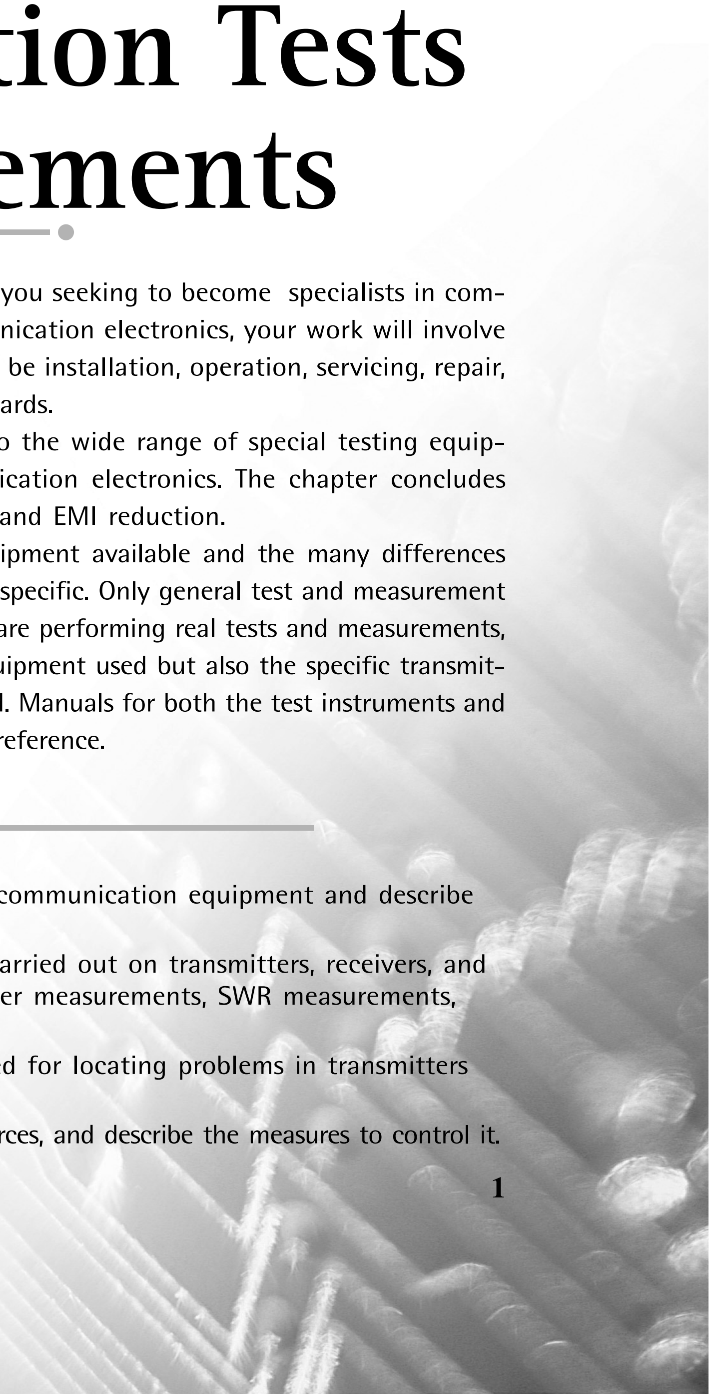
chapter 22

Communication Tests and Measurements



This book was written primarily to educate those of you seeking to become specialists in communication electronics. If you are employed in communication electronics, your work will involve some form of testing and measurement. The work may be installation, operation, servicing, repair, and maintenance or testing to specifications or standards.

The purpose of this chapter is to introduce you to the wide range of special testing equipment and measurement procedures used in communication electronics. The chapter concludes with a special section on troubleshooting techniques and EMI reduction.

Because of the wide range of communication equipment available and the many differences from manufacturer to manufacturer, it is difficult to be specific. Only general test and measurement procedures are given. Just keep in mind that when you are performing real tests and measurements, you must familiarize yourself with not only the test equipment used but also the specific transmitter, receiver, or other communication device being tested. Manuals for both the test instruments and the communication equipment should be available for reference.

Objectives

After completing this chapter, you will be able to:

- List 10 common test instruments used in testing communication equipment and describe the basic operation of each.
- Name common communication equipment tests carried out on transmitters, receivers, and antennas including frequency measurements, power measurements, SWR measurements, sensitivity, and spectrum analyses.
- Describe the basic troubleshooting procedures used for locating problems in transmitters and receivers.
- Define electromagnetic interference (EMI), list its sources, and describe the measures to control it.

22–1 Communication Test Equipment

This section gives a broad overview of the many different types of test instruments available for use with communication equipment. It is assumed that you already know basic test and measurement techniques used with conventional low-frequency test equipment such as multimeters, signal generators, and oscilloscopes. In your communication work, you will continue to use standard oscilloscopes and multimeters for measuring voltages, currents, and resistance. Coverage of these basic test instruments will not be repeated here. We will, however, draw upon your knowledge of the principles of those instruments as they apply to the test equipment discussed in this section.

Voltage Measurements

The most common measurement obtained for most electronic equipment is voltage. This is particularly true for dc and low-frequency ac applications. In RF applications, voltage measurements may be important under some conditions, but power measurements are far more common at higher frequencies, particularly microwave. In testing and troubleshooting communication equipment, you will still use a dc voltmeter to check power supplies and other dc conditions. There are also occasions when measurement of RF, that is, ac, voltage must be made.

There are two basic ways to make ac voltage measurements in electronic equipment. One is to use an ac voltmeter. Most conventional voltmeters can measure ac voltages from a few millivolts to several hundred volts. Typical bench or portable ac multimeters are restricted in their frequency range to a maximum of several thousand kilohertz. Higher-frequency ac voltmeters are available for measuring audio voltages up to several hundred thousand kilohertz. For higher frequencies, special RF voltmeters must be used. The second method is to use an oscilloscope as described below.

RF voltmeter

RF Voltmeters. An *RF voltmeter* is a special piece of test equipment designed to measure the voltage of high-frequency signals. Typical units are available for making measurements up to 10 MHz. Special units capable of measuring voltages from microvolts to hundreds of volts at frequencies up to 1 to 2 GHz are also available.

Root mean square (rms)

RF voltmeters are made to measure sine wave voltages, with the readout given in *root mean square (rms)*. Most RF voltmeters are of the analog variety with a moving pointer on a background scale. Measurement accuracy is within the 1 to 5 percent range depending upon the specific instrument. Accuracy is usually quoted as a percentage of the reading or as a percentage of the full-scale value of the voltage range selected. RF voltmeters with digital readout probes are also available with somewhat improved measurement accuracy.

RF probe (detector probe)

RF Probes. One way to measure RF voltage is to use an *RF probe* with a standard dc multimeter. RF probes are sometimes referred to as *detector probes*. An RF probe is basically a rectifier (germanium or hot carrier) with a filter capacitor that stores the peak value of the sine wave RF voltage. The external dc voltmeter reads the capacitor voltage. The result is a peak value that can easily be converted to root mean square by multiplying it by 0.707.

Most RF probes are good for RF voltage measurements to about 250 MHz. The accuracy is about 5 percent, but that is usually very good for RF measurements.

Analog oscilloscope

Oscilloscopes. Two basic types of oscilloscopes are used in RF measurements: the *analog oscilloscope* and the *digital storage oscilloscope (DSO).*

Digital storage oscilloscope (DSO; digital, or sampling, oscilloscope)

Analog oscilloscopes amplify the signal to be measured and display it on the face of a CRT at a specific sweep rate. They are available for displaying and measuring RF voltages to about 500 MHz. As a rule, an analog oscilloscope should have a bandwidth of 3 or more times the highest-frequency component (a carrier, a harmonic, or a sideband) to be displayed.

Digital storage oscilloscopes, also known as *digital,* or *sampling, oscilloscopes,* are growing in popularity and rapidly replacing analog oscilloscopes. DSOs use high-speed sampling or A/D techniques to convert the signal to be measured to a series of digital words that are stored in an internal memory. Sampling rates vary depending upon the oscilloscope but can range from approximately 20 million samples per second to more than 8 billion samples per second. Each measurement sample is usually converted to an 8- or 10-bit parallel binary number that is stored in an internal memory. Oscilloscopes with approximately 512 kbytes of memory or more are available depending upon the product.

GOOD TO KNOW

The main disadvantage of equivalent time sampling is the time required to acquire enough samples to start the display.

Today, more than 50 percent of oscilloscope sales are of the digital sampling type. DSOs are very popular for high-frequency measurements because they provide the means to display signals with frequencies up to about 30 GHz. This means that complex modulated microwave signals can be readily viewed, measured, and analyzed.

Power Meters

Power meter

As indicated earlier, it is far more common to measure RF power than it is to measure RF voltage or current. This is particularly true in testing and adjusting transmitters that typically develop significant output power. One of the most commonly used RF test instruments is the *power meter*.

Power meters come in a variety of sizes and configurations. One of the most popular is a small in-line power meter designed to be inserted into the coaxial cable between a transmitter and an antenna. The meter is used to measure the transmitter output power supply to the antenna. A short coaxial cable connects the transmitter output to the power meter, and the output of the power meter is connected to the antenna or dummy load.

A more sophisticated power meter is the bench unit designed for laboratory or production line testing. The output of the transmitter or other device whose power is to be measured is connected by a short coaxial cable to the power meter input.

Power meters may have either an analog readout meter or a digital display. The dial or display is calibrated in milliwatts, watts, or kilowatts. The dial can also be calibrated in terms of dBm. This is the decibel power reference to 1 milliwatt (mW). In the smaller, handheld type of power meter, an SWR measurement capability is usually included.

The operation of a power meter is generally based on converting signal power to heat. Whenever current flows through a resistance, power is dissipated in the form of heat. If the heat can be accurately measured, it can usually be converted to an electric signal that can be displayed on a meter.

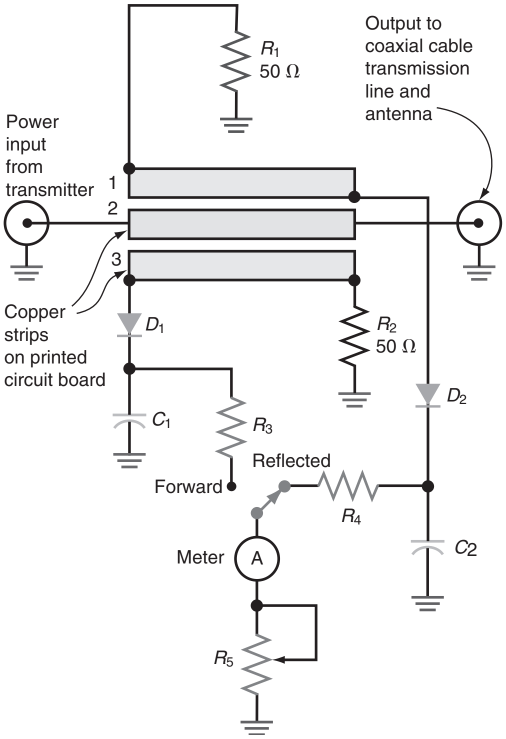
Example 22–1

An RF voltmeter with a detector probe is used to measure the voltage across a 75-Ω resistive load. The frequency is 137.5 MHz. The measured voltage is 8 V. What power is dissipated in the load?

An RF power meter with a detector probe produces a peak reading of voltage V_P:

$$\begin{aligned} V_P &= 8 \text{ V} \\ V_{\text{rms}} &= 0.707 V_P \\ &= 0.707(8) = 5.656 \text{ V} \\ \text{Power} &= \frac{V^2}{R} = \frac{(5.656)^2}{75} \\ &= \frac{32}{75} = 0.4265 \text{ W} \\ &= 426.5 \text{ mW} \end{aligned}$$

Figure 22-1 Monomatch power/SWR meter.



Power can also be measured indirectly. If the load impedance is known and resistive, you can measure the voltage across the load and then calculate the power with the formula $P = V^2/R$.

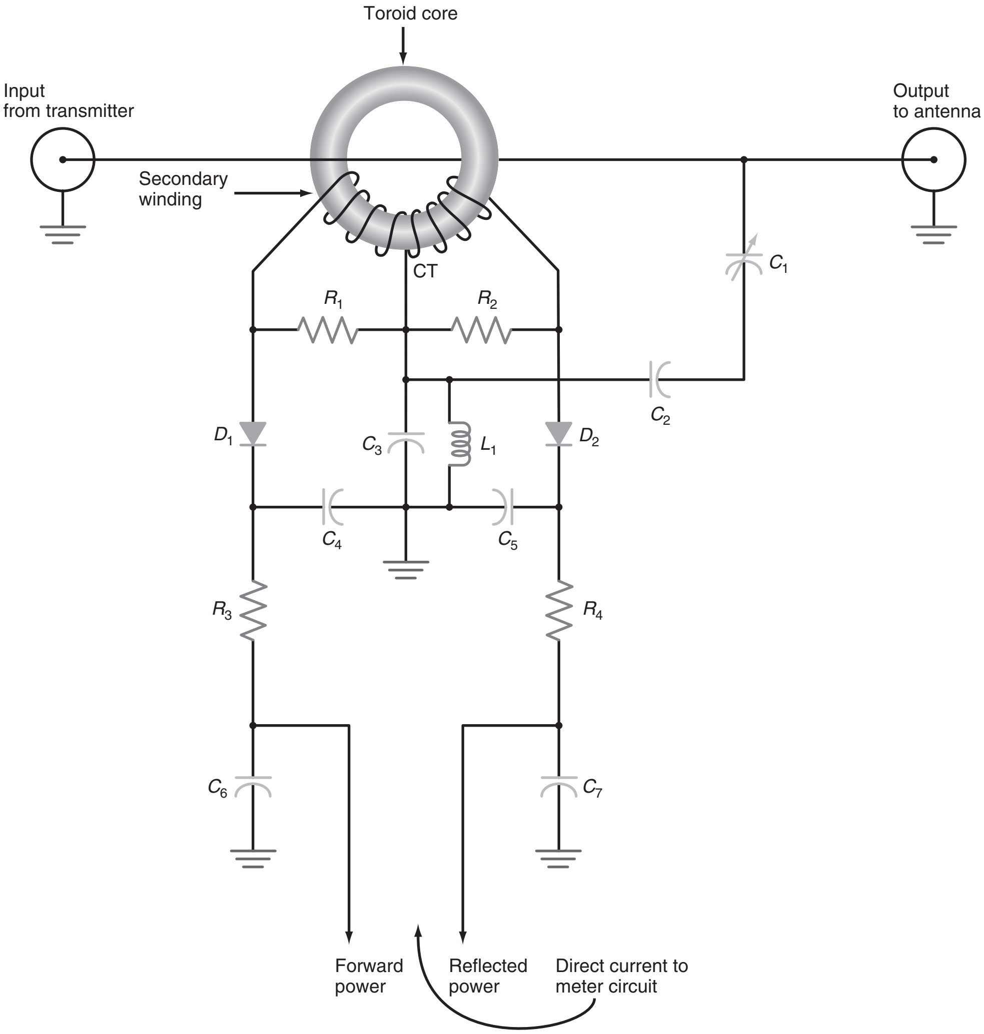
Power Measurement Circuits

Relatively simple circuits can be used to measure power in transmitters and RF power circuits. An example is the monomatch circuit shown in Fig. 22-1. It uses a 50-Ω transmission line made with a microstrip on a small printed-circuit board (PCB). The center conductor is the segment labeled 2 in the schematic. On each side of the center conductor are narrower pickup loops labeled 1 and 3. An RF voltage proportional to the forward and reverse (reflected) power is produced as the result of capacitive and inductive coupling with the center conductor. The voltage in segment 3 represents the forward power. It is rectified by diode D_1 and filtered by C_1 into a proportional dc voltage. This voltage is applied through multiplier resistors R_3 and R_5 to a meter whose scale is calibrated in watts of power. Note the 50-Ω resistors that terminate the pickup loops for impedance matching.

The voltage induced in pickup loop 1 is proportional to the reflected power. It is rectified by D_2 and filtered into a proportional direct current by C_2. A switch is used to select the display of either the forward or the reflected power. Resistor R_5 is used to calibrate the meter circuit, using an accurate power meter as a standard.

Another popular power measurement circuit is the directional coupler shown in Fig. 22-2. A short piece of 50-Ω coaxial cable serves as the single-turn primary winding on a transformer made with a toroid core and a secondary winding of many turns of fine wire. When RF power is passed through the coaxial section, a stepped-up voltage is induced into the secondary winding. Equal-value resistors R_1 and R_2 divide the voltage equally between two diode rectifier circuits made up of D_1 and D_2 and the related components.

Figure 22-2 Directional coupler power measurement.



A voltage divider made up of C_1, C_2, C_3, and L_1 samples the voltage at the output of the circuit. This voltage is applied to both diode rectifiers along with the voltages from the transformer secondary. When these voltages are combined, the rectified outputs are proportional to the forward and reflected voltages on the line. Low-pass filters R_3-C_6 and R_4-C_7 smooth the rectified signals into direct current. A meter arrangement like that in Fig. 22-1 is used to display either forward or reflected power.

Both circuits can be designed to handle power levels from a few milliwatts to many kilowatts. When low-level signals are used, the diodes must be of the germanium or hot carrier type with low bias threshold voltages (0.2 to 0.4 V) to provide sufficient accuracy of measurement. With careful design and adjustment these circuits can give an accuracy of 90 percent or better. Because the circuits are so small, they are often built into the transmitter or other circuit along with the meter and switch.

Example 22-2

If the forward power and reflected power in a circuit are known, the SWR can be calculated. If the forward power is 380 W and the reflected power is 40 W, what is the SWR?

$$\begin{aligned} \text{SWR} &= \frac{1 + \sqrt{P_R/P_F}}{1 - \sqrt{P_R/P_F}} \\ &= \frac{1 + \sqrt{40/380}}{1 - \sqrt{40/380}} \\ &= \frac{1 + 0.324}{1 - 0.324} = \frac{1.324}{0.675} = 1.96 \end{aligned}$$

Dummy Loads

Dummy load

A *dummy load* is a resistor that is connected to the transmission line in place of the antenna to absorb the transmitter output power. When power is measured or other transmitter tests are done, it is usually desirable to disconnect the antenna so that the transmitter does not radiate and interfere with other stations on the same frequency. In addition, it is best that no radiation be released if the transmitter has a problem or does not meet frequency or emission standards. The dummy load meets this requirement. The dummy load may be connected directly to the transmitter coaxial output connector, or it may be connected to it by a short piece of coaxial cable.

