CHAPTER 8: NOISE AND NOISE REDUCTION TECHNIQUES

1. NOISE SOURCES

Noise can be characterized as any disturbance that tends to obscure a desired signal. Noise can be generated within a circuit or picked up from external natural or artificial sources. When noise is generated within a circuit, it is called intrinsic noise. When noise is picked up from an external source, it is called extrinsic noise

Interference is noise that tends to obscure the useful signal. It is usually caused by electrical sources but can be induced from other physical sources such as mechanical vibration, acoustical feedback, or electrochemical sources. In addition to characterizing noise by its source, it is useful to distinguish noise by its frequency spectrum and amplitude distribution. When noise power has a flat frequency distribution, it is called white noise (from the analogy of white light containing all frequencies). If you double the bandwidth of a system, you double the white-noise power. Noise that is inversely proportional to frequency is called 1/f, or pink, noise. Pink noise is present in many physical systems but is particularly important in low-frequency systems. In electrical systems, pink noise is generated when a current flows through a non-homogeneous material, such as in a carbon-composition resistor (a mixture of carbon and other semi-conductive materials). Pink noise is also generated in switches and other contact surfaces that are composed of dissimilar metals; it is then referred to as *contact noise*

2. INTRINSIC NOISE

Intrinsic noise sets a lower limit on measurements and it is present in all electronic measuring systems. There are three important sources of intrinsic noise: (1) thermal noise generated by random motion of electrons in any resistance, (2) contact noise caused by the flow of current across the imperfect boundary formed between two materials, and (3) shot noise caused by the flow of current across a potential barrier, such as a *pn* junction.

a. Thermal noise:

Thermal noise is produced by the motion of free electrons in a resistance due to temperature. It is generated even when the resistance is not connected to a circuit but is due to the random fluctuations in charge at either end of the resistance. Thermal noise is often called Johnson noise. The noise power in thermal noise is constant per unit of bandwidth across the usable electronic spectrum. Because of this, it is a form of white noise. The maximum noise power available from a thermal noise source is given by the equation:

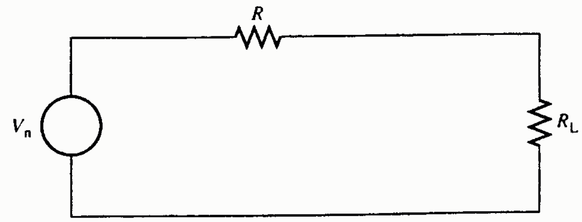
$$P_n = kTB$$

Pn= noise power, W
k= Boltzmann's constant, 1.38×10^{-23} J/K
T= absolute temperature
B=bandwidth

Thermal noise can be expressed in terms of a voltage for a resistor, as in Figure 12-1. Since noise is random and unpredictable, the noise voltage is given as the rms value. In order to compute the thermal noise that is delivered from a resistance, it is convenient to draw a Thevenin circuit composed of a noiseless resistor in series with a fictitious noise voltage source. A load resistor with no noise of its own is assumed. The maximum power than can be transferred occurs when the Thevenin source resistance R is equal to the load resistance R_L, as shown in Figure 12-1. The noise voltage is divided between R and R_L. Therefore, the noise power delivered to the load resistor is:

$$P_n = \frac{\left(\frac{V_n}{2}\right)^2}{R} \quad \text{then} \quad V_n = \sqrt{4kTBR}$$

FIGURE 12–1
Thermal noise in a resistor.



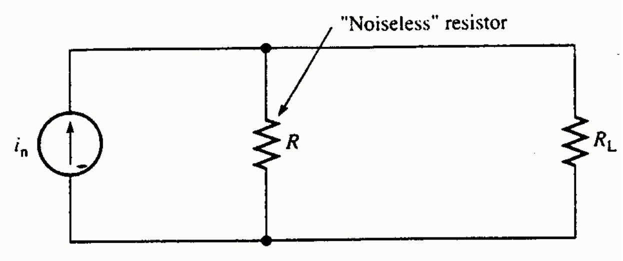
This equation allows to find the equivalent Thevenin circuit of a thermal noise source of resistance R. This is the noise voltage found at the terminals of a resistor; it sets a lower boundary on the noise voltage from any resistive source. Notice that a perfect conductor has no thermal noise. Thermal noise in a practical system is limited by the bandwidth of the system but is small. For example, a room-temperature 10kOhms resistor operating in a system with a 1 MHz bandwidth generates about 10 uV of noise. Note that the *thermal* noise has nothing to do with the physical size or composition of a resistor - it is the same for the most expensive low-noise resistor as for an ordinary carbon resistor, provided both resistors are the same value and are measured at the same temperature and bandwidth.

Thermal noise can also be modeled as a Norton current source. In this case, the thermal noise is considered to be a current source with a noiseless resistor in parallel with the current source, as shown in Figure 12-2. The magnitude of the current source is given by:

$$i_n = \sqrt{\frac{4ktB}{R}}$$

i_n=rms noise current of a resistance

FIGURE 12–2
Noise current.



where V_n = equivalent rms noise voltage of a resistance, V
R = resistance, Ω

b. Contact noise

All resistors have noise voltages in excess of the thermal noise due to other noise-generation mechanisms. This additional noise is called contact noise; it is dependent on the quantity of current and the type of resistor. Contact noise is also called excess noise, flicker noise, or pink noise. Pink noise can be formed by passing white noise through a low-pass filter with roll-off of -3 dB per octave. Causes of contact noise are not well understood; however, it has been observed in many experiments. Types of resistors are (1) carbon-composition. (2) carbon film, (3) metal film, and (4) wirewound resistors. The noisiest of these is the carbon- composition resistor, and the quietest are the metal film and the wirewound types. In addition, variable resistors generate noise due to the wiper junction.

Contact, or flicker, noise is found in both field-effect transistors (FETs) and bipolar junction transistors (BJTs). Causes of such noise vary with the type of device. In bipolar transistors, it is a function of base current and leakage currents and increases as these currents rise.

