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AN INTRODUCTION TO ULTRASONIC PULSER PREAMPS

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An ultrasonic pulser preamplifier ("pulser preamp") is an electronic system generally used to improve the performance of ultrasonic systems when the transducers are connected to the instrumentation by "long" cables. The pulser preamp is located close to the transducer and connected to it by a "short" cable. For acoustic emission applications the pulser section is not required and just a preamplifier is adequate.

Using long cables can adversely affect signals in the cables in several ways:

- Reflections from the ends of the cable and reflections from impedance changes along the cable such as joins and slip rings.
- Attenuation of the signals propagating through the cable. Attenuation may be frequency dependent so that the shape of the signal changes.
- Noise from external interference.
- Delays which may affect time measurements. It takes a finite time for a signal to travel the length of a cable and this may be important in some applications.

Sensitive applications like TOFD may not be practical without the use of preamps, or pulser preamps.

WHAT IS A LONG CABLE?

As a rule of thumb, a cable is "long" if the length is greater than about 1/10 of the wavelength of the signal in the cable. This can be estimated if the frequency of the signal and the velocity of propagation of the cable are known.

If we take the velocity of light in a vacuum to be $3*10^8$ metres/second (the exact value is closer to 299,792,458 m/s), the wavelength (λ) for a 1 MHz signal is

λ_{vacuum} = (velocity in a vacuum)/frequency = $(3*10^8/1*10^6)$ metres = 300 metres.

In a coaxial cable, we multiply by the velocity of propagation percentage.

λ_{cable} = (wavelength in a vacuum)*(% velocity of propagation).

Most manufacturers of coaxial cable will publish values of velocity of propagation for their products and they will identify the material used for the insulator layer. So, for a 1 MHz signal in RG58/U cable with a polyethylene insulator, the velocity of propagation = 66% (from Belden Cables).

λ_{RG58} = (300*66/100) metres = 198 metres.

A long cable in this case is a cable that is longer than (198/10) metres, or 19.8 metres. A convenient way to calculate the wavelength at a frequency in MHz in a cable is

$$\lambda_{fcable} = (300 *V)/(F*100) = 3*V/F$$

A long cable is longer than $\lambda_{fcable}/10$, or

$$\lambda_{long\ cable} = 0.3*V/F$$

where
300 = the wavelength (in metres) of 1 MHz in a vacuum
V = the velocity of propagation in the cable as a % published by the cable manufacturer
F = the frequency in MHz

For a 5 MHz signal in RG58 cable a long cable would be longer than 4 metres, and at 10 MHz, a long cable would be longer than 2 metres.

Keep in mind that a pulse or a complex signal is actually made up of a range of frequencies, so a cable that is "short" for the lower frequencies in the signal may be "long" for the higher frequencies in the same signal.

Reflections in cables

For a pulse to travel along a cable there must be a return path back to the source of the pulse to form a complete circuit. A pulse travelling through a long cable will eventually arrive at the end of the cable, which, in effect is the start of the return path back to the source. The return path may be the screen of a coaxial cable, the other half of a twisted pair cable, or some other conducting path from the cable end back to its beginning.

How the cable connects to the return path is called the "termination". Open circuits and short circuits are both types of termination. Ultrasonic transducers form a complex termination which can be considered to be made up of a network of capacitors, inductors and resistances. In simulation or theoretical models of transducers, some of the capacitances may be negative. Amplifier inputs or outputs generally form a simpler termination.

At each frequency, the termination can be represented by a value of "impedance", which is usually expressed as a complex number with real and imaginary parts. The real part is a resistance, and the imaginary part relates to the phase of the signal. The cable itself has a characteristic impedance value, which may be different from that of the termination.

Impedance mismatches between the cable and the termination lead to reflection of pulses from the cable ends, much the same as ultrasonic pulses are reflected by discontinuities in impedance in materials. If the cable is short, the reflected pulse merges with the initial pulse, but in longer cables the reflected pulse can travel back to the beginning of the cable and then reflect back again. The reflected pulse will be separate and delayed relative to the initial pulse. For a receiver, reflected pulses can appear as spurious echoes. For a transmitter, reflected pulses can pulse the transducer again, giving rise to further spurious echoes. For certain lengths of cable constructive or destructive interference between incident and reflected signals can occur. Cable lengths that are a multiple of a quarter of the wavelength may be an issue, for example.