The load is a resistor whose value is equal to the output impedance of the transmitter and that has sufficient power rating. For example, a CB transmitter has an output impedance of 50 Ω and a power rating of about 4 W. The resistor dummy load must be capable of dissipating that amount of power or more. For example, you could use three 150-Ω, 2-W resistors in parallel to give a load of 150/3, or 50, Ω and 3 × 2, or 6, W. Standard composition carbon resistors can be used. The tolerance is not critical, and resistors with 5 or 10 percent tolerance will work well.

For low-power transmitters such as CBs and amateur radios, an incandescent light bulb makes a reasonably good load. A type 47 pilot light is widely used for transmitter outputs of several watts. An ordinary lightbulb of 75 or 100 W, or higher, can also be used for higher-power transmitters.

The best dummy load is a commercial unit designed for that purpose. These units are usually designed for some upper power limit such as 200 W or 1 kW. The higher-power units are made with a resistor immersed in oil to improve its heat dissipation capability without burning up. A typical unit is a resistor installed in a 1-gal can filled with insulating oil. A coaxial connector on top is used to attach the unit to the transmitter. Other units are mounted in an aluminum housing with heat fins to improve heat dissipation. The resistors are noncritical, but they must be noninductive. The resistor should be as close to pure resistance at the operating frequency as possible.

Standing Wave Ratio Meters

Standing wave ratio meters

The SWR can be determined by calculation if the forward and reflected power values are known. Some SWR meters use the monomatch or directional coupler circuits described above and then implement the SWR calculation given in Example 22-2 with op amps and analog multiplier ICs. But you can also determine SWR directly.

Figure 22-3 Bridge SWR meter.

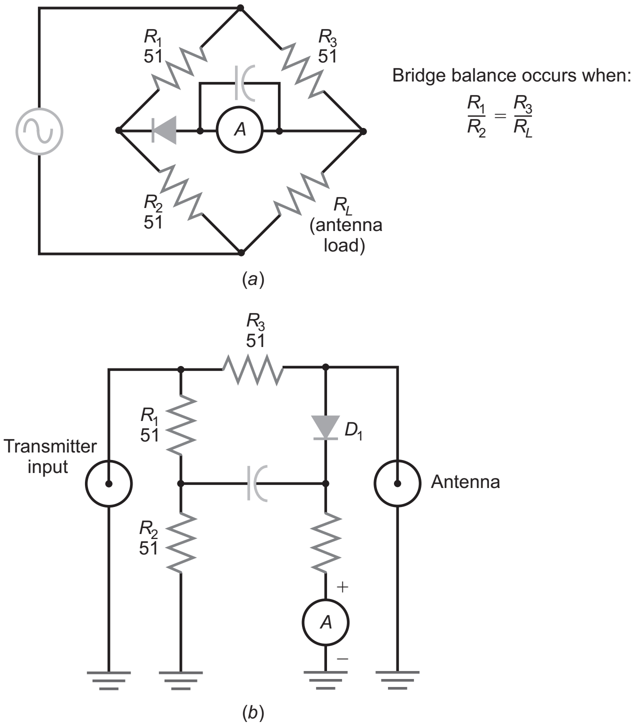


Figure 22-3(*a*) shows a bridge SWR meter. A bridge is formed of precision, noninductive resistors and the antenna radiation resistance. In some SWR meters, resistors are replaced with a capacitive voltage divider. The meter is connected to measure the unbalance of the bridge. The transmitter is the ac power source.

Figure 22-3(*b*) shows the circuit rearranged so that the meter and one side of the bridge are grounded, thereby creating a better match to unbalanced coaxial transmission lines. Note the use of coaxial connectors for the transmitter input and the antenna and transmission line. The meter is a basic dc microammeter. Diode D_1 rectifies the RF signal into a proportional direct current. If the radiation resistance of the antenna is 50 Ω, the bridge will be balanced and the meter reading will be zero. The meter is calibrated to display an SWR of 1. If the antenna radiation resistance is not 50 Ω, the bridge will be unbalanced and the meter will display a reading that is proportional to the degree of unbalance. The meter is calibrated in SWR values.

Signal Generators

A *signal generator* is one of the most often needed pieces of equipment in communication equipment servicing. As its name implies, a signal generator is a device that produces an output signal of a specific shape at a specific frequency and, in communication applications, usually with some form of modulation. The heart of all signal generators is a variable-frequency oscillator that generates a signal that is usually a sine wave. Audio-frequency sine waves are required for the testing of audio circuits in communication equipment, and sine waves in the RF range from approximately 500 kHz to 30 GHz are required to test all types of RF amplifiers, filters, and other circuits. This section provides a general overview of the most common types of signal generators used in communication testing and servicing.

Signal generator

Function generator

GOOD TO KNOW

A function generator is one of the most flexible generators available. It covers all the frequencies needed for audio testing and provides signals in the low-RF range.

Function Generators. A *function generator* is a signal generator designed to generate sine waves, square waves, and triangular waves over a frequency range of approximately 0.001 Hz to about 3 MHz. By changing capacitor values and varying the charging current with a variable resistance, a wide range of frequencies can be developed. The sine, square, and triangular waves are also available simultaneously at individual output jacks.

A function generator is one of the most flexible signal generators available. It covers all the frequencies needed for audio testing and provides signals in the low-RF range. The precision of the frequency setting is accurate for most testing purposes. A frequency counter can be used for precise frequency measurement if needed.

The output impedance of a function generator is typically 50 Ω. The output jacks are BNC connectors which are used with 50- or 75-Ω coaxial cable. The output amplitude is continuously adjustable with a potentiometer. Some function generators include a switched resistive attenuator that allows the output voltage to be reduced to the millivolt and microvolt levels.

Because of the very low cost and flexibility of a function generator, it is the most popular bench instrument in use for general testing of radio amplifiers, filters, and low-frequency RF circuits. The square wave output signals also make it useful in testing digital circuits.

RF signal generator

RF Signal Generators. Two basic types of RF signal generators are in use. The first is a simple, inexpensive type that uses a variable-frequency oscillator to generate RF signals in the 100-kHz to 500-MHz range. The second type is frequency-synthesized.

These simple RF signal generators contain an output level control that can be used to adjust the signal to the desired level, from a few volts down to several millivolts. Some units contain built-in resistive step attenuators to reduce the signal level even further. The more sophisticated generators have built-in level control or automatic gain control (AGC). This ensures that the output signal remains constant while it is tuned over a broad frequency range.

Most low-cost signal generators allow the RF signal being generated to be amplitude-modulated. Normally, a built-in audio oscillator with a fixed frequency somewhere in the 400- to 1000-Hz range is included. A modulation level control is provided to adjust the modulation from 0 to 100 percent. Some RF generators have a built-in frequency modulator.

Such low-cost signal generators are useful in testing and troubleshooting communication receivers. They can provide an RF signal at the signal frequency for injection into the antenna terminals of the receiver. The generator can produce signals that can substitute for local oscillators or can be set to the intermediate frequencies for testing IF amplifiers.

The output frequency is usually set by a large calibrated dial. The precision of calibration is only a few percent, but more precise settings can be obtained by monitoring the signal output on a frequency counter.

When any type of generator based on *LC* or *RC* oscillators is being used, it is best to turn the generator on and let it warm up for several hours before it is used. When a generator is first turned on, its output frequency will drift because of changes in capacitance, inductance, and resistance values. Once the circuit has warmed up to its operating temperature, these variations cease or drop to a negligible amount.

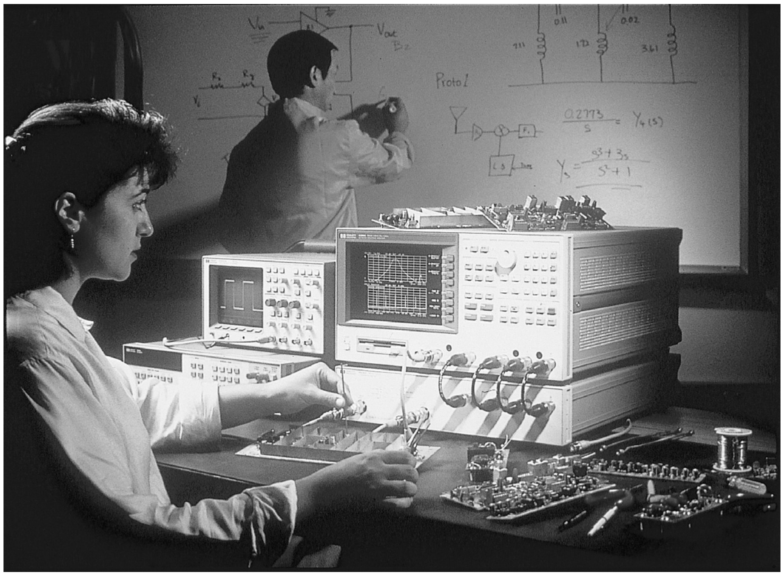
Newer generators use *frequency synthesis* techniques. These generators include one or more mixer circuits that allow the generator to cover an extremely wide range of frequencies. The great value of a frequency-synthesized signal generator is its excellent frequency stability and precision of frequency setting.

Frequency synthesis

Most frequency-synthesized signal generators use a front panel keyboard. The desired frequency is entered with the keypad and displayed on a digital readout. As with other signal generators, the output level is fully variable. The output impedance is typically 50 Ω, with both BNC- and N-type coaxial connectors being required.

Frequency-synthesized generators are available for frequencies into the 20- to 30-GHz range. Such generators are extremely expensive, but they may be required if precision measurement and testing is necessary.

Careers are available in the repair and testing of communication equipment. Such equipment varies widely from one manufacturer to another, so manuals are needed for both the test equipment and the products to be tested. Here, a technician uses RF equipment for vector network analysis, spectrum analysis, and instrument controller testing.



Sweep Generators. A *sweep generator* is a signal generator whose output frequency can be linearly varied over some specific range. Sweep generators have oscillators that can be frequency-modulated, where a linear sawtooth voltage is used as a modulating signal. The resulting output waveform is a constant-amplitude sine wave whose frequency increases from some lower limit to some upper limit (see Fig. 22-4).

Sweep generator

Sweep generators are normally used to provide a means of automatically varying the frequency over a narrow range to plot the frequency response of a filter or amplifier or to show the bandpass response curve of the tuned circuits in equipment such as a receiver. The sweep generator is connected to the input of the circuit, and the upper and lower frequencies are determined by adjustments on the generator. The generator then automatically sweeps over the desired frequency range.

At the same time, the output of the circuit being tested is monitored. The amplitude of the output will vary according to the frequency, depending on the type of circuit being tested. The output of the circuit is connected to an RF detector probe. The resulting signal is the envelope of the RF signal as determined by the output variation of the circuit being tested. The signal displayed on the oscilloscope is an amplitude plot of the frequency response curve. The horizontal axis represents the frequency being varied with time, and the output represents the amplitude of the circuit output at each of the frequencies.

Figure 22-4 Sweep generator output.

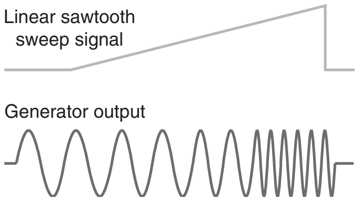


Figure 22-5 Testing frequency response with a sweep generator.

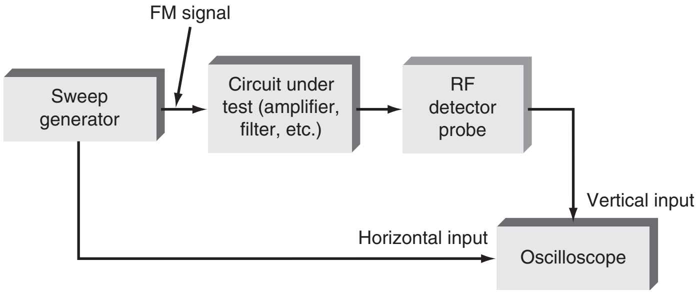


Figure 22-5 shows the general test setup. The linear sweep from the sweep generator is used in place of the oscilloscope's internal sweep so that the displayed response curve is perfectly synchronized with the generator.

Most sweep generators also have *marker capability;* i.e., one or more reference oscillators are included to provide frequency markers at selected points so that the response curve can be actively interpreted. Marker increments may be 100 kHz or 1 MHz. They are added to (linearly mixed with) the output of the RF detector probe, and the composite signal is amplified and sent to the vertical input of the oscilloscope. Sweep generators can save a considerable amount of time in testing and adjusting complex tuned circuits in receivers and other equipment.

Marker capability

Most function generators have built-in sweep capability. If sweep capability is not built in, often an input jack is provided so that an external sawtooth wave can be connected to the generator for sweep purposes.

Arbitrary Waveform Generators. A newer type of signal generator is the *arbitrary waveform generator*. It uses digital techniques to generate almost any waveform. An arbitrary waveform generator stores binary values of a desired waveform in a memory. These binary words are fed sequentially to a digital-to-analog converter that produces a stepped approximation of the desired wave. Most arbitrary waveform generators come with preprogrammed standard waves such as sine, rectangular, sawtooth, and triangular waves, and amplitude modulation. These generators are set up so that you can program a waveform. The arbitrary waveform generator provides a fast and easy way to generate almost any signal shape. Because digital sampling techniques are used, the upper frequency limit of the output is usually below 1 GHz.

Arbitrary waveform generator

Frequency Counters

Frequency counter

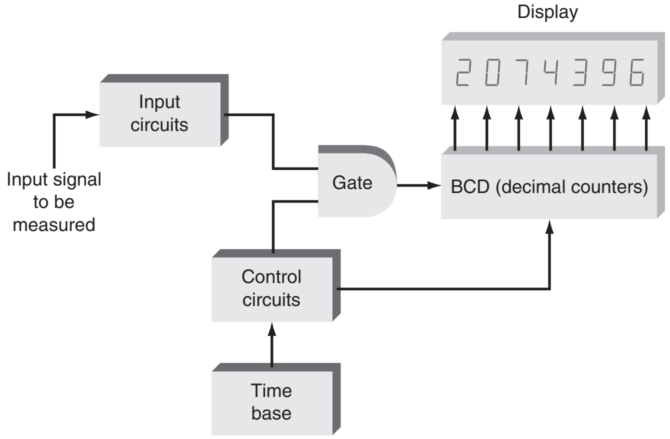
One of the most widely used communication test instruments is the *frequency counter*. It measures the frequency of transmitters, local and carrier oscillators, frequency synthesizers, and any other signal-generating circuit or equipment. It is imperative that the frequency counter operate on its assigned frequency to ensure compliance with rules and regulations and to avoid interference with other services.

A frequency counter displays the frequency of a signal on a decimal readout. Counters are available as bench instruments or portable battery-powered units. A block diagram of a frequency counter is shown in Fig. 22-6. Almost all digital counters are made up of six basic components: input circuit, gate, decimal counter, display, control circuits, and time base. In various combinations, these circuits permit the counter to make time and frequency measurements.

Frequency Measurement. *Frequency* is a measure of the number of events or cycles of a signal that occur in a given time. The usual unit of frequency measurement is hertz (Hz), or cycles per second. The time base generates a very precise signal that is used to open, or enable, the main

Frequency

Figure 22-6 Block diagram of a frequency counter.



gate for an accurate period of time to allow the input pulses to pass through to the counter. The time base accuracy is the most critical specification of the counter. The counter accumulates the number of input cycles that occur during that 1-s interval. The display then shows the frequency in cycles per second, or hertz.

The number of decade counters and display digits also determines the resolution of the frequency measurement. The greater the number of digits, the better the resolution will be. Most low-cost counters have at least 5 digits of display. This provides reasonably good resolution on most frequency measurements. For very high-frequency measurements, resolution is more limited. However, good resolution can still be obtained with a minimum number of digits by optimum selection of the time base frequency.

In most counters that have a selectable time base, the position of the display decimal point is automatically adjusted as the time base signal is adjusted. In this way, the display always shows the frequency in units of hertz, kilohertz, or megahertz. Some of the more sophisticated counters have an automatic time base selection feature called *autoranging*. Special autoranging circuitry in the counter automatically selects the best time base frequency for maximum measurement resolution without overranging. *Overranging* is the condition that occurs when the count capability of the counter is exceeded during the count interval. The number of counters and display digits determines the count capability and thus the overrange point for a given time base.

Autoranging

Overranging

Prescaling. All the techniques for measuring high frequencies involve a process that converts the high frequency to a proportional lower frequency that can be measured with conventional counting circuitry. This translation of the high frequency to the lower frequency is called *down conversion*.

Down conversion

Prescaling is a down-conversion technique that involves the division of the input frequency by a factor that puts the resulting signal into the normal frequency range of the counter. It is important to realize that although prescaling permits the measurement of higher frequencies, it is not without its disadvantages, one of which is loss of resolution. One digit of resolution is lost for each decade of prescaling incorporated.

Prescaling

The prescaling technique for extending the frequency-measuring capability of a counter is widely used. It is simple to implement with modern, high-speed ICs. It is also the most economical method of extending the counting range. Prescalers can be built into the counter and switched in when necessary. Alternatively, external prescalers, which are widely available for low-cost counters, can be used. Most prescalers operate in the range of 200 MHz to 20 GHz. For frequencies beyond 20 GHz, more sophisticated down-conversion techniques must be used.

GOOD TO KNOW

Perhaps the most widely used RF spetrum analyzer is the superheterodyne type.

Spectrum Analyzers

Spectrum analyzer

The *spectrum analyzer* is one of the most useful and popular communication test instruments. Its basic function is to display received signals in the frequency domain. Oscilloscopes are used to display signals in the time domain. The sweep circuits in the oscilloscope deflect the electron beam in the CRT across the screen horizontally. This represents units of time. The input signal to be displayed is applied to deflect the electron beam vertically. Thus, electronic signals that are voltages occurring with respect to time are displayed on the oscilloscope screen.

The spectrum analyzer combines the display of an oscilloscope with circuits that convert the signal to the individual frequency components dictated by Fourier analysis of the signal. Signals applied to the input of the spectrum analyzer are shown as vertical lines or narrow pulses at their frequency of operation.

Figure 22-7 A frequency display of a spectrum analyzer.

