Communications Electronics Circuits

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Preface

This text is intended for use as a second course in electronics circuitry. It is aimed primarily at the level of the engineering technician. Whereas the previous volume (*General Electronics Circuits*) discussed circuits that might be found in *any* area of the electronics field, this follow-up volume deals specifically with circuits used in the broad area of electronic communications.

Up until about 1940, the "electronics" industry was concerned only with the transmission and reception of voice and music through the air. In fact, the term radio (rather than electronics) was used to describe this field. Today, with industrial and computer applications, electronics has spread until it touches almost every aspect of our lives — not only in the entertainment area, but into medicine, commerce, transportation, and industry. Yet, in spite of these rapid advances, the field of production, transmission, and reception of radio-frequency waves is still — by far — the most important and largest application of electronics, and it is still growing. The intelligence transmitted via radio waves (in addition to voice and music) is now used for aircraft and vessel navigational systems; depth, range, and altitude finders; missile guidance; detection and tracking of moving targets; anticollision devices; and telemetry systems.

The many varieties of radar devices are functionally the same as the radio transmitter at a broadcasting station and the radio receiver at a listener's home. The entire space industry would collapse were it not for the ability to "communicate" with satellite or space vehicle. Control signals are transmitted to the vehicle to change its trajectory, or to start (or stop) some device such as a camera or recorder. Pictures or scientific data gathered by a space probe are sent back to earth stations. All of this requires radio communications.

Prerequisite to understanding the subject matter in this volume is a good foundation in direct-current fundamentals, alternating-current fundamentals, vacuum-tube and semiconductor characteristics, and basic electronic circuitry, such as power supplies and untuned amplifiers. A background in algebra, vector algebra, and basic trigonometry is also required. A knowledge of calculus, although not essential, would enhance an understanding of the mathematical aspects of this book.

The author uses the same direct, personal approach and conversational style that has proved to be successful in previous texts. The emphasis is on practical considerations without sacrificing technical depth or accuracy. Extensive use is made of circuit diagrams, illustrative problems, and problems at the end of each chapter, to illustrate the practical applications of theory. Numerous review questions are also given at the end of each chapter. These can be used for self-evaluation by the student, or for classroom discussion, using the *programmed machine question* technique discussed in the *Instructional Notes.*

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Instructional Notes

Many studies of the psychology of learning have shown that effective learning must involve active participation by the learner, and his correct responses must be "rewarded." Teaching machines developed in keeping with these basic principles have been very successful. In general, these machines give factual information; ask questions (in small steps) based on this information; elicit some form of response; and finally give or confirm the correct answer.

However, machines have serious limitations. One type, although it allows the student to make any answer, merely states the correct response and continues. Another type restricts the student to a choice of one out of only four answers. If a wrong response is selected, the machine indicates why it is wrong and then allows the student to make another response. When he selects the correct response, the program advances to the next step.

In a classroom situation, a live instructor can combine the better features of each type of machine. Not only can he allow a student complete freedom of response, but he can also modify his teaching "program" instantaneously to fit any response.

This text was written with such a teaching technique in mind. In the body of the text, factual information is given and circuit operation is described in more detail than usual, so that the instructor will not have to spend valuable class time lecturing at length to supplement missing items or skimpy treatment. Instead, the lesson time can be spent using a question-discussion-guidance technique, with heavy emphasis on student participation. To help implement this type of lesson, the author has incorporated many review questions at the end of each chapter. These questions follow the text sequence and represent small "bits" of each topic, much in the manner of a teaching machine. Sufficient class time should also be allowed for a satisfying analysis of all problems assigned for homework. If additional time is available, it can be well spent in enriching and motivating each lesson from the instructor's own practical experience.

This system has been tested by the author with several classes, with very gratifying results. Not only were class averages raised, but even more important, the students actually enjoyed these lessons and came to class better prepared to join in the general discussion. An interesting development is that some students began applying this learning technique to their other subjects, making up their own "small-bit" questions for self study, or bringing the questions into class for discussion.

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Resonant Circuits

In the early 1900s, radio communications—the transmission and reception of voice and music through the air—was probably the only application of electronics of any significance. In radio broadcasting, the intelligence signal, voice or music, is "raised" to some high radio-frequency (r-f) level. The specific frequency selected is called the *carrier frequency,* and the process of elevation is called *modulation.* The end result is a *modulated wave,* which contains the original intelligence as a relatively narrow band of component frequencies to either side of the carrier. These components are known as *sidebands.* The total frequency spread of carrier and *sidebands* is often referred to as a *channel.* By using a variety of channels within the radio-frequency spectrum, it is possible to transmit many programs simultaneously. At the receiving locations, the voltage developed by these radio waves is extremely low, in the order of a few microvolts. It is necessary first to amplify these signals by means of *r-f voltage amplifiers,* and then to extract the intelligence from the amplified r-f wave. This latter process, which brings the voice or music back to its own natural frequency range, is called *demodulation* or *detection.* Meanwhile, back at the transmitting location, before modulation can take place, the carrier frequency itself must be generated. This is the function of *oscillator* circuits. Furthermore, if the transmitted signals are to be picked up at remote locations, high transmitting power levels are needed. For this purpose, *r-f power amplifiers* are used. Finally, to get these signals into space, *transmission lines* serve to feed the r-f energy up to the *antenna,* and the antenna radiates this energy into space. These terms are presented here merely by way of introduction. They will be discussed in detail in the chapters to follow.