To minimize reflection problems, cables must be terminated correctly. Terminations can be at the source or the load end of the cable, or both. A proper termination at the load end of the cable will minimize reflection back to the source. Proper termination at the source will minimize reflection of the reflected pulse back to the load end of the cable again.

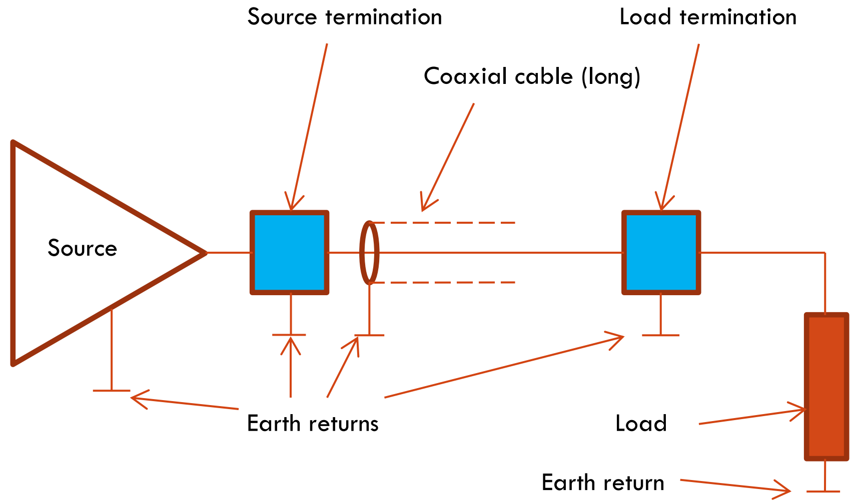

FIGURE 1: CABLE TERMINATION

For a cable from a transmitter to a transducer, the source will be the transmitter circuit and the load will be the transducer. For reception the source will be the transducer and the load will be the receiver input. In a pulse-echo configuration the same cable performs both functions. If the cable is long, there may be reflection problems for both transmission and reception. These can be difficult to resolve. Using a well-designed pulser preamp at the load end of the long cable allows the transmitter and receiver functions of the transducer to be separated and the termination optimized.

Figure 1 shows the general layout of a load (i.e. a transducer) attached to a source by a long cable. The Earth connections from the various terminations, the load, and the screen of the coaxial cable all terminate back at the source. Note that a series termination will not have an Earth connection. Ideally, all the Earth connections connect to the same potential. If not, external interference may add noise to the wanted signal via the return path (an "Earth loop").

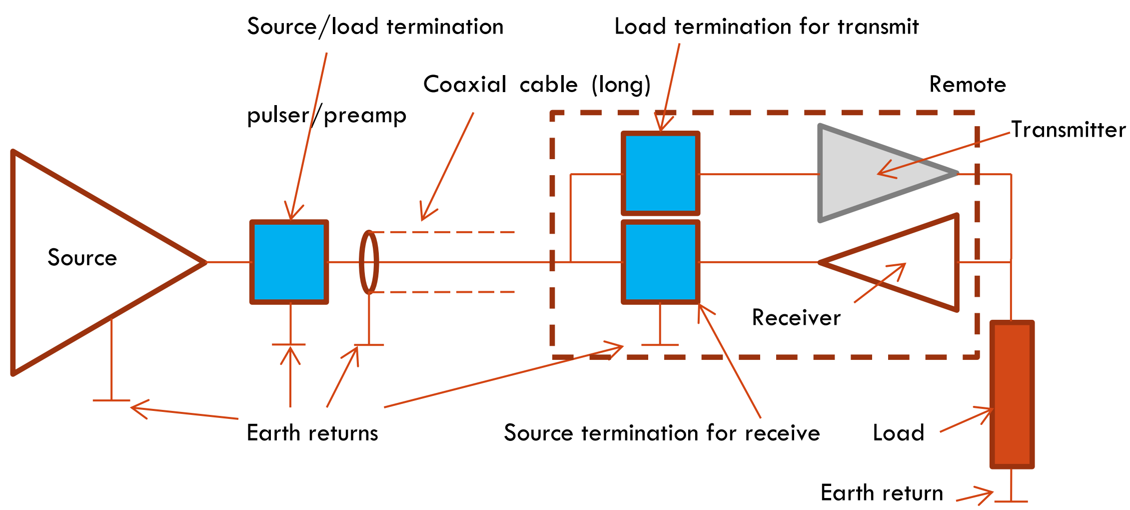

FIGURE 2: REMOTE PULSER PREAMP

Figure 2 shows a remote pulser preamp configured to work through a single coaxial cable. The transmit and receive functions now have separate terminations at the transducer end of the cable, allowing both functions to be optimized for reflection and avoiding the complexity of impedance matching the transducer to the cable. It is also possible to run separate transmit and receive coaxial cables.

