10^{-12}} = \frac{1}{(2\pi\times854.3)^2 230\times10^{-12}}$

$F^2 = \frac{854.3^2 \times 230}{97}$

$F = 854.3\sqrt{\frac{230}{97}} = \underline{\underline{1315.5}}$ kcs.

SOLUTION PROBLEM 9
CONDENSERS USED IN RADIO

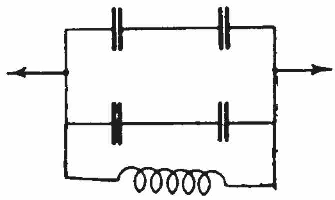
(A) THE OPERATING FREQUENCY OF YOUR TELEVISION TRANSMITTER IS 60 MC. AND YOU REQUIRE A TOTAL CAPACITY IN THE TANK OF 100 $\mu\mu$F. WHAT IS THE LEAST NUMBER OF 100 $\mu\mu$F CONDENSERS THAT SHOULD BE EMPLOYED IF EACH CONDENSER IS RA TED AT 2 AMPERES RMS AT 60 MC AND 100 VOLTS PEAK?. HOW SHOULD THEY BE CONNECTED? THE TANK CURRENT MAY BE AS HIGH AS 4 AMPERES RMS.

$X_C = 1 / 2\pi fC = 1 / (6.28 \times 6 \times 10^7 \times 10^{-10}) = 26.5$ OHMS

$E = IX_C$ SINCE MAXIMUM CURRENT IS EXPECTED TO BE 4 AMPERES RMS THEN THE CONDENSERS MUST BE ARRANGED SO THEIR RATINGS OF 100 VOLTS PEAK IS NOT EXCEEDED.

$4 \times 26.5 = 106$ VOLTS RMS $\times 1.414 = 150$ VOLTS PEAK

THE BEST POSSIBLE COMBINA TION OF THE 4 CONDENSERS IS IN SERIES PARALLEL,



THE VOLTAGE RATING OF THIS COMBINATION WILL BE $2 \times 100 = 200$ VOLTS WHICH EXCEEDS THE MAXIMUM EXPECTED VOLTAGE OF 150 VOLTS. NOTE THAT ONLY 2 AMPERES FLOWS THROUGH ANY ONE CONDENSER SO THE VOLTAGE DROP IS KEPT DOWN TO $2 \times 1.414 \times 26.5 = 75$ VOLTS PEAK PER CONDENSER. THE TOTAL CAPACITY OF THE COMBINATION WILL BE 100 $\mu\mu$F.

(B) REFERENCE (A). THE SERIES RESISTANCE OF EACH CONDENSER AT THE OPERATING FREQUENCY IS 0.531 OHM. WHAT IS THE POWER FACTOR OF THE TOTAL TANK CAPACITY AT THE OPERATING FREQUENCY? WITH 3.5 AMPERES RMS IN THE TANK CIRCUIT, WHAT IS THE VOLTAGE ACROSS EACH CONDENSER AND THE POWER LOSS IN THE COMBINATION?
SINCE EACH CONDENSER HAS A SERIES RESISTANCE OF 0.531 OHM THE TOTAL R OF THE COMBINATION WILL BE

$$\frac{1}{\dfrac{1}{.531 + .531} + \dfrac{1}{.531 + .531}} = .531\ \Omega$$

POWER FACTOR $= R\omega C = .531 \times 6.28 \times 6 \times 10^7 \times 10^{-10} = .02$ OR 2 PER CENT

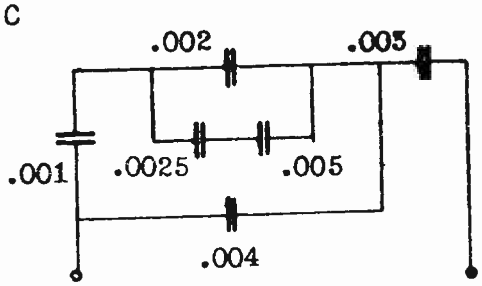
WITH 3.5 AMPERES IN THE TANK CIRCUIT THE TOTAL VOLTAGE ACROSS THE COMBINATION IS $3.5 \times 26.5 = 92.75$ VOLTS RMS OR 46.375 VOLTS RMS PER CONDENSER.

