SECTION 2

ADVANCED PRACTICAL RADIO ENGINEERING

TECHNICAL ASSIGNMENT

SERIES-PARALLEL CIRCUITS

219D

SERIES-PARALLEL CIRCUITS

FOREWORD

This assignment gives you an opportunity to test your overall knowledge of applied mathematics and a.c. circuit theory in applications to radio frequency networks. Almost all r.f. circuits can be broken down into series or parallel circuits or combinations of the two. In the preliminary design state almost any group of specifications may be given with the requirement that the remainder be calculated.

For example, the tuned r.f. network between a transmitter power amplifier and an antenna may include a tuned tank circuit, a harmonic suppression circuit, a tuned antenna circuit and provision for coupling the first to the last. In addition, in a television transmitter there also will be a vestigial side-band filter to remove a portion of one of the side-bands. This is usually—but not always—done between the power amplifier and the antenna. Normally most of the L, C and R values must be calculated on the basis of given frequency, required power output, known amplifier tube characteristics, and measured antenna resistance. If a directional antenna array is to be used, the factor of phase angle becomes important. Practically all television and FM broadcasting radiating systems employ multi-element units which require the use of phasing networks.

This assignment will give you an overall picture of such r.f. circuits and will prepare you to handle specific applications of such circuits when they are taken up in later assignments.

Note particularly in this assignment how easily the most complex circuit is broken down for analysis into simple component circuits. *This is extremely important.* Just as the expert mathematician looks at a complex algebraic equation as a series of simple algebraic processes and attacks the problem in a systematic manner, so should the solution of a complex electrical circuit be viewed and attacked. Problems such as those studied in this assignment will help you to acquire the habit of orderly thinking. Nothing else will simplify the analysis of complex circuit operation so much as the orderly approach.

The fact that you have reached this assignment indicates that you have the necessary background to handle it without difficulty. You should enjoy it immensely. When you have completed the exam, check your work carefully and then go on to the next assignment which takes up practical radio applications of r.f. tuned circuits.

E. H. Rietzke,
President.

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SIMPLE PARALLEL CIRCUIT: THE CHARACTERISTICS OF PARALLEL CIRCUITS HAVE BEEN COMPARED WITH THE CHARACTERISTICS OF SERIES CIRCUITS UNDER SIMILAR CONDITIONS. MOST OF THE CHARACTERISTICS ARE EXACTLY OPPOSITE IN THE TWO TYPES OF CIRCUITS. CONDITIONS HAVE BEEN ASSUMED AND BOTH SERIES AND PARALLEL CIRCUITS HAVE BEEN DISCUSSED BOTH THEORETICALLY AND MATHEMATICALLY. IT IS NECESSARY TO THOROUGHLY UNDERSTAND THE PARALLEL CIRCUIT MATHEMATICALLY IN ORDER THAT THE OPERATION OF SUCH A CIRCUIT MAY BE PREDICTED FROM ITS KNOWN VALUES. A MATHEMATICAL UNDERSTANDING OF A CIRCUIT WILL GREATLY SIMPLIFY THE STUDY OF THE THEORY AND OPERATION OF THAT CIRCUIT. BEFORE PROCEEDING TO A MORE COMPLEX CIRCUIT ANOTHER SIMPLE PARALLEL CIRCUIT PROBLEM WILL BE SOLVED. PARALLEL LCR CIRCUITS AND COMBINATIONS INVOLVING SUCH CIRCUITS ARE VERY EXTENSIVELY USED IN RADIO, BOTH TRANSMITTERS AND RECEIVERS.

CONSIDER THE CIRCUIT IN FIGURE 1. THIS REPRESENTS A PARALLEL TUNED CIRCUIT IN WHICH THE RESISTANCE SHOWN IN SERIES WITH THE INDUCTANCE IS THE RESISTANCE DISTRIBUTED THROUGHOUT THE INDUCTANCE COIL, AND THE RESISTANCE IN SERIES WITH THE CAPACITY REPRESENTS THE RESISTANCE LOSSES IN THE CONDENSER, PARTLY IN THE DI-ELECTRIC AND PARTLY IN THE PLATES AND CONNECTING LEADS. AS WAS SHOWN IN THE STUDY OF SERIES CIRCUITS, THE EFFECTS OF THESE RESISTANCES ARE AS IF THE RESISTANCES WERE LUMPED IN SERIES WITH PURE INDUCTANCE AND PURE CAPACITY. IT IS EVIDENT THAT EACH BRANCH OF THE PARALLEL CIRCUIT MUST BE TREATED FIRST AS A SEPARATE SERIES CIRCUIT.

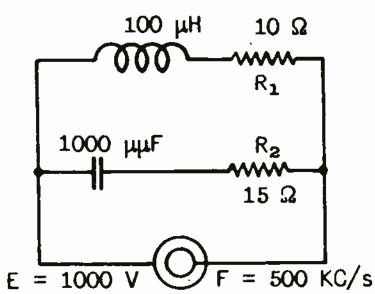


FIG. 1.

IN ORDER TO FIND THE TOTAL IMPEDANCE OF A PARALLEL CIRCUIT IT IS FIRST

NECESSARY TO DETERMINE THE TOTAL CURRENT IN THE EXTERNAL CIRCUIT, THAT TOTAL CURRENT DIVIDED INTO THE APPLIED VOLTAGE GIVING THE TOTAL IMPEDANCE OF THE CIRCUIT AT THAT FREQUENCY. THE EXTERNAL CIRCUIT CURRENT EQUALS THE VECTOR SUM OF THE CURRENTS THROUGH THE INDIVIDUAL BRANCHES. THE CURRENT THROUGH EACH BRANCH CIRCUIT EQUALS THE APPLIED VOLTAGE DIVIDED BY THE IMPEDANCE OF THAT BRANCH. THE IMPEDANCE OF EACH BRANCH CIRCUIT IS A FUNCTION OF THE RESISTANCE AND REACTANCE OF THAT INDIVIDUAL BRANCH. IN THE SOLUTION OF THIS PROBLEM IT IS CLEAR THAT EACH BRANCH CIRCUIT MUST FIRST BE SOLVED INDIVIDUALLY. FIRST, SOLVE FOR ALL THE VALUES OF THE UPPER CIRCUIT CONSISTING OF AN INDUCTANCE OF 100 MICROHENRIES AND RESISTANCE OF 10 OHMS. STATED IN EQUATION FORM:

$$R_1 = 10 \text{ OHMS}$$

$$X_L = 2\pi FL = 628 \times 5 \times 10^{-1} = 314 \text{ OHMS}$$

$$Z_1 = \sqrt{R^2 + X_L^2} = \sqrt{10^2 + 314^2} = 314.1 \text{ OHMS}$$

$$I_L = E/Z = 1000/314.1 = 3.18 \text{ AMPERES}$$

$$\text{TAN } \theta_1 = X/R = 314/10 = 31.4$$

$$\theta_1 = 88^\circ 10' \text{ LAG}$$

IN THE INDUCTIVE BRANCH THE IMPEDANCE IS 314.1 OHMS, THE CURRENT IS 3.18 AMPERES, AND THE CURRENT LAGS 88 DEGREES 10 MINUTES BEHIND THE APPLIED VOLTAGE. THIS CURRENT IS SHOWN IN FIGURE 2 AS I_L. IN THE CAPACITY BRANCH:

$$R_2 = 15 \text{ OHMS}$$

$$X_C = 1/2\pi FC = \frac{10^6}{628 \times 5} = 318.4 \text{ OHMS}$$

$$Z_2 = \sqrt{R^2 + X_C^2} = \sqrt{15^2 + 318.4^2} = 318.7 \text{ OHMS}$$

$$I_C = E/Z = 1000/318.7 = 3.13 \text{ AMPERES}$$

$$\text{TAN } \theta_2 = X/R = 318.4/15 = 21.2$$

$$\theta_2 = 87^\circ 18' \text{ LEAD}$$

IN THE CAPACITY BRANCH THE IMPEDANCE IS 318.7 OHMS, THE CURRENT 3.13 AMPERES, AND THE CURRENT LEADS THE APPLIED VOLTAGE BY 87 DEGREES AND 18 MINUTES.

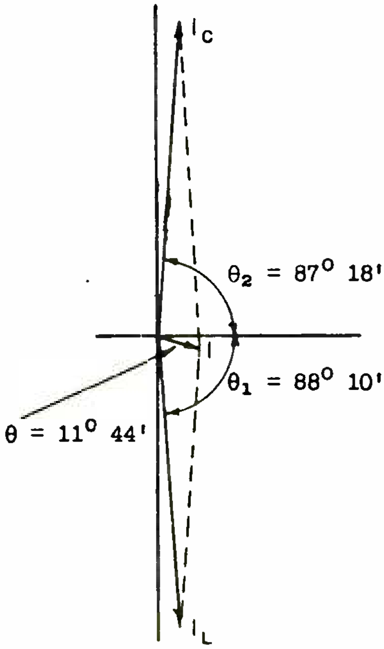


FIG. 2.

THIS CURRENT IS SHOWN ON FIGURE 2 AS I_C.

THERE ARE TWO CURRENTS, I_L AND I_C, BOTH CAUSED TO FLOW THROUGH THEIR RESPECTIVE CIRCUITS BY THE SAME APPLIED VOLTAGE, E. THEY MAY THEREFORE BE CONSIDERED AS TWO FORCES ACTING UPON A COMMON POINT, AND THE TOTAL RESULTING CURRENT IN THE EXTERNAL CIRCUIT IS EQUAL TO THE VECTOR SUM OF THE INDIVIDUAL CURRENTS.

A REFERENCE TO THE ASSIGNMENTS ON VECTOR ANALYSIS AND PARALLEL CIRCUITS WILL SHOW THE METHOD OF HANDLING THIS PROBLEM. SINCE THE ANGLE BETWEEN THE TWO CURRENTS IS NEITHER ZERO DEGREES NOR 180 DEGREES, THAT IS, THEY ARE NEITHER EXACTLY IN PHASE NOR EXACTLY OPPOSITE, IT IS NECESSARY TO FIND THE TWO COMPONENTS OF EACH CURRENT IN ORDER TO ADD THEM vectorially, Each current HAS TWO FORCES ACTING ON IT, REACTANCE AND RESISTANCE. EACH CURRENT THEREFORE HAS A RESISTANCE COMPONENT AND A REACTIVE COMPONENT. THE RESISTANCE COMPONENT OF CURRENT TENDS TO FLOW IN PHASE WITH E AND IS EQUAL TO I Cos θ. THE REACTIVE COMPONENT TENDS TO LEAD OR LAG BY 90^o AND IS EQUAL TO I SIN θ. A STUDY OF FIGURE 2 WILL SHOW THAT THE RESISTANCE COMPONENTS OF BOTH ARE TO THE RIGHT OF THE VERTICAL BISECTOR THEREFORE ADDING. THE TOTAL RESISTANCE COMPONENT IS EQUAL TO $I_C \text{Cos } 87^o18' + I_L \text{Cos } 88^o10'$.