Another type of frequency-dependent noise occurs at higher frequencies and is related to the transient time of charge carriers in the transistor. These effects are important when the period of the signal is comparable to the transit time of the charge carriers in the device. This occurs at very high frequencies-typically more than 500 MHz. Above these frequencies, FETs have an advantage over bipolar transistors in terms of noise because of faster transit times.

c. Shot noise

The flow of current is not continuous in a circuit but rather is associated with random variations in the number of charge carriers passing some voltage boundary. Charge is limited by the smallest unit of charge available-that of the charge on an electron. Shot noise, like thermal noise, has the same power per unit of bandwidth; hence it is a type of white noise. When amplified, it sounds something like lead shot raining on a metal roof-hence the term shot noise. Shot noise is given in terms of a current and is found from the equation

$$\mathbf{i_{sh} = \sqrt{2eI_{DC}B}}$$

i_{sh}=rms shot noise current
e=electron charge, $1.6\text{x}10^{-19}$C

Shot noise occurs in virtually all active devices. The shot noise depends on a number of variables, so it is convenient to represent noise sources by assuming a noise –free device with external noise sources connected to it. One way of specifying the random noise contribution is an active device is to assign an "effective noise temperature" to the input. This temperature, labeled Te, is added to the effective input noise temperature Tin to obtain an equivalent operating temperature of an active device. The noise temperature of a device does not mean that the device is actual operating at that temperature; rather, it gives an equivalent temperature of a thermal source with the same noise power. The output noise power of a transistor can be written as:

$$\mathbf{P_n = Gk(T_e + T_{in})B}$$

G=transistor gain
T_e=effective noise temperature, K
T_{in}=effective input noise temperature, K

d. Combining noise sources

Superposition theorem is applied to find total noise. Since the rms voltage are represented by random variations in sources, the result is found by taking the square root of the sum of the square of the n noise sources:

$$V_t = \sqrt{V_1^2 + V_2^2 + V_3^2 + \cdots + V_n^2}$$

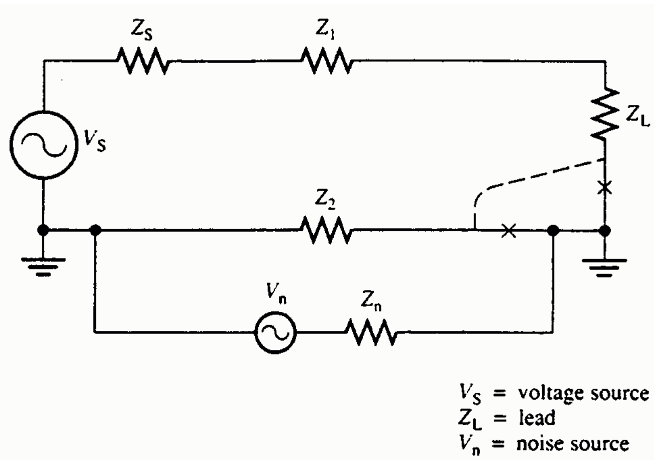
3. EXTRINSIC NOISE

Extrinsic noise is induced from an external source and can cause unsatisfactory operation of a circuit (interference). The source of noise may be from another circuit on the same circuit board (often referred to as cross talk), or it may be external to the equipment. For interference to occur, there needs to be a source of noise and a means of coupling it into the circuit. The external source may come from conduction, capacitive coupling, magnetic coupling, or radiation. To reduce the effects of interference, the interference can be suppressed at the source, the source can be isolated by shielding or filtering, the coupling path can be reduced, or the receiving circuit can be made less sensitive to noise.

Conductive coupling

Conductive coupling of noise requires at least two or more conductive paths to the noise source. There cannot be a complete circuit for the noise if the conductive path to reduce to only one conductor.

FIGURE 12–4
Hypothetical noise-source model. Noise is caused by a difference in reference (ground) potentials due to conductive coupling. The problem can be corrected by breaking the circuit at the x's and reconnecting as shown with the dashed line.



Electric and magnetic fields:

When a current flows through a conductor, electric and magnetic fields are present. Electric field interference is also called capacitive coupled interference since all the configurations of conductors have capacitance between them, allowing a coupling path. Magnetic field interference can come from inductors, transformers, conductors, or any low-impedance source in a circuit.

EMI: Any material will either absorbs, reflect or allow EMI to pass through and will be subjected to EMI.

Power line interference:

Power line interference, sometimes called hum in audio systems, can be caused by an external source that introduces unwanted voltage in the circuit or it can be internally generated from a power supply. Both 60Hz and harmonics of the power can be the sources of noise.

4. NOISE MEASURING

Noise is unavoidable. Proper shielding and design can obtain the lowest noise level, but there will always be intrinsic noise in electronic systems, even if the power source is turned off. In interpreting and measuring noise, it is necessary to take into account the bandwidths involved and the type of noise. White noise, in theory, is infinite in bandwidth, having an even distribution from dc to infinity. This infinite bandwidth implies infinite noise power when applied to a resistor. In practice, electronic systems are bandwidth-limited, so the noise is *not* infinite in energy. An important aspect of measuring noise is that the noise energy will increase as the bandwidth of the measurement system increases. For example, two meters may obtain different results when measuring noise in *V* rms on the same circuit because the bandwidth of the two meters may differ; the measurement equipment must have a bandwidth larger than the system being measured. Often filters are used to limit the bandwidth of the noise. For example, noise above 20 kHz is inaudible and does not diminish the signal quality in an audio system; therefore the measurement system is filtered above 20 kHz.