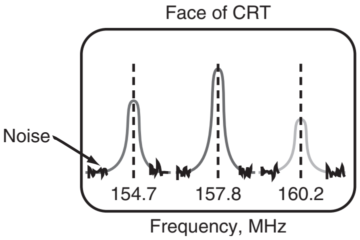


Figure 22-7 shows the display of a spectrum analyzer. The horizontal display is calibrated in frequency units, and the vertical part of the display is calibrated in voltage, power, or decibels. The spectrum analyzer display shows three signals at frequencies of 154.7, 157.8, and 160.2 MHz. The vertical height represents the relative strength of the amplitude of each signal. Each signal might represent the carrier of a radio transmitter. A spectrum analysis of any noise between the signals is shown.

The spectrum analyzer can be used to view a complex signal in terms of its frequency components. A graticule on the face of the CRT allows the frequency spacing between adjacent frequency components to be determined. The vertical amplitude of the scale is calibrated in decibels. The spectrum analyzer is extremely useful in analyzing complex signals that may be difficult to analyze or whose content may be unrecognizable.

The four basic techniques of spectrum analysis are bank of filters, swept filter, swept spectrum superheterodyne, and fast Fourier transform (FFT). All these methods do the same thing, i.e., decompose the input signal into its individual sine wave frequency components. Both analog and digital methods are used to implement each type. The superheterodyne and FFT methods are the most widely used and are discussed below.

A spectrum analyzer from Tektronix, covering frequencies to 14 GHz.

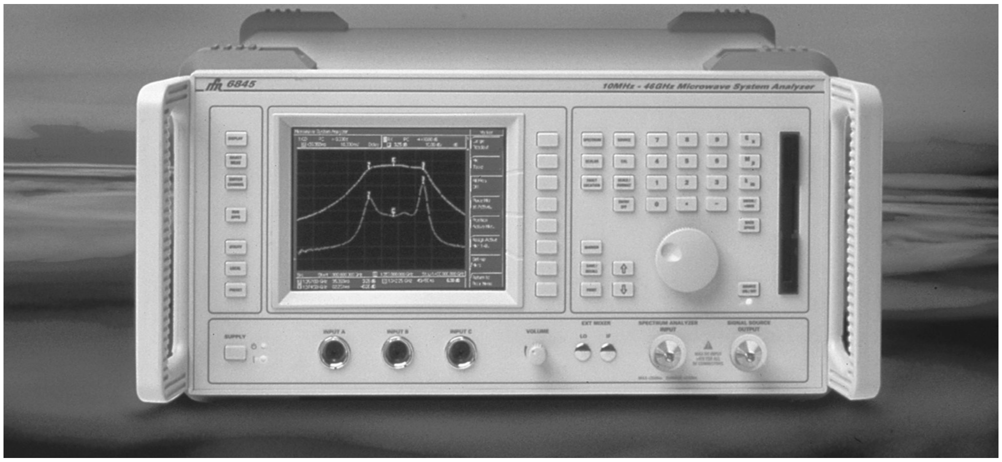
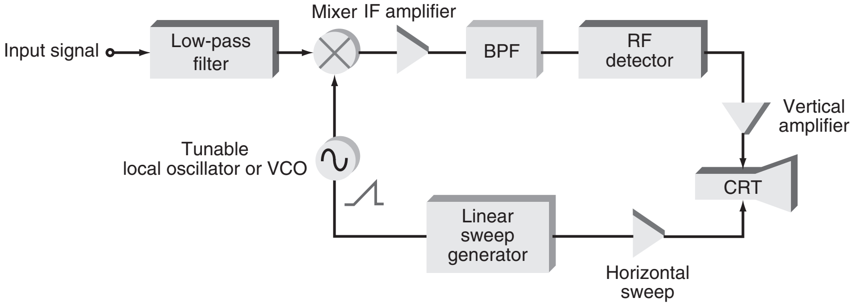


Figure 22-8 Superheterodyne RF spectrum analyzer.



Superheterodynes. Perhaps the most widely used RF spectrum analyzer is the *superheterodyne* type (see Fig. 22-8). It consists of a broadband front end, a mixer, and a tunable local oscillator. The frequency range of the input is restricted to some upper limit by a low-pass filter in the input. The mixer output is the difference between the input signal frequency component and the local-oscillator frequency. This is the *intermediate frequency (IF)*.

Superheterodyne RF spectrum analyzer

As the local-oscillator frequency increases, the output of the mixer stays at the IF. Each frequency component of the input signal is converted to the IF value by the varying local-oscillator signal. If the frequency components are very close to one another and the bandwidth of the IF bandpass filter (BPF) is broad, the display will be just one broad pulse. Narrowing the bandwidth of the IF BPF allows more closely spaced components to be detected. Most spectrum analyzers have several switchable selectivity ranges for the IF.

Intermediate frequency (IF)

Spectrum analyzers are available in many configurations with different specifications, and they are designed to display signals from approximately 100 kHz to approximately 30 GHz. Most RF and microwave spectrum analyzers are superheterodynes. Spectrum analyzers are usually calibrated to provide relatively good measurement accuracy of the signal. Most signals are displayed as power or decibel measurements, although some analyzers provide for voltage level displays. The input is usually applied through a 50-Ω coaxial cable and connector.

FFT Spectrum Analyzers. The *fast Fourier transform (FFT)* method of spectrum analysis relies on the FFT mathematical analysis. FFT spectrum analyzers give a high-resolution display and are generally superior to all other types of spectrum analyzers. However, the upper frequency of the input signal is limited to frequencies in the tens of megahertz range.

Fast Fourier transform (FFT) spectrum analyzer

In addition to measuring the spectrum of a signal, spectrum analyzers are useful in detecting harmonics and other spurious signals generated unintentionally. Spectrum analyzers can be used to display the relative signal-to-noise ratio, and they are ideal for analyzing modulation components and displaying the harmonic spectrum of a rectangular pulse train.

Despite their extremely high prices (usually $10,000 to $50,000), spectrum analyzers are widely used. Many critical testing and measurement applications demand their use, especially in developing new RF equipment and in making final tests and measurements of manufactured units. Spectrum analyzers are also used in the field for testing cable TV systems, cellular telephone systems, fiber-optic networks, and other complex communication systems.

Network Analyzers

A *network analyzer* is a test instrument designed to analyze linear circuits, especially RF circuits. It is a combination instrument that contains a wide-range sweep sine wave generator and a

Network analyzer

CRT output that displays not only frequency plots as does a spectrum analyzer but also plots of phase shift versus frequency.

Network analyzers are used by engineers to determine the specific performance characteristics of a circuit they are designing, such as a filter, an amplifier, or a mixer. They are also useful in analyzing transmission lines and even individual components. The network analyzer applies a swept-frequency sine wave and measures the circuit output. The resulting measurement data is then used to produce an output display such as an amplitude versus frequency plot, a phase shift versus frequency, or even a plot of complex impedance values on a Smith chart display.

GOOD TO KNOW

Although network analyzers are expensive, they are invaluable for determining the performance characteristics of components or circuits producing results in a display.

Network analyzers completely describe the performance or characterization of a circuit. This type of information is useful not only to engineers creating the circuits but also to those in manufacturing who have to produce and test the circuit. Despite their very high cost, these instruments are widely used because of the valuable information they provide and the massive amount of design and test time they save.

Field strength meter (FSM)

Field Strength Meters

One of the least expensive pieces of RF test equipment is the *field strength meter (FSM)*, a portable device used for detecting the presence of RF signals near an antenna. The FSM is a sensitive detector for RF energy being radiated by a transmitter into an antenna. It provides a relative indication of the strength of the electromagnetic waves reaching the meter.

The field strength meter is a vertical whip antenna, usually of the telescoping type, connected to a simple diode detector. The diode detector is exactly like the circuit of a simple crystal radio or a detector probe, as described earlier, but without any tuned circuits so that the unit will pick up signals on any frequency.

The field strength meter does not give an accurate measurement of signal strength. In fact, its only purpose is to detect the presence of a nearby signal (within about 100 ft or less). Its purpose is to determine whether a given transmitter and antenna system are working. The closer the meter is moved to the transmitter and antenna, the higher the signal level.

A useful function of the meter is the determination of the radiation pattern of an antenna. The field strength meter is adjusted to give the maximum reading in the direction of the most radiation from the antenna. The meter is moved in a constant-radius circle around the antenna for 360°. Every 5° or 10°, a field strength reading is taken from the meter. The resulting set of readings can be plotted on polar graph paper to reveal the horizontal radiation pattern of the antenna.

Other types of field strength meters are available. A simple meter may be built to incorporate a resonant circuit to tune the input to a specific transmitter frequency. This makes the meter more sensitive. Some meters have a built-in amplifier to make the meter even more sensitive and useful at greater distances from the antenna.

An *absolute* (rather than *relative*) *field strength meter* is available for accurate measurements of signal strength. The strength of the radiated signal is usually measured in microvolts per meter (μV/m). This is the amount of voltage the signal will induce into an antenna that is 1 m long. An absolute field strength meter is calibrated in units of microvolts per meter. Highly accurate signal measurements can be made.

Absolute field strength meter

Other Test Instruments

There are hundreds of types of communication test instruments, most of which are very specialized. The ones described previously in this chapter, plus those listed in the above table, are the most common, but there are many others including the many special test instruments designed by equipment manufacturers for testing their production units or servicing customers' equipment.

Instrument	**Purpose**
Absorption wave meter	Variable tuned circuit with an indicator that tells when the tuned circuit is resonant to a signal coupled to the meter by a transmitter; provides a rough indication of frequency.
Impedance meter	An instrument, usually of the bridge type, that accurately measures the impedance of a circuit, a component, or even an antenna at RF frequencies.
Dip oscillator	A tunable oscillator used to determine the approximate resonant frequency of any deenergized *LC*–resonant circuit. The oscillator inductor is coupled to the tuned circuit inductor, and the oscillator is tuned until its feedback is reduced as energy being taken by the tuned circuit, which is indicated by a “dip,” or reduction, in current on a built-in meter. The approximate frequency is read from a calibrated dial.
Noise bridge	Bridge circuit driven by a random noise voltage source (usually a reverse-biased zener diode that generates random “white” or pseudorandom “pink” noise) that has an antenna or coaxial cable as one leg of the bridge; used to make antenna characteristic impedance measurements and measurements of coaxial cable velocity factor and length.

Absorption wave meter

Impedance meter

Dip oscillator

Noise bridge

22-2 Common Communication Tests

Hundreds, even thousands, of different tests are made on communication equipment. However, some common tests are widely used on all types of communication equipment. This section summarizes the most common tests and measurements made in the servicing of communication equipment.

Most of the tests described here focus on standard radio communication equipment. Tests for transmitters, receivers, and antennas will be described, as will special microwave tests, fiber-optic cable tests, and tests on data communication equipment. Keep in mind that the test procedures described are general. To make specific tests, follow the test setups recommended by the test equipment manufacturer. Always have the manuals for the test equipment and the equipment being serviced on hand for reference.

Transmitter Tests

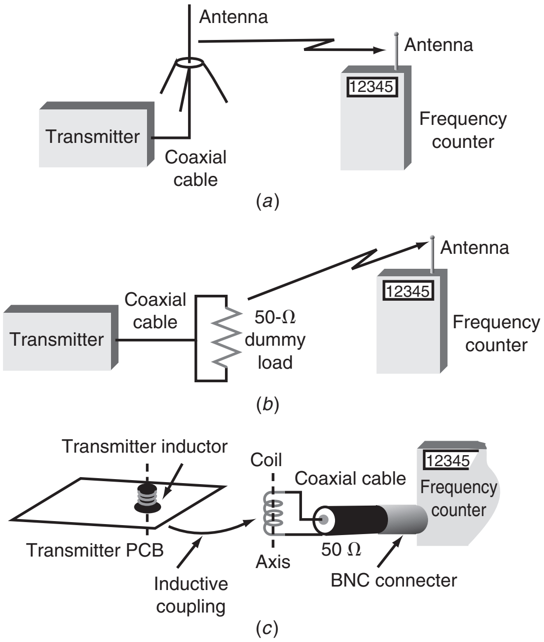
Four main tests are made on most transmitters: tests of frequency, modulation, and power, and tests for any undesired output signal component such as harmonics and parasitic radiations. These tests and measurements are made for several reasons. First, any equipment that radiates a radio signal is governed by Federal Communications Commission (FCC) rules and regulations. For a transmitter to meet its intended purpose, the FCC specifies frequency, power, and other measurements to which the equipment must comply. Second, the tests are normally made when the equipment is first installed to be sure that everything is working correctly. Third, such tests may be performed to troubleshoot equipment. If the equipment is not working properly, these tests are some of the first that should be made to help identify the trouble.

GOOD TO KNOW

To make specific tests, always follow the test setups recommended by the test equipment manufacturer. Keep the manuals for test equipment and for the equipment being serviced on hand for reference.

Frequency Measurement. Regardless of the method of carrier generation, the frequency of the transmitter is important. The transmitter must operate on the assigned frequency to comply with FCC regulations and to ensure that the signal can be picked up by a receiver tuned to that frquency.

Figure 22-9 Transmitter frequency measurement.



The output of a transmitter is measured directly to determine its frequency. The transmitted signal is independently picked up and its frequency measured on a frequency counter. Figure 22-9 shows several methods of picking up the signal. Many frequency counters designed for communication work come with an antenna that picks up the signal directly from the transmitter [see Fig. 22-9(*a*)]. The transmitter is keyed up (turned on) while it is connected to its regular antenna, and the antenna on the counter picks up the signal and translates it to one that can be measured by the counter circuitry. No modulation should be applied, especially if FM is used.

The transmitter output can be connected to a dummy load [see Fig. 22-9(*b*)]. This will ensure that no signal is radiated, but that there will be sufficient signal pickup to make a frequency measurement if the counter and its antenna are placed near the transmitter.

Another method of connecting the counter to the transmitter is to use a small coil, as shown in Fig. 22-9(*c*). A small pickup coil can be made of stiff copper wire. Enamel copper wire, size AWG 12 or 14 wire, is formed into a loop of two to four turns. The ends of the loop are connected to a coaxial cable with a BNC connector for attachment to the frequency counter. The loop can be placed near the transmitter circuits. This method of pickup is used when the transmitter has been opened and its circuits have been exposed. For most transmitters, the loop has been placed only in the general vicinity of the circuitry. Normally the loop picks up radiation from one of the inductors in the final stage of the transmitter. Maximum coupling is achieved when the axis of the turns of the loop is parallel to the axis of one of the inductors in the final output stage.

Once the signal from the transmitter is coupled to the counter, the counter sensitivity is adjusted, and the counter is set to the desired range for displaying the frequency. The greater the number of digits the counter can display, the more accurate the measurement.

Normally this test is made without modulation. If only the carrier is transmitted, any modulation effects can be ignored. Modulation must not be applied to an FM transmitter, because the carrier frequency will be varied by the modulation, resulting in an inaccurate frequency measurement.

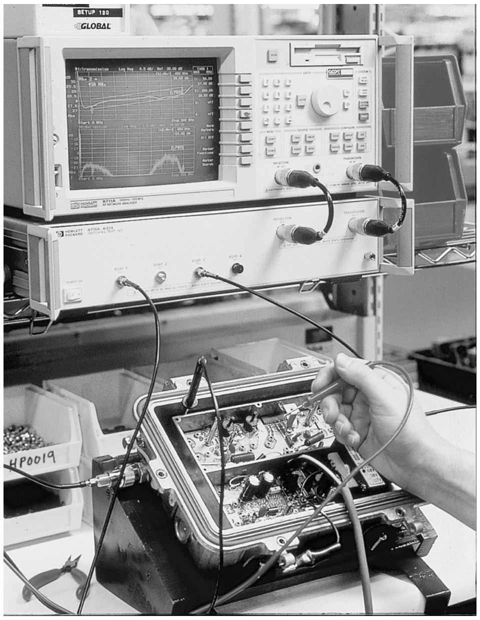
The quality of crystals today is excellent; thus, off-frequency operation is not common. If the transmitter is not within specifications, the crystal can be replaced. In some critical pieces of equipment, the crystal may be in an oven. If the oven temperature control circuits are not working correctly, the crystal may have drifted off frequency. This calls for repair of the oven circuitry or replacement of the entire unit.

If the signal source is a frequency synthesizer, the precision of the reference crystal can be checked. If it is within specifications, perhaps an off-frequency operation is being caused by a digital problem in the phase-locked loop (PLL). An incorrect frequency-division ratio, faulty phase detector, or poorly tracking voltage-controlled oscillator (VCO) may be the problem.

Modulation Tests. If AM is being used in the transmitter, you should measure the percentage of modulation. It is best to keep the percentage of modulation as close to 100 as possible to ensure maximum output power and below 100 to prevent signal distortion and harmonic radiation. In FM or PM transmitters, you should measure the frequency deviation with modulation. The goal with FM is to keep the deviation within the specific range to prevent adjacent channel interference.

The best way to measure AM is to use an oscilloscope and display the AM signal directly. To do this, you must have an oscilloscope whose vertical amplifier bandwidth is sufficient to cover the transmitter frequency. Figure 22-10(*a*) shows the basic test setup. An audio signal generator is used to amplitude-modulate the transmitter. An audio signal of 400 to 1000 Hz is applied in place of the microphone signal.

This network analyzer helps designers predict how multiple components will behave together and helps manufacturers know whether final products will meet performance specifications.



The transmitter is then keyed up, and the oscilloscope is attached to the output load. It is best to perform this test with a dummy load to prevent radiation of the signal. The oscilloscope is then adjusted to display the AM signal. The display will appear as shown in Fig. 22-10(*b*).

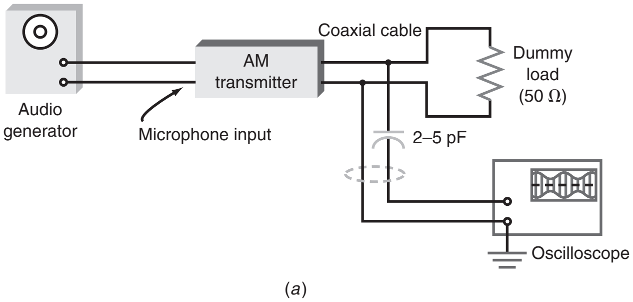
Power Measurements. Most transmitters have a tune-up procedure recommended by the manufacturer for adjusting each stage to produce maximum output power. In older transmitters, tuned circuits between stages have to be precisely adjusted in the correct sequence. In modern solid-state transmitters, there are fewer adjustments, but in most cases there are some adjustments in the driver and frequency multiplier stages as well as tuning adjustments for resonance at the operating frequency to the final amplifier. There may be impedance-matching adjustments in the final amplifier to ensure full coupling of the power to the antenna. The process is essentially that of adjusting the tuned circuits to resonance. These measurements are generally made while monitoring the output power of the transmitter.