THE REACTIVE COMPONENTS, I SIN θ, ARE IN EXACT OPPOSITION, THE SMALLER THEREFORE SUBTRACTING FROM THE LARGER AND THE TOTAL REACTIVE COMPONENT EQUALLING $I_L \text{Sin } 88^o10' - I_C \text{Sin } 87^o18'$.

IN THIS CASE WHERE THE DIFFERENCE BETWEEN THE REACTIVE COMPONENTS IS VERY SMALL AND A CASUAL INSPECTION DOES NOT INDICATE WHICH IS THE LARGER, THE SINE

VALUE OF I_L OR THE SINE VALUE OF I_C, THE TOTAL MAY BE WRITTEN AS ABOVE AND IF THE RESULTS SHOW $I_C \sin\theta$ AS GREATER THAN $I_L \sin\theta$ IT MAY BE REVERSED AND WRITTEN $I_C \sin\theta - I_L \sin\theta$, OR THE RESULT MAY SIMPLY BE CONSIDERED AS A NEGATIVE VALUE.

AGAIN REFERRING TO VECTOR ANALYSIS, THE RESULTANT IS EQUAL TO THE HYPOTENUSE OF A RIGHT TRIANGLE FORMED BY THE TOTAL RESISTANCE COMPONENT AND THE TOTAL REACTIVE COMPONENT. THE TOTAL CURRENT IS THEN,

$$I = \sqrt{I_R^2 + I_X^2}$$

BUT, $I_R = I_C \cos 87^\circ 18' + I_L \cos 88^\circ 10'$

AND $I_X = I_L \sin 88^\circ 10' - I_C \sin 87^\circ 18'$

THEREFORE, $I = \sqrt{(I_C \cos 87^\circ 18' + I_L \cos 88^\circ 10')^2 + (I_L \sin 88^\circ 10' - I_C \sin 87^\circ 18')^2}$

$I_L = 3.18$ AMPERES $\qquad I_C = 3.13$ AMPERES

$\cos 87^\circ 18' = .04711 \qquad \sin 87^\circ 18' = .99889$

$\cos 88^\circ 10' = .03199 \qquad \sin 88^\circ 10' = .99949$

THEREFORE, $I_C \cos 87^\circ 18' = 3.13 \times .04711 = .1475$

$I_L \cos 88^\circ 10' = 3.18 \times .03199 = .1017$

AND $I_L \sin 88^\circ 10' = 3.18 \times .99949 = 3.1783$

$I_C \sin 87^\circ 18' = 3.13 \times .99889 = 3.1265$

SUBSTITUTING THESE VALUES FOR THE SYMBOLS IN THE ABOVE EQUATION, IT BECOMES

$$I = \sqrt{(.1475 + .1017)^2 + (3.1783 + 3.1265)^2}$$

ADDING, $I = \sqrt{.2492^2 + .0518^2}$

SQUARING THE VALUES AND ADDING,

$$I = \sqrt{.0621 + .00268} = \sqrt{.06478}$$

EXTRACTING THE SQUARE ROOT, $I = .254$ AMPERE.

IT WILL BE SEEN THAT THERE IS A CURRENT OF 3.18 AMPERES IN THE INDUCTIVE BRANCH AND 3.13 AMPERES IN THE CAPACITY BRANCH BUT ONLY .254 AMPERE IN THE EXTERNAL CIRCUIT OR LINE THROUGH THE ALTERNATOR. THE TOTAL IMPEDANCE IS EQUAL TO

$$E/I = 1000/.254 = 3936 \text{ OHMS.}$$

THIS CIRCUIT, EVEN THOUGH NOT OPERATED EXACTLY AT RESONANCE, HAS AN IMPED-

ANCE OF 3936 OHMS WHILE THE INDIVIDUAL IMPEDANCES OF THE TWO BRANCHES IN PARALLEL ARE ONLY 314 AND 318 OHMS RESPECTIVELY. THE SMALL DIFFERENCE BETWEEN THE TWO IMPEDANCES SHOWS THAT THE FREQUENCY OF 500 KC/S IS NOT FAR FROM THE RESONANT FREQUENCY OF THE CIRCUIT AT WHICH FREQUENCY THE RESULTING IMPEDANCE WOULD HAVE BEEN SOMEWHAT HIGHER.

SINCE THE REACTIVE VALUE OF I_L IS SLIGHTLY GREATER THAN THE REACTIVE VALUE OF I_C, THE RESULTING CURRENT WILL TEND TO LAG BEHIND THE APPLIED VOLTAGE. THE TANGENT OF THE ANGLE OF LAG OF THE LINE CURRENT BEHIND THE APPLIED VOLTAGE IS EQUAL TO THE TOTAL REACTIVE COMPONENT OF CURRENT DIVIDED BY THE TOTAL RESISTIVE COMPONENT. THE EQUATION THEN BECOMES

$$\text{Tan } \theta = I_X/I_R = \frac{I_L \text{Sin } \theta - I_C \text{Sin } \theta}{I_C \text{Cos } \theta + I_L \text{Cos } \theta}$$

$$\text{Tan } \theta = \frac{.0518}{.2492} = .20786$$

$$\theta = 11^\circ 44' \text{ Lag.}$$

TABULATING THE RESULTS OF THIS PROBLEM IT IS FOUND THAT AT A FREQUENCY OF 500 KC/S WITH AN APPLIED VOLTAGE OF 1000 VOLTS,

TOTAL IMPEDANCE = 3936 OHMS

TOTAL CURRENT = .254 AMPERE

TOTAL CURRENT LAGS THE VOLTAGE BY $11^\circ 44'$

AT THE RESONANT FREQUENCY OF THE CIRCUIT THE RESULTING CURRENT WOULD HAVE BEEN STILL LESS AND THE TOTAL IMPEDANCE HIGHER. THE RESONANT FREQUENCY IS FOUND BY THE USE OF THE EQUATION

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

L IN HENRIES, C IN FARADS, F IN CYCLES.

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

$$C = 1000 \times 10^{-12} = 10^{-9} \text{ F}$$

$$L = 100 \times 10^{-6} = 10^{-4} \text{ H}$$

THEREFORE, $$F = \frac{1}{628 \cdot 10^{-2} \cdot \sqrt{10^{-9} \times 10^{-4}}}$$

$$F = \frac{1}{628 \cdot 10^{-2} \sqrt{10 \times 10^{-14}}} = \frac{1}{628 \cdot 10^{-2} \sqrt{10} \cdot 10^{-7}}$$

$$F = \frac{1}{628 \cdot \sqrt{10} \cdot 10^{-9}} = \frac{10^9}{628 \sqrt{10}} = \frac{10^9}{628 \times 3.16}$$

$$F = \frac{10^{11}}{198448} = 503{,}910 \text{ cycles or } 503.91 \text{ KC/s.}$$

It has been shown in a preceding lesson that at a frequency lower than its resonant frequency, the circuit will act as an inductance. At resonance the circuit acts as a resistance. In this problem the circuit has a resonant frequency of 503.91 KC/s. It is operated at a lower frequency of 500 KC/s and a current lag of slightly more than 11 degrees results. A lagging current is the result of an inductive circuit, this circuit therefore has the effect of a high resistance and a comparatively small inductance in series.

In circuit calculations it is often helpful to replace a complex circuit with an equivalent more simple circuit. It is interesting at this point to see just what components an equivalent series circuit must have to replace the parallel combination of Figure 1 at 500 KC/s without changing in any way the load on the generator. The equivalent series circuit must be such that the same generator current, .254 ampere, will flow under the pressure of 1000 volts with a current lag of 11°44'. The equivalent circuit will obviously consist of inductance and resistance in series. See Figure 3(a). Z = 3936 ohms, made up of a large resistance which will be the "in phase" or Cosine component, and a comparatively small inductive reactance which will be the "quadrature" or Sine component. This is shown in Figure 3(b).

$Z = \sqrt{R^2 + X^2} = 3936$ ohms

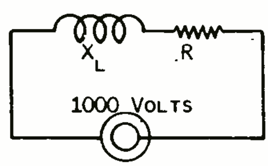


Fig. 3(a).

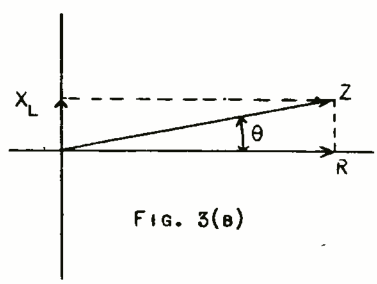


Fig. 3(b)

From Figure 3(b) it is evident that $R = Z \cos\theta$ and $X_L = Z \sin\theta$.

$$R = Z\cos\theta = 3936 \cos 11^\circ 44' = 3936 \times .97910 = 3854 \text{ ohms}$$

$$X_L = Z\sin\theta = 3936 \sin 11^\circ 44' = 3936 \times .20336 = 800 \text{ ohms}$$

$$L = \frac{X_L}{2\pi F} = \frac{800}{6.28 \times 5 \times 10^5} = 254.7\ \mu H.$$

Thus at this frequency, 500 KC/s, so far as the load effect on the generator is concerned, the parallel circuit of Figure 1 could be replaced with the equivalent series circuit of Figure 3(a) having the following constants: R = 3854 ohms, L = 254.7 µH.

A mental concept of the operation of a complex circuit may often be simplified by resolving it into a simple equivalent circuit.

In the parallel circuit problem discussed above, when solving for the impedance of the entire parallel circuit it was necessary first to find the current through each of the branches, and after adding those currents vectorally to divide the resulting current into the applied voltage to obtain the impedance; Z = E/I. Tuned circuits of this type will ordinarily be used with varying voltages, and when it is required to find the impedance no voltage will be specified. In that case it is merely necessary to assume a voltage. This is seen to be correct when it is remembered that the current through any circuit varies directly as the voltage. If the voltage is doubled the current through the circuit is also doubled. If the voltage is decreased to one-half its normal value the current is also decreased to one-half.