The type of noise can affect the way noise is measured and calculated. For example, white noise, in the time domain, has a Gaussian voltage or power distribution about a dc level (the dc level is the signal level at any given period of time) and is best measured in terms of rms values of volts or power. Rms measurements are useful because they disregard the polarity of the noise. However, if the noise is an impulse (spike), then the peak or peak-to-peak value may have more meaning. For example, ignition noise may add very little to the rms value, but the effects can be very noticeable over a radio receiver. A look at the noise, using an oscilloscope and/or a spectrum analyzer, may be needed to determine the significant *spectrum* and the *type* of noise so the proper method of measuring the noise may be used.

a. SNR

The effects of noise on a signal are best analyzed as a ratio of the signal compared to the noise. This ratio is called the signal-to-noise ratio (S/N) and is often expressed in decibels. The noise is often referred to as the noise floor because its level stays fixed as the signal is varied in amplitude above it. There are three basic ways to improve the S/N ratio: (1) increase the signal strength, (2) decrease the noise level, and (3) limit the noise bandwidth. The larger S/N, the less the noise will affect the signal. If reducing the noise is not possible or practical or if increasing the signal will cause distortions elsewhere, then reducing the noise bandwidth may be the only approach to improving S/N.

Although signal-to-noise ratio is normally expressed as a power ratio, it can be expressed as a voltage ratio. If voltage ratios are used, then care must be taken to retain a constant impedance at the point of measurement. Measuring the noise with one instrument and measuring the signal with another instrument may cause errors if the loading effects on the circuit by the instruments are not the same. If the measurements are in volts, then S/N is calculated by:

$$\mathbf{S/N(dB) = 20\log\frac{Vs}{Vn}} \quad \text{or} \quad \mathbf{S/N(dB) = 10\log\frac{Ps}{Pn}}$$

b. Sensitivity

Radio-receiver performance is often expressed as sensitivity. In the absence of any signal, noise is present at the audio output of the receiver. As the radio-carrier signal is increased, the noise is decreased. Sensitivity is determined by first measuring the noise at the output of the audio amplifier using a true rms voltmeter, without any radio-carrier signal present. The carrier is supplied and increased until the noise is down by -20 dB; at that point, the signal strength of the carrier is measured. This level is called the sensitivity. The sensitivity is expressed in microvolts at -20 dB quieting.

c. Noise Factor

The **noise factor** is a means of specifying the added contribution of an amplifier to the signal-to-noise ratio due to noise generated within the amplifier. As such, it is a measure of the quality of the amplifier and includes the overall effect of all noise sources within the amplifier. Like S/N, noise factor is a dimensionless number that can be expressed as a power ratio or as decibel equivalent. Noise factor can be defined as

$$\mathbf{F = \frac{S_i / N_i}{S_o / N_o}} \quad \textbf{or} \quad \mathbf{F = \frac{S_i}{S_o} x \frac{N_o}{N_i}} \qquad \mathbf{F = \frac{N_o}{A_p N_i}}$$

N_i=input noise power deliver to the amp.
N_o=output noise power delivered by the amp.
A_p=amp. power gain

Noise factor is frequently expressed as a decibel ratio. As a decibel ratio, noise factor is generally called **noise figure**:

$$\mathbf{F_{dB} = 10 \log F}$$

All real amplifiers contribute their own internally generated noise from several causes. The output noise from such an amplifier can be expressed as the sum of the amplifier input noise and the internal generated in the amplifier:

$$\mathbf{N_o = A_p N_i + N_a} \qquad \textbf{then} \qquad \mathbf{F = 1 + \frac{N_a}{A_p N_i}}$$

Na= internal noise power generated in the amplifier.

The amount of noise in a system is a function of the bandwidth. To measure noise factor, the noise can be measured in a very narrow band and compared with the power gain of the system at that frequency. This measurement of noise factor is called the single-frequency noise factor. Noise factor can also be measured over a large bandwidth compared to the system under test. The result is called the integrated noise factor.

d. Equivalent noise temperature

Sometimes it is convenient to specify the noise performance of an amplifier using an equivalent temperature instead of the noise factor. The observed noise at the input of an amplifier can be expressed as if it were generated by thermal noise in the source resistance at some temperature. As you have seen, the thermal noise voltage associated with a resistor is given by the equation:

$$V_n = \sqrt{4kTBR}$$

There is an equivalent temperature for a source resistance that delivers the same input noise to an amplifier as the observed input noise. The amplifier then adds a noise contribution to this input noise. This added amplifier noise can be thought of as being due to an increase in the reference temperature of the source resistor by an amount that produces the observed output noise. This temperature is defined as the equivalent noise temperature of the amplifier. The standard reference temperature of the source resistance is 290 K. The increase in this temperature due to noise generated in the amplifier defines an equivalent input- noise temperature. The equivalent input-noise temperature of the amplifier can be found from the equation:

$$T_{eq} = 290(F - 1)$$

Teq= equivalent input-noise temperature of the amplifier, ^{O}K.

- ## Equipment to measure noise:

1. True rms meter

Noise measurements can be made using a very sensitive true rms meter. In order to obtain the needed accuracy with a meter, the following should be observed:

1. The meter needs to be a *true* rms meter. Some meters have an ac scale indicating rms, but this may be an averaging meter and not a true rms meter. If in doubt, refer to the operator's manual.
2. The meter needs to be sensitive enough to measure the expected levels of noise. For example, you will not be able to measure a few microvolts of noise with a millivolt meter.
3. The passband of the meter needs to be wide enough to measure the spectrum of the noise. Remember, noise energy is proportional to bandwidth.
4. The normal two-wire lead set that comes with most common meters may not provide enough shielding against interference, causing errors in the readings. You may need to provide other means of connecting to the meter, such as coax cable.
5. The loading effects of the meter should be taken into consideration. For example, probing a high-impedance circuit with a meter could cause the noise to be shunted to ground through the lower impedance of the meter. The measured amplitude of the noise would then be less than actual.

The technique for measuring noise is straightforward. Disconnect any signal sources from the circuit so the output is “quiet." Connect the true rms meter from a reference point to the point to be measured. Most often the reference point will be chassis common (ground), but this is not always the case; if you were measuring a stereo system for example, the meter should be across the speaker. The rms value of the noise can then be measured directly with the meter in volts rms. The desired level of signal is then applied to the circuit and, using the same connections, the rms value of the signal is read in volts rms. Signal-to-noise ratios can then be calculated.