ATTENUATION AND IMPEDANCE OF CABLES

Cables behave differently at low and high frequencies. In particular, coaxial cables have a transition from low frequency behavior to high frequency behavior that can occur within the same frequency range that may be of interest in many NDT applications. For cables, high frequencies are those that are higher than the transition zone frequency range, and low frequencies are lower than the transition zone frequency range. For attenuation and impedance, the frequency transition zones are similar, but not necessarily the same. In RG58 coaxial cable, for example, the transition frequency range is around 100 KHz. While this frequency range is low for conventional ultrasonic NDT, it may be of concern for acoustic emission and ultrasonic guided wave applications.

Coaxial cables really only act like transmission lines at higher frequencies.

Attenuation in cables has three main causes.

1. Skin effect losses in the conductors.
2. Dielectric losses in the insulators.
3. DC resistance losses in the conductors due to the resistivity of the conductor.

Attenuation due to the skin effect or to dielectric losses is frequency dependent. At low frequencies DC and skin effect losses dominate, and the effective impedance of the cable can be a lot higher than the characteristic impedance. At higher frequencies dielectric losses dominate.

Manufacturers publish attenuation data for coaxial cables. The attenuation tends to increase as the OD of the cable decreases, so that cables like RG58 or RG59 have attenuations of about 6-10 dB/100 metres at 50 MHz, smaller diameter cables like RG174 or RG178 have attenuations around 22-35 dB/100 metres. The attenuations are lower at lower frequencies.

Cable manufacturers publish the DC resistance of the conductors in cables in Ohms/km. In the following table (using data from Belden), DC resistance is expressed in Ohms/100 metres as a more useful measure. Cable capacitance is published as pF/metre. The capacitance depends on the material used for the inner insulator.

Cable	**Attenuation dB/100m @ 50MHz**	**DC resistance Ohms/100m (at low frequency)**	**Capacitance pf/m**	**OD mm**	**Core**
RG179/U	27.9	82	64	2.54	stranded
RG178/U	34.4	82	95	1.83	stranded
RG174/U	21.7	31.8	101	2.56	stranded
RG59/U	5.9	20.2	53-69	6.15	solid
RG58/U	10.5	2.9	85-101	4.95	stranded

FIGURE 3: CABLE ATTENUATION (DATA FROM BELDEN CABLES)

The DC resistance of the cable may need to be considered at ultrasonic frequencies, and will contribute to the thermal noise at the receiver input.

In short cables and at lower frequencies below transition, the cable can be considered as a series resistor shunted by a capacitor, with values determined from DC resistance and capacitance data like that in Figure 3. As cable length increase to more than 1/10 wavelength, and the frequency increases, the cable behaves more like a transmission line.

Finally, it should be noted that ultrasonic signals and transmit pulses are not single frequencies, but are actually sets of frequencies, and the effect of cable capacitance, or transmission line effects, may be different for the higher end of the frequency set than at the lower end. This can be seen when spike style transmit pulses are transmitted over long cables. See Figure 4.