Since Z = E/I, if the applied voltage is 100 volts and the current is one ampere, the impedance is equal to 100/1 or 100 ohms. If the voltage is increased by ten times, the current will also be increased ten times, and the equation Z = E/I becomes Z = 1000/10 = 100 ohms, the same as before. It is evident that the impedance of the circuit does NOT change with a variation of the applied voltage and therefore ANY voltage may be assumed when solving for the impedance.

IT MUST BE REMEMBERED HOWEVER THAT THE SAME ASSUMED VOLTAGE MUST BE USED THROUGHOUT THE ENTIRE PROBLEM. WHEN WORKING WITH FAIRLY HIGH VALUES OF IMPEDANCE IT IS USUALLY SOMEWHAT MORE SIMPLE IF A COMPARATIVELY HIGH ASSUMED VOLTAGE IS USED BECAUSE UNDER THAT CONDITION COMPARATIVELY LARGE CURRENTS WILL BE OBTAINED IN THE PARALLEL BRANCH CIRCUITS. THE HIGHER VALUES OF CURRENT ARE USUALLY CONSIDERED EASIER TO HANDLE THAN VERY SMALL DECIMAL AMOUNTS. OF COURSE, IF A CERTAIN VOLTAGE IS SPECIFIED IN THE PROBLEM, IT IS UNNECESSARY TO USE AN ASSUMED VOLTAGE.

PARALLEL COMBINATION OF SERIES LCR CIRCUITS: IT MAY BE NECESSARY TO DETERMINE THE ACTUAL VOLTAGE ACROSS A PARALLEL CIRCUIT AND THE TOTAL CURRENT IN THE EXTERNAL OR GENERATOR CIRCUIT WHEN ONLY THE CIRCUIT CONSTANTS AND THE CURRENT THROUGH ONE BRANCH OF THE PARALLEL CIRCUIT ARE GIVEN. THE FREQUENCY MUST BE SPECIFIED IN ALL A. C. WORK INVOLVING INDUCTANCE AND CAPACITY. SEE FIGURE 4.

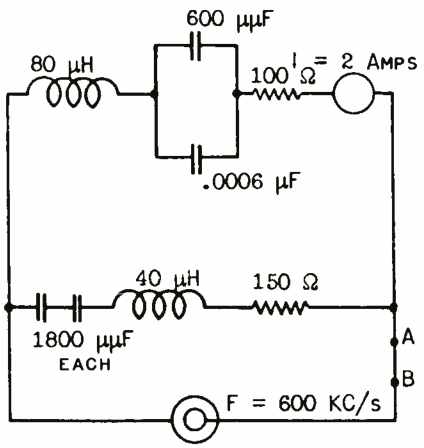


FIG. 4.

IN THIS DIAGRAM THERE ARE TWO SERIES CIRCUITS, EACH COMPOSED OF L, C AND R, IN PARALLEL.

IT IS FIRST NECESSARY TO SOLVE FOR THE IMPEDANCE, ANGLE OF LEAD OR LAG, AND THE CURRENT IN EACH BRANCH.

NO APPLIED VOLTAGE IS SPECIFIED BUT THE CURRENT THROUGH THE UPPER BRANCH IS GIVEN AS 2 AMPERES. SINCE E = IZ, IF THE IMPEDANCE OF THE UPPER BRANCH IS FIRST DETERMINED, THE VOLTAGE ACROSS THE CIRCUIT MAY BE FOUND BY MULTIPLYING THAT IMPEDANCE BY THE CURRENT OF 2 AMPERES. THIS BEING A PARALLEL CIRCUIT, THE SAME VOLTAGE IS ALSO APPLIED ACROSS THE LOWER BRANCH, AND BY DIVIDING THIS COMMON VOLTAGE BY THE IMPEDANCE OF THE LOWER BRANCH, THE CURRENT THROUGH THE LOWER BRANCH MAY ALSO BE CALCULATED. THIS PROBLEM IS STARTED IN THE SAME WAY AS WAS THE PRECEDING

PROBLEM, I. E., THE INDIVIDUAL BRANCHES ARE TREATED AS SIMPLE SERIES CIRCUITS AND SOLVED FOR IMPEDANCES AND CURRENTS.

UPPER BRANCH:

$R = 100$ OHMS.

$X_L = 2\pi FL = 628 \times 6 \times 8 \times 10^{-2} = 301$ OHMS.

$C = 600\ \mu\mu F + .0006\ \mu F = 600 + 600 = 1200\ \mu\mu F.$ (THE TWO CAPACITIES BEING IN PARALLEL, ADD.)

$$X_C = \frac{1}{628 \times 6 \times 12 \times 10^{-7}} = \frac{10^7}{45216} = 221 \text{ OHMS.}$$

$Z_1 = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{100^2 + (301 - 221)^2} = \sqrt{100^2 + 80^2} = 128$ OHMS.

TAN $\theta_1 = X/R = 80/100 = .8$

$\theta_1 = 39^0$ LAG. (X_L IS GREATER THAN X_C)

$E = IZ = 2 \times 128 = 256$ VOLTS.

AS WAS PREVIOUSLY EXPLAINED, THIS IS ALSO THE VOLTAGE ACROSS THE LOWER BRANCH; IN OTHER WORDS, THE TOTAL APPLIED VOLTAGE. SOLVING FOR THE LOWER BRANCH IN A SIMILAR MANNER:

$R = 150$ OHMS.

$X_L = 628 \times 6 \times 4 \times 10^{-2} = 151$ OHMS.

$$C = \frac{1}{\frac{1}{1800} + \frac{1}{1800}} = \frac{1}{\frac{2}{1800}} = \frac{1800}{2} = 900\ \mu\mu F$$ (THE TWO CAPACITIES ARE IN SERIES.)

$$X_C = \frac{1}{628 \times 6 \times 9 \times 10^{-7}} = \frac{10^7}{33912} = 295 \text{ OHMS.}$$

$Z_2 = \sqrt{R^2 + (X_C - X_L)^2} = \sqrt{150^2 + (295 - 151)^2} = \sqrt{150^2 + 144^2} = 208$ OHMS

TAN $\theta_2 = X/R = 144/150 = .960$

$\theta_2 = 44^0$ LEAD. (X_C IS GREATER THAN X_L.)

$I_2 = E/Z = 256/208 = 1.23$ AMPERES.

IT HAS BEEN DETERMINED THAT THE APPLIED VOLTAGE OF 256 VOLTS CAUSES A CURRENT FLOW OF 2 AMPERES, I_1, IN THE UPPER BRANCH, THAT CURRENT LAGGING 39^0 BEHIND THE APPLIED VOLTAGE; ALSO THAT THE SAME VOLTAGE CAUSES A CURRENT FLOW OF 1.23 AMPERES, I_2, THROUGH THE LOWER BRANCH, THIS CURRENT LEADING THE SAME VOLT-

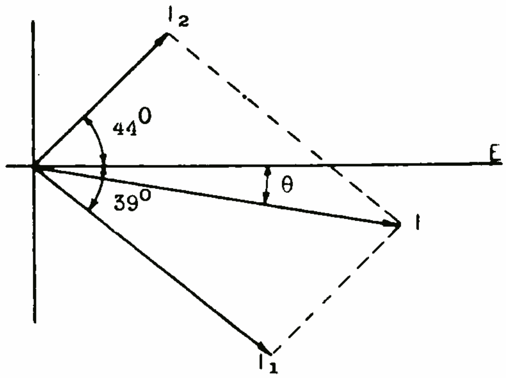


FIG. 5.

BY 44^0. THIS IS SHOWN vectorially in FIGURE 5.

THE RESULTANT CURRENT, THAT IS, THE LINE CURRENT IN THE EXTERNAL CIRCUIT, IS ALSO SHOWN AS THE VECTOR SUM OF THE CURRENTS THROUGH THE INDIVIDUAL BRANCHES. THE VECTOR SUM OF THE CURRENTS MAY BE EXPRESSED BY THE FOLLOWING EQUATION:

$$I = \sqrt{(I_1 \text{Cos } 39^0 + I_2 \text{Cos } 44^0)^2 + (-I_1 \text{Sin } 39^0 + I_2 \text{Sin } 44^0)^2}$$

$I_1 \text{Cos } 39^0 = 2 \times .777 = 1.554$ AMPERES

$I_2 \text{Cos } 44^0 = 1.23 \times .719 = .884$ AMPERES

$I_1 \text{Sin } 39^0 = 2 \times .629 = 1.258$ AMPERES

$I_2 \text{Sin } 44^0 = 1.23 \times .695 = .855$ AMPERES

REPLACING THESE FIGURES IN THE ABOVE EQUATION, IT BECOMES

$$I = \sqrt{(1.554 + .884)^2 + (-1.258 + .855)^2}$$

$$I = \sqrt{(2.438^2 + .403^2} = \sqrt{6.1062} = 2.47 \text{ AMPERES.}$$

$$\text{Tan } \theta = I_X / I_R = \frac{-.403}{2.438} = -.165$$

$$\theta = 9.5^0 \text{ Lag.}$$

SINCE THE TOTAL IMPEDANCE OF A PARALLEL CIRCUIT IS EQUAL TO THE APPLIED VOLTAGE DIVIDED BY THE TOTAL CURRENT, THE IMPEDANCE OF THIS PARALLEL COMBINATION IS EQUAL TO:

$$Z = E/I = 256/2.47 = 103 \text{ OHMS.}$$

TABULATING THE RESULTS:

I (UPPER BRANCH) = 2 AMPERES

θ " " = 39^0 LAG

I (LOWER BRANCH) = 1.23 AMPERES

θ " " = 44^0 LEAD

Total current = 2.47 amperes

θ (Total current)= 9.5° Lag

Applied voltage = 256 volts.

Z(Total circuit) = 103 ohms.

<u>Addition of series circuit to parallel combination</u>: Suppose it is desired to add another impedance, composed of L, C and R in series, to the parallel combination and in series with it. In Figure 6 is shown the series circuit, and its component values. This circuit is to be inserted between points A and B in Figure 4 and those points are also shown in Figure 6.

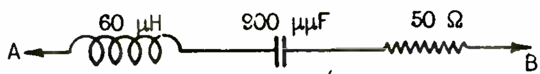


Fig. 6.

The frequency is the same as in Figure 4, i. e., 600 KC/s.

$R = 50$ ohms

$X_L = 2\pi fL = 628 \times 6 \times 6 \times 10^{-2} = 226$ ohms.