2. <u>Oscilloscope</u>

Noise measurement with an oscilloscope can be done accurately if the noise has a Gaussian voltage distribution around the signal and is non-periodic. That is, for any given signal level, the noise must be distributed equally above and below the mean value of the signal, as seen in Figure 12-30.

Before discussing how to measure noise using an oscilloscope, it would be beneficial to mention how *not* to measure noise with an oscilloscope. You cannot measure noise by reading the peak-to-peak levels of the noise, because the observed peak-to-peak reading is far too ambiguous. For example, if the intensity of the oscilloscope is turned down, the peak-to-peak level of the noise appears much less than if the intensity is turned up.

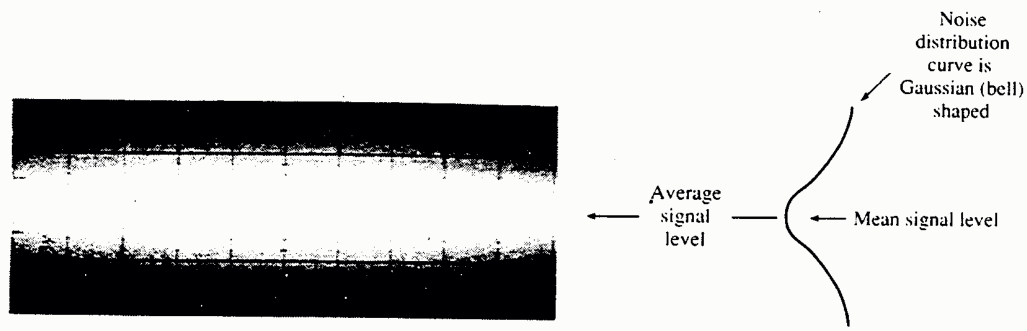
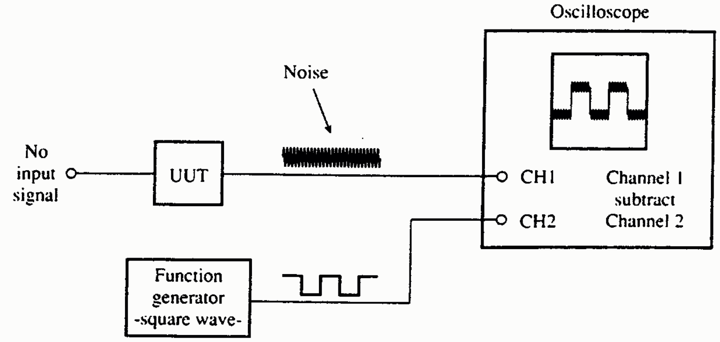


FIGURE 12–30
Noise that is Gaussian distributed.

The following method provides a high degree of accuracy in measuring noise that is non-periodic and Gaussian. It requires a low-noise square-wave oscillator and a dual-channel oscilloscope.

1. Connect the oscilloscope as shown in Figure 12-31.
2. Select channel 1 subtract channel 2. The vertical sensitivity (VOLTS/DIV) of each channel must match throughout this test. They will be changed as needed to view the noise, but channel 2's attenuation must match channel's attenuation.
3. Set the function generator for a square-wave signal at about 1 kHz.
4. The oscilloscope should not be locked to any signal. Adjust the frequency of the square wave so it traverses quickly across the display, giving the effect of two parallel lines (traces) as shown in Figure 12-32(d)
5. Increase the sensitivity of both channel 1 and channel 2 (by the same amount) to enlarge the noise display; at the same time, reduce the amplitude of the function generator so both traces remain on the screen. Increase the sensitivity as far as you can on both channels until the scope has no further gain or the noise patterns are filling the screen.
6. Reduce the output of the function generator until the two bands of noise just blend together, as in Figure 12-32(c); then stop.
7. Remove the source of the noise and measure the peak-to-peak level of the square wave, as shown in Figure 12-32(d). Divide this value by 2; the result is the rms value of the noise.

FIGURE 12–31
Connections to an oscilloscope to measure noise.



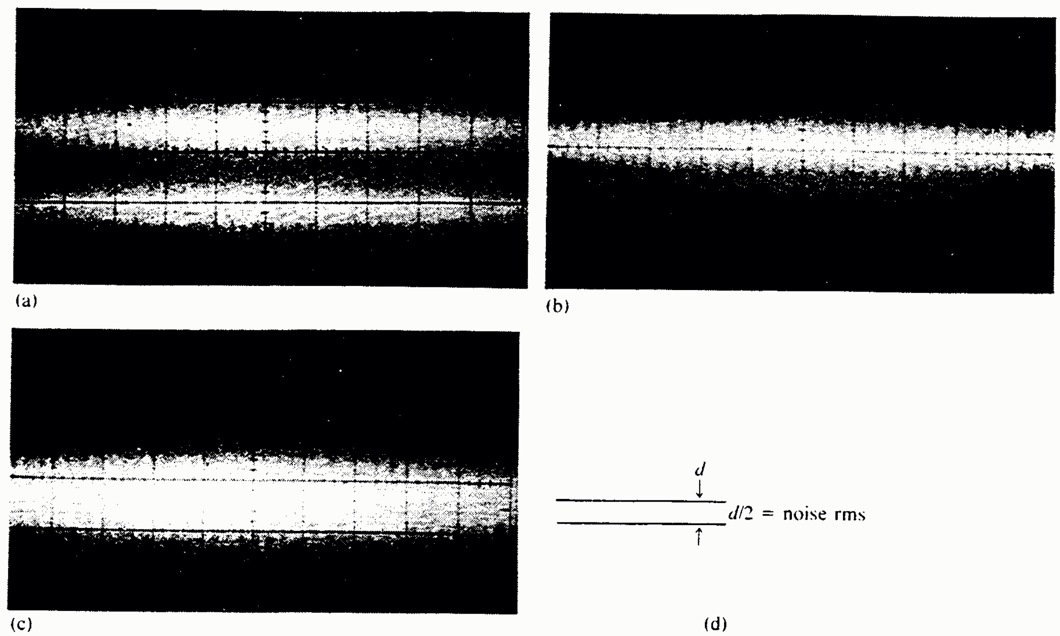


FIGURE 12–32
A square wave and noise source are mixed in the CH1-CH2 mode of an oscilloscope. The square-wave signal free-runs at a rapid rate, so the appearance is two bands, as in (d).