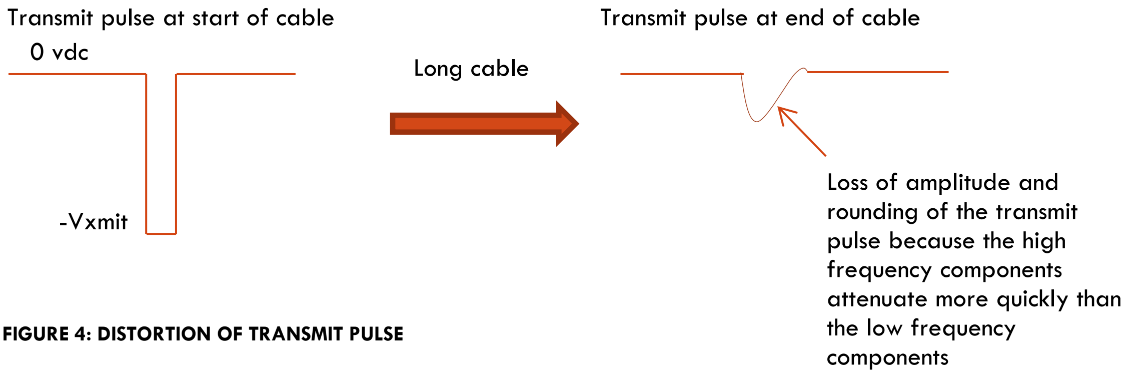

FIGURE 4: DISTORTION OF TRANSMIT PULSE

TRANSMIT PULSE RECONSTRUCTION

Pulser preamps from NTS Ultrasonics reconstruct the transmit pulse if it has been degraded by a long cable. The circuit has its own pulser and high voltage supply, and a new –ve pulse is generated when a degraded pulse is received via the cable. The received pulse can be the original transmit pulse from the ultrasonic flaw detector, or a low voltage synch pulse.

CABLE SHIELDING

If a wire conducting an electric signal is subject to an external electromagnetic field, interference voltages will be superimposed onto the signal in the wire. Shielding is one way of minimizing the effect of external interference. Electric motors, in particular stepper motors, and switch mode power supplies may be strong sources of electromagnetic interference in ultrasonic systems.

Cables carrying strong signals can also radiate electromagnetic signals which may couple into nearby cables (cross-talk) or cause interference in sensitive electronic equipment located nearby. Cable shielding minimizes the radiation of interfering signals.

Coaxial cables incorporate shielding by virtue of how they are constructed. Twisted pair cables may have an external shield covering the pair of cables. There are three basic types of cable shield:

1. Conductive foil
    a. 100% coverage
    b. Best at high frequencies
    c. High DC resistance
2. Woven wire
    a. 40% to 98% coverage
    b. Good at low frequencies
    c. May be OK at high frequencies
    d. Low DC resistance
3. Wrapped wire (spiral shield)
    a. Coverage over 90%
    b. Low DC resistance
    c. Only suitable for audio frequencies

Higher quality shielded cable may have a combination of foil and wire shields.

- Combine 100% coverage of braid with low DC resistance of braid

- Good over a wide range of frequencies

Manufacturers specify the shielding type, % coverage, and shield DC resistance in their cable specifications. Coaxial cables like RG58 and RG59 are available in different grades with braid shields, foil shields, or combination braid/foil shields. Other coaxial cable types, such as RG174, may only be available with braid shields.

A true story

Several years ago NTS Ultrasonics designed and built some acoustic emission equipment for a client to use on a site in rural Victoria (a state of Australia). As long cables were required, a preamplifier and cable driver was built into each of the AE transducers. The client's system also incorporated other sensors such as temperature and humidity sensors connected by long cables but without any signal conditioning.

The system was installed and commissioned successfully. However, after a short while the end user noticed that late in the afternoon and early evening, some of the sensor data became "noisy". The AE data was OK, but the other sensors were picking up some sort of interference.

After some interesting investigation it was discovered that there was a legal brothel located just down the road from the site where the equipment was installed. The brothel specialized in servicing truck drivers, and the girls got onto the CB radios late in the day to call in customers.

The AE sensors with the preamplifier/cable driver were unaffected by the CB radio signals, but the other sensors were susceptible.

FIGURE 5: AE SENSORS WITHN PREAMPS

Figure 5 shows some of the AE sensors with built-in preamp/cable driver electronics. Power is supplied through the signal cable.

CHARACTERISTICS OF PREAMPLIFIERS

The preamplifier portion of a pulser preamp provides voltage gain to amplify the received signal from the transducer, and if a cable driver output stage is used, it provides current gain as well.