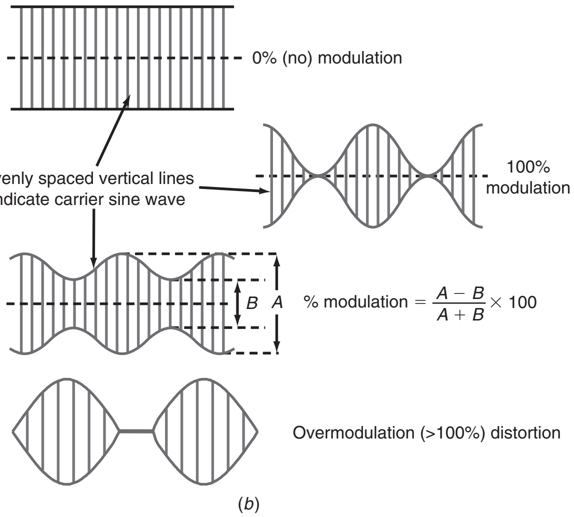
The procedure for measuring the output power is to connect the transmitter output to an RF power meter and the dummy load, as shown in Fig. 22-11. The transmitter is keyed up without modulation, and adjustments are made on the transmitter circuit to tune for maximum power output. With the test arrangement shown, the power meter will display the output power reading.

Once the transmitter is properly tuned up, it can be connected to the antenna. The power into the antenna will then be indicated. If the antenna is properly matched to the transmission line, the amount of output power will be the same as that in the dummy load. If not, SWR measurements should be made. Most modern power meters measure both forward and reflected power, so SWR measurements are easier to make. It may be necessary to adjust the antenna or a matching circuit to ensure maximum output power with minimum SWR.

Harmonics and Spurious Output Measurements. A common problem in transmitters is the radiation of undesirable harmonics or spurious signals. Ideally, the output of the transmitter should be a pure signal at the carrier frequency with only those sideband components produced by the modulating

Figure 22–10 AM measurement. (*a*) Test setup. (*b*) Typical waveforms.

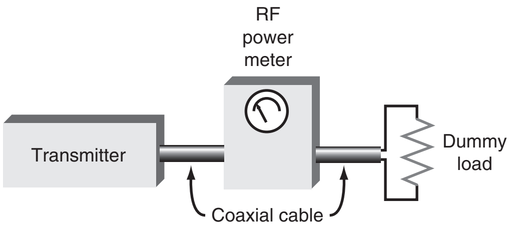




signal. However, most transmitters will generate some harmonics and spurious signals. Transmitters that use class C, class D, and class E amplifiers generate a high harmonic content. If the tuned circuits in the transmitter are properly designed, the Q's will be high enough to reduce the harmonic content level sufficiently. However, this is not always the case.

Another problem is that other spurious signals can be generated by transmitters. In high-power transmitters particularly, parasitic oscillations can occur. These are caused by the excitation of small tuned circuits whose components are the stray inductances and capacitances in the circuits or the transistors of the tubes involved. Parasitic oscillations can reach high levels and cause radiation on undesired frequencies.

Figure 22–11 Power measurement.



For most transmitters, the FCC specifies maximum levels of harmonic and spurious radiation. Intermodulation distortion in mixers and nonlinear circuits also produces unwanted signals. Normally these signals must be at least 30 or 40 dB down from the main carrier signal. The best way to measure harmonics and spurious signals is to use a spectrum analyzer. The transmitter output is modulated with an audio tone, and its output is monitored directly on the spectrum analyzer. It is usually best to feed the transmitter output into a dummy load for this measurement. The spectrum analyzer is then adjusted to display the normal carrier and sideband pattern. The search for high-level signals can begin for spurious outputs by tuning the spectrum analyzer above and below the operating frequency. The spectrum analyzer can be tuned to search for signals at the second, third, and higher harmonics of the carrier frequency. If signals are detected, they can be measured to ensure that they are sufficiently low in power to meet FCC regulations and/or the manufacturer's specifications. The spectrum analyzer is then tuned over a broad range to ensure that no other spurious nonharmonic signals are present.

It may be possible to reduce the harmonic and spurious output content by making a minor transmitter tuning adjustment. If not, to meet specifications, it is often necessary to use filters to eliminate unwanted harmonics or other signals.

Antenna and Transmission Line Tests

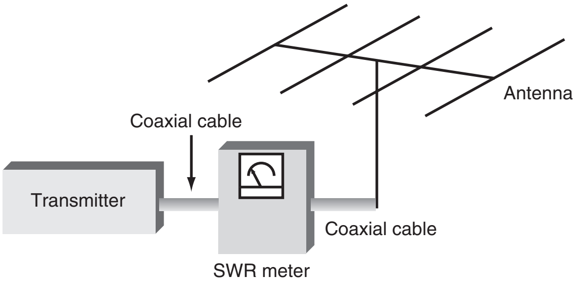
If the transmitter is working correctly and the antenna has been properly designed, about the only test that needs to be made on the transmission line and antenna is for standing waves. It will tell you whether any further adjustments are necessary. If the SWR is high, you can usually tune the antenna to reduce it.

You may also run into a transmission line problem. It may be open or short-circuited, which will show up on an SWR test as infinite SWR. But there may be other problems such as a cable that has been cut, short-circuited, or crushed between the transmitter and receiver. These kinds of problems can be located with a time-domain reflectometer test.

SWR Tests. The test procedure for SWR is shown in Fig. 22-12. The SWR meter is connected between the transmission line and the antenna. Check with the manufacturer of the SWR meter to determine whether any specific connection location is required or whether other conditions must be met. Some of the lower-cost SWR meters must be connected directly at the antenna or a specific number of half wavelengths from the antenna back to the transmitter.

Once the meter is properly connected, key up the transmitter without modulation. The transmitter should have been previously tuned and adjusted for maximum output power. The SWR can be read directly from the instrument's meter. In some cases, the meter will give measurements for the relative amount of incident or forward and reflected power or will read out in terms of the reflection coefficient, in which case you must calculate the SWR as described earlier. Other meters will read out directly in SWR. The maximum range is usually 3:1.

Figure 22-12 SWR measurement.



The ideal SWR is 1 or 1:1, which means that all the power generated by the transmitter is absorbed by the antenna load. Nevertheless, in even the best systems, perfect matching is rarely achieved. Any mismatch will produce reflected power and standing waves. If the SWR is less than 2:1, the amount of power that will be lost or reflected will be minimal.

The primary procedure for reducing the SWR is to make antenna adjustments, usually in the form of modifying the element lengths to more closely tune the antenna to the frequency of operation. Using many antennas makes it possible to adjust their length over a narrow range to fine-tune the SWR. Other antennas permit adjustment to provide a better match of the transmission line to the driven element of the antenna. These adjustments can be made one at a time, and the SWR monitored.

Time-domain reflectometry

TDR Tests. *Time-domain reflectometry (TDR)* is a pulse for cables and transmission lines of all types. It is widely used in finding faults in cables used for digital data transmission, but it can be used for RF transmission lines. (Refer to the section Data Communication Tests later in this chapter for details.)

Receiver Tests

The primary tests for receivers involve sensitivity and noise level. The greater the sensitivity of the receiver, the higher its gain and the better job it does of receiving very small signals.

As part of the sensitivity testing, the signal-to-noise (*S*/*N*) ratio is also usually measured indirectly. The ability of a receiver to pick up weak signals is just as much a function of the receiver noise level as it is of overall receiver gain. The lower the noise level, the greater the ability of the receiver to detect weak signals.

As part of an overall sensitivity check, some receiver manufacturers specify an audio power output level. Since receiver sensitivity measurements are usually made by measuring the speaker output voltage, power output can also be checked if desired.

GOOD TO KNOW

The ability of a receiver to pick up weak signals is just as much a function of receiver noise level as it is of overall receiver gain. The lower the noise level, the greater the ability of the receiver to detect weak signals.

In this section, some of the common tests made on receivers are described. The information is generic, and the actual testing procedures often differ from one receiver manufacturer to another.

Equipment Required. To make sensitivity and noise measurements, the following equipment is necessary:

1. ***Dual-Trace Oscilloscope.*** The vertical frequency response is not too critical, for you will be viewing noise and audio frequency signals.
2. ***RF Signal Generator.*** This generator provides an RF signal at the receiver operating frequency. It should have an output attenuator so that signals as low as 1 μV or less can be set. This may indicate the need for an external attenuator if the generator does not have built-in attenuators or output level adjustments. The generator must also have modulation capability, either AM or FM, depending upon the type of receiver to be tested.
3. ***RF Voltmeter.*** The RF voltmeter is needed to measure the RF generator output voltage in some tests. Some higher-quality RF generators have an RF voltmeter built in to aid in setting the output attenuator and level controls.
4. ***Frequency Counter.*** A frequency counter capable of measuring the RF generator output frequency is needed.
5. ***Multimeter.*** A multimeter capable of measuring audio-frequency (AF) voltage levels is needed. Any analog or digital multimeter with ac measurement capability in the AF range can be used.
6. ***Dummy Loads.*** A dummy load is needed for the receiver antenna input for the noise test. This can be either a 50- or a 75-Ω resistor attached to the appropriate coaxial input connector. A dummy load is needed for the speaker. Since most noise and sensitivity tests are made with maximum receiver gain

including audio gain, it is not practical or desirable to leave the speaker connected. Most communication receivers have an audio output power capability of 2 to 10 W, which is sufficiently high to make the output signal level too high for comfort. A speaker dummy load of 4, 8, or 16 Ω, depending upon the speaker impedance, is needed. Be sure that the dummy load can withstand the maximum audio power output of the receiver. Do not use wire-wound resistors for this application, for they have too much inductance. Check the receiver's specifications for both the impedance and the maximum power level specification.

Noise

Noise Tests. *Noise* consists of random signal variations picked up by the receiver or caused by thermal agitation and other conditions inside the receiver circuitry. External noise cannot be controlled or eliminated. However, noise contributed by the receiver can be controlled. Every effort is made during the design to minimize internally generated noise and thus to improve the ability of the receiver to pick up weak signals.

Most noise generated by the receiver occurs in the receiver's front end, primarily the RF amplifier and the mixer. Careful attention is given to the design of both these circuits so that they contribute minimum noise.

Because noise is a totally random signal that is a composite of varying frequency and varying amplitude signals, it is somewhat difficult to measure. However, the following procedure has become a common and popular method that is easy to implement.

Refer to the test setup shown in Fig. 22-13. The antenna is removed from the receiver, and a dummy load of the correct impedance is used to replace it. A carbon composition resistor of 50 or 75 Ω can be used. The idea is to prevent the receiver from picking up any signals while maintaining the correct impedance.

At the output of the receiver, the speaker is replaced with a dummy load. Most speakers have an output impedance of 4 or 8 Ω. Check the receiver's specifications, and connect an appropriate value of resistor in place of the speaker. Be sure that the dummy load resistors can withstand the output power.

Finally, connect the dual-trace oscilloscope across the dummy speaker load. The same signal should be displayed on both channels of the oscilloscope. The displayed signal will be an amplified version of the noise produced by the receiver and amplified by all the stages between the antenna input and the speaker. Follow this step-by-step procedure:

GOOD TO KNOW

To determine the noise level when the horizontal spacing on the oscilloscope and the vertical sensitivity are known, multiply the horizontal spacing by the sensitivity and divide by 2.

1. Turn on the receiver, and tune it to a channel where no signal will be received.
2. Set the receiver volume control to maximum. If the receiver has any type of RF or IF gain control, it too should be set to its maximum setting.
3. Set the oscilloscope input for the lower trace (channel B) to ground. Most oscilloscopes have a switch that allows the input to be set for ac measurements, dc measurements, or ground. Grounding the channel B input will prevent any signal from being displayed. At this time you will see a straight horizontal line for the lower trace. Adjust that lower trace so that it lines up with one of the horizontal graticule lines near the bottom of the oscilloscope screen. This will provide a voltage measurement reference.

Figure 22-13 Noise test setup.

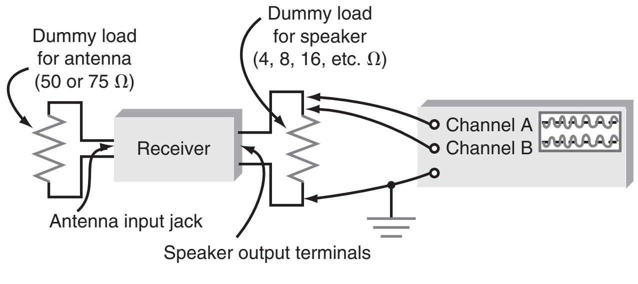
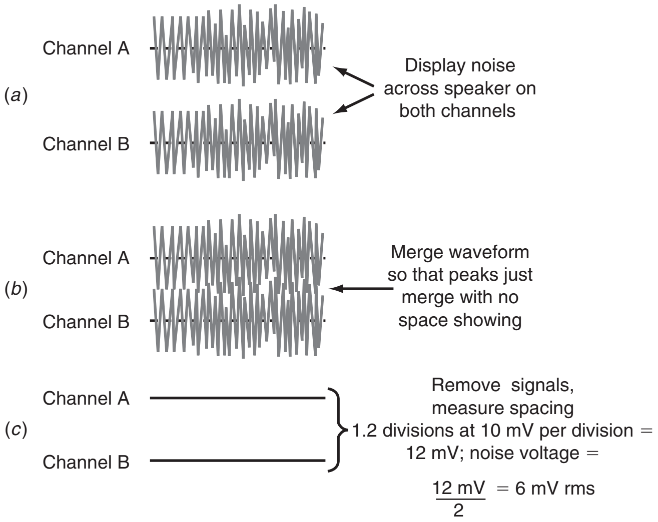


Figure 22-14 Noise measurement procedure.



4. Set the channel B input and the channel A input to alternating current. Adjust the vertical sensitivities of channels A and B so that they are on the same range. Make the adjustments so that the signal is displayed something like that shown in Fig. 22-14(*a*). You should see exactly the same noise pattern on both channels.
5. Using the vertical position control on the upper or A channel, move the upper noise trace downward so that it begins to merge with the noise signal on channel B. The correct adjustment for the position of the channel A noise signal is such that the peaks of the upper and lower signals just barely merge. This will generally be indicated at the point where there is no blank space between upper and lower traces. The signal should look something like that shown in Fig. 22-14(*b*).
6. Now set both oscilloscope inputs to ground, thereby preventing the noise signal from being displayed. You will see two straight horizontal lines. The distance between the two lines is a measure of the noise voltage. The value indicated is 2 times the root mean square (rms) noise voltage [see Fig. 22-14(*c*)].

Assume that the adjustments described above were made and the separation between the two horizontal traces is 1.2 vertical divisions. If the vertical gains of both channels are set to the 10 mV per division range, the noise reading is 1.2 × 10 mV =12 mV. The rms noise voltage is one-half of this figure, or 12 mV/2 = 6 mV.

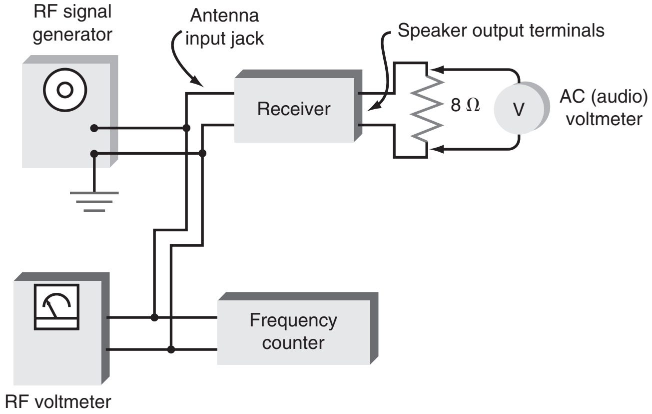
Power Output Tests. Sometimes it is necessary to measure the receiver's total power output capability. This is a good general test of all the receiver circuits. If the receiver can supply the manufacturer's specified maximum output power into the speaker with a given low RF signal level input, the receiver is operating correctly.

The test setup for the power output test is shown in Fig. 22-15. An RF signal generator for the correct frequency is used as the primary signal source. It must also be possible to modulate this generator with either AM or FM depending upon the type of receiver.

It is also desirable to connect a frequency counter to the signal generator output to provide an accurate measure of the receiver input frequency. Most communication receivers operate on specific frequency channels. For the test to be valid, the generator output frequency must be set to the center of the receiver frequency channel. This will usually be known from the receiver's specifications. The signal generator is tuned, and the frequency is set by monitoring the digital readout on the frequency counter.

Be sure to replace the speaker with a resistive load of an impedance equal to that of the speaker, such as 8 Ω. The dummy speaker load should also be able to carry the maximum rated output power of the receiver. Finally, connect an ac voltmeter across the speaker dummy load.

Figure 22-15 Power output test.



Turn on the receiver, and set the volume control to the maximum. If the receiver has a variable RF or IF gain control, you must set it to the maximum setting also. At this time, any other receiver features should be disabled. For example, in an FM receiver, the squelch should be turned off or disabled. In an AM receiver, if a noise limiter is used, it too should be turned off.

To begin the test, follow this procedure:

1. Set the RF generator output level to 1 mV. If the RF signal generator has a built-in RF voltmeter, use it to make this setting. Otherwise, an external RF voltmeter may be needed, as shown in Fig. 22-15.
2. Set the signal generator for modulation of the appropriate type. If AM is used, set the percentage of modulation for 30. If FM is used, set the deviation for ±3 kHz. In most signal generators, the percentage of AM and the frequency deviation for FM are fixed. Refer to the signal generator specifications to find out what these values are.
3. With everything appropriately adjusted, measure the ac voltage across the speaker dummy load. This will be an rms reading.
4. To determine the receiver power output, use the standard power formula $P = V^2/R$.