$X_C = \dfrac{1}{628 \times 9 \times 6 \times 10^{-7}} = \dfrac{10^7}{628 \times 9 \times 6} = 295$ ohms.

$Z = \sqrt{R^2 + (X_C - X_L)^2} = \sqrt{50^2 + (295 - 226)^2} = \sqrt{50^2 + 69^2} = 85$ ohms

$\tan\theta = X/R = 69/50 = 1.38$

$\theta = 54^{\circ}$ Lead (X_C is greater than X_L.)

The impedance of the parallel circuit Z_P was found to be 103 ohms and to be such as to cause a current lag of 9.5 degrees. The impedance of the series circuit Z_S is 85 ohms and its effect is to cause a current lead of 54 degrees. The total impedance of the two circuits, <u>in series</u>, will be the vector sum of Z_P and Z_S and is shown in Figure 7. Both will have an effect on the current flow through the circuit according to their individual magnitudes and angles.

The total impedance for the entire circuit consisting of the parallel combination shown in Figure 4 in series with the series combination shown in Figure 6 is expressed in the following equation:

$$Z = \sqrt{(Z_P \text{Cos } 9.5^0 + Z_S \text{Cos } 54^0)^2 + (Z_S \text{Sin } 54^0 - Z_P \text{Sin } 9.5^0)^2}$$

$Z_P \text{Cos } 9.5^0 = 103 \times .987 = 101.6$

$Z_S \text{Cos } 54^0 = 85 \times .588 = 49.9$

$Z_S \text{Sin } 54^0 = 85 \times .809 = 68.7$

$Z_P \text{Sin } 9.5^0 = 103 \times .165 = 16.9$

REPLACING SYMBOLS WITH NUMERICAL VALUES, THE EQUATION BECOMES:

$$Z = \sqrt{(101.6 + 49.9)^2 + (68.7 - 16.9)^2} = \sqrt{151.5^2 + 51.8^2} = 160 \text{ OHMS.}$$

$\text{TAN } \theta = X/R = 51.8/151.5 = .341$

$\theta = 19^0$ LEAD

THE TOTAL IMPEDANCE OF THE TWO CIRCUITS CONNECTED IN SERIES IS 160 OHMS AT A FREQUENCY OF 600 KC/S. THE REACTIVE COMPONENT OF Z_S IS LARGER THAN THE REACTIVE COMPONENT OF Z_P, THEREFORE SINCE THE EFFECT OF Z_S IS TO CAUSE A LEADING CURRENT THE EFFECT OF THE TOTAL IMPEDANCE IS TO CAUSE A CURRENT LEAD OF 19^0.

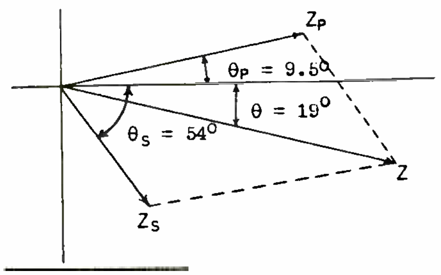


FIG. 7.

COMPLEX NETWORK: IN ORDER TO DEMONSTRATE THE EASE WITH WHICH ALL THE VOLTAGE, CURRENT, AND IMPEDANCE RELATIONS IN A SOMEWHAT COMPLEX NETWORK MAY BE DETERMINED FROM WHAT MAY AT FIRST APPEAR TO BE RELATIVELY LITTLE INFORMATION, CONSIDER THE SOLUTION OF THE CIRCUIT OF FIGURE 8.

FUNDAMENTALLY THIS IS A SERIES CIRCUIT CONSISTING OF Z_{P_1}, R_3 AND Z_{P_2} IN SERIES. IT IS FIRST NECESSARY TO SOLVE FOR Z_{P_1} AND Z_{P_2} IN TERMS OF OHMS AND θ. IN A PROBLEM OF THIS TYPE THE MOST ESSENTIAL FACTOR IS AN ORDERLY AND METHODICAL ATTACK.

TO FIND THE LINE CURRENT I_T, THE IMPEDANCE OF THE TOTAL LOAD ACROSS THE GENERATOR, THE GENERATOR VOLTAGE, AND THE PHASE ANGLE OF THE LOAD.

FIRST, SOLVE Z_{P_1}.

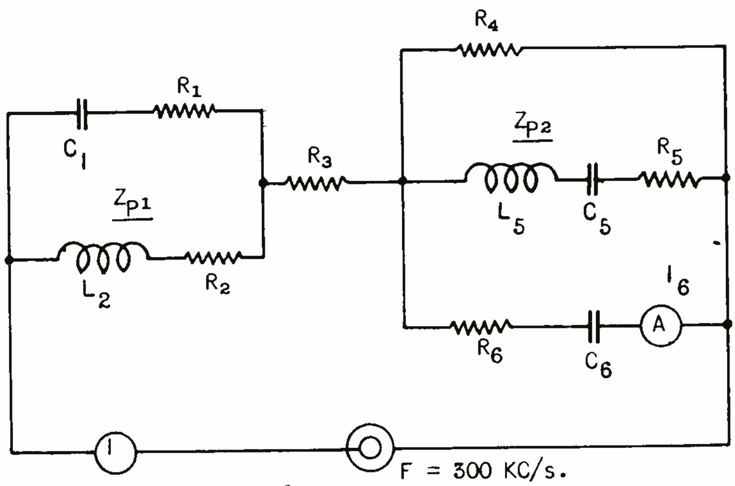


FIG. 8.

$C_1 = .004\ \mu F$
$C_5 = .0015\ \mu F$
$C_6 = 1000\ \mu\mu F$
$L_2 = 200\ \mu H$
$L_5 = 400\ \mu H$
$R_1 = 100$ OHMS
$R_2 = 200$ OHMS
$R_3 = 300$ OHMS
$R_4 = 400$ OHMS
$R_5 = 200$ OHMS
$R_6 = 300$ OHMS
$I_6 = 3$ AMPERES

UPPER BRANCH: Z_{P_1}

$R_1 = 100$ OHMS

$$X_{C_1} = \frac{1}{6.28 \times .3 \times 10^6 \times 4 \times 10^{-9}} = \frac{10^3}{7.536} = 133 \text{ OHMS}$$

$$Z_1 = \sqrt{R^2 + X_{C_1}^2} = \sqrt{100^2 + 133^2} = 166 \text{ OHMS}$$

$$\text{TAN } \theta_1 = \frac{X}{R} = \frac{133}{100} = 1.33 \qquad \theta_1 = 53^0 \text{ LEAD}$$

ASSUME VOLTAGE DROP IS 166 VOLTS, THEN $I_1 = \frac{166}{166} = 1$ AMP.

LOWER BRANCH:

$R_2 = 200$ OHMS

$$X_{L_2} = 6.28 \times 3 \times 10^5 \times 2 \times 10^{-4} = 37.68 \times 10 = 376.8 \text{ OHMS}$$

$$Z_2 = \sqrt{200^2 + 376.8^2} = 427 \text{ OHMS}$$

$$\text{TAN } \theta_2 = \frac{X}{R} = \frac{376.8}{200} = 1.88 \qquad \theta_2 = 62^0 \text{ LAG}$$

$$I_{2(\text{ASSUMED})} = \frac{166}{427} = .39 \text{ AMPERE}$$

THE ASSUMED CURRENTS ARE SHOWN IN THE VECTOR OF FIG. 9. TO FIND THE TOTAL LINE CURRENT WE MUST COMBINE THE TWO BRANCH CURRENTS VECTORIALLY AS FOLLOWS:

$$I_T = \sqrt{(I_1 \cos 53^0 + I_2 \cos 62^0)^2 + (I_1 \sin 53^0 - I_2 \sin 62^0)^2}$$

$$= \sqrt{(.602 + .183)^2 + (.799 - .344)^2} = \sqrt{.785^2 + .455^2}$$

$$= .907 \text{ AMPERE}$$

$$Z_{P_1} = \frac{E \text{ ASSUMED}}{I \text{ ASSUMED}} = \frac{166}{.907} = \underline{\underline{183 \text{ OHMS}}}$$

$$\tan \theta_{P_1} = \frac{.455}{.785} = .58 \qquad \theta_{P_1} = \underline{\underline{30^\circ \text{ LEAD}}}$$

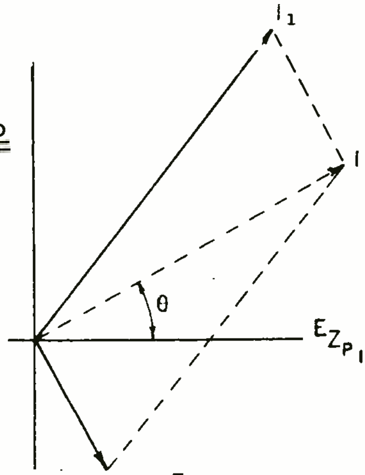


FIG. 9.

THIS IS THE TRUE IMPEDANCE OF Z_{P_1} EVEN THOUGH AN ASSUMED VOLTAGE WAS USED IN ITS DETERMINATION. THE ASSUMED VOLTAGE AND THE BRANCH CURRENTS WILL NOT BE USEFUL FOR ANY OTHER WORK IN THIS PROBLEM.

NEXT CONSIDER THE THREE BRANCH PARALLEL COMBINATION Z_{P_2}. THIS WILL BE SOLVED IN A SIMILAR MANNER TO THE FIRST CIRCUIT BUT IT WILL NOT BE NECESSARY TO ASSUME A VOLTAGE IN THIS CASE SINCE ONE BRANCH CURRENT IS GIVEN.

Z_{P_2}

LOWER BRANCH:

$R_6 = 300$ OHMS $\qquad C_6 = 1000 \ \mu\mu F = 10^{-9}$ FARAD $\qquad I_6 = 3$ AMP.

$$X_{C_6} = \frac{1}{6.28 \times 3 \times 10^5 \times 10^{-9}} = \frac{10^4}{18.84} = 531 \text{ OHMS}$$

$$Z_6 = \sqrt{300^2 + 531^2} = 609 \text{ OHMS} \qquad \tan \theta_6 = \frac{531}{300} = 1.77$$

$= 60.5^\circ$ LEAD

$E_{Z_{P_2}} = I_6 Z_6 = 3 \times 609 = 1827$ VOLTS (THIS IS THE ACTUAL VOLTAGE ACROSS THE CIRCUIT, NO ASSUMED VOLTAGE NECESSARY).