3. <u>Spectrum analyzer</u>

The spectrum analyzer can be used to measure the amplitude of the noise as well as display the spectrum of the noise. The spectrum of the noise is an important factor as it gives information about the types of noise sources. For example, if the noise rolls off in amplitude at higher frequencies, then the noise might be pink noise or the amplifier might be bandwidth- limited. If the noise is pink noise, then it can possibly be improved by changing certain resistors from carbon to film types. If the noise has a roll-off due to the circuit's bandwidth, then the noise level should be measured at specific frequencies within the bandwidth. If the noise is higher in amplitude at a specific frequency, then the "noise" may actually be interference from an adjacent circuit such as from a local oscillator used elsewhere to decode the signal.

S/N measurement can easily be accomplished using a spectrum analyzer. The gain of the spectrum analyzer is adjusted so the level of the signal of interest is set to 0 dB (at the top of the

CRT display); the noise level is viewed on the graticule in terms of decibels down from the reference signal. The accuracy of this measurement can be increased by connecting a precision step attenuator to the circuit, as shown in Figure 12-33.

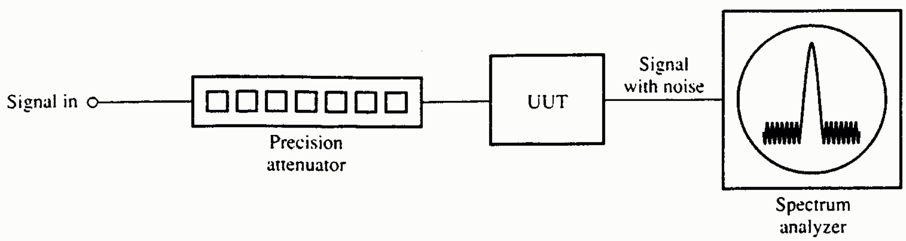
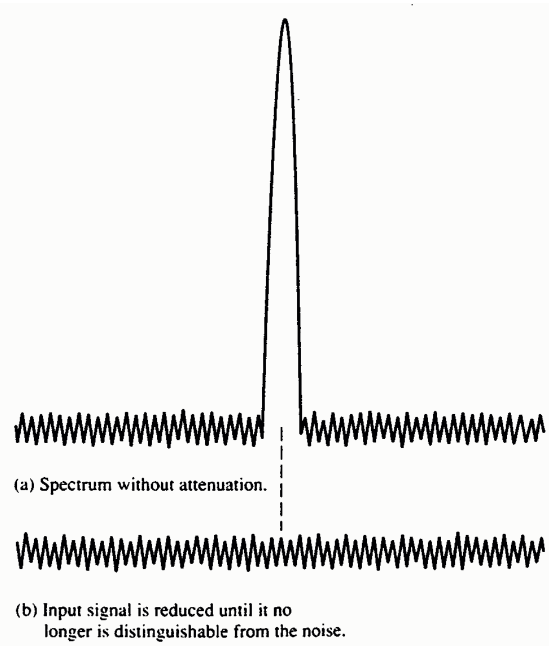


FIGURE 12–33
Connection to a spectrum analyzer to measure S/N ratio.

Figure 12-34(a) shows what a spectrum may look like with one frequency used as a reference and the associated noise; the precision attenuator is set to 0 dB. The reference signal is then attenuated by the attenuator *just* until it is indistinguishable from the noise, as shown in Figure 12-34. The S/N is read directly from the attenuator settings. This method has the benefit of attenuating the effects of the noise of the test signal; it does not lessen the added noise from the spectrum analyzer's circuits.

FIGURE 12–34
Use an attenuator to reduce the signal in (a) to look like that in (b). Read the S/N ratio in decibels from the attenuator.



5. NOISE REDUCTION

An instrumentation system may consist of a chain of modules as shown in Figure 1 below, the input impedance of one module acting as a load on the output of the preceding module. It has been shown that maximum power is transferred to the load when the source and load impedances are equal (Zin = Zout). In instrumentation, however, when the signal is a voltage, what we need to transfer is not maximum power but maximum voltage. This suggests that Zin should be infinite greater than Zout, but in that case, no power would be transferred. The usual practice therefore is to make the input impedance of one module 10 or 20 times as big as the output impedance of the preceding module so that the voltage across the input terminals is fairly high proportion of the source voltage.

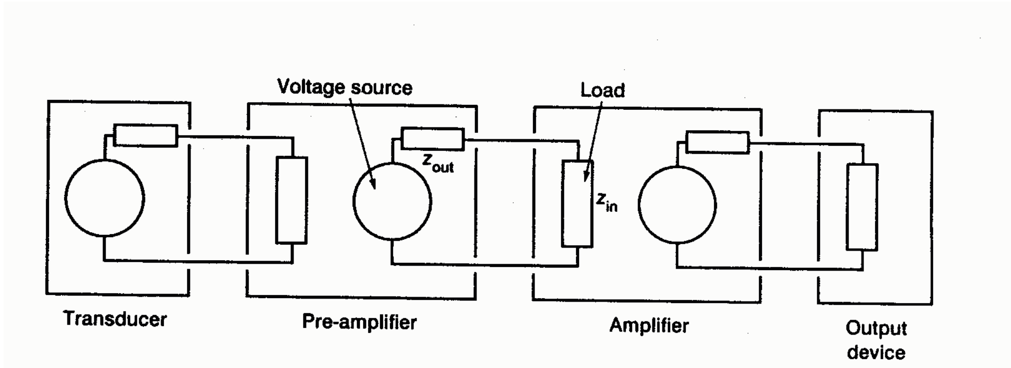


Figure 1: An instrumentation system is a chain of voltage source and load

The output of the transducer is usually in the form of a voltage. Unfortunately between the transducer and the output device, noise voltage are liable to appear and be amplified together with the wanted signal. If we define "noise" as any unwanted alteration of the signal, it can appear in the following forms:

a. *Drift:* Drift may be caused by variations in power supply or by temperature changes within the amplifier. The remedy is stabilized power supply and to keep temperatures constant as far as possible. A much slower drift effect may be caused by the ageing of components within the amplifier.