Assume that you measure an rms voltage of 4 V across an 8-Ω speaker. The power output will be

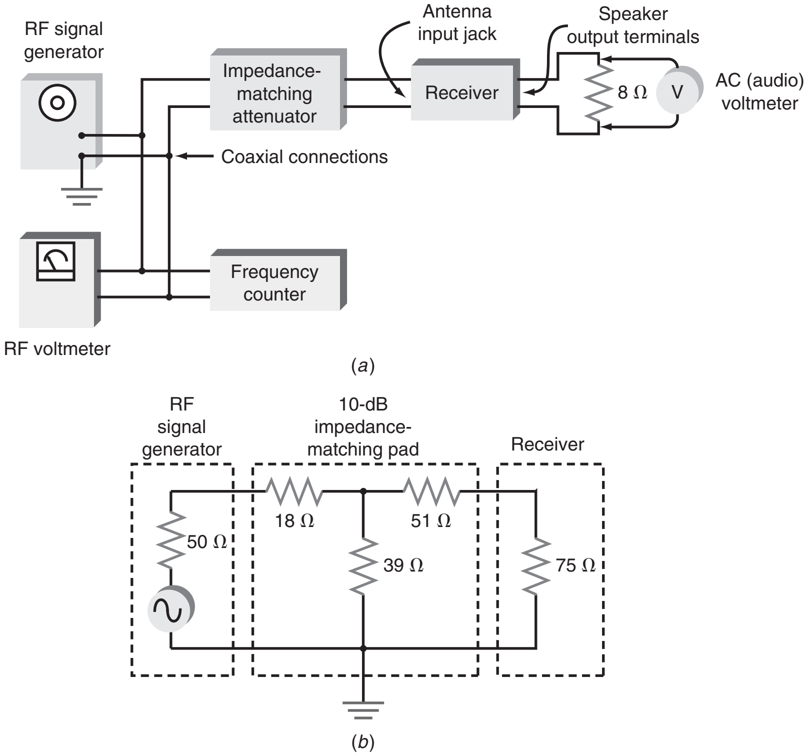
$$P = \frac{V^2}{R} = \frac{4^2}{8} = \frac{16}{8} = 2\text{ W}$$

An optional test is to observe the signal across the speaker load with an oscilloscope. Most RF generators modulate the input signal with a sine wave of 400 Hz or 1 kHz. If an oscilloscope is placed across the dummy speaker load, the sine wave will be seen. This will indicate whether the receiver is distorting. The oscilloscope can also be used in place of the audio voltmeter to make the voltage measurement across the dummy speaker load. Remember that oscilloscope measurements are peak to peak. The peak-to-peak value must be converted to root mean square to make the power output calculation.

20-dB Quieting Sensitivity Tests. In most cases, the sensitivity of a receiver is expressed in terms of the minimum RF voltage at the antenna terminals that will produce a specific audio output power level. Most measurements factor in the effect of noise.

The method of sensitivity measurement is determined according to whether AM or FM is used. Since most modern radio communication equipment uses frequency modulation, measuring FM receiver sensitivity

Figure 22-16 (*a*) Quieting method of FM receiver sensitivity measurement. (*b*) T-type impedance-matching attenuator.



is illustrated. There are two basic methods, quieting and SINAD. The *quieting method* measures the amount of signal needed to reduce the output noise to 20 dB. As the signal level increases, the noise level decreases until the limiters in the IF section begin to start their clipping action. When this happens, the receiver output "quiets"; i.e., its output is silent and blanks out the noise.

Quieting method

SINAD test

The *SINAD test* is a measure of the input signal voltage that will produce at least a 12-dB signal-to-noise ratio. The noise value includes any harmonics that are produced by the receiver circuits because of distortion.

The test setup for receiver sensitivity measurements is shown in Fig. 22-16(*a*). It consists of an RF signal generator, an RF voltmeter, a frequency counter, the receiver to be tested, and a voltmeter to measure the output across the speaker dummy load.

Impedance-matching pad

It is often necessary to provide an impedance-matching network between the generator and the receiver antenna input terminals. Most RF generators have a 50-Ω output impedance. This may match the receiver input impedance exactly. However, some receiver input impedances may be different. For example, if a receiver has a 75-Ω input impedance, some form of impedance matching will be required. This is usually handled by a resistive attenuator known as an *impedance-matching pad,* which is a resistive T network that provides the correct match between the receiver input and the generator. A typical impedance-matching pad is shown in Fig. 22-16(*b*). It matches the 50-Ω generator output to the 50-Ω receiver antenna input. Since resistors are used, the impedance-matching circuit is also an attenuator. With the values given in Fig. 22-16(*b*), the signal attenuation is 10 dB. This must be factored into all signal generator measurements to obtain the correct sensitivity figure. Different values of resistors can be used to create a pad with the correct impedance-matching qualities but with lower or higher values of attenuation.

Some manufacturers specify a special input network made up of resistors, inductors, and/or capacitors for this or other sensitivity tests. This network helps simulate the antenna accurately in equipment that uses special antennas.

Follow this procedure to make the 20-dB quieting measurement:

1. Turn on the receiver, and set it to an unused channel.
2. Leave the signal generator off so that no signal is applied.
3. Set the receiver gain to maximum with any RF or IF gain control, if available.
4. Adjust the volume control of the receiver so that you read some convenient value of noise voltage on the meter connected across the speaker. One volt rms is a good value if you can achieve it; but if not, any other convenient value will do.
5. Turn on the signal generator, but set the output level to zero or some very low value. Adjust the generator frequency to the center of the receiver's channel setting. Turn off the modulation so that the generator supplies carrier only.
6. Increase the signal generator output signal level a little at a time, and observe the voltage across the speaker. The noise voltage level will decrease as the carrier signal gets strong enough to overpower the noise. Increase the signal level until the noise voltage drops to one-tenth of its previous value.
7. Measure the generator output voltage on the generator meter or the external RF voltmeter.
8. If an attenuator pad or other impedance-matching network was used, subtract the loss it introduces. The resulting value is the voltage level that produces 20 dB of quieting in the receiver.

Assume that you measured a generator output of 5 μV that produces the 20-dB noise decrease. This is applied across a 50-Ω load producing an input power of $P^2 = V^2/R = (5 \times 10^{-6})^2/50 = 0.5$ pW. This is attenuated further by the 10-dB matching pad to a level of one-tenth, or 0.05 pW, which translates to a voltage level across 50 Ω as

$$V = \sqrt{PR} = \sqrt{0.05 \times 10^{-12} \times 50} = 1.58 \times 10^{-6} = 1.58\ \mu\text{V}$$

This is the receiver sensitivity. It takes 1.58 μV of a signal to produce 20 dB of quieting in the receiver.

For a good communication receiver, the 20-dB quieting value should be under 1 μV. A typical value is in the 0.2- to 0.5-μV range. The lower the value, the better the sensitivity.

Blocking and Third-Order Intercept Tests. As the spectrum has become more crowded and as modulation advances have permitted higher speed per hertz of bandwidth, the potential for adjacent channel interference has significantly increased. To ensure minimum adjacent channel interference, receiver specifications have become tighter. This is especially true in cell phones. Whole suites of tests must be passed by the receiver in order to meet the specifications of a specific cell phone standard such as GSM or CDMA.

An example is the receiver blocking test that makes measurements to ensure that signals from an adjacent channel do not block or desensitize the channel being used. A very strong signal near the receiving frequency has the effect of lowering the gain of the receiver. Any small signal being received will be decreased in amplitude or even blocked completely. Some specifications call for the receiver to be able to receive a weak signal when the adjacent channel signal is 60 to 70 dB greater in level. The ability to meet this test depends upon the filtering selectivity of the receiver.

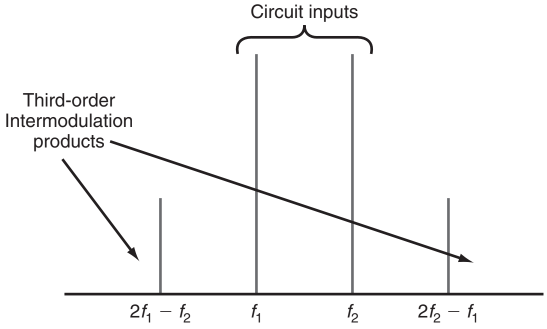
GOOD TO KNOW

The third-order intercept test determines whether a cell phone will filter out large nearby signals that can be mistakenly interpreted by the cell phone as its receiving frequency.

But perhaps the most difficult test is the *third-order intercept test,* designated *TOI* or *IP3.* This test is a measure of the linearity of amplifiers, mixers, and other circuits. When two signals are applied to a circuit, any nonlinearity in the circuit causes a mixing or modulation effect. The larger the input signals, the more likely the amplifier will be driven into a nonlinear region where mixing will occur. Sum and difference signals will be produced. Some of the resulting so-called intermodulation products are problematic because they occur at a frequency near or inside the receiver bandpass and interfere with the signal being received. Such signals,

Third-order intercept test (TOI or IP3)

Figure 22-17 Third-order intermodulation products.



because they are so close to the desired signal, cannot be filtered out. These intermodulation signals must be reduced as much as possible in the design of the receiver by selecting more linear components or giving greater attention to biasing schemes and operating points.

Figure 22-17 shows two signals f_1 and f_2 that appear at the input to an amplifier. The nonlinear action of the amplifier generates a wide range of sums and differences, including those with the second and third harmonics. Most of these undesired products will be filtered out by the receiver IF filters. The third-order products cause the most problems since they will most likely fall within the receiver IF bandpass. The third-order products are $2f_1 \pm f_2$ and $2f_2 \pm f_1$, where the terms $2f_1 - f_2$ and $2f_2 - f_1$ cause the most problems.

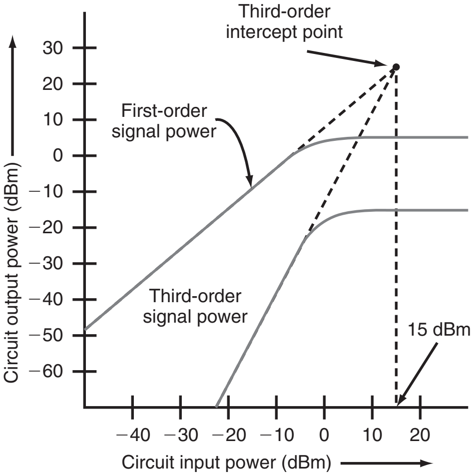
GOOD TO KNOW

The third-order products that most often interfere with a signal are $2f_1 - f_2$ and $2f_2 - f_1$.

To measure the third-order problem, two equal power signals are applied to the amplifier or other circuit to be tested. The frequency spacing is usually small and often made equal to the normal channel spacing used. The power of the input signals is gradually increased, and measurements are made on the amplifier output to determine the levels of the test signals and the third-order products. As the power levels of the input signals increase, the third-order signal power increases as the cube of the input power change. On a logarithmic scale, the rate of increase of third-order products is 3 times that of the original signals.

Refer to Fig. 22-18. If you plot the output signal amplitudes versus input signal power increases, at some point the power levels reach their limit and flatten out. If you extend the linear

Figure 22-18 Third-order intercept plot of an RF amplifier.



portions of the two curves, they will meet at a theoretical point where the initially lower third-order signals equal the main input signals in amplitude. This is the third-order intercept point. The input power at that point is used as a measure of the intermodulation. In Fig. 22-18 the IP3 point is at 15 dBm. Typical IP3 values are between 0 and 35 dBm. The higher the IP3 value, the better the circuit linearity and the lower the intermodulation products.

Microwave Tests

Microwave tests are generally similar to those performed on standard transmitters and receivers. Transmitter measurements include output power, deviation, harmonics, and spurious signals as well as modulation. The techniques are similar but require the use of only those test instruments whose frequency response is in the desired microwave region. The same goes for receiver measurements and antenna transmission line tests. The procedures are generally the same, but the equipment is different. For example, with power measurements, a directional coupler is normally used as the transmitter output to reduce the signal to a proper level for measurement with the power meter.

Data Communication Tests

The tests for wireless data communication equipment are essentially the same as those for standard RF communication as described above. The only difference is the type of modulation used to apply the binary signal to the carrier. FSK and its many variants, as well as PSK and spread spectrum, are the most widely used. Special FSK and PSK deviation and modulation meters are available to make these measurements.

For data communication applications in which binary signals are baseband on coaxial and twisted-pair cables, such as in LANs, more conventional testing methods may be used. For example, binary test patterns may be initiated in the transmitting equipment, and the signal viewed on the oscilloscope at the receiving end. Tests of signal attenuation and wave shape can then be made.

Eye Diagrams. A common method of analyzing the quality of binary data transmitted on a cable is to display what is known as the *eye diagram* on a common oscilloscope. The eye diagram, or pattern, is a display of the individual bits overlapped with one another. The resulting output looks like an open eye. The shape of the pattern and the degree that the eye is “open” can be used to determine many things about the quality of transmission.

Eye diagram

Eye diagrams are used for testing because it is difficult to display long streams of random serial bits on an oscilloscope. The randomness of the data prevents good synchronization of the oscilloscope with the data, and thus the display jitters and changes continuously. Sending the same pattern of bits such as repeating the ASCII code for the letter U (alternating 1s and 0s) may help the synchronization process, but the display of one whole word on the screen usually does not provide sufficient detail to determine the nature of the signal. The eye diagram solves these problems.

Figure 22-19(*a*) shows a serial pulse train of alternating binary 0s and 1s that is applied to a transmission line. The transmission line, either coaxial or twisted pair, is a low-pass filter, and therefore it eliminates or at least greatly attenuates the higher-frequency components in the pulse train. It also delays the signal. The result is that the signal is rounded and distorted at the end of the cable and the input to the receiver [see Fig. 22-19(*b*)].

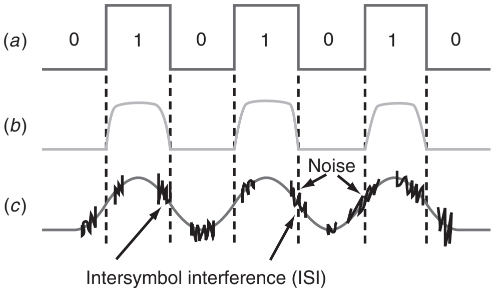
GOOD TO KNOW

The eye diagram is an excellent way to get a nonprecise, quick, qualitative check of a signal. The eye pattern tells at a glance the degree of bandwidth limitation, signal distortion, jitter, and noise margin.

The longer the cable and/or the higher the bit rate, the greater the distortion. The pulses tend to blur into one another, causing what is called *intersymbol interference (ISI)*. ISI makes the voltage levels for binary 1 and 0 closer together with 1 bit smearing or overlapping into the other. This makes the receiver’s job of clearly distinguishing a binary 1 from a binary 0 more difficult. Further, noise is usually picked up along the transmission path, making the received signal a poor representation of the original data signal. Too much signal rounding or ISI introduces bit errors. Figure 22-19(*c*) is a severely distorted, noisy data signal.

Intersymbol interference (ISI)

Figure 22-19 (*a*) Ideal signal before transmission. (*b*) Signal attenuated, distorted, and delayed by medium (coaxial or twisted pair). (*c*) Severely attenuated signal with noise.



The eye pattern provides a way to view a serial data signal and to make a determination about its quality. To display the eye diagram, you need an oscilloscope with a bandwidth at least 5 times the maximum bit rate. For example, if the bit rate is 10 Mbps, the oscilloscope bandwidth should be at least 10 × 5 MHz, or 50 MHz. The higher the better. The oscilloscope should have triggered sweep. Either a conventional analog or a digital oscilloscope can be used.

Apply the baseband binary signal at the end of the cable and the receiver input to the vertical input. Adjust the sweep rate of the oscilloscope so that a 1-bit interval takes up the entire horizontal width of the screen. Use the variable sweep control to fine-tune the display and use the trigger controls to stabilize the display. The result is an eye diagram.

Several different eye patterns are shown in Fig. 22-20. The multiple lines represent the overlapping pulses occurring over time. Their amplitude and phase shift are slightly shifted from sweep to sweep, thereby giving the kind of pattern shown. If the signal has not been severely rounded, delayed, or distorted, it might appear as shown in Fig. 22-20(*a*). The eye is “wide open” and has a trapezoidal shape. This is a composite display of the rise and fall times of the pulses overlapping one another. The steeper the sides, the less the distortion. The eye pattern in Fig. 22-20(*a*) indicates wide bandwidth of the medium.

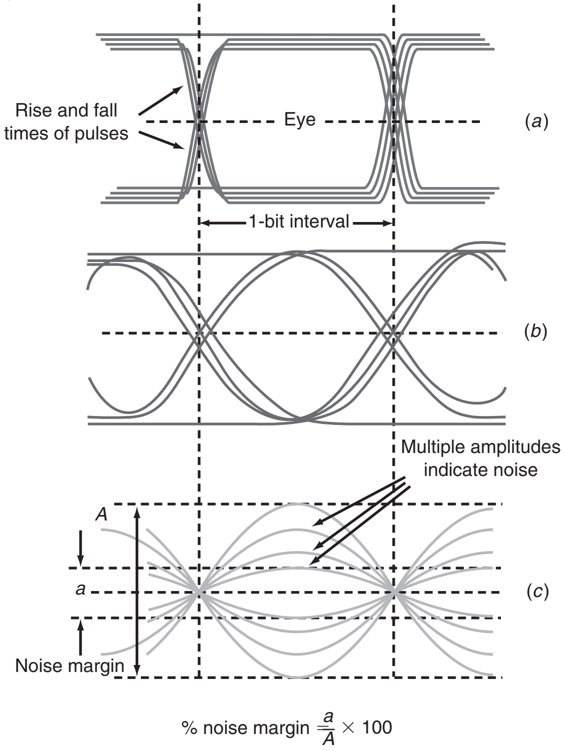
In Fig. 22-20(*b*), the pattern looks more like an open eye. The pulses are rounded, indicating that the bandwidth is limited. In fact, the pulses approach the shape of a sine wave. The pattern shown in Fig. 22-20(*c*) indicates more severe bandwidth limiting. This reduces the amplitude of the rounded pulses, resulting in a pattern that appears to be an eye that is closing. The more the eye closes, the narrower the bandwidth, the greater the distortion, and the greater the intersymbol interference. The difference between the binary 0 and 1 levels is less, and the chance is greater for the receiver to misinterpret the level and create a bit error.

Note further in Fig. 22-20(*c*) that the amplitudes of some of the traces are different from others. This is caused by noise varying the amplitude of the signal. The noise can further confuse the receiver, thus producing bit errors. The amount of voltage between the lowest of the upper patterns and the highest of the lower patterns as shown is called the *noise margin*. The smaller this value, the greater the noise and the greater the bit error rate. Noise margin is sometimes expressed as a percentage based upon the ratio of the noise margin level *a* in Fig. 22-20(*c*) to the maximum peak-to-peak value of the eye *A*.

Noise margin

The eye diagram is not a precise measurement method. But it is an excellent way to get a quick qualitative check of the signal. The eye pattern tells at a glance the degree of bandwidth limitation, signal distortion, jitter, and noise margin.