MIDDLE BRANCH:

$R_5 = 200$ OHMS

$$X_{L_5} = 6.28 \times 3 \times 10^5 \times 4 \times 10^{-4} = 75.36 \times 10 = 753.6 \text{ OHMS}$$

$$X_{C_5} = \frac{1}{6.28 \times 3 \times 10^5 \times 15 \times 10^{-8}} = \frac{10^3}{282.6} = 354 \text{ OHMS}$$

$$Z_5 = \sqrt{200^2 + (753.6 - 354)^2} = \sqrt{200^2 + 399.4^2} = 447 \text{ OHMS}$$

$$\tan \theta_5 = \frac{399.4}{200} = 1.997 \qquad \theta_5 = 63.5^\circ \text{ LAG}$$

$I_5 = \frac{1827}{447} = 4.09$ AMPERES

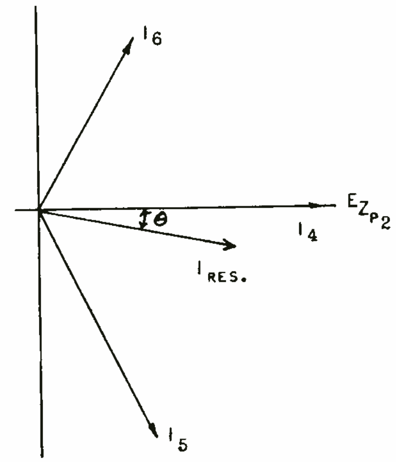


FIG. 10.

UPPER BRANCH:

$Z = R_4 = 400$ OHMS $\theta_4 = 0^0$

$I_4 = \frac{1827}{400} = 4.57$ AMPERES

THE CONDITIONS IN EACH PART OF THE CIRCUIT ARE CLEARLY SHOWN IN FIG. 10. I_6 LEADS THE APPLIED VOLTAGE OR VOLTAGE DROP ACROSS Z_{P2}, I_5 LAGS AND I_4 IS IN PHASE WITH E. FIG. 11 MORE CLEARLY SHOWS THE OPERATION OF THE CIRCUIT AS A WHOLE. IT IS SEEN THAT THE TOTAL CURRENT THROUGH Z_{P2} IS QUITE LARGE AND THE CURRENT LAGS THE CIRCUIT VOLTAGE BY A FEW DEGREES. THE TOTAL CURRENT I WILL NEXT BE FOUND. FIRST NOTE THAT IN FIG. 11 THE CURRENTS ARE THOSE FOUND FROM ACTUAL CALCULATION WITHOUT ASSUMING ANY VOLTAGE AND THE REFERENCE VECTOR IS THE VOLTAGE DROP ACROSS THE PARALLEL COMBINATION. THE TOTAL CURRENT LAGS THIS VOLTAGE DROP AS SHOWN IN THE FIGURE.

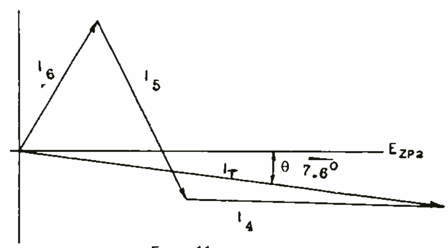


FIG. 11.

THE TOTAL APPLIED VOLTAGE TO THE ENTIRE CIRCUIT IS THE VECTOR SUM OF THE VOLTAGE DROPS ACROSS THE SEPARATE CIRCUITS Z_{P1}, R_3, AND Z_{P2}. THIS CAN BE USED AS A CHECK ON THE VOLTAGE AS FOUND LATER AND ON THE SOLUTION AS A WHOLE.

$$I_T = \sqrt{(I_6 \cos 60.5^0 + I_5 \cos 63.5^0 + I_4)^2 + (I_5 \sin 63.5^0 - I_6 \sin 60.5^0 + I_4 \sin 0^0)^2}$$

$$= \sqrt{(3\cos 60.5 + 4.09\cos 63.5 + 4.57)^2 + (4.09 \sin 63.5 - 3\sin 60.5 + 0)^2}$$

$$= \sqrt{(1.48 + 1.82 + 4.57)^2 + (3.66 - 2.61)^2}$$

$$= \sqrt{7.87^2 + 1.05^2} = 7.94 \text{ AMPERE}$$

$\tan\theta = \dfrac{1.05}{7.87} = .133$ $\qquad \theta_{P2} = \underline{7.6^\circ \text{ LAG}}$

$Z_{P2} = \dfrac{1827}{7.94} = \underline{230 \text{ OHMS}}$

NOTE THAT THIS CURRENT I_T IS THE TRUE CURRENT OF THE ENTIRE CIRCUIT WHICH IS SUPPLIED BY THE GENERATOR.

NOW THAT THE THREE PARTS OF THE ORIGINAL CIRCUIT OF FIG. 8 HAVE BEEN SOLVED THEY CAN BE CONSIDERED AS AN EQUIVALENT SERIES CIRCUIT AS ILLUSTRATED BY THE VECTORS IN FIG. 12 WHICH CAN THEN BE COMBINED INTO A RESULTANT TOTAL IMPEDANCE AS SHOWN IN FIG. 13.

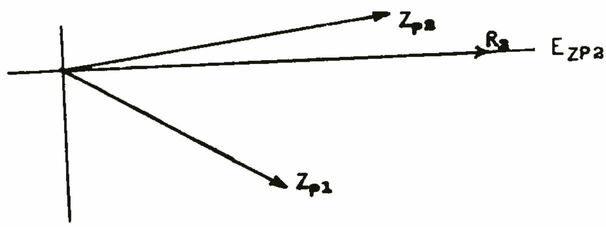


FIG. 12.

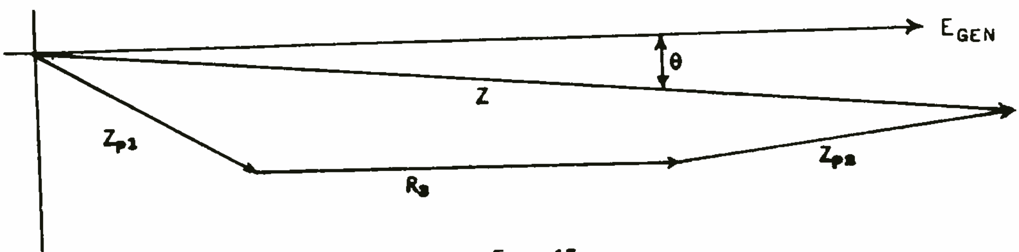


FIG. 13.

THE SOLUTION OF TOTAL Z CAN BE DONE GRAPHICALLY BY PLOTTING THE VECTORS TO SCALE OR BY TRIGONOMETRY AS SHOWN BELOW:

$$Z = \sqrt{(Z_{P1}\cos 30^\circ + Z_{P2}\cos 7.6^\circ + R_3)^2 + (Z_{P1}\sin 30^\circ - Z_{P2}\sin 7.6^\circ)^2}$$

$$= \sqrt{(183\cos 30^\circ + 230\cos 7.6^\circ + 300)^2 + (183\sin 30^\circ - 230\sin 7.6^\circ)^2}$$

$$= \sqrt{(158 + 228 + 300)^2 + (91.5 - 30.4)^2} = \sqrt{686^2 + 61.1^2} = 689 \text{ OHMS}$$

$I_T = 7.94$ AMP. $\qquad E_{GEN} = IZ = 7.94 \times 689 = 5471$ VOLTS

AS A CHECK WE CAN SOLVE FOR THE VECTORIAL SUM OF THE VOLTAGES.

$E_{ZP1} = 183 \times 7.94 = 1453$ VOLTS 30° LEAD $\qquad E_3 = 300 \times 7.94 = 2382$ V.

$$E_G = \sqrt{(1827\cos 7.6 + 1453\cos 30 + 2382)^2 + (1827\sin 7.6 - 1453\sin 30)^2}$$

$$= \sqrt{(1827 \times .9912 + 1453 \times .866 + 2382)^2 + (1827 \times .13226 - 1453 \times .5)^2}$$

$$= \sqrt{(5451)^2 + (513.5)^2} = 5452 \text{ VOLTS (A CLOSE CHECK)}$$

TAN θ = 61.1/686 = .08906

θ = 5.1° LEAD.

THIS IS THE ENTIRE SOLUTION. THIS COMPLEX CIRCUIT HAS A TOTAL IMPEDANCE AT 300 KC/S OF 689 OHMS. TO CAUSE 3 AMPERES TO FLOW IN THE BRANCH CIRCUIT C_6R_6 REQUIRES A GENERATOR VOLTAGE OF 5471 VOLTS, AND THIS VOLTAGE CAUSES A TOTAL LINE CURRENT OF 7.94 AMPERES WHICH LEADS THE GENERATOR VOLTAGE BY 5.1°. SO FAR AS THE GENERATOR LOAD IS CONCERNED, THIS COMPLEX CIRCUIT COULD BE REPLACED BY A SIMPLE SERIES CIRCUIT CONSISTING OF RESISTANCE AND CAPACITY, THE TOTAL IMPEDANCE AND PHASE ANGLE AT THIS FREQUENCY BEING EQUAL TO THE CALCULATED VALUE, THAT IS, Z = 689 OHMS, θ = 5.1° LEAD. THIS WOULD REQUIRE A RESISTANCE OF 686 OHMS AND CAPACITY SUCH THAT X_C = 61.1 OHMS, AS IS APPARENT FROM THE FINAL EQUATION FOR Z ABOVE.

IT SHOULD BE NOTED THAT, EVEN THOUGH AT FIRST GLANCE THE SOLUTION OF THIS CIRCUIT SEEMS QUITE COMPLEX, ACTUALLY WHEN HANDLED IN A SYSTEMATIC MANNER IT IS NOT AT ALL DIFFICULT. ANY SERIES-PARALLEL COMBINATION CAN BE SOLVED BY THE GENERAL METHODS USED IN THIS PROBLEM. IT SHOULD BE EMPHASIZED THAT THE SOLUTION IS CORRECT ONLY FOR THE SINGLE FREQUENCY AT WHICH THE CALCULATIONS ARE MADE.

VARIOUS PRACTICAL APPLICATIONS OF SERIES AND PARALLEL CIRCUITS WILL BE DISCUSSED IN CONSIDERABLE DETAIL ALONG WITH THEIR CONSTRUCTION, IN FOLLOWING LESSONS.