b. *Internally generated random noise:* There are two sources for internally generated random noise: thermal noise and shot noise. *Thermal noise* comes from electron movement due to thermal vibration of the atoms. This is a *white noise* (all frequency noise). This noise level is proportional to the square root of the absolute temperature of the conductor. *Shot noise* is also white noise. It comes from random fluctuations in the passage of charge carriers through semiconductor material. Usually the signal-to-noise ratio (SNR) is so high that we are unaware of these two types of noise. Remedy for this type of noise is to improve system SNR, a preamp should be placed as close to the transducer as possible.

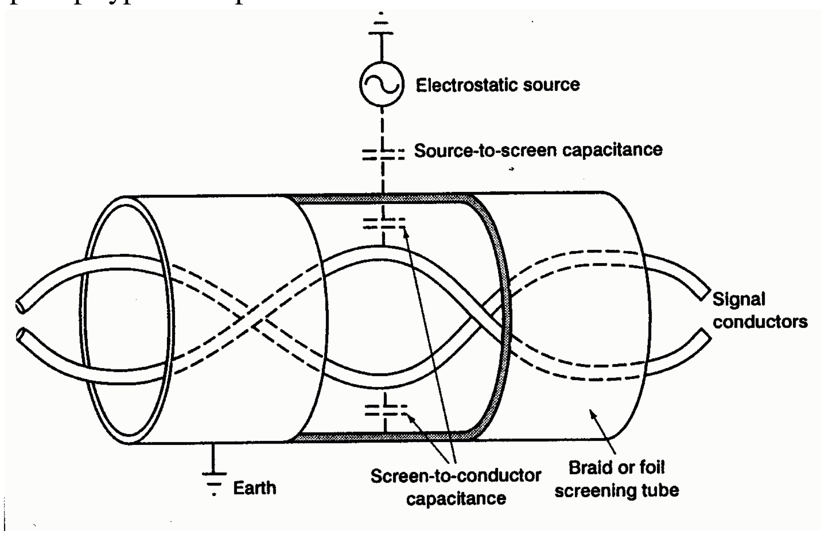
c. *External noise:* Noise may be picked up from the surrounding by capacitive pick-up (from *electrostatic field*) or inductive pick-up (from *electromagnetic field)* or it may be introduced into equipment through its power leads. The remedy is to place the equipment as far as possible the source of noise such as 60Hz power cables, electric motors, generators or switch gears.

Noise in any electrical system needs to be reduced as much as possible, the following techniques are to be used to suppress noise

1. Screening techniques

Capacitive and inductive pick-up may be reduced by screening This means enclosing cables, amplifiers, etc.., in metal which is earthed so that the voltages picked up by the screening are short-circuited to earth. To screen against capacitive pick-up, the metal forming the screen need only be good conductor – copper or aluminum. To screen against inductive pick-up, the screening must be off iron or other magnetic material, and it must be thick enough to be effective – two or three millimeters thickness is needed for screening out 60 Hz magnetic fields.

Figure below shows the screening of a conductor, the screening greatly reduce capacitive pick-up by capturing charges which could otherwise reach the signal conductors, but it must be earthed or the charges will still reach the conductors through screen-to-conductor capacitances. The twisting together of the conductors reduces inductive pick-up by ensuring that signal-carrying pairs will pick-up identical; inductive noise voltages. These can be cancelled out by connecting the output of the cable to an op-amp type of amplifier.



Earth loops can create large noise voltages. They occur when earth connecting are made more than one point as shown in Figure 8.14. This arrangement can pick up noise in two ways:

a. From current flow: If a current happens to be flowing thru the material to which earthing points are connected, some of the current will flow through the screening which, if the current is noisy, will transmit the noise by the capacitance to the signal wires.
b. By induction: The complete earth loop can act as a loop of wire in a magnetic field, having noise currents induced in it by the alternating magnetic field of a noise source. The noise is transferred to the signal wires by capacitive pick-up.

Another earth loop exists if one of the signal conductors is also earthed at each end by being connected to the earthed casing of the transducer at one end and the earthed casing of the amplifier at the other end (Figure 14 a and b), these earth loops should be broken. The screening and the signal conductor are earthed at the transducer end only and the input to the differential amplifier is allowed to "float". Note that although there may be no direct connection between the transducer and earth it may in effect be earthed by capacitance.

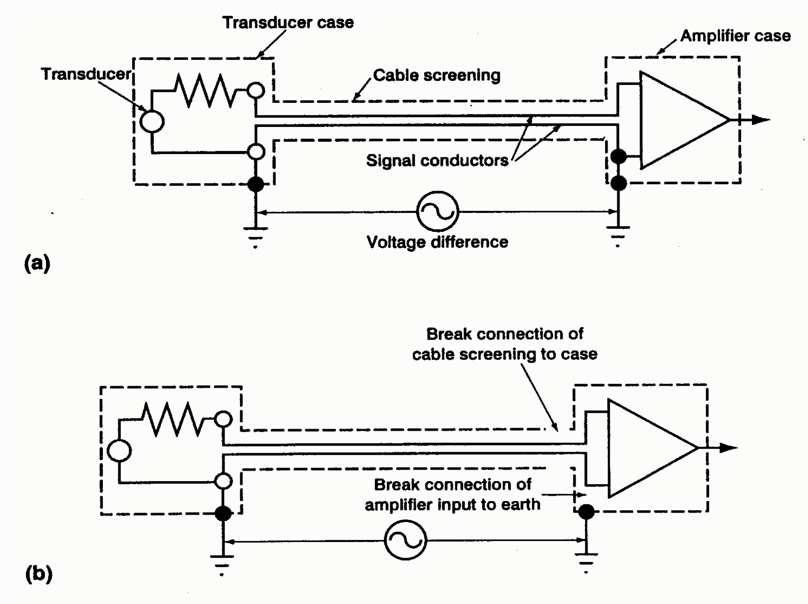


Figure 8.14 (a) Typical earth loop (b) breaking the loop

2. Suppressors

These are used to suppressed electrical nose caused by sparking at the brushes of electrical motors or sparking at the contacts of relays which are switching reactive loads. The noise may be transferred by electromagnetic radiation or along the power supply cable if the noise source and instrumentation equipment share the same power supply. Suppression, which is best applied as close to the noise source as possible, can take the form of capacitors, chokes or varistors.