Electronics, since those early days, has spread until it touches almost every aspect of our lives—not only in the entertainment area, but into medicine, commerce, transportation, and industry. Yet, with all this expansion, the field of production, transmission and reception of radio-frequency waves is still by far the most important and largest application of electronics. The intelligence transmitted via radio waves (in addition to voice and music) now includes aircraft and vessel navigational systems; depth, range and altitude finders; missile guidance; detection and tracking of moving targets; anticollision devices; and telemetering systems. The same basic functions, mentioned above with regard to radio communications, apply equally well to these newer uses. In addition, high power r-f waves are also used for many industrial applications of induction and dielectric heating, including cooking. These industrial applications have increased the importance of radio frequency circuits in the study of electronics.

Circuits designed to operate at radio frequencies are generally limited to a specific frequency, or to a relatively narrow band of frequencies, within the radio-frequency (r-f) spectrum. The specific frequency is the *resonant* frequency of the circuit, and the narrow band is the *bandwidth* of the circuit. In this chapter these factors are discussed as they apply to series and parallel resonant circuits. The characteristics of these circuits are analyzed in detail, in preparation for the circuit applications to follow in subsequent chapters.

SERIES RESONANT CIRCUITS

In order for resonance to occur, a circuit must contain inductance and capacitance; it may also (and generally does) have some resistance. This resistance may be the effective resistance of the coil itself (all practical coils have some resistance), or it may be a resistor deliberately introduced to create some desired effect. Although the value of resistance greatly affects current and voltage values of a circuit that is in resonance, it does not determine *when* resonance will occur. Before we tackle the condition known as resonance, let us review briefly the mathematical relationships pertinent to *any* series circuit containing R, L, and C:

1. $X_L = 2\pi fL$
2. $X_C = 1/(2\pi fC)$
3. $X_o = X_L - X_C$
   where X_o is the *net* reactance, and is a positive value (inductive)

if X_L is greater than X_C, or a negative value (capacitive) if X_C is greater than X_L.

*4. $Z = \sqrt{R^2 + X_o^2}$

5. $I = E/Z$

Resonance occurs in an R-L-C circuit when the inductive reactance equals the capacitive reactance, or when $X_L = X_C$. Regardless of the value of inductance and capacitance used, there is always a frequency at which these two reactances are equal. This resonant frequency (f_o) can be found by equating the two reactance values:

$$X_L = X_C \qquad \text{or} \qquad 2\pi f_o L = 1/(2\pi f_o C)$$

Solving for frequency, we get $(2\pi f_o)^2 = \dfrac{1}{LC}$ and

$$f_o = \frac{1}{2\pi\sqrt{LC}} \tag{1-1}$$

At this resonant frequency (since $X_L = X_C$), the net reactance (X_o) is zero. Obviously, then, the circuit impedance (Z) must be a minimum and equal to the circuit resistance R. Since the impedance is a minimum, the line current will be a maximum, and since the impedance is purely resistive, the line current is in phase with the line voltage. The circuit phase angle (θ_c) is zero. Summarizing these key points concerning a series-resonant circuit, we get

1. $X_L = X_C$
2. $f_o = \dfrac{1}{2\pi\sqrt{LC}}$
3. $Z = \text{minimum} = R$
4. $I = \text{maximum}$
5. $\theta_c = 0$ deg

Example 1

A series circuit consists of $L = 15.8$ mh, $C = 0.1\ \mu$f, $R = 10$ ohms, and a line voltage $E_T = 10$ volts. Find the resonant frequency, the cur-

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* As a simplification, it should be noted that $Z = X_o$ if the reactance is equal to or greater than ten times the resistance value. (The error from such an assumption is less than 1 percent even for $X = 8R$.) Similarly, the impedance Z can be considered to be equal to the resistance value, for $X = 0.1R$ or smaller.

rent at this frequency, and the voltage across each component at this frequency.

Solution

1. $f_o = \frac{1}{2\pi\sqrt{LC}} = \frac{0.159}{\sqrt{15.8 \times 10^{-3} \times 0.1 \times 10^{-6}}} = \mathbf{4000\ cycles}$

2. Since the circuit is resonant ($X_L = X_C$), $Z = R$, and

$$I = \frac{E}{R} = \frac{10}{10} = \mathbf{1.0\ amp}$$

3. To find the voltage across L and across C we must first find X_L and X_C.

(*a*) $X_L = 2\pi fL = 2\pi \times 4000 \times 15.8 \times 10^{-3} = 398$ ohms

(*b*) $X_C = \frac{1}{2\pi fC} = \frac{0.159 \times 10^6}{4000 \times 0.1} = 398$ ohms

(Notice that $X_L = X_C$. This checks our calculations so far.)

(*c*) $E_L = IX_L = 1.0 \times 398 = 398$ volts

$E_C = IX_C = 1.0 \times 398 = 398$ volts

$E_R = IR = 1.0 \times 10 = 10$ volts

Q Rise in Voltage

Notice the value of the voltage across the reactive components in the above problem. With a line voltage of only 10 volts, the voltage across the inductor and capacitor are each 398 volts. Such a rise will occur in any resonant circuit—if the resistance is low compared to the inductive and capacitive reactances. But the ratio of inductive reactance to resistance—with reference to a coil—is a measure of the quality of the coil, and is known as the Q of the coil. Similarly, in a complete circuit, the ratio of reactance to circuit resistance is known as the *Q of the circuit.* It does not matter here whether the circuit resistance is due to the coil, the capacitor, or to a separate resistive component. The resistance is *total resistance* R_T. In calculating the circuit Q at resonance, either reactance (X_L or X_C) can be used, since they are equal values.

To find the Q of the circuit in the above problem, we proceed as follows: the reactances X_L and X_C are each 398 ohms, and the circuit resistance is 10 ohms; therefore,

$$Q_c = \frac{X_L}{R_T} = \frac{398}{10} = 39.8$$