SUMMARIZING THE VOLTAGE, CURRENT AND IMPEDANCE RELATIONS IN SERIES AND IN PARALLEL CIRCUITS:

1. SERIES.

VOLTAGE ACROSS CIRCUIT EQUALS VECTOR SUM OF INDIVIDUAL VOLTAGES.

CURRENT IS THE SAME THROUGH ALL PARTS OF A SERIES CIRCUIT.

IMPEDANCE IS EQUAL TO THE VECTOR SUM OF THE INDIVIDUAL IMPEDANCES.

2. PARALLEL.

VOLTAGE IS THE SAME ACROSS EACH BRANCH OF THE CIRCUIT.

CURRENT EQUALS THE VECTOR SUM OF THE INDIVIDUAL CURRENTS.

IMPEDANCE EQUALS THE TRUE OR ASSUMED VOLTAGE DIVIDED BY THE TRUE OR ASSUMED CURRENT WHICH THE TRUE OR ASSUMED VOLTAGE FORCES THROUGH THE CIRCUIT.

THE LC TABLE.

THE LC TABLE, A COPY OF WHICH IS INCLUDED IN THE BACK OF THIS LESSON, IS ONE OF THE MOST CONVENIENT TABLES USED IN RADIO WORK. IT HAS BEEN SHOWN THAT FOR ANY ONE FREQUENCY OR ANY ONE WAVELENGTH, THERE IS ONLY ONE VALUE OF THE LC PRODUCT. THAT IS, THE INDIVIDUAL L AND C VALUES FOR TWO CIRCUITS MAY BE ENTIRELY DISSIMILAR BUT SO LONG AS THE PRODUCTS OF L TIMES C IN THE TWO CIRCUITS ARE THE SAME, BOTH CIRCUITS WILL HAVE THE SAME WAVELENGTH OR RESONANT FREQUENCY.

WHY IS THIS LC TABLE SO USEFUL? BECAUSE IN ALMOST ANY TYPE OF RADIO PROBLEM DEALING WITH WAVELENGTH OR FREQUENCY THE LC PRODUCT IS ENCOUNTERED. FOR EXAMPLE,

FREQUENCY $= \frac{1}{2\pi\sqrt{LC}}$ F IN CYCLES, L AND C IN UNITS.

FREQUENCY $= \frac{159}{\sqrt{LC}}$ F IN KILOCYCLES, L AND C IN MICRO-UNITS.

WAVELENGTH $= 1884\sqrt{LC}$. WAVELENGTH IN METERS, L AND C IN MICRO-UNITS.

GIVEN A CIRCUIT CONSISTING OF KNOWN VALUES OF INDUCTANCE AND CAPACITY, IT IS POSSIBLE OF COURSE TO FIND EITHER THE WAVELENGTH OR THE RESONANT FREQUENCY FROM ONE OF THE EQUATIONS SHOWN ABOVE. THIS INVOLVES SEVERAL STEPS IN EITHER CASE. BY THE USE OF THE TABLES, HOWEVER, IT IS ONLY NECESSARY TO MULTIPLY THE VALUES OF L AND C, (BOTH IN MICRO-UNITS), AND REFER TO THE TABLE FOR THE CORRESPONDING VALUE OF EITHER WAVELENGTH OF FREQUENCY. IT SHOULD BE OBSERVED THAT IN THE ENCLOSED TABLES, FREQUENCY IS DESIGNATED BY "N" AND IS EXPRESSED IN CYCLES. TO CONVERT TO KILOCYCLES IT IS ONLY NECESSARY TO DIVIDE THE FREQUENCY IN CYCLES BY 1000.

ANOTHER EXAMPLE WHERE THE LC TABLE CAN BE USED TO ADVANTAGE. SUPPOSE THERE IS GIVEN A CIRCUIT OF KNOWN WAVELENGTH or RESONANT FREQUENCY, AND THE VALUE OF C; TO FIND L. IT IS ONLY NECESSARY TO REFER TO THE LC PRODUCT FOR THE KNOWN FREQUENCY OR WAVELENGTH AND DIVIDE THE LC PRODUCT BY THE KNOWN VALUE OF C IN MICROFARADS. THE ANSWER WILL BE THE INDUCTANCE IN MICROHENRIES. IF L IS KNOWN AND C MUST BE DETERMINED, THE LC PRODUCT IS DIVIDED BY THE VALUE OF L IN MICROHENRIES, THE ANSWER BEING THE CAPACITY IN MICROFARADS.

THE ENCLOSED TABLES ARE COMPUTED FOR A MINIMUM WAVELENGTH OF 100 METERS OR 3000 KILOCYCLES. IN MODERN RADIO WORK IT IS OFTEN NECESSARY TO CALCULATE VALUES IN WAVELENGTHS MUCH SHORTER THAN 100 METERS. IT IS A VERY SIMPLE MATTER TO USE THE LC TABLE FOR SUCH VALUES.

FOR EXAMPLE, THE LC PRODUCT FOR A WAVELENGTH OF 1000 METERS IS .282; FOR 100 METERS THE LC PRODUCT IS .00282; FOR 10 METERS THE LC PRODUCT WILL BE .0000282.

THE LC PRODUCT FOR 3000 METERS IS 2.53; FOR 300 METERS, THE LC PRODUCT IS .0253; FOR 30 METERS THE LC PRODUCT WILL BE .000253; FOR 3 METERS, .00000253.

IN OTHER WORDS, FOR EACH PLACE IN THE WAVELENGTH COLUMN THE DECIMAL POINT IS MOVED TO THE LEFT, THE DECIMAL POINT MUST BE MOVED <u>TWO</u> PLACES TO THE LEFT IN THE COLUMN OF LC PRODUCTS. THIS IS DUE TO THE FACT THAT THE WAVELENGTH VARIES AS THE <u>SQUARE ROOT</u> OF THE LC PRODUCT; WAVELENGTH = $1884\sqrt{LC}$. IN EXTRACTING THE SQUARE ROOT OF THE PRODUCT OF LC, THE PRODUCT IS POINTED OFF <u>IN GROUPS OF TWO PLACES</u> FROM THE DECIMAL POINT.

FREQUENCY VALUES MAY BE HANDLED IN A SIMILAR MANNER EXCEPT THAT AS THE DECIMAL POINT IN THE NUMERICAL VALUE OF FREQUENCY IS MOVED <u>ONE PLACE TO THE LEFT</u>, THE DECIMAL POINT IN THE LC PRODUCT IS MOVED <u>TWO PLACES TO THE RIGHT</u>. THIS IS DUE TO THE FACT THAT THE FREQUENCY VARIES <u>INVERSELY AS THE SQUARE ROOT</u> OF THE LC PRODUCT: $F = \frac{1}{2\pi\sqrt{LC}}$.

Regular use of the LC tables will greatly decrease the time required in the solution of problems involving L, C, wavelength and frequency, and will also decrease the chances of error.

A problem involving these values will show clearly the use of this table. Given a variable condenser of 500 micro-microfarads maximum capacity and 40 micro-microfarads minimum. It is desired to use the condenser with an inductance that will enable the circuit to be tuned to 550 meters with all the capacity in the circuit. What must be the effective value of inductance?

Referring to the LC table, it is found that the LC product at 550 meters is .0852; 500 µµF = .0005 µF. L = LC/C = .0852/.0005 = 170.4 µH.

With this value of inductance what will be the shortest wavelength to which this circuit can be tuned? Minimum capacity is 40 µµF or .00004 µF. L is 170.4 µH. LC = 170.4 x .00004 = .006816.

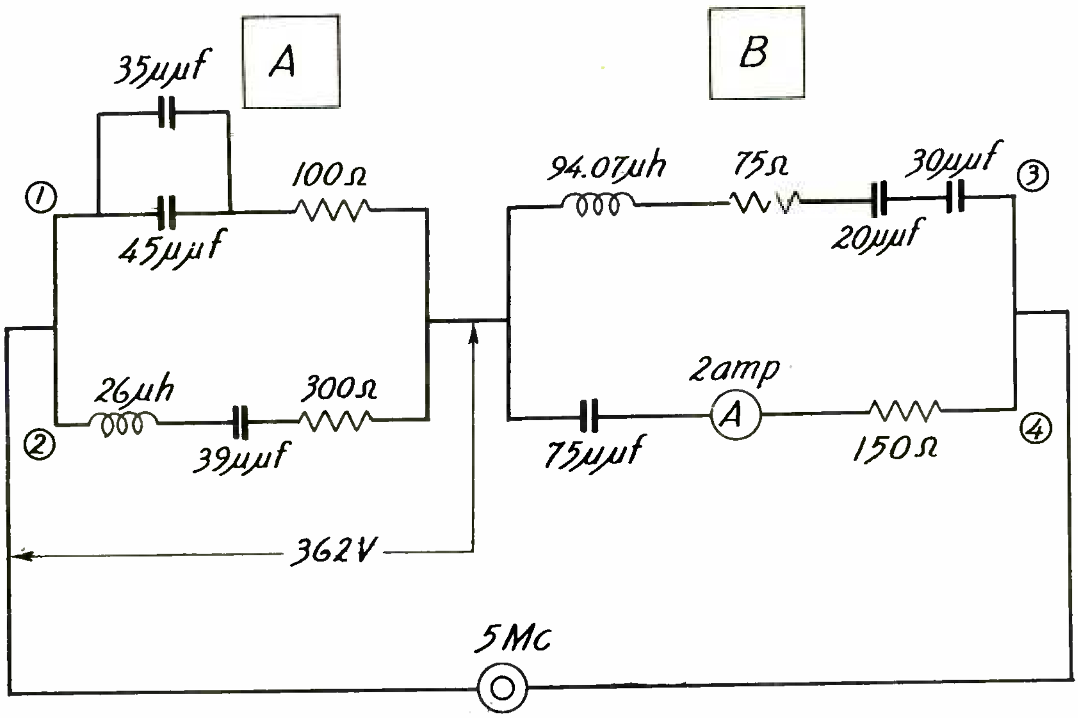
The LC table states that .00633 represents a wavelength of 150 meters and that .00721 represents 160 meters. .006816 is about half-way between these two values so that this circuit would tune down to approximately 155 meters. An accurate figure could be determined by interpolation, but greater accuracy is usually not necessary in a problem of this type.

When working with quite high frequencies, that is, frequencies in excess of 1000 KC;s, the frequency is commonly expressed in megacycles. Thus 15,000 KC/s = 15 MC, 8700 KC/s = 8.7 MC, 2300 KC/s = 2.3 MC, 120,000 KC/s = 120 MC, etc. One megacycle equals one thousand kilocycles. To convert MC to KC, multiply by 10^3. To convert KC to MC, multiply by 10^{-3}.