3. Capacitors

Capacitors are used as reservoirs to smooth out voltage variations and to conduct high frequency transient to earth. Figure below shows a circuit of the type used to suppress electrical noise from small electric motors.

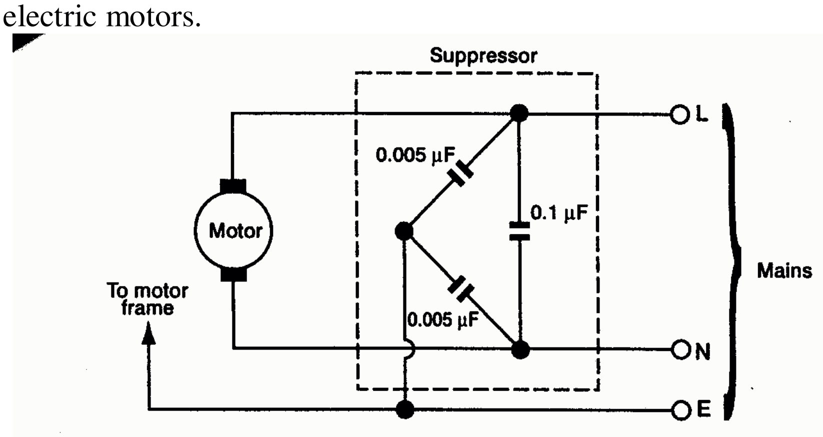


Figure 8.15 Suppressor-capacitor for a small electric motor

4. Chokes

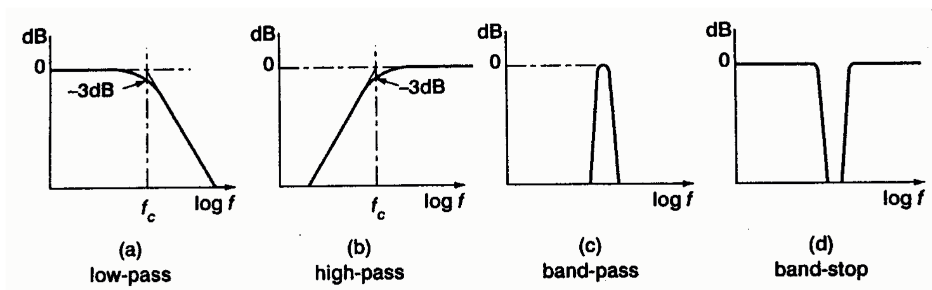
Chokes are simply inductances which smooth out rapid variations of current, so they are put in series with power supply leads to act as barriers to noise.

5. Varistors

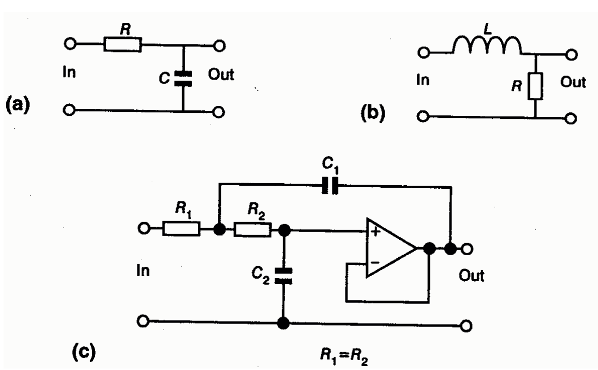
Varistors are connected across power supply leads to short-circuit transient high-voltage "spike". They are semiconductors which have a high resistance at voltages up to a stated maximum; voltages in excess of that maximum however, cause the resistance to drop to a low value until the excess energy has been dissipated.

6. Filters:

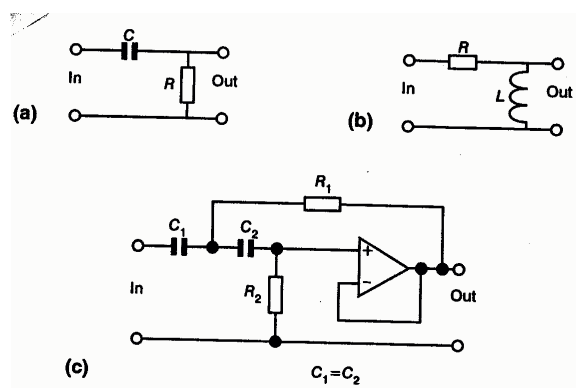
Filters are used to exclude unwanted bandwidth from a signal. The filter may be needed to exclude high frequencies because they carry only noise (LPF) or to exclude low frequency for the same reason (HPF). If the wanted signal is contained in a narrow frequency, a BPF is used. Conversely, if unwanted signal or noise is concentrated in a narrow frequency, a band-stop or notch filter is used.