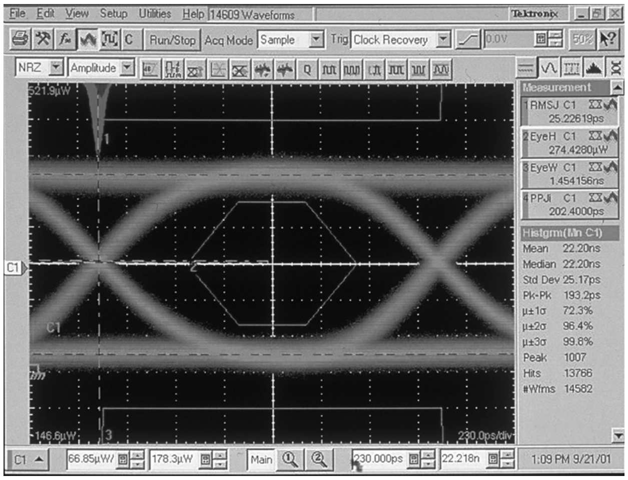
Figure 22-20 Eye diagrams. (*a*) Good bandwidth. (*b*) Limited bandwidth. (*c*) Severe bandwidth limitation with noise.



Pattern generator

Bit error rate (BER) analyzer

An eye diagram on an oscilloscope that is optimized for optical data communication testing.



Measurement
1 RMSJ C1 25.22619ps
2 EyeH C1 274.4280µW
3 EyeW C1 1.454156ns
4 PPJi C1 202.4000ps

Histgm(Mn C1)
Mean 22.20ns
Median 22.20ns
Std Dev 25.17ps
Pk-Pk 193.2ps
µ±1σ 72.3%
µ±2σ 96.4%
µ±3σ 99.8%
Peak 1007
Hits 13766
#Wfms 14582

Pattern Generators. A *pattern genertor* is a device that produces fixed binary bit paterns in serial form to use as test signals in data communication systems. The pattern generator may generate a repeating ASCII code or any desired stream of 1s and 0s. Pattern generators are used to replace the actual source of data such as the computer. Their output patterns can be changed to standard codes or messages or may be programmable to some desired sequence. A pattern generator may be implemented in software at the sending computer.

Bit Error Rate Tests. At the other end of the link, the pattern generator sequence is detected and compared to the known actual pattern or message sent. Any errors in the comparison indicate errors. The instrument that detects the pulse's pattern and compares it is called a *bit error rate (BER) analyzer*. It compares on a bit-by-bit basis the transmitted and received data to point out every bit error made. It keeps track of the total number of bits sent and the number of errors that occur and then computes the BER by dividing the number of errors by the number of bits sent. The BER tester must of course know the exact pattern or message sent by the pattern generator.

$$\text{Percent BER} = \frac{\text{number of errors detected}}{\text{numbers of bits sent}} \times 100$$

TDR Tests with an Analyzer. Special data communication test instruments are also available. A popular instrument is the *TDR tester*, also known as a *cable analyzer* or *LAN meter*. This instrument, often handheld, is connected to coaxial or twisted-pair cable and is able to make tests and measurements, some of which are

TDR tester (cable analyzer or LAN meter)

1. Tests for open or short circuits and impedance anomalies on coaxial or twisted-pair cables.
2. Measurements of cable length, capacitance, and loop resistance.
3. Measurements of cable attenuation.
4. Tests for cable miswiring such as so-called split pairs.

Split pair

A *split pair* is a wiring error often made when a cable contains multiple twisted-pair lines. One of the wires from one twisted pair is wrongly paired with one wire from another twisted pair.

Many tests are based upon what is called *time-domain reflectometry (TDR)*. The TDR technique can be used on any cable or transmission line, such as antenna lines or LAN cables, to determine SWR, short and open circuits, and characteristic impedance mismatches between cable and load. It can even determine the distance to the short or open circuit or to any other glitch anywhere along the line. TDR testing is based upon the presence of standing waves on the line if impedances are not matched.

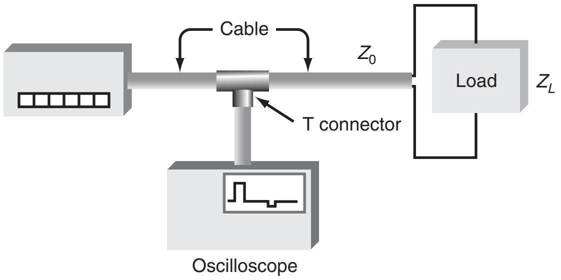
time-domain reflectometry (TDR)

The basic TDR process is to apply a rectangular pulse to the cable input and to monitor the signal at the input. The test setup is shown in Fig. 22-21. If the load impedance is matched, the pulse will be absorbed by the load and no reflections will occur. However, if there is a short or open circuit or impedance mismatch, a pulse will be reflected from the point of the mismatch.

Protocol Analyzers. The most sophisticated data communications test equipment is the *protocol analyzer*. Its purpose is to capture and analyze the data transmitted in a particular system. Most data communication systems transmit data in frames or packets that include preamble information such as sync bits or frames, start of header codes, addresses of source and destination, and a finite block of data, followed by error detection codes. A protocol analyzer can capture these frames, analyze them, and tell you whether the system is operating properly. The analyzer will determine the specific protocol being captured and then indicate whether the data transmitted is following the protocol or whether there are errors in transmission or in formatting the frame.

Protocol analyzer

Figure 22-21 TDR test setup.



Protocol analyzers contain microcomputers programmed to recognize a wide range of data communication protocols such as Bisync, SDLC, HDLC, Ethernet, SONET, and other LAN and network protocols. These instruments normally cost tens of thousands of dollars and may, in fact, be primarily a computer containing the stored protocols and software that read and store and then compare and analyze the received data so that it can report any differences or errors. Most protocol analyzers have a video display.

Special Test Sets. As communications equipment, especially wireless, has become more complex, it has been necessary to develop special test systems for specific protocols. For example, special test sets have been developed for GSM and CDMA cell phones and Bluetooth. These test sets combine multiple instruments into a common enclosure along with a computer for control. The instruments include signal generators (synthesizers) operating on the desired frequency bands along with the proper modulation and protocol for a given standard. This part of the test set permits testing of the receiver. Another section will include a calibrated receiver set up to receive any transmitted signal. An internal computer is programmed to conduct a precise sequence of tests and then to record and analyze the data. Test sets automate the testing procedure and identify those units (cell phones, etc.) that pass or fail the tests. These automated systems usually include internal spectrum analyzers for display of results.

Fiber-Optic Test Equipment and Measurements

A variety of special instruments are available for testing and measuring fiber-optic systems. The most widely used fiber-optic instruments are the *automatic splicer* and the *optical time-domain reflectometer (OTDR)*.

Automatic splicer

Optical-time-domain reflectometer (OTDR)

Automatic Splicers. Splicing fiber-optic cable is a common occurrence in installing and maintaining fiber-optic systems. This operation can be accomplished with hand tools especially made for cutting, polishing, and splicing the cable. However, as the cable thickness has gotten finer, hand splicing has become more difficult than ever. It is very difficult to align the two cable ends perfectly before the splice is made.

To overcome this problem, a special splicer has been developed by several manufacturers. It provides a way to automatically align the cable ends and splice them. The two cables to be spliced are stripped and cleaved by hand and then placed in the unit. A special mechanism holds the two cable ends close together. Then an optical system with a light source, lenses, and light sensors detects the physical alignment of the two cables, and a servo feedback mechanism drives a motor so that the two cable ends are perfectly centered on each other. An optical viewing screen is provided so that the operator can view the alignment from two directions at 90° to each other.

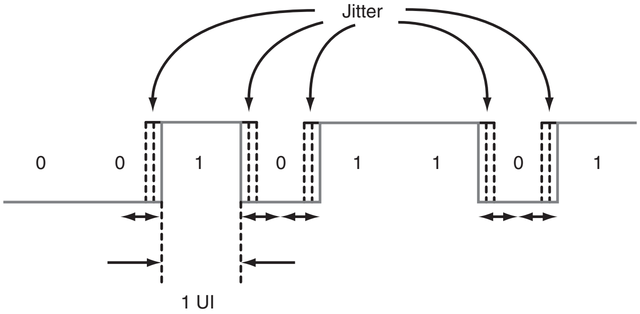
Once the alignment is perfect, the splicer is activated. The splicer is a pair of probes centered over the junction of the two cable ends. Pressing the "splice" button causes the probes to generate an electric arc hot enough to fuse the two glass cable ends together.

The automatic splicer is very expensive, but it must be used because it is not possible for human beings to make good splices visually and by hand. Handmade splices have high attenuation, whereas minimum attenuation is best achieved with the automatic splicer.

Optical Time-Domain Reflectometer. Another essential instrument for fiber-optic work is the optical TDR, or OTDR. It is an oscilloscopelike device with a CRT display and a built-in microcomputer.

The OTDR works as a standard TDR in that it generates a pluse, in this case, a light pulse, and sends it down a cable to be tested. If there is a break or defect, there is a light reflection, just as there is a reflection on an electric transmission line. The reflection is detected. Internal circuitry measures the time between the transmitted and reflected pulses so that the location of the break or other fault can be calculated and displayed. The OTDR also detects splices, connectors, and other anomalies such as dents in the cable. The attenuation of each of these irregularities can be determined and displayed.

Figure 22-22 Jitter on a data signal.



Optical Signal Analyzer. A newer breed of versatile optical test instrument makes multiple measurements. In addition to providing the OTDR measurement, this unit is a sampling oscilloscope capable of displaying signals of more than 10 Gbps. It can also be used to show eye patterns, optical output power, and jitter.

Optical signal analyzer

Jitter

Jitter is a type of noise that shows up as a time variation of the leading and trailing edges of a binary signal. See Fig. 22-22. It appears as a kind of phase or frequency shift in which the time period for 1 bit is lengthened or shortened at a rapid rate. Jitter shows up on an oscilloscope as a blurring of the 0-to-1 and 1-to-0 transitions of a binary signal. It is not much of a problem at lower data rates, but as data rates go above 1 GHz, jitter becomes more prevalent. On fiber-optic data systems, jitter is a major problem. Furthermore, jitter is difficult to measure. Most optical fiber communication networks such as SONET have jitter specifications that must be met. Therefore, some accurate method of measurement is needed. Some of the newer optical signal analyzers have a jitter measurement capability. Jitter is usually expressed as a percentage of the *unit interval (UI)*. The UI is the bit time of the data signal. For example, a jitter measurement may be 0.01 UI or 10 mUI.

GOOD TO KNOW

Jitter is noise that is a time variation at the beginning and end of a binary signal.

unit interval (UI)

22-3 Troubleshooting Techniques

Some of the main duties of a communication expert are to troubleshoot, service, and maintain communication equipment. Most communication equipment is relatively reliable and requires little maintenance. However, equipment does fail. Most electronic communication equipment fails because of on-the-job wear and tear. Of course, it is still possible for equipment to fail as the result of component defects. The equipment might fail eventually because of poor design, exceeding of product capabilities, or misapplication. In any case, you must locate such failures and repair them. This is where troubleshooting techniques are valuable. The goal is to find the trouble quickly, solve the problem, and put the equipment back into use as economically as possible.

General Servicing Advice

One of the main decisions you must make in dealing with any kind of electronic equipment is to repair or not to repair. Because of the nature of electronic equipment today, repairing it may not be the fastest and most economical approach.

Assume that you have a defective radio transceiver. One of your options is to send the unit out for repair. Repair rates run anywhere from $25 per hour to over $100 per hour depending upon the equipment, the manufacturer, and other factors. If the problem is a difficult one, it may take several hours to locate and repair it. Many communication transceivers are inexpensive units that may cost less to buy new than to repair.

There are two types of repair approaches: (1) replace modules or (2) troubleshoot to the component level and replace individual components. Some electronic equipment is built in sections or modules. The module is, in most cases, a separate PCB containing a portion of the circuitry inside the unit. The typical arrangement might be for the receiver to be on one PCB, the transmitter on another, and the power supply on still another, with another unit such as a tuner or frequency synthesizer also separate. A fast and easy way to troubleshoot and repair a unit is to replace the entire defective module. If you are a manufacturer repairing your own units in volume for customers, or if your organization does many repairs of a similar nature on a particular brand or model of equipment, repair at the component level is the best approach.

Common Problems

Many repairs can be made quickly and easily because they result from problems that occur on a regular basis. Some of the most common problems in communication equipment are power supply failures, cable and connector failures, and antenna troubles.

Power Supplies. All equipment is powered by some type of dc power supply. If the power supply doesn't work, the equipment is completely inoperable. Therefore, one of the first things you should do is to check that the power supply is working.

If the unit is used in a fixed location and operates from standard ac power lines, the first test should be to check for ac power and the availability of the correct dc power supply voltages. Is the unit plugged in, and if so, does ac power actually get to the outlet? If ac power is indeed available, check the power supply inside the unit next. These power supplies convert ac power to one or more dc voltages to operate the equipment. Open the equipment and, using the manufacturer's service information, determine the power supply voltages. Then use a multimeter to verify that they are at the correct levels. Most power supplies these days are regulated, and therefore the voltages should be very close to those specified, at least within ±5 percent. Anything outside that range should be suspect. Any voltages that are obviously quite different from the specified value indicate a power supply problem.

Another common power supply problem is bad batteries. With continuous usage, batteries quickly run down. If primary batteries are used, the batteries must be replaced with new ones. If secondary or rechargeable batteries continue to fail even after short periods of use after charging, it means that they, too, should be replaced. Most rechargeable batteries can be charged and discharged only so many times before they are no longer effective.

Cables and Connectors. Perhaps the most common failure points in any electronic system or equipment are the mechanical components. Connectors and cables are mechanical and can be a weak link in electronic equipment. Once it has been confirmed that the power supplies are operating correctly in the equipment, the next step is to check the cables and connectors. Start by verifying that the connectors are correctly attached. Another common problem is for the cable attached to the connector to break internally. Most of the time the cable does not break completely, but one or more wires in the cable may be broken while others remain attached.

GOOD TO KNOW

Cables and connectors are a weak link in electronic equipment.

Occasionally connectors get dirty. Removing the connector and cleaning the connections often solve the problem. It may be necessary to replace the connectors to ensure a reliable physical connection, however.

Antennas. Another common failure in communication systems is the antenna. In most cases, antennas on portable equipment are fragile. A bad antenna is a common problem on handheld transceivers, cordless telephones, cellular telephones, and similar equipment.

Documentation

Before you begin any serious detailed troubleshooting and repair of communication equipment, be sure that you have all the necessary documentation. This includes the manufacturer's user operation manual and any technical service manuals that you can acquire. Nothing speeds up troubleshooting and repair faster than having all the technical information before you begin. Manufacturers often regularly identify common problems and suggest troubleshooting approaches. But perhaps most important, manufacturers provide specifications as well as measurement data and procedures that are critical to the operation of the equipment. By having this information, you will be able to make the necessary tests, measurements, and adjustments to ensure that the equipment complies with the specifications.

Troubleshooting Methods

There are two basic approaches to troubleshooting transmitters, receivers, and other equipment: signal tracing and signal injection. Both methods work equally well and may often be used together to isolate a difficult problem.

Signal tracing

Signal Tracing. A commonly used technique in troubleshooting communications equipment is called *signal tracing*. The idea is to use an oscilloscope or other signal detection device to follow a signal through the various stages of the equipment. As long as the signal is present and of the correct amplitude, the circuits are good. The point at which you lose the signal in the equipment or at which the signal no longer conforms to specifications is the location of the problem.

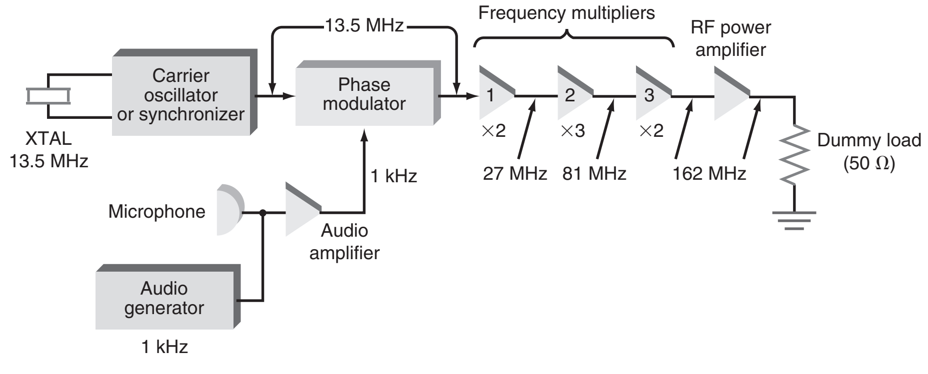
To perform signal tracing in a transmitter, you need some type of monitoring or measuring instrument: an RF voltmeter or an oscilloscope, an RF detector probe on an oscilloscope, a spectrum analyzer, and power meters and frequency counters.

Figure 22-23 is a block diagram of a generic FM communication transmitter. It is assumed that the power supply is working and that it is supplying the correct voltage to all the circuits. Further, it is assumed that the transmitter has been declared inoperable. A quick verification of this should be made by testing the transmitter to see whether it is putting out a signal. A good overall check is to connect a dummy load, key up the transmitter, and attempt to pick up the signal on a nearby frequency counter or field strength meter with antenna. If no signal is indicated, troubleshooting can begin.

To troubleshoot the transmitter, connect a dummy load to the antenna jack and turn on the power. Using the signal-tracing method, start with the carrier signal source. Locate the carrier crystal oscillator or the frequency synthesizer responsible for generating the basic carrier signal. Monitor the output of this circuit on the oscilloscope to see that it is generating a sine wave carrier of the correct amplitude and frequency. The frequency of the signal can be checked with a frequency counter. For the circuit in Fig. 22-23, you should measure and observe a 13.5-MHz sine wave.

If the carrier oscillator or frequency synthesizer is working correctly, you can go on to the next stages. Most transmitters have additional buffer amplifiers, frequency multipliers, and power amplifiers.

Figure 22-23 FM transmitter.



Each should be checked in sequence from one step to the other. In Fig. 22-23, the carrier signal passes through a phase modulator to a sequence of three frequency multipliers. The output of the phase modulator should be the carrier frequency. The output of the first multiplier, a doubler, should be 27 MHz. The output of the second multiplier should be 3 × 27, or 81, MHz. The output of the third multiplier should be 2 × 81, or 162, MHz. This is also the output of the final power amplifier stage.

The output of every individual stage or circuit should be verified. The schematics or service manual will usually provide typical values of signal level at the output of each stage or at selected points in the transmitter. When discrete component circuits are used, it is easy to check each transistor stage. In modern equipment each stage is implemented with one or more ICs. In such cases you can verify the input and determine what outputs are available. Then you can determine what you should expect at the outputs.