Meters	n	L x C	Meters	n	L x C	Meters	n	L x C	Meters	n	L x C	Meters	n	L x C	Meters	n	L x C
100	3,000,000	0.00282	800	375,000	0.1801	1600	187,500	0.721	3200	93,800	2.88	5500	54,500	8.52	11000	27,300	34.1
110	2,727,000	0.00341	805	373,000	0.1824	1610	186,300	0.730	3220	93,200	2.92	5550	54,100	8.67	11100	27,000	34.7
120	2,500,000	0.00405	810	370,000	0.1847	1620	185,100	0.739	3240	92,600	2.96	5600	53,600	8.83	11200	26,800	35.3
130	2,308,000	0.00476	815	368,000	0.1870	1630	184,000	0.748	3260	92,000	2.99	5650	53,100	8.99	11300	26,500	35.9
140	2,143,000	0.00552	820	366,000	0.1893	1640	182,900	0.757	3280	91,500	3.03	5700	52,700	9.15	11400	26,300	36.6
150	2,000,000	0.00633	825	364,000	0.1916	1650	181,800	0.766	3300	90,900	3.06	5750	52,200	9.31	11500	26,100	37.2
160	1,875,000	0.00721	830	361,000	0.1939	1660	180,700	0.776	3320	90,400	3.10	5800	51,700	9.47	11600	25,900	37.9
170	1,764,000	0.00813	835	359,000	0.1962	1670	179,600	0.785	3340	89,800	3.14	5850	51,300	9.63	11700	25,600	38.5
180	1,667,000	0.00912	840	357,000	0.1986	1680	178,500	0.794	3360	89,300	3.18	5900	50,900	9.80	11800	25,400	39.2
190	1,579,000	0.01016	845	355,000	0.201	1690	177,400	0.804	3380	88,800	3.22	5950	50,400	9.96	11900	25,200	39.9
200	1,500,000	0.01126	850	353,000	0.203	1700	176,400	0.813	3400	88,300	3.25	6000	50,000	10.13	12000	25,000	40.5
210	1,429,000	0.01241	855	351,000	0.206	1710	175,400	0.823	3420	87,700	3.29	6050	49,600	10.30	12100	24,800	41.2
220	1,364,000	0.01362	860	349,000	0.208	1720	174,400	0.833	3440	87,200	3.33	6100	49,200	10.47	12200	24,600	41.9
230	1,304,000	0.01489	865	347,000	0.211	1730	173,400	0.842	3460	86,700	3.37	6150	48,800	10.65	12300	24,400	42.6
240	1,250,000	0.01621	870	345,000	0.213	1740	172,400	0.852	3480	86,200	3.41	6200	48,400	10.82	12400	24,200	43.3
250	1,200,000	0.01759	875	343,000	0.216	1750	171,400	0.862	3500	85,700	3.45	6250	48,000	11.00	12500	24,000	44.0
260	1,154,000	0.01903	880	341,000	0.218	1760	170,500	0.872	3520	85,300	3.49	6300	47,600	11.17	12600	23,800	44.7
270	1,111,000	0.0205	885	339,000	0.220	1770	169,500	0.882	3540	84,800	3.53	6350	47,200	11.35	12700	23,600	45.4
280	1,071,000	0.0221	890	337,000	0.223	1780	168,500	0.892	3560	84,300	3.57	6400	46,900	11.53	12800	23,400	46.1
290	1,034,000	0.0237	895	335,000	0.225	1790	167,600	0.902	3580	83,800	3.61	6450	46,500	11.71	12900	23,300	46.8
300	1,000,000	0.0253	900	333,000	0.228	1800	166,700	0.912	3600	83,400	3.65	6500	46,200	11.89	13000	23,100	47.6
310	968,000	0.0270	905	331,000	0.231	1810	165,700	0.922	3620	82,900	3.69	6550	45,800	12.08	13100	22,900	48.3
320	938,000	0.0288	910	330,000	0.233	1820	164,800	0.932	3640	82,400	3.73	6600	45,500	12.26	13200	22,700	49.0
330	909,000	0.0306	915	328,000	0.236	1830	163,900	0.943	3660	82,000	3.77	6650	45,100	12.45	13300	22,600	49.8
340	883,000	0.0325	920	326,000	0.238	1840	163,000	0.953	3680	81,500	3.81	6700	44,800	12.64	13400	22,400	50.5
350	857,000	0.0345	925	324,000	0.241	1850	162,200	0.963	3700	81,100	3.85	6750	44,400	12.83	13500	22,200	51.3
360	834,000	0.0365	930	323,000	0.243	1860	161,300	0.974	3720	80,700	3.90	6800	44,100	13.02	13600	22,100	52.1
370	811,000	0.0385	935	321,000	0.246	1870	160,400	0.984	3740	80,200	3.94	6850	43,800	13.21	13700	21,900	52.8
380	790,000	0.0406	940	319,000	0.249	1880	159,600	0.995	3760	79,800	3.98	6900	43,500	13.40	13800	21,700	53.6
390	769,000	0.0428	945	317,000	0.251	1890	158,700	1.005	3780	79,400	4.02	6950	43,200	13.60	13900	21,600	54.4
400	750,000	0.0450	950	316,000	0.254	1900	157,900	1.016	3800	79,000	4.06	7000	42,900	13.79	14000	21,400	55.2
410	732,000	0.0473	955	314,000	0.257	1910	157,100	1.026	3820	78,600	4.11	7050	42,600	13.99	14100	21,300	56.0
420	715,000	0.0496	960	313,000	0.259	1920	156,300	1.037	3840	78,200	4.15	7100	42,300	14.19	14200	21,100	56.8
430	698,000	0.0520	965	311,000	0.262	1930	155,400	1.048	3860	77,700	4.19	7150	42,000	14.39	14300	21,000	57.6
440	682,000	0.0545	970	309,000	0.265	1940	154,600	1.059	3880	77,300	4.24	7200	41,700	14.59	14400	20,800	58.4
450	667,000	0.0570	975	308,000	0.268	1950	153,800	1.070	3900	76,900	4.28	7250	41,400	14.79	14500	20,700	59.2
460	652,000	0.0596	980	306,000	0.270	1960	153,100	1.081	3920	76,500	4.32	7300	41,100	15.00	14600	20,600	60.0
470	639,000	0.0622	985	305,000	0.273	1970	152,300	1.092	3940	76,200	4.37	7350	40,800	15.21	14700	20,400	60.8
480	625,000	0.0649	990	303,000	0.276	1980	151,500	1.103	3960	75,800	4.41	7400	40,500	15.41	14800	20,300	61.6
490	612,000	0.0676	995	302,000	0.279	1990	150,800	1.114	3980	75,400	4.46	7450	40,300	15.62	14900	20,100	62.5
500	600,000	0.0704	1000	300,000	0.282	2000	150,000	1.126	4000	75,000	4.50	7500	40,000	15.83	15000	20,000	63.3
505	594,000	0.0718	1010	297,100	0.287	2020	148,500	1.148	4020	74,700	4.55	7550	39,700	16.04	15100	19,870	64.2
510	588,000	0.0732	1020	294,200	0.293	2040	147,100	1.171	4040	74,300	4.59	7600	39,500	16.26	15200	19,740	65.0
515	583,000	0.0747	1030	291,300	0.299	2060	145,600	1.194	4060	73,900	4.64	7650	39,200	16.47	15300	19,610	65.9
520	577,000	0.0761	1040	288,500	0.304	2080	144,200	1.218	4080	73,500	4.69	7700	39,000	16.69	15400	19,480	66.7
525	572,000	0.0776	1050	285,700	0.310	2100	142,900	1.241	4100	73,200	4.73	7750	38,700	16.90	15500	19,350	67.6
530	566,000	0.0791	1060	283,000	0.316	2120	141,500	1.265	4120	72,800	4.78	7800	38,500	17.12	15600	19,230	68.5
535	561,000	0.0806	1070	280,400	0.322	2140	140,200	1.289	4140	72,500	4.82	7850	38,200	17.34	15700	19,110	69.4
540	556,000	0.0821	1080	277,800	0.328	2160	138,900	1.313	4160	72,100	4.87	7900	38,000	17.56	15800	18,990	70.3
545	551,000	0.0836	1090	275,200	0.334	2180	137,600	1.338	4180	71,800	4.92	7950	37,700	17.79	15900	18,870	71.2
550	546,000	0.0852	1100	272,700	0.341	2200	136,400	1.362	4200	71,500	4.96	8000	37,500	18.01	16000	18,750	72.1
555	541,000	0.0867	1110	270,300	0.347	2220	135,100	1.387	4220	71,100	5.01	8050	37,300	18.24	16100	18,630	73.0
560	536,000	0.0883	1120	267,900	0.353	2240	133,900	1.412	4240	70,800	5.06	8100	37,000	18.47	16200	18,510	73.9
565	531,000	0.0899	1130	265,500	0.359	2260	132,700	1.438	4260	70,400	5.11	8150	36,800	18.70	16300	18,400	74.8
570	527,000	0.0915	1140	263,200	0.366	2280	131,600	1.463	4280	70,100	5.16	8200	36,600	18.93	16400	18,290	75.7
575	522,000	0.0931	1150	260,900	0.372	2300	130,400	1.489	4300	69,800	5.20	8250	36,400	19.16	16500	18,180	76.6
580	517,000	0.0947	1160	258,600	0.379	2320	129,300	1.515	4320	69,500	5.25	8300	36,100	19.39	16600	18,070	77.6
585	513,000	0.0963	1170	256,400	0.385	2340	128,200	1.541	4340	69,100	5.30	8350	35,900	19.62	16700	17,960	78.5
590	509,000	0.0980	1180	254,200	0.392	2360	127,100	1.568	4360	68,800	5.35	8400	35,700	19.86	16800	17,850	79.4
595	504,000	0.0996	1190	252,100	0.399	2380	126,000	1.594	4380	68,500	5.40	8450	35,500	20.1	16900	17,740	80.4
600	500,000	0.1013	1200	250,000	0.405	2400	125,000	1.621	4400	68,200	5.45	8500	35,300	20.3	17000	17,640	81.3
605	496,000	0.1030	1210	247,900	0.412	2420	124,000	1.648	4420	67,900	5.50	8550	35,100	20.6	17100	17,540	82.3
610	492,000	0.1047	1220	245,900	0.419	2440	122,900	1.676	4440	67,600	5.55	8600	34,900	20.8	17200	17,440	83.3
615	488,000	0.1065	1230	243,900	0.426	2460	121,900	1.703	4460	67,300	5.60	8650	34,700	21.1	17300	17,340	84.2
620	484,000	0.1082	1240	241,900	0.433	2480	121,000	1.731	4480	67,000	5.65	8700	34,500	21.3	17400	17,240	85.2
625	480,000	0.1100	1250	240,000	0.440	2500	120,000	1.759	4500	66,700	5.70	8750	34,300	21.6	17500	17,140	86.2
630	476,000	0.1117	1260	238,100	0.447	2520	119,000	1.787	4520	66,400	5.75	8800	34,100	21.8	17600	17,050	87.2
635	472,000	0.1135	1270	236,200	0.454	2540	118,100	1.816	4540	66,100	5.80	8850	33,900	22.0	17700	16,950	88.2
640	469,000	0.1153	1280	234,400	0.461	2560	117,200	1.845	4560	65,800	5.85	8900	33,700	22.3	17800	16,850	89.2
645	465,000	0.1171	1290	232,600	0.468	2580	116,300	1.874	4580	65,500	5.90	8950	33,500	22.5	17900	16,760	90.2
650	462,000	0.1189	1300	230,800	0.476	2600	115,400	1.903	4600	65,200	5.96	9000	33,300	22.8	18000	16,670	91.2
655	458,000	0.1208	1310	229,000	0.483	2620	114,500	1.932	4620	65,000	6.01	9050	33,100	23.1	18100	16,570	92.2
660	455,000	0.1226	1320	227,300	0.490	2640	113,600	1.962	4640	64,700	6.06	9100	33,000	23.3	18200	16,480	93.2
665	451,000	0.1245	1330	225,600	0.498	2660	112,800	1.991	4660	64,400	6.11	9150	32,800	23.6	18300	16,390	94.3
670	448,000	0.1264	1340	223,900	0.505	2680	111,900	2.02	4680	64,100	6.17	9200	32,600	23.8	18400	16,300	95.3
675	444,000	0.1283	1350	222,200	0.513	2700	111,100	2.05	4700	63,900	6.22	9250	32,400	24.1	18500	16,220	96.3
680	441,000	0.1302	1360	220,600	0.521	2720	110,300	2.08	4720	63,600	6.27	9300	32,300	24.3	18600	16,130	97.4
685	438,000	0.1321	1370	219,000	0.528	2740	109,500	2.11	4740	63,300	6.32	9350	32,100	24.6	18700	16,040	98.4
690	435,000	0.1340	1380	217,400	0.536	2760	108,700	2.14	4760	63,000	6.38	9400	31,900	24.9	18800	15,960	99.5
695	432,000	0.1360	1390	215,800	0.544	2780	107,900	2.18	4780	62,800	6.43	9450	31,700	25.1	18900	15,870	100.5
700	429,000	0.1379	1400	214,300	0.552	2800	107,100	2.21	4800	62,500	6.49	9500	31,600	25.4	19000	15,790	101.5
705	426,000	0.1399	1410	212,800	0.560	2820	106,400	2.24	4820	62,300	6.54	9550	31,400	25.7	19100	15,710	102.6
710	423,000	0.1419	1420	211,300	0.568	2840	105,600	2.27	4840	62,000	6.59	9600	31,300	25.9	19200	15,630	103.7
715	420,000	0.1439	1430	209,800	0.576	2860	104,900	2.30	4860	61,800	6.65	9650	31,100	26.2	19300	15,540	104.8
720	417,000	0.1459	1440	208,300	0.584	2880	104,200	2.33	4880	61,500	6.70	9700	30,900	26.5	19400	15,460	105.9
725	414,000	0.1479	1450	206,900	0.592	2900	103,400	2.37	4900	61,200	6.76	9750	30,800	26.8	19500	15,380	107.0
730	411,000	0.1500	1460	205,500	0.600	2920	102,700	2.40	4920	61,000	6.81	9800	30,600	27.0	19600	15,310	108.1
735	408,000	0.1521	1470	204,100	0.608	2940	102,000	2.43	4940	60,800	6.87	9850	30,500	27.3	19700	15,230	109.2
740	405,000	0.1541	1480	202,700	0.616	2960	101,300	2.47	4960	60,500	6.92	9900	30,300	27.6	19800	15,150	110.3
745	403,000	0.1562	1490	201,300	0.625	2980	100,700	2.50	4980	60,300	6.98	9950	30,200	27.9	19900	15,080	111.4
750	400,000	0.1583	1500	200,000	0.633	3000	100,000	2.53	5000	60,000	7.04	10000	30,000	28.2	20000	15,000	112.6
755	397,000	0.1604	1510	198,700	0.642	3020	99,400	2.57	5050	59,400	7.18	10100	29,700	28.7	20200	14,850	114.8
760	395,000	0.1626	1520	197,400	0.650	3040	98,700	2.60	5100	58,800	7.32	10200	29,400	29.3	20400	14,710	117.1
765	392,000	0.1647	1530	196,100	0.659	3060	98,100	2.64	5150	58,300	7.47	10300	29,100	29.9	20600	14,560	119.4
770	390,000	0.1669	1540	194,800	0.667	3080	97,400	2.67	5200	57,700	7.61	10400	28,800	30.4	20800	14,420	121.8
775	387,000	0.1691	1550	193,500	0.676	3100	96,800	2.70	5250	57,200	7.76	10500	28,600	31.0	21000	14,290	124.1
780	385,000	0.1712	1560	192,300	0.685	3120	96,200	2.74	5300	56,600	7.91	10600	28,300	31.6	21200	14,150	126.5
785	382,000	0.1734	1570	191,100	0.694	3140	95,500	2.78	5350	56,100	8.06	10700	28,000	32.2	21400	14,020	128.9
790	380,000	0.1756	1580	189,900	0.703	3160	95,000	2.81	5400	55,600	8.21	10800	27,800	32.8	21600	13,890	131.3
795	377,000	0.1779	1590	188,700	0.712	3180	94,400	2.85	5450	55,100	8.36	10900	27,500	33.4	21800	13,760	133.8