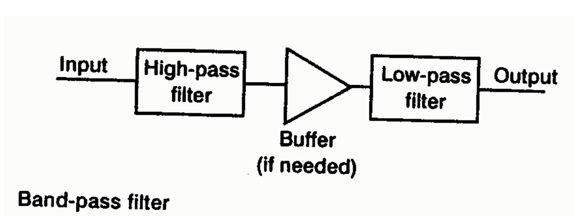
Filter responses



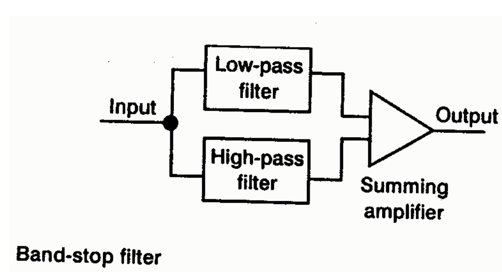
LPF



HPF



BPF



Band stop filter

Phase effect: Capacitors and inductors are energy storage devices and so they cause phase shifts in the signal. The LPF introduces a phase lag (negligible at frequency up to 0.1fc, increases 45 degrees at fc and approaches 90 degrees at frequencies above 10fc. The HPF introduces a similar phase lead over the same frequency range. With continuous signals, a phase shift is not of great significant but if the signal consists of pulses or sudden changes of level, phase effects can cause considerable distortion and phase correction circuits (all pass filter) may have to be used.

7. Grounds, Shielding and connecting wires

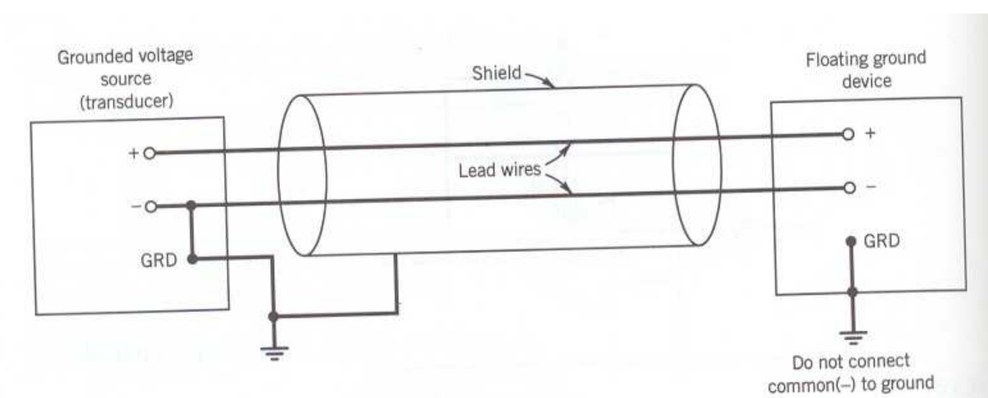
The type of connecting wires used between electrical devices can have a significant impact on the noise level of signal. Low-level signals of <100mV are particularly susceptible to errors induced by noise. Three simple rules will help to keep noise levels low: (1) keep the connecting wires as short as possible; (2) keep signal wires away from noise sources; and (3) use a wire shield and proper ground.

a. Ground and ground loops

A ground is simply a return path to earth. A network of wires that form the return path to earth would likely act as antennae and pick up some voltage potential relative to earth ground, therefore any instrument grounded at the outlet would be referenced back to this voltage potential, not earth ground. Thus if the signal is grounded at 2 points, say at a power source ground and earth ground, the grounds could be at different voltage levels. This voltage is called the common-mode voltage. This can lead to problems.

Ground loops are brought on by connecting a signal circuit to two or more grounds that are at a different potential. A ground wire of finite resistance will usually carry some current and will develop a potential, thus two separate and different grounds, even in close proximity, can be at different potential levels. When these ground points are connected into a circuit, the potential different itself drives a current, the result is an electrical interference induced on the signal. This is a ground loop. A ground loop can manifest itself in various from, such as a sinusoidal signal or simply a voltage bias.

Figure below shows a proper connection between a ground voltage source, such as a transducer, and a measuring device. Note that the common (-) line at the measuring device is not grounded. As such, it is referred to as being isolated or as floating ground device. Many devices are grounded through their ac power lines by mean of the third prong. This can set up a ground loop relative to other circuit ground. To create a floating ground, one must break this ground connection by using a three to two prong adapter, but be sure to take proper precautions to guard against electrical shock and to ensure that the system has only one ground point.



b. Shields

Long wires act as antennae and will pick up stray signals from nearby electrical fields. The most common problem is ac line noise. Electrical shields are effective against such noise. A shield is a piece of metal foil or wire braid wrapped around the signal wires and connected to ground, it intercepts external electrical fields and return them to ground. A shield ground loop is prevented by grounding the shield at only one point, usually the signal ground at the transducer (see figure above).

A common source of electrical fields is from the ac power supply transformer. A capacitance coupling between the 60Hz power supply wires and the signal wires is set up. For example, a 1pF cap. will superimpose a 40mV interference on a 1mV signal. Another source of noise is from the magnetic field. The best prevention is to separate the signal lead wires from such sources. Twisting the lead wires together also tends to cancel any induced voltage, as the currents through the two wires are in opposite directions. A final resource is the use of a magnetic shield made from a material having a high ferromagnetic permeability.

c. Connecting Wires

There are several types of wires available. Single cable refers to a single length of common wire or wire strand. Single cable is efficient only for connections of several centimeters and involving only a few wires. Flat cable is similar but consists of multiple conductors arranged in parallel strips, usually in groups of 4, 9, or 25. Flat cable is commonly used for short connections between adjacent electrical boards, but in such applications the signals are of order of 1V or more. Neither of these two types of wires offers shielding.

Twisted pairs are widely used to interconnect transducers and equipment. The intertwining of the wires offers some immunity to noise. Cables containing several twisted pairs are available. Shielded twisted pair wraps the twisted pair within the metallic foil shield. Shielded twisted pairs are one of the best choices for most applications.

Coaxial cable consists of an electrically insulated inner single conductor surrounded within an outer conductor made a stranded wire. The cable also contains shield. Coaxial cable is the choice for high-frequency signals. Signals can be sent over a long distance with little loss. A variation of coaxial cable is triaxial cable, which contains two inner conductors. It is used in applications as with twisted pairs but offers superior noise immunity.

Optical cable is widely used to transmit low-level signal over long distances. This cable may contain one or more fiber optic ribbons within a polystyrene shell. Optical cable is virtually noise free from magnetic fields and harsh environments.