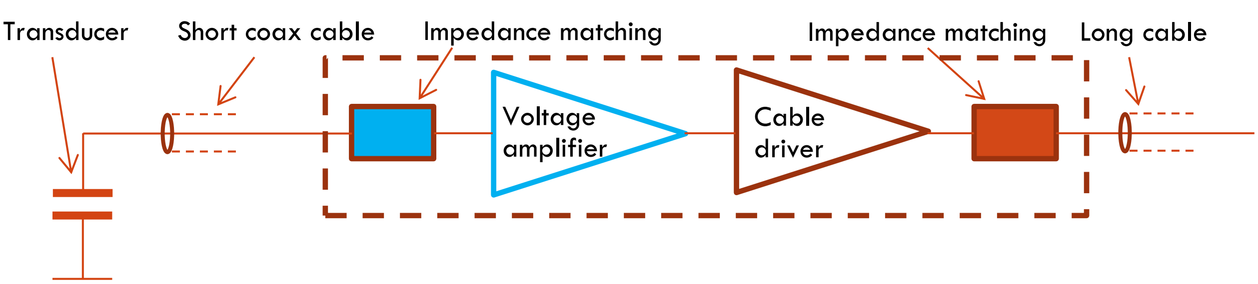

FIGURE 6: PARTS OF A PREAMPLIFIER

Input

Impedance matching at the input optimizes the quality of the signal from the transducer and the signal to noise ratio at the input of the voltage amplifier stage. Any part of the transducer, cable, and impedance matching circuit (which may also include input protection components) that can be represented partly by a resistance will contribute electrical noise and degrade the input signal to noise ratio.

Voltage amplifier

The voltage amplifier stage boosts the voltage of the signal from the transducer.

- To compensate for losses due the long cable between the preamplifier and the main ultrasonic instrumentation.
    - Cable losses will be a function of cable type (i.e. materials and construction)
    - Cable length
    - Frequency of the signals (see discussion above on "Attenuation and Impedance of Cables").
- To improve the signal to noise ratio of the signal transmitted through the long cable.

How much voltage gain should be provided by a preamplifier is difficult to calculate. Not only must the cable losses and signal to noise ratio be considered, but so must the input voltage range of the ultrasonic instrumentation at the far end of the long cable. For example, if the flaw detector has an input voltage range of +/- 5 volts (i.e. any signal greater than +5 volts or less than – 5 volts will be clipped), the signal delivered to the flaw detector should be less than +/- 5 volts if the signal to noise ratio is to be maintained. It is better to determine the optimum gain by trial and error.

Preamplifiers can have different types of gain setting.

- **Fixed gain**. 20 dB and 40 dB are common gains used for preamplifiers. No user adjustment.
- **Switchable gain**. The user can use an internal switch in the preamplifier to select one of two or three gain settings.
- **Variable gain**. The user sets the gain of the preamp to a suitable value by manually setting a control on the preamplifier.
- **Remotely controlled switchable or variable gain.** The preamp has additional control inputs (e.g. an SPI port) that allows the gain to be controlled externally and remotely.

Noise

Voltage amplifiers used in preamps typically have very low noise characteristics. Noise can be in the form of random voltages ("voltage noise") or currents ("current noise") superimposed onto wanted signals, and depending on the circuit, one or the other, or both will be important. The noise component of the signal on the long cable running from the preamplifier to the flaw detector will have contributions from the transducer, the impedance matching and protection circuit, and the amplifier, all multiplied by the gain of the preamplifier. A well designed preamplifier minimizes the noise contributions from these sources.

There are electronic design techniques for minimizing electrical noise, but it cannot be removed altogether. There are also different ways of specifying the amount of noise in a signal, and different suppliers use different methods, making comparisons between different pulser preamplifiers difficult.

How to compare the noise performance of different preamplifiers with different types of noise performance specification is beyond the scope of this note to explain. However, the following notes may help.

Noise performance depends on the frequency bandwidth of the input and output signals: wider bandwidth gives a higher level of noise. It should also be noted that for the purpose of calculating noise performance, amplifiers are modelled with an input noise source representing all the noise generated by the amplifier, followed by a perfect "noiseless" amplifier which provides the gain of the amplifier. Noise at the input is called "input referred noise". "Output referred noise" is the input referred noise multiplied by the gain of the amplifier.

The following terms may be used in specifications to describe the noise performance of a preamplifier.

- **Noise voltage** (density): usually expressed in nanovolts divided by the square root of the frequency bandwidth.
  - To get the rms noise voltage multiply the noise voltage by the square root of the bandwidth.
  - The input referred voltage noise of an amplifier does not take into account the voltage noise generated by the cable or transducer, or the matching and protection circuit.
- **Noise current** (density): usually expressed in PicoAmps divided by the square root of the frequency bandwidth.
  - To get the rms noise current, multiply the noise voltage by the square root of the bandwidth.
  - The input referred current noise of an amplifier does not take into account the current noise generated by the cable or transducer, or the matching and protection circuit.
- **Equivalent input noise**: usually quoted in uV_{p-p} (microvolts peak to peak) over a bandwidth.