EXERCISE PROBLEMS

SERIES AND PARALLEL CIRCUITS



1). Impedance, and current of branch 1

2). Impedance, and current of branch 2

3). Impedance, and current of circuit [A] By *two* methods

4). Impedance, and voltage of branch 4

5). Impedance, and current of branch 3

6). Impedance, and current of circuit [B] by *two* methods

7). Total Impedance of the circuit by two methods

8). Total line current

9). Total voltage drop

10). Total Power dissipated in the circuit by *two* methods.

(Note: Vector diagrams for each circuit will be helpful).

ANSWERS

1. $Z_1 = 100 - j398.0 = 410.4\angle{-75°54'}$

   $I_1 = .882$ amps.

2. $Z_2 = 300 + j0 = 300\angle{0°}$ ohms

   $I_2 = 1.206$ amps.

3. $Z_A = 186.93 - j112.54 = 218.2\angle{-31°4'}$ ohms

   $I_A = 1.66$ amps.

4. $Z_2 = 150 - j424.6 = 450.2\angle{-70°32'}$ ohms

   $E_4 = 900.4$ volts

5. $Z_3 = 75 + j300 = 309.8\angle{75°58'}$ ohms

   $I_3 = 2.906$ amps

6. $Z_B = 449.23 + j303.67 = 542.3\angle{34°4'}$ ohms

   $I_B = 1.66$ amps.

7. $Z_t = 636.14 + j191.13 = 664.45\angle{16°43'}$ ohms

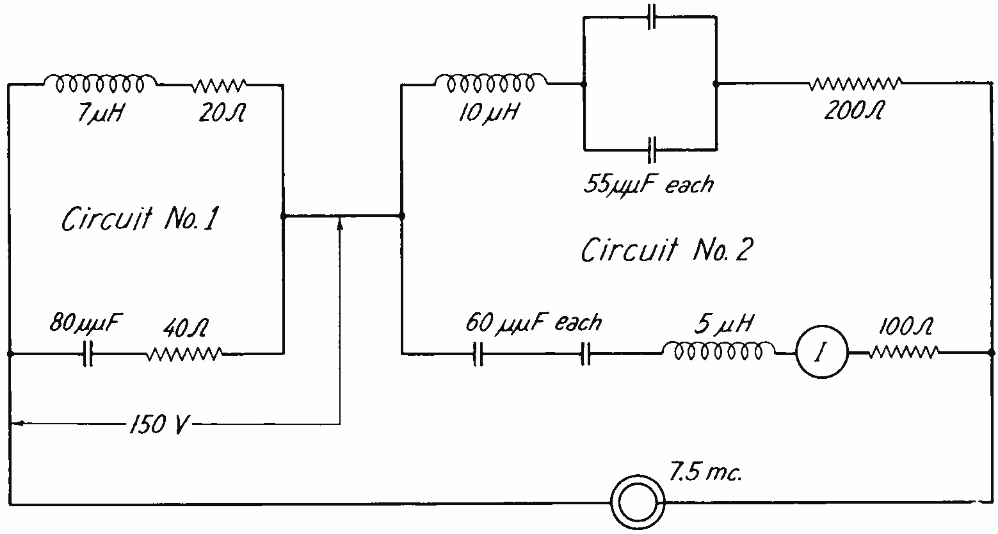
8. $I_t = 1.66$ amps.

9. $E_t = 1102$ volts.

10. $P_t = 1752$ watts.

SERIES-PARALLEL CIRCUITS

EXAMINATION



FIND:

1. Impedance of circuit No. 1.

2. Impedance of circuit No. 2.

3. Total impedance of both circuits.

4. Voltage drop across circuit No. 2.

5. Current through lower branch circuit No. 2.

6. Power supplied by generator (power loss each branch equals I^2R).

   All steps should be shown just as in the solution of the circuit in Fig. 8 of text. Tabulate the answers 1 to 6 for easy inspection of your work as a whole.

7. What LC product corresponds to a frequency of 40.3 kilocycles? 4095 kilocycles?

8. You are designing a 50 mc circuit and decide to use a 10 micromicrofarad condenser:

   (A) What value of L will you use?

   (B) What will be the L/C ratio?

9. What frequencies correspond to the following LC values?

   (A) .1801

   (B) .01903

   (C) 18.01

10. (A) What will be the LC product for a wavelength of 1,550 meters?

   (B) If a circuit tuned to this wavelength employs a capacity of 860 micromicrofarads, what will be the inductance of the circuit?