$P = \omega CE^2 P.F. = 6.28 \times 6 \times 10^7 \times 10^{-10} \times 92.75^2 \times .02 = 6.28 \times 12 \times 8.6 \times 10^{-2} =$ 6.5 WATTS

PROOF: $P = I^2R = 3.5 \times 3.5 \times .531 = 6.5$ WATTS

Condensers Used In Radio
Exam Solution

FIND TOTAL C



THE EQUIVALENT CAPACITY OF THE .0025 AND .005 µF CONDENSERS IN SERIES IS:

$$C = \frac{C_1 C_2}{C_1 + C_2} = \frac{.0025 \times .005}{.0025 + .005} = .00166\ \mu F$$

COMBINING THIS CAPACITY WITH THAT OF THE .002 µF CONDENSER WITH WHICH IT IS IN PARALLEL GIVES A TOTAL CAPACITY OF:

$$C = .00166 + .002 = .00366\ \mu F$$

THIS CAPACITY IS ACTING IN SERIES WITH THE .001 µF CAPACITY, CREATING A TOTAL CAPACITY OF:

$$C = \frac{C_1 C_2}{C_1 + C_2} = \frac{.00366 \times .001}{.00366 + .001} = .000785\ \mu F$$

THE CAPACITY OF .000785 µF IS IN PARALLEL WITH THE .004 µF CONDENSER, GIVING A TOTAL CAPACITY OF:

$$C = .004 + .000785 = .004785\ \mu F$$

THE CAPACITY OF .004785 µF IS ACTING IN SERIES WITH THE .003 µF CONDENSER PRODUCING A NET CIRCUIT CAPACITY BETWEEN TERMINALS OF:

$$C = \frac{.004785 \times .003}{.004785 + .003} = .001845\ \mu F \qquad \text{ANS.}$$

Note: A common error of analysis in this problem is the assumption that in a straight line capacity condenser, the capacity of the condenser varies as the dial setting. This assumption overlooks the fact that in all variable condensers there is a residual or minimum capacity at zero dial setting. It is only the *excess* of capacity over the minimum capacity value which may vary directly as the dial setting.

SOLUTION OF PROBLEM 10
CONDENSERS USED IN RADIO

A tuned circuit consists of an inductance and a straight line capacity condenser having a maximum capacity of 230 $\mu\mu F$ and a minimum capacity of 40 $\mu\mu F$. The condenser dial is divided into 100 divisions. At 100 divisions $C = 230\ \mu\mu F$ and the circuit has a wavelength of 350 meters. What is the resonant frequency of the circuit when the condenser dial setting is 30 divisions?

The term "straight line capacity" means that the curve of capacity plotted as a function of dial reading would be a straight line, indicating that a certain *change* in dial setting (say one division) will produce the same *change* in the capacity of the condenser, no matter what the original dial settings are.

Thus the capacity change per division = $230 - 40/100 = 1.9\ \mu\mu F$ at any dial setting.

The capacity at 30 divisions would be:

$$230 - (100 - 30)\ 1.9 = 97\ \mu\mu F$$

or

$$40 + 30\ (1.9) = 97\ \mu\mu F$$

The ratio of the capacity at the dial setting of 30 divisions to that at the upper dial setting of 100 divisions is

$$\frac{C}{C_{max}} = \frac{97}{230}$$

From the relation $\lambda = 1884 \sqrt{LC}$ it is seen that the resonant wavelength varies as $\sqrt{C}$ where L is fixed. Thus the wavelength at 30 divisions is given by