Noise voltage and noise current are sometimes called "noise densities" because they must be divided by a bandwidth factor to get an estimate of the actual noise.

Other terms such as **Noise Factor** and **Noise Figure** may be encountered in discussions of electronic noise in amplifiers, but are rarely used in specifications for preamplifiers for ultrasonic NDT and AE use. The Noise Factor is the ratio of input to output signal to noise ratios. The Noise Figure is the base 10 logarithm of the Noise Factor. The Noise Factor and Noise Figure are meaningless without knowing the bandwidth.

Note that some commercial suppliers of preamplifiers and pulser preamps for ultrasonic NDT use noise specifications incorrectly or in confusing ways that do not allow the noise performance to be worked out and compared to other preamplifiers.

When a preamplifier specification quotes an input noise specification of close to 1 nV/sqrtHz, it may be quoting the input noise value for the integrated circuit used in the input stage of the amplifier (with possibly the input shorted to ground) and not the input noise for the whole input circuit with impedance matching, feedback, and protection included.

The noise performance of a preamplifier can be improved by the use of high, low, or bandpass filters. So, a preamplifier with a bandwidth of 80 MHz or 100 MHz will have its noise performance improved if the bandwidth is restricted to less than 25 MHz, for example. Noise density is proportional to the square root of the bandwidth, so a 100 MHz bandwidth will produce twice the noise density (nV_{rms}/sqrtHz) of a preamplifier with a 25 MHz bandwidth.

Worked examples

Example 1. A very low noise amplifier with all sources of input noise combined to give an input referred noise (density) of 1 nV/sqrtHz will produce 1nV*sqrt(1000000) = 1nV*1000 = 1 uV rms noise over a 1 MHz bandwidth.

Example 2. A preamplifier specification quotes 5 uV_{p-p} over a 2 MHz bandwidth. First, estimate the rms value of the noise voltage. 5 uV_{p-p} = +/- 2.5 uV_p. 2.5 uV_p = 2.5*0.707 uV_{rms}, = 1.77 uV_{rms}.

The square root of 2 MHz = 1414.2 sqrtHz. Therefore the input noise density = 1.77/1414.2 uV/sqrtHz = 0.0013 uV/sqrtHz = 1.3 nV/sqrtHz.

Logarithmic Preamplifiers

In some applications it is desirable to compress the transducer signal to capture the full dynamic range without large amplitude signals being clipped (or limited) by the output voltage swing of the preamplifier. One way to achieve this is to deliberately distort the signal as it is amplified by amplifying large amplitude signals less than small amplitude signals. It is convenient to do this using a logarithmic scale for the distortion.

Strictly speaking, only positive values of voltage can be compressed logarithmically (i.e. rectified signals or a DC logarithmic amplifier), but it is possible electronically to compress a negative voltage signal in the same way as a positive signal, forming an AC logarithmic amplifier, also called a “baseband” logarithmic amplifier.

Input and output voltage swing

While most signal output from an ultrasonic transducer are very small, it is possible to have output signals with peak values of several volts in response to very strong echoes. Also, if the transducer face is knocked, the resulting voltage may be several 10s of volts, which may be enough to damage the preamplifier if unprotected.

Preamplifiers for ultrasonic applications are usually protected from large input voltages. Voltages greater than the protection levels are clipped to the protection level. However, the protection levels, maybe +/- 5 vdc for example, represent very large signals which may be too large for the amplifier to amplify without serious distortion. If a preamplifier has a +/- 10 vdc output swing and a gain of 20 dB (i.e. a gain of 10), the maximum input range to produce an undistorted output will be +/- 1 vdc.

Some of the modern integrated circuits that offer very low noise performance for ultrasonic applications and which may be used in ultrasonic preamplifiers have input voltage ranges as low as +/- 0.275 vdc. This may be insufficient for some NDT applications as some wanted signals may be clipped. It may be necessary to use an input attenuator between the transducer and the preamplifier to reduce the amplitude of the signals. However, using an attenuator may worsen the signal to noise ratio, so careful consideration needs to be given to dynamic range, noise, and input and output voltage swings.