You may lose the signal at some point as you follow it through the stages. For example, you may be tracing the signal through a sequence of frequency multipliers and power amplifiers, as shown in Fig. 22-23. Assume that the carrier oscillator is working correctly, as was the first multiplier. You measure the correct frequency at the output of the first multiplier. This signal also appears at the input to the next stage. But suppose you can measure no signal at the output of the second multiplier. If this is the case, you have effectively isolated the problem to the second frequency multiplier circuit. It has an input but no output.

The most likely problem is a bad transistor or IC. Active components such as transistors and ICs fail more often than passive components such as resistors, capacitors, and inductors or transformers. You should verify bias voltages to determine that they are correct; but if they are and the circuit still does not operate, usually there is an open or short-circuited transistor.

Other components may also fail. Capacitors fail more often than any other type of component except the semiconductor devices. Resistors are less likely to fail but can open or change in value. Inductors rarely fail. Delicate, sensitive components such as crystal, ceramic, and SAW filters can also break. Once you isolate the problem to a particular component, turn off the power, replace the suspected part, and repeat the tests. Continue testing until the transmitter delivers a signal to the dummy load.

If the carrier circuits are working but the unit is not receiving modulation, verify that the microphone is operating correctly. In portable and mobile operation, the microphone is a separate unit attached by a cable to the transmitter. Microphone cables and connectors frequently fail because of the continuous stress they receive. Microphones are also subject to physical damage because they are banged around and almost universally abused in a mobile operating environment.

If the microphone is OK, start checking the audio amplifier and modulator circuits. You can use a simple audio signal generator to inject the signal into the audio amplifiers and follow it through with an oscilloscope. A common test is to use a 1-kHz sine wave at a low level to prevent distortion. Then follow the signal through the circuitry with an oscilloscope, noting both the amplitude and any distortion that may occur. Distortion is really the result of applying too much signal to the input. Remember, microphones are very low-level voltage-generating devices. The audio circuits are designed to provide a substantial amount of gain even with signal input voice signals that are in the microvolt or millivolt range.

Using higher output voltage from a signal generator will overload the circuitry and cause slipping and distortion. If you see that the audio signals you are tracing are square or otherwise distorted, back off on the signal generator output voltage until the distortion disappears. Then continue with the signal tracing. The point at which you lose the signal or at which the signal becomes distorted or attenuated is the location of the problem. Once the transmitter is delivering power to the dummy load, you will want to run frequency, power output, and deviation tests to ensure that everything is working correctly and that the unit meets manufacturer's specifications and FCC regulations.

You can also perform signal tracing on a receiver. You will need an RF signal generator with appropriate modulation and an oscilloscope, RF voltmeter, or other signal-measuring instrument with which to trace the signal. You may prefer to use a speaker dummy load rather than the speaker itself.

Signal injection

Signal Injection. *Signal injection* is somewhat similar to signal tracing. It is normally used with receivers. The process is to use signal generators of the correct output frequency to inject a signal into the various stages of the receiver and to check for the appropriate output response, usually a correct signal in the speaker.

GOOD TO KNOW

Testing of communication products is done with special test sets designed to match the specifications and features of the communication standard. Products tested in this way include such items as cell phones, wireless LAN transceivers, and fiber-optic systems.

Signal injection is the opposite of signal tracing, for it starts at the speaker output and works backward through the receiver from speaker to antenna. The signal injection begins by testing the audio power output amplifier. You inject a 1-kHz sine wave from an audio oscillator or function generator into the input of the amplifier. Follow the receiver documentation's information with regard to how much signal should be present at the outputs of each stage. If an audio signal is heard, the speaker and power amplifier are OK. Then inject the audio signal into any other audio amplifier stages back to the demodulator circuit output.

The next injection takes place at the input to the second mixer. Set the RF signal generator to 4.5 MHz with appropriate audio modulation. You should hear the audio tone in the speaker. If you do not, check the local-oscillator and IF stages as described before. Do not overlook the demodulator. Keep in mind that you may not actually be able to get to the inputs and outputs of some circuits because they may be contained within an IC. If this is the case, you can restrict the injection to the IC input while monitoring the output. If you get no output, replace the IC.

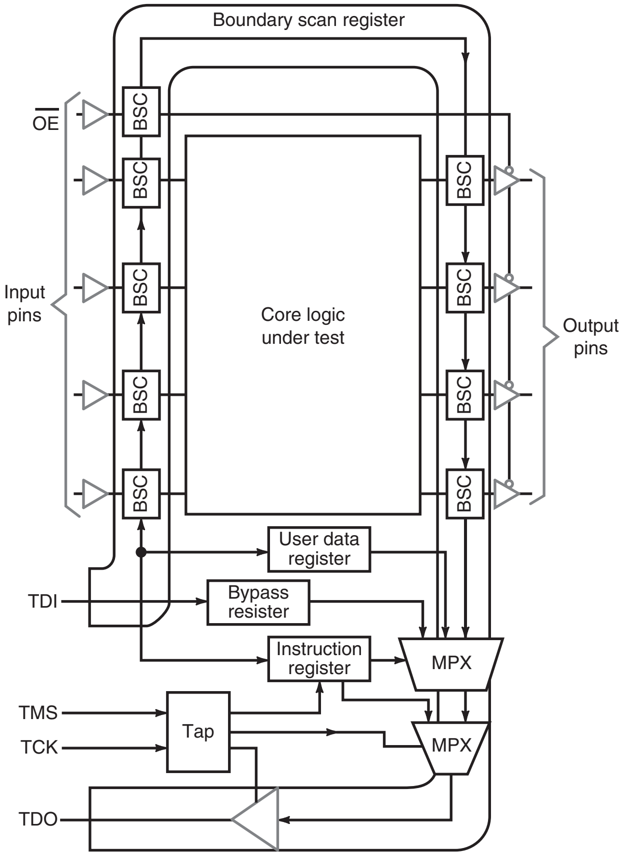
Next, inject a signal of 45 MHz with modulation at the input to the first mixer. You should hear the tone; but if you do not, inspect and test the first IF stages and local oscillator. Finally, test the RF amplifier with a signal at the receive frequency of 478 MHz.

Modern Troubleshooting. Although signal tracing and signal injection are valid troubleshooting approaches, they are more difficult than ever when applied to a modern communications device. Examples are cell phones and wireless LAN transceivers or line cards in a router. These devices use only one or more ICs to implement the entire signal chain. It is not possible to access the internal circuits of the chips, making the procedures described previously impossible, if not more difficult. These techniques have limited use in such highly integrated devices, although the principles are still valid.

Boundary Scan and the JTAG Standard. Modern networking and communications equipment is made up primarily of digital ICs. These are large-scale devices made for surface mounting on a printed-circuit board (PCB). It is difficult and sometimes not possible to access the pins on an IC, making signal tracing or injection worthless in troubleshooting. Realizing this, IC designers eventually figured out a way not only to test the chip after it is made and packaged, but also to test the equipment built with these chips. This method is called boundary scan.

The purpose of boundary scan is to provide a way to observe test points inside the chip that are not normally accessible and to observe signals at IC pins inaccessible because of their surface mounting on a PCB. And it provides a way to apply test signals to selected points in the circuit and then to monitor the results. Figure 22-24 shows the boundary scan circuitry that is built into many complex ICs. The logic circuitry to be tested is in the center and referred to as core logic. Surrounding the core is a series of boundary scan cells (BSCs). Each BSC is made up of a pair of flip-flops and some multiplexers that can receive inputs and store them or output their contents when interrogated. The BSC flip-flops are also connected to form a large shift register, the boundary scan register. This register provides the basic storage unit for inputting and outputting data. The input and output are serial. Serial data can be input to the register via the TDI line. Data stored in the register can be read out serially by monitoring the TDO line. An external clock signal TCK and a test mode select (TMS) signal control the serial data speed through the

Figure 22-24 The boundary scan circuitry is built into the IC.



Note: The boundary scan register is shifted TDI to TDO.

test access port (TAP) controller. The function of the boundary scan circuitry is determined by a binary-coded instruction that is entered serially.

To read the data in at the internally monitored points, the boundary scan circuits are fed a serial instruction called INTEST. This is stored in the instruction register and decoded. The internal circuits are then configured by the logic to read the data from the core logic and store it in the BSCs. The data in the boundary scan register is then shifted out and read serially. This serial data is generally sent to a computer where a program uses it to determine if the results are correct.

Other instructions may also be entered to control the various functions. A SAMPLE/PRELOAD instruction is used to set the core logic to some desired state before a test is run. The CLAMP instruction can also be used to set the core logic levels to some predetermined pattern. The RUNBIST instruction causes a predetermined, built-in self-test (BIST) to be executed.

The boundary scan circuitry and its operation have been standardized by the Institute of Electrical and Electronics Engineers (IEEE) and is designated as the Joint Test Action Group (JTAG) 1149.1 standard. Most large complex ICs now contain a JTAG interface and internal circuitry. It is used to test the chip. Then later it may be used by the equipment manufacturer as a way to implement a larger test program for the equipment. Because a computer is programmed to use the JTAG interface, most testing and troubleshooting can be automated. An engineer or technician can actually sit in front of a computer, running the test software and exercise and test the equipment and monitor the results.

22-4 Electromagnetic Interference Testing

Electromagnetic interference (EMI)

Radio-frequency interference (RFI)

TV interference (TVI)

A growing problem in electronic communication is *electromagnetic interference (EMI).* Also known in earlier years as *radio-frequency interference (RFI)* and *TV interference (TVI),* now EMI is defined as any interference to a communication device by any other electronic device. Since all electronic circuits and equipment emit some form of EMI, they are potentially sources of interference with sensitive communication devices such as cell phones, cordless phones, radio and TV sets, pagers, and wireless LANs. As the number of computers has increased and as more and more cell phones and other wireless devices have come into use, the EMI problem has become a major one. The problem is so great that the FCC has created interference standards that must be met by all electronic devices. Before any electronic equipment can be sold and used, it must be tested and certified by the FCC to ensure that it does not emit radiation in excess of the allowed amount. Such strict rules and regulations have made design and manufacturing more difficult and have increased the cost of electronic products. But the result has been fewer interference problems between electronic products and a reduction in disruption of their use.

Today, a large part of the work of a communication technician or engineer is EMI testing and EMI minimization in products. This section briefly describes EMI, its sources, common techniques for reducing EMI, and EMI testing procedures.

Sources of Electromagnetic Interference

Any radio transmitter is a source of EMI. Although transmitters are assigned to a specific frequency or band, they can nevertheless cause interference because of the harmonics, intermodulation products, or spurious signals they produce.

Receivers are also a source of EMI. A local oscillator or frequency synthesizer generates low-level signals that, if not minimized, can interfere with nearby equipment.

Almost all other electronic devices can also generate EMI. Perhaps the worst offenders are computers. Computers contain millions of logic circuits that switch off and on at rates up to and in excess of 2 GHz. Because of the short pulses with fast rise and fall times that are generated, these circuits naturally generate a massive number of harmonics. The problem is so severe that computer manufacturers must comply with some of the FCC's toughest EMI reduction rules. Computer manufacturers use every trick in the book to get the radiation level down to the FCC specifications.

GOOD TO KNOW

The local oscillator of a receiver can be a source of electromagnetic interference.

Of course, any electronic equipment that uses an embedded microcontroller, which today is almost every electronic device, is a potential source of EMI.

Another major source of EMI is switching power supplies. More than 80 percent of all power supplies in use today are of the switching variety, and this percentage is increasing. Power supplies that use switching regulators generate very high levels of pulse energy and radiate many high-amplitude harmonics. Inverters (dc-to-ac converters) in uninterruptible power supplies (UPS) and dc-to-dc converters also use switching methods and therefore produce harmonics and radiation.

The 60-Hz power line is another source of interference. Electrical transient pulses caused by high-power motors and other equipment turning off or on can disrupt computer operation or create a type of noise for communication equipment. Just the large magnetic and electric fields produced by the ubiquitious power lines can cause hum in stereo amplifiers, noise in sensitive medical equipment, and interference in communication receivers.

Another form of EMI is *electrostatic discharge (ESD).* This is the dissipation of a large static electric field. Lightning is the perfect example. The huge pulse of current produced by lightning generates an enormous number of harmonics that show up as noise in radio receivers. Anyplace where static buildup occurs can produce ESD, which not only can destroy integrated circuits and transistors but also can generate pulses that manifest themselves as noise in a receiver.

Electrostatic discharge (ESD)

EMI is transmitted between electronic devices by several means. Interfering signals may travel by way of electromagnetic radiation (radio) from one unit to another. EMI may also be passed along by inductive or capacitive coupling when two units are close to each other. Cross talk on adjacent cables is an example. And interfering signals may be passed along from one piece of equipment to another by way of the ac power line that both use as the main power source.

Reduction of Electromagnetic Interference

The three basic techniques for reducing the level of EMI are grounding, shielding, and filtering. All these methods are used in the design of new equipment as well as in reducing EMI in applications in which the equipment is already deployed. Here is a brief summary of the techniques most often used.

Grounding. A poor electrical ground often causes EMI. As you know, a *ground* is the common reference point for most, if not all, voltages in a circuit. This ground shows up in many different physical forms. It may be a metal chassis or rack, the metal frame of a building, or water pipes. The best ground is an earth ground formed when a long copper rod is driven into the ground. Inside the equipment, the ground is formed on the PCBs on which the components are mounted. The ground is usually a wide copper strip or in some cases a broad copper ground plane formed on one side of the PCB.

Ground

In the design of equipment, especially RF circuits, the ground is a key consideration. Much care is taken in forming it, routing it, and connecting to it. Short, wide, and very low-resistance connections are the best. In equipment that uses both analog (linear) and digital circuits, separate grounding paths are usually formed for each type of circuit. This helps minimize interference to the sensitive analog circuits by the noisier digital circuits. The two ground systems are eventually connected, of course, but at only one point in the equipment.

Circuit grounds in equipment are in place and cannot be changed. But it is possible for the grounding connections of different pieces of equipment in a system to cause some form of EMI. Many times, the EMI can be eliminated or greatly reduced by simply experimenting with different ground arrangements. These are some useful guidelines:

1. If a piece of equipment does not have a ground, add one. A connection to a large common ground is preferred, especially one connected to earth ground.
2. Ground connections should always be kept as short as possible. Ground wires should be no longer than $\lambda/4$ at the highest frequency of operation.
3. Ground cables should be large and have low resistance. Stranded copper wire of a size greater than AWG 10 is preferred. The size should be greater if the ground carries a large current. Copper braid as wide as practical also makes a good ground connection.
4. If multiple pieces of equipment are involved and signals are passed from one unit to another, ground loops may exist. A *ground loop* is formed when multiple circuits or pieces of equipment are connected to a common ground but at different points. See Fig. 22-25. Current flow in the ground connection can produce a voltage drop across a part of the ground. That voltage then shows up in series, with the very small signals at the inputs to other circuits or equipment causing interference. Ground loops are eliminated by connecting all circuits or equipment to a single point on the common ground. See Fig. 22-26.

Ground loop

Figure 22-25 Grounds are not perfect short circuits, especially at high frequencies, where skin effect makes the resistance higher and permits ground loops to form.

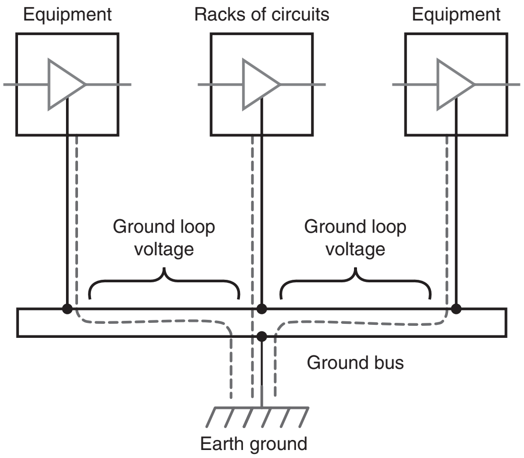
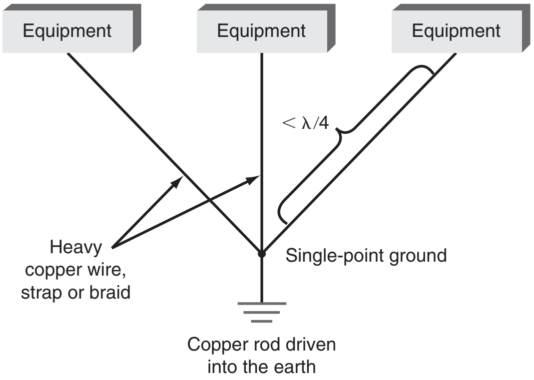


Figure 22-26 Single-point grounds are best because they minimize the formation of ground loops.



5. EMI is often caused by the incorrect connection of coaxial cable shields. The shield braid may be broken or open at one of the connectors. In some applications, grounding only one end of the shield instead of at both ends of the cable reduces EMI. This is also true of any shielded wire. Experimentation with the cable shields and grounds can often reduce EMI.
6. Remember that all ac power connections have a ground associated with them. In two-wire ac connections, the neutral wire is grounded at the entry point of the alternating current. In three-wire systems, the third wire is also a ground used primarily for safety purposes. However, the lack of a third ground can also cause interference. Adding the third ground wire often solves EMI problems.

Shielding. *Shielding* is the process of surrounding EMI-emitting circuits or sensitive receiving circuits with a metal enclosure to prevent the radiation or pickup of signals. Often, just placing a metal plate between circuits or pieces of equipment to block radiation is sufficient to reduce or eliminate EMI. The metal reflects any radiated signals and can actually absorb some of the radiated energy.

Shielding

Almost all communication equipment is made with extensive use of shielding. Oscillators and frequency synthesizers are almost always packaged in a shielded can or enclosure. Individual transmitter or receiver stages are often shielded from one another with blocking plates or completely surrounding enclosures. Switching power supplies are always shielded in their own enclosure. Just remember that when shielding is used, ventilation holes are usually necessary to release any heat produced by the circuits being shielded. These holes must be as small as possible. If the holes have a diameter that is near $\lambda/2$ of the signals being used, the holes can act as slot antennas and radiate the signals more effectively. Good initial design prevents this problem.