$$\lambda = \sqrt{\frac{97}{230}} \times 350 = 227 \text{ meters}$$

Or, from the relation for the resonant frequency

$$f_r = \frac{1}{2\pi \sqrt{LC}}$$

it is noted that the resonant frequency varies *inversely* as the $\sqrt{C}$. Thus if the frequency at 100 divisions is 300000/350 or 857 kc/s, then the frequency at the 30 division setting is:

$$f = \sqrt{\frac{230}{97}} \times 857 = 1320 \text{ kc/s}$$

$$\lambda = \frac{300000}{1320} = 227 \text{ meters, check}$$

(over)

You are getting an occasional "flash over" in a transmitter neutralizing condenser which is set at 22 $\mu\mu F$. You decide to reduce the voltage drop across this condenser by 25 percent by the use of a fixed condenser in series. What capacity ratio must exist between the two condensers? What should be the capacity of the fixed condenser and the new capacity setting of the variable condenser?

The R.F. voltage divides across two condensers in series in direct proportion to their reactances. 75 percent of the voltage is to appear across the variable condenser, 25 per cent across the fixed condenser. The reactance of the variable condenser is to be 75/25 or three times the reactance of the fixed condenser.

Since the reactance of a condenser varies inversely as the capacity, the capacity of the variable condenser is to be 1/3rd that of the fixed condenser. If the variable condenser capacity is designated by C_V and the fixed condenser capacity by C_F, then:

$$C_V = \frac{C_F}{3}$$

$$C_F = 3\ C_V \qquad \text{Ans.}$$

Also the total capacity of the two condensers in series is to be brought back to the original value of 22 $\mu\mu F$ by an adjustment of the variable condenser. When this adjustment has been made, then the following relation will hold:

$$C_T = 22 = \frac{C_V C_F}{C_V + C_F}$$

$$22\ C_V + 22\ C_F = C_V C_F$$

But since C_F is 3 C_V:

$$22\ C_V + 66\ C_V = 3\ C_V^2$$

Dividing both members by C_V

$$88 = 3\ C_V$$

$$C_V = 88/3 = 29.3\ \mu\mu F$$

$$C_F = 3\ C_V = 87.9\ \mu\mu F$$

SOLUTION PROBLEMS 7 AND 8

You have a 500 $\mu\mu F$ variable condenser, the minimum capacity of whi[ch] is 40 $\mu\mu F$. You require a capacity variation of 100 $\mu\mu F$ which must be spread over as much of the dial as possible. What fixed series capacity will you use?

The capacity offered by two condensers in series can be determined by the product-over-sum method. If the variable condenser is designated by C_V and the fixed series capacity by C_F then the total capacity will be:

$$C_T = \frac{C_V C_F}{C_V + C_F}$$

The difference in total capacity at the settings of $C_V = 500\ \mu\mu F$ and $C_V = 400\mu\mu F$ is 100 $\mu\mu F$. In other words:

$$\frac{500\ C_F}{500 + C_F} - \frac{40\ C_F}{40 + C_F} = 100$$

Dividing both members of the equation by 100 to avoid handling lar[ge] numbers:

$$\frac{5\ C_F}{500 + C_F} - \frac{.4\ C_F}{40 + C_F} = 1$$

Multiplying both members by the common denominator $(500 + C_F)\ (40 + C_F)$:

$$5C_F(40 + C_F) - .4C_F(500 + C_F) = (500 + C_F)\ (40 + C_F)$$

$$200C_F + 5C_F^2 - 200C_F - .4C_F^2 = 20000 + 540C_F + C_F^2$$

$$3.6C_F^2 - 540C_F - 20000 = 0$$

$$C_F = \frac{540 \pm \sqrt{540^2 - 4(3.6)\ (-20000)}}{7.2} = \frac{540 \pm \sqrt{579600}}{7.2} = \frac{540 + 761}{7.2} = 181\ \mu\mu F$$