Cable driving

One way to limit interference from external sources in cables is to amplify the driving signal to the cable so that any noise interference represents a smaller proportion of the conducted signal. When a transducer outputs a signal it must be conducted by cable to the ultrasonic instrumentation. A basic transducer has no signal amplification and options for maintaining the signal to noise ratio are limited if a preamplifier is not used when the cable is long.

A preamplifier provides voltage amplification for the output signal from a transducer. Following the voltage amplifier stage, a cable driver will provide additional current amplification, and many preamplifiers are actually a preamplifier/cable driver combination. The current amplifying output stage will have low output impedance which can be easily matched to the impedance of the cable being driven.

USING PULSER PREAMPLIFIERS

When a “long” cable is required to connect a transducer to an ultrasonic instrument, many of the problems discussed above may be reduced by placing a pulser preamp close to the transducer and running the long cable from the remote pulser preamp to the ultrasonic instrument. The transducer connects to the pulser preamp by a short cable.

Providing power to the pulser preamplifier

Power can be provided to a remote pulser preamp in several ways.

- Battery.
  - If the pulser preamp is not designed for very low power consumption it will be necessary to have an ON/OFF switch.
- External power source.
  - External power needs to be “clean”. Any noise or switching transients from switching circuits or motors will introduce noise into the power supply.
- Through the signal cable.
  - It is possible to feed DC power into the signal cable at a convenient location and separate it from the signal at the pulser preamp. This is a very attractive option as it simplifies wiring: only a single cable is required for signal and cable. However, additional protection is required to protect the amplifier output from damage from the transmit pulse.

Using the transmitter

It is possible to use an ultrasonic instrument in T/R mode with separate cables for transmit and receive and just a preamplifier. The transducer connects directly to the transmit cable and the receive signal is taken from this cable, amplified by the preamplifier, and transmitted back to the instrument using a separate cable.

This approach requires two cables between the instrument (flaw detector) and the transducer and preamplifier. A remote pulser is not used, so the transmit pulse will be degraded by the long transmit cable.

It is better to use the pulser preamp to reconstruct the transmit pulse, as described above. This provided a reconstructed transmit pulse to drive the transducer. However, reconstruction of the transmit pulse introduces a small delay which must be taken into account when analyzing the ultrasonic data.

A transmitter is not required in acoustic emission applications.

Pulser preamplifiers from NTS Ultrasonics

NTS Ultrasonics does not supply off the shelf pulser preamplifiers. Off the shelf units are rarely optimized for any specific application. It is better that these circuits are custom designed to achieve optimum performance in specific applications, taking into account the characteristics of the transducer being used, the available cabling, the physical space, the inputs characteristics of the flaw detector or instrumentation, and the available sources of power.

Design experience at NTS Ultrasonics includes preamps and pulser preamplifiers for ultrasonic NDT (e.g. TOFD, ROV, and diver applications), AE applications, and high frequency sonar applications.

FIGURE 7: PULSER PREAMPLIFIER (WITH MORE ELECTRONICS ON THE BACK)

Figure 7 shows a pulser preamp designed and built by NTS Ultrasonics for a client to use in a subsea application. The circuit incorporates transmit pulse reconstruction, an on-board high voltage generator, a variable gain preamplifier, a cable driver with variable output impedance, with connections for a single coaxial cable or a single twisted pair cable. Power is supplied through the cable.

This pulser preamp is an example of custom designed ultrasonic equipment from NTS Ultrasonics. An example of a custom designed preamplifier for a 1 MHz towed sonar array application is shown in Figure 8. This circuit uses separate signal and power cables.

FIGURE 8: SONAR PREAMP

APPENDIX: A NOTE ABOUT CABLES.

In terms of transmitting ultrasonic signals, the most commonly used type of cable is the coaxial cable. However, in some applications, such as when ultrasonic instrumentation is deployed sub-sea, the ultrasonic instrumentation may have to use whatever cabling is available in the ROV umbilical cable, which may only be a twisted pair.