In some cases, RF signals leak from shielded enclosures where the various panels of metal come together. A continuous shield is the most effective, but most shielded boxes must have a removable panel or two to permit assembly and repair access. If the panels are not securely mated with a low-resistance contact, RF will leak out of the opening. Securely attaching panels with multiple screws and making sure that the metal is not dirty or oxidized will solve this problem. If not, special flexible metal seals have been designed to attach to enclosures and panels that must mate with one another. These seals will eliminate the leakage.

Finally, radiation EMI can sometimes be reduced in a larger system by moving the equipment around. By placing the offending units farther apart, the problem can be eliminated or at least minimized. Remember that the strength of a radiated signal varies as the square of the distance between the transmitting and receiving circuits. Even a short-distance move is all that may be needed to reduce the interference to an acceptable level.

Filtering. The third method of EMI reduction is *filtering.* Filters allow desired signals to pass and undesired signals to be significantly reduced in level. Filters are not much help in curing radiation or signal coupling problems, but they are a very effective way to deal with conducted EMI, interference that is passed from one circuit or piece of equipment to another by actual physical conduction over a cable or other connection.

Filtering

Some types of filters used in reducing EMI include

1. Bypass and decoupling circuits or components used on the dc power supply lines inside the equipment. Typical decoupling circuits are shown in Fig. 22-27. Instead of using a physical inductor (usually called a *radio-frequency choke*, or *RFC*) in series with the dc line, small cylindrical ferrite beads can be placed over a wire conductor to form a small inductance. These beads are widely used in high-frequency equipment. The bypass capacitors must have a very low impedance, even for RF signals; i.e., ceramic or mica capacitors must be used. Any plastic dielectric or electrolytic capacitors used for decoupling must be accompanied by a parallel ceramic or mica to make the filtering effective at the higher frequencies.

Radio-frequency choke (RFC)

2. High- or low-pass filters used at the inputs and outputs of the equipment. A common example is the low-pass filter that is placed at the output on most transmitters to reduce harmonics in the output.

Figure 22-27 Decoupling circuits are low-pass filters that keep high-frequency signals out of the power supply.

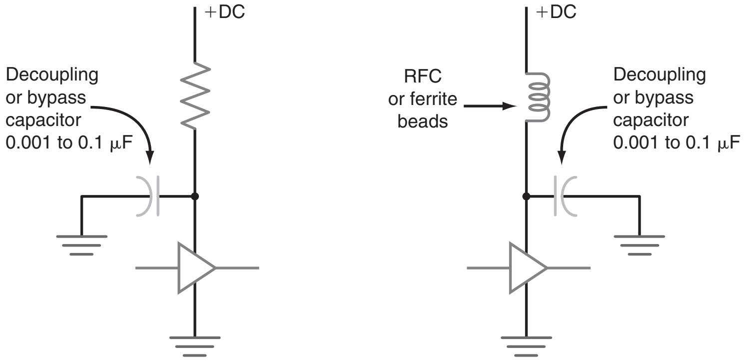
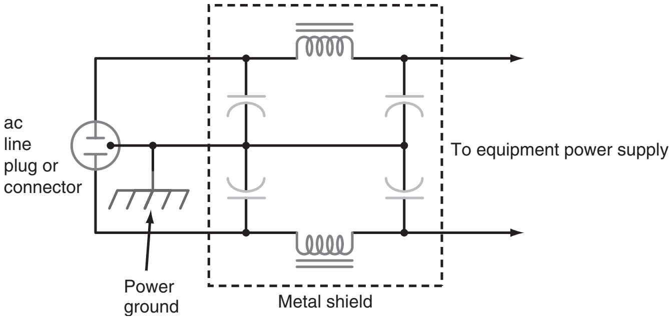


Figure 22-28 Alternating-current power line filter works both ways, removing high-frequency signals on input and output.



3. ac power line filters. These are low-pass filters placed at the ac input to the equipment power supplies to remove any high-frequency components that may pass into or out of equipment connected to a common power line. Figure 22-28 shows a common ac power line filter that is now built into almost all types of electronic equipment, especially computers and any equipment using sensitive high-gain amplifiers (medical, stereo sound, industrial measuring equipment, communications receivers, etc.).
4. Filters on cables. By wrapping several turns of a cable around a toroid core, as shown in Fig. 22-29, interfering signals produced by inductive or capacitive coupling can be reduced. Any common-mode signals induce voltages into the core, where they are canceled out. This approach works on ac power cords or any signal-carrying cable.

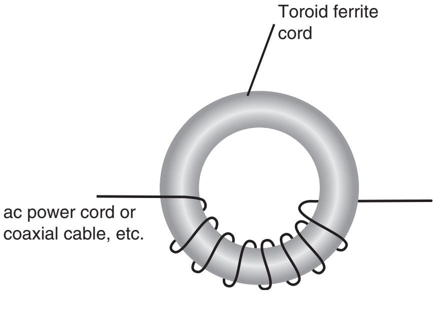
Measurement of Electromagnetic Interference

The rules and regulations pertaining to EMI are given in the Code of Federal Regulations, Title 47, Parts 15 and 18. Anyone working in the communication field should have copies of the code, which can be obtained from the Government Printing Office. Essentially these guidelines state the maximum signal strength levels permitted for certain types of equipment. The accepted levels of radiation vary considerably depending upon the type of equipment, the environment in which it is used, and the frequency range. The FCC also distinguishes between intentional radiators such as wireless LANs and other wireless units and unintentional radiators such as computers. Radiation is measured with a field strength meter. It may be a simple device, as described earlier in this chapter, or a sensitive broadband communication receiver with a calibrated antenna. In either case, the measurement unit is microvolts per meter (μV/m). This is the amount of received signal picked up by an antenna 1 m long at some specified distance.

GOOD TO KNOW

Radiation is measured with a field strength meter in units of microvolts per meter (μV/m).

Figure 22-29 A toroid core cancels common-mode signals picked up by radiation or through capacitive or inductive coupling.

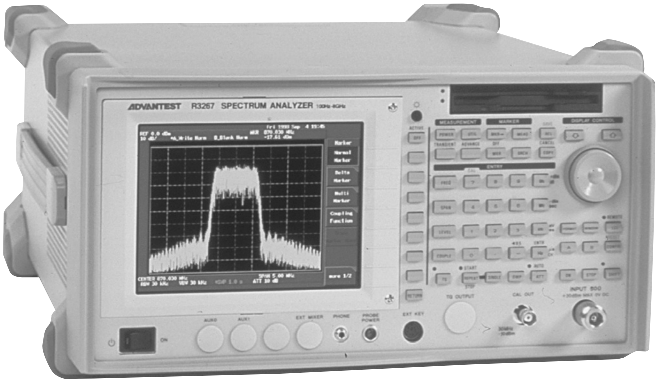


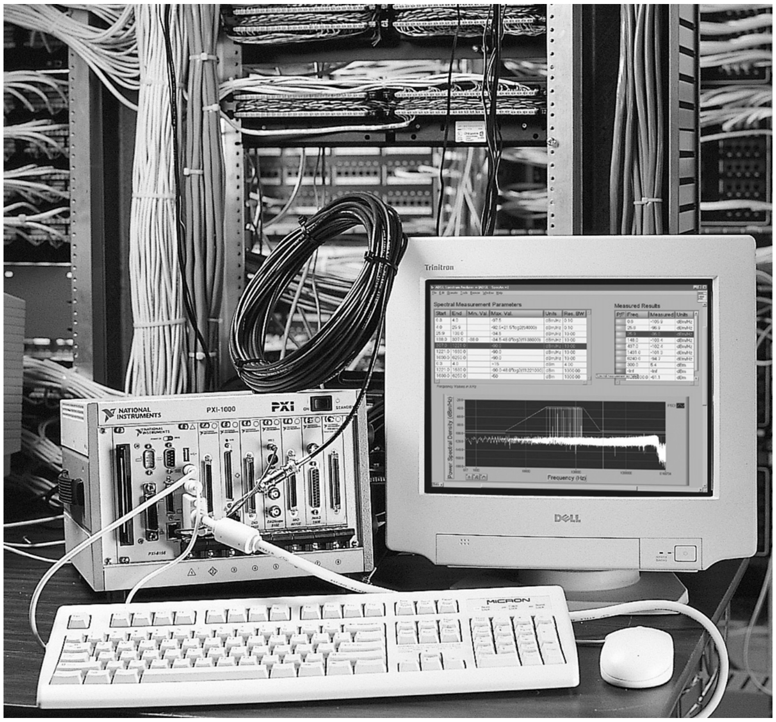
Consider the FCC regulations for a computer. Conducted EMI must not exceed 250 μV over the frequency range of 450 kHz to 30 MHz on the ac power line. Radiated emissions may not exceed a specific field strength level at a given distance for specified frequency ranges. The measurement distance is either 3 or 10 ft. At 10 ft the received signal strength may not exceed

100 μV/m between 30 and 88 MHz
150 μV/m between 88 and 216 MHz
200 μV/m between 216 and 960 MHz
500 μV/m above 960 MHz

Several manufacturers make complete EMI test systems that are sophisticated field strength meters or special receivers with matched antennas that are used to "sniff out" EMI. Some units have inductive or capacitive accessory probes that are designed to pick up magnetic or electric fields radiated from equipment. These probes are good for finding radiation leaks in shielded enclosures, connectors, or cables. The antennas are directional so that they can be scanned around an area or a piece of equipment to help pinpoint the radiation source and its frequency. Once the nature of the radiation is determined, grounding, shielding, or filtering steps can be taken to eliminate it.

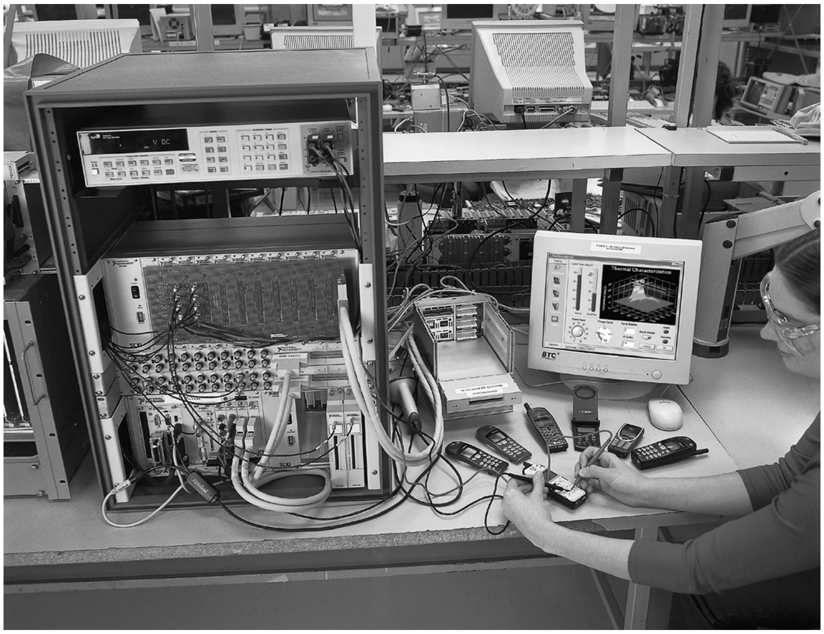
As discussed in the text, there's no need for cables when communication devices have Bluetooth. Several hundred million Bluetooth devices are sold each year. Thus there is a need to accurately and quickly test products before they come to market. This spectrum analyzer has Bluetooth wireless test capability.





Devices such as PDAs and cell phones use flat-panel displays. To inspect these displays, technicians use software such as Labview by National Instruments. A technician can test the audio, electrical, and RF components. By using this program, it is possible to diagnose problems with alignment, pixel defect, color, and contrast.

Testing communication products with specialized computer software.



CHAPTER REVIEW

SUMMARY

The work performed by communication electronics experts will involve some form of testing and measurement over the course of equipment installation, operation, servicing, repair, and maintenance. Engineering and manufacturing engineers and technicians will also perform a wide range of tests and measurements in their work, including verifying and making final adjustments to specifications. It is important, therefore, for them to be familiar with the types of malfunctions that can occur and the factors to consider in repair and maintenance of equipment.

There exist a wide range of choices in electronic communication testing equipment such as oscilloscopes and multimeters for measuring ac and dc voltages, current, resistance, and frequency. Measurements are routinely made of frequency, power, modulation, and SWRs. Some equipment is manufactured with its own testing microcomputers built in; other equipment must be tested with separate equipment. Because electronic communication equipment is so complex and varied in makeup, the manufacturers' own manuals are the best resource in diagnosing and repairing their equipment.

Most modern communications products are made up of complex ICs that contain all or most of the circuitry required for the application. This makes testing and troubleshooting that use older procedures difficult. Many modern digital circuits are tested by way of a built-in testing system referred to as boundary scan that permits IC pins and internal circuit points not brought out to pins to be monitored. Boundary scan permits automated testing and troubleshooting by computer.

This chapter also described the importance of electromagnetic interference (EMI) in communication work. Most electronic equipment generates signals that can potentially interfere with other electronic equipment. Computers and other digital devices are the major offenders. EMI can the minimized by a combination of good initial design plus a mix of grounding, shielding, and filtering techniques.

QUESTIONS

1. What is the most important specification of an ac voltmeter for measuring radio-frequency voltages?
2. What is a digital oscilloscope? Name the major sections of a DSO, and describe how they work.
3. What kind of resistors must be used in a dummy load?
4. Name two common types of SWR meters.
5. Name two common power-measuring circuits.
6. Show how the SWR can be determined from power measurements.
7. What is the name of the versatile generator that generates sine, square, and triangular waves?
8. How is the output level of an RF generator controlled?
9. What is the typical output impedance of an RF generator?
10. What cautions should you take and what guidelines should you follow when connecting measuring instruments to the equipment being tested? Why should you allow an RF generator to warm up before using it?
11. What is a sweep generator, and how does it work?
12. Name two applications for a sweep generator.
13. How is the output of the circuit being tested with a sweep generator detected and displayed?
14. Name the six main sections of a frequency counter.
15. What is a prescaler? Name two types.
16. What is a network analyzer? How is it used?
17. What is displayed on the CRT of a spectrum analyzer? Explain.
18. State the function of a field strength meter. What is its circuit?
19. Name the four most common transmitter tests.
20. What test instrument is used to measure the modulation of an AM transmitter?
21. What kind of test instrument is best for detecting the presence of harmonics and spurious radiation from a transmitter?
22. Generally, what level of SWR should not be exceeded in normal operation?
23. What does *SINAD* mean?
24. What does the receiver blocking test determine?
25. What does the third-order intercept test in a receiver measure?
26. What does an eye pattern show?
27. What does a “closing eye” usually indicate about the medium or circuit being tested?
28. Explain how an excessively noisy binary bit stream appears in an eye diagram.
29. What kind of instrument is used for bit error rate testing?
30. Describe the basic process of bit error rate testing.
31. What is a protocol analyzer? How does it display its results?
32. What types of components are most likely to fail in communication equipment?
33. What circuits should be tested first before any troubleshooting is initiated?
34. Besides the right test equipment, what should you have on hand before you attempt to service or troubleshoot any kind of communication equipment?
35. Name two ways in which an antenna may be defective.
36. Name the two basic types of troubleshooting methods used with communication equipment. Which is more likely to be used on receivers? Transmitters?
37. What test instruments are needed to carry out the two troubleshooting methods given above?
38. Name four measurements often made in fiber-optic systems.
39. In what type of equipment and in what frequency range is jitter a problem?
40. What is jitter?
41. What is the common unit for jitter measurement?
42. Why are large-scale ICs difficult to test by signal injection and tracing?
43. What is the name of the internal circuitry built into many large-scale ICs for test purposes?
44. By what circuit is the test data entered or accessed?
45. How is data entered and monitored with built-in test circuits?
46. What controls the function of the test circuits?
47. Name the standard of this test method.
48. Define EMI.
49. Who mandates EMI control?
50. How can receivers be a source of EMI?
51. How can a power supply be an EMI source?
52. Explain the role of the 60-Hz ac power line in EMI.
53. Name three ways by which EMI is transmitted.
54. What is the most common source of EMI?
55. List the three techniques used to reduce EMI.

56. What is considered the ground on a PCB?
57. What is the best type of ground?
58. What is a ground loop? What causes it?
59. How are ground loop problems eliminated?
60. State the conductor requirements for a good ground.
61. How does shielding minimize EMI?
62. What can be done to prevent radiation leakage from a shield?
63. What is the effect of power supply decoupling circuits on EMI?
64. What can be used in place of an RFC in a decoupling circuit?
65. Explain what ac power line filters do.
66. What type of interference does a toroid core deal with most effectively?
67. Where can rules and regulations for EMI be found?
68. Name two types of EMI radiation testing equipment.
69. What is the basic measuring unit for radiated EMI? What does it mean?
70. What components in an EMI test system allow you to pinpoint the source of radiation?

PROBLEMS

1. Explain the theory behind the operation of an arbitrary waveform generator. What is its main limitation? ◆
2. Explain the operation of a superheterodyne spectrum analyzer. What determines the resolution of the analyzer?
3. A noise test is performed on a receiver. Where is the noise measured? The spacing between the two horizontal lines on the oscillope screen is 2.3 divisions. The vertical sensitivity calibration is 20 mV per division. What is the noise level? (Use the procedure described in the text.) ◆
4. Refer to the transmitter diagram in Fig. 22-23. No modulation is applied to the circuit. The transmitter output power across the dummy load is zero. A measurement of the signal at the output of the phase modulator reveals a sine wave of 14.8 MHz. What is the problem? Explain why there is no output. Solve this problem in two ways: (*a*) Assume that the carrier frequency is as shown in Fig. 22-23. (*b*) Assume a carrier crystal of 14.8 MHz.
5. In Fig. 22-23, the output of the third multiplier is OK, but there is no output across the dummy load. What component is most likely defective? ◆
6. A small radio transmitter puts out 5 W of forward power but produces 1 W of reflected power. What is the SWR?

◆ *Answers to Selected Problems follow Chap. 22.*

CRITICAL THINKING

1. State two benefits of DSOs over analog oscilloscopes.
2. How do you lower the SWR if it is too high?
3. A handheld cellular telephone worth approximately $175, consumer retail price, was obtained free when the cellular service was first initiated. It does not work. A call to the dealer indicates that this model can be repaired, but the labor rate is $75 per hour, and most repairs require a minimum of 2 h to fix. Parts charges are extra. Should you have the telephone fixed, or should you buy a new one? Give your reasons for the decision you make.
4. Give three examples of how household appliances could produce EMI and the electronic equipment they may interfere with.
5. State the potential for CB radios, FM family radios, and amateur radio equipment to interfere with other household electronic equipment.
6. Can the JTAG system test analog/RF circuits?