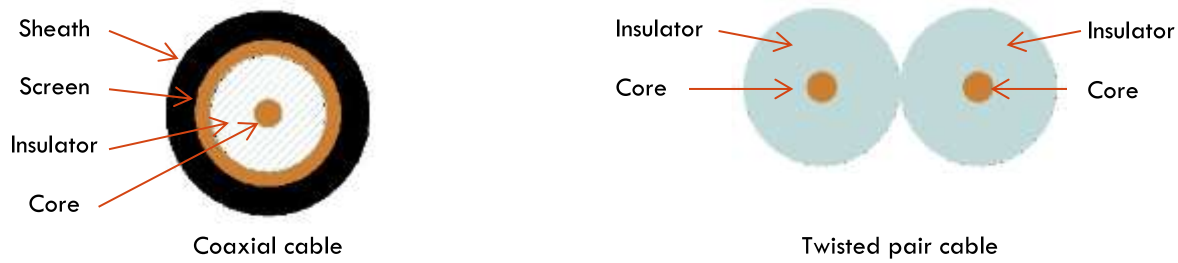

FIGURE 9: CABLE TYPES

Coaxial cables are generally used as single cables with a single core, although twin coax cables are available, and twin core cables (“twinax”) are also available. Twisted pair cables are often grouped together in multicore cables. Within the multicore cable, individual twisted pairs may have screens.

Coaxial cables are generally preferred for higher frequency applications and twisted pair cables for lower frequency, low cost applications. However, recent improvements in the design of twisted pair cables for applications such as gigabit Ethernet, so that Cat 6A cables are rated for use up to 500 MHz over 100 metres (with 45 dB loss).

Cable cores.

The cable core is the central conductor that carries the signal. Cores can be “solid” with a single wire, or “braided” with multiple thin conductors twisted together. Braided cores are better for high frequency, low voltage use, and solid cores are better for low frequency, high voltage use. Braided cores are more flexible and better suited for most ultrasonic applications.

Key cable specifications for ultrasonic applications.

The theory associated with the use of cables is complex and best left to electronic engineers. Practitioners of ultrasonics, however, do need to understand something about how cables are specified. In particular: cable impedance, velocity of propagation, and screening.

Cable impedance.

The value given in cable specifications is actually the “characteristic impedance” of the cable. This is a theoretical value that ideally represents a hypothetical measurement taken on an infinitely long cable. That is, the measurement can be taken before the signal arrives at the other end, and so the measurement represents the cable and not the combination of the cable and what it is attached to. For a coaxial cable, the measurement takes into account the influence of the core, the shield, and the insulator between them.

The characteristic impedance of the cable is independent of the length of the cable.

Typical impedances for coaxial cables are 50 Ohms, 75 Ohms, and 93 Ohms. A typical impedance value for twisted pair cables is 100 Ohms, although many twisted pair cables are poorly characterized and an impedance value may not be given.

Changes in impedance along a cable cause reflection, much the same as in ultrasonics. For this reason connectors for cables also have characteristic impedance which should match that of the cable.

Velocity of propagation.

Electronic signals travelling along a cable travel at less than the speed of light. This is quite well characterized for coaxial cables. The value depends on the material used for the cable insulation. Cable specifications give the velocity of propagation as a % of the speed of light.

Cable	Insulator	Velocity of propagation (% speed of light)	Impedance (Ohms)
RG179/U	Teflon	69.5%	75
RG178/U	Teflon	69.5%	50
RG174/U	Polyethylene	66%	50
RG59/U	Cellular polyethylene	78%	75
RG59/U	Polyethylene	66%	75
RG58/U	Cellular polyethylene	78%	50
RG58A/U	Cellular polyethylene	78%	50
RG58/U	Polyethylene	66%	50

FIGURE 10: VELOCITY OF PROPAGATION FOR COMMON CABLE TYPES USED IN NDT (DATA FROM BELDEN)

Insulator material.

The effect of the insulator material in a coaxial cable is quite significant. The properties of the insulator affect the velocity of propagation for the cable, the capacitance of the cable, and the attenuation of the cable.

Screening.

The traditional screen of a coaxial cable is usually woven or wrapped using very thin wire. This allows the cable to be flexible. However, it does not provide 100% effective screening from external electromagnetic interference. This interference adds to the signal and degrades the signal to noise ratio. Some coaxial cables and many twisted pair cables use an additional screen consisting of a conductive polymer. This maintains the flexibility of the cable and improves the screening.

In coaxial cables the screen provides the return path for the signals to and from the transducer and is usually connected to Earth at one end. If the screen is connected to Earth at both ends, there is the possibility of ground loop currents running through the cable inducing unwanted signals onto the central conductor. Ground loops can also be a problem if the transducer has a metal body with is earthed.

The same consideration about earth loops applies to twisted pair cables.