A LOW-COST AND HIGHLY RELIABLE AMPLITUDE MODULATOR DESIGN FOR PC-BASED PCI PLUG ULTRASONIC PULSER RECEIVER BOARDS

DR AHMET TURAN ÖZDEMIR FROM ERCIYES UNIVERSITY IN TURKEY PRESENTS A NON-INVASIVE TESTING TECHNIQUE FOR DETERMINING THE INTEGRITY OF A MATERIAL OR QUANTITATIVELY MEASURING ITS DESIRED CHARACTERISTICS WITHOUT DAMAGING IT

Non-Destructive Evaluation (NDE) is a non-invasive testing technique used for determining the integrity of materials or for quantitatively measuring their desired characteristics without damaging them. Moreover NDE techniques can be used to detect deformed areas, cracks, porosity and leaks, to characterize structures, measure dimensions and determine locations.

There are many NDE techniques around, such as visual inspection, tap testing, laser interferometry, thermography, x-rays, magnetic particles, acoustic emission, liquid penetrant, flux leakage, microwave, eddy current etc. However, ultrasonic non-destructive evaluation or ultrasonic testing (UT) is one of the most preferred inspection techniques in the field of composite material testing.

Ultrasonic Non-Destructive Testing

Through Transmission (TT) is the most common UT technique used for composite material inspection in the aerospace industry. A TT system consists of a pulser, digitizer, transmitter transducer and receiver transducer. Figure 1 shows a PCI plug TT system with its peripherals. The aim of the TT method is to carry ultrasonic waves between the transmitter and receiver transducers. The inspected material is placed between these transducers and the measured signals on the digitizer side are used to monitor the material's characteristics.

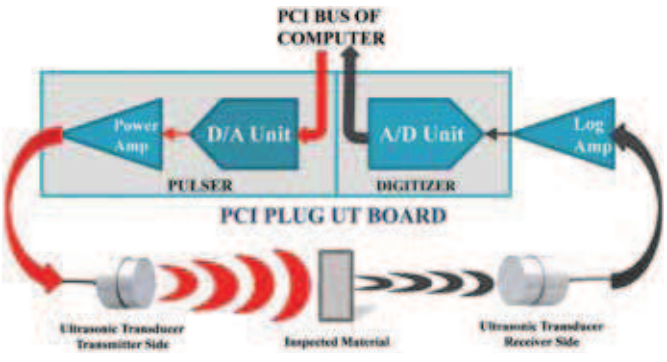


Figure 1: Basic configuration of a PCI plug TT system

A logarithmic amplifier is an optional peripheral needed on the digitizer side when the inspected material is thick, as thick composite materials (> 4cm honeycomb composites) are highly attenuative. The gap between the minimum and maximum signal amplitudes increases with attenuation. If the ultrasonic signal attenuation is too drastic, it is impossible to keep the amplitude variation within limits of the digitizer's analog-to-digital converter (ADC), because its sensitivity is generally 2V and this range can be easily exceeded. Figure 2 shows the typical relationship between the input and output signal of a logarithmic power amplifier.

The logarithmic power amplifier detects the burst envelope and produces logarithmic response as a function of the input voltage. A sinusoidal input signal consists of five different amplitude levels: 1mV, 10mV, 100mV, 1V and 10V (see Figure 2). The input signal varies from 0 to 10V peak voltage; however, the amplifier output varies from 0.1V to 1.53V. The amplifier output's slope is 0.2441V, which is ten times the voltage difference of the amplifier input. The 1mV and 10mV sinusoidal signals cannot be shown in the figure because of the linear graphical representation of the amplitude axis. The amplifier response was produced in Matlab environment.

The output signal of the logarithmic power amplifier is an envelope function of the burst pulses that becomes a DC signal level. The amplifier output cannot be read if the sampling unit has a high-pass or band-pass filter. The high- and band-pass filters need at least one frequency threshold, and it usually starts from 0.6MHz in PCI plug UT boards.

TT tests can be performed in an immersion tank, or with a water squirter or air scanning systems. Air is a highly attenuating medium, therefore large amplitude losses appear in the ultrasonic waves in the air. However, water is a good medium that carries ultrasonic waves between transmitter and receiver transducers with small losses.

In this work, a water squirter scanning system was used to carry ultrasonic waves (see Figure 3). There are two nozzles in the figure; the one on the left covers the piezoelectric transmitter transducer and the one on the right covers the piezoelectric receiver transducer.

PCI Plug UT Boards On The Market

Digitizer and pulser units can be separate or integrated. There are many integrated PCI plug UT boards available on the market; some are shown in Table 1. All of these boards have a band-pass filter on their digitizer side. Only the TB 1000 makes it possible for a user to disable the filtering and to read DC signals. This limitation becomes problematic when logarithmic amplification is needed in the TT system, because the amplifier output becomes a DC signal if the logarithmic amplification is made by a logarithmic power amplifier, and a converter unit is needed to read the amplifier output of UT boards on the market. Because of this problem, a cheap and reliable amplitude modulator has been designed. This modulator is necessary when using fast logarithmic power amplifiers with digitizer units with built-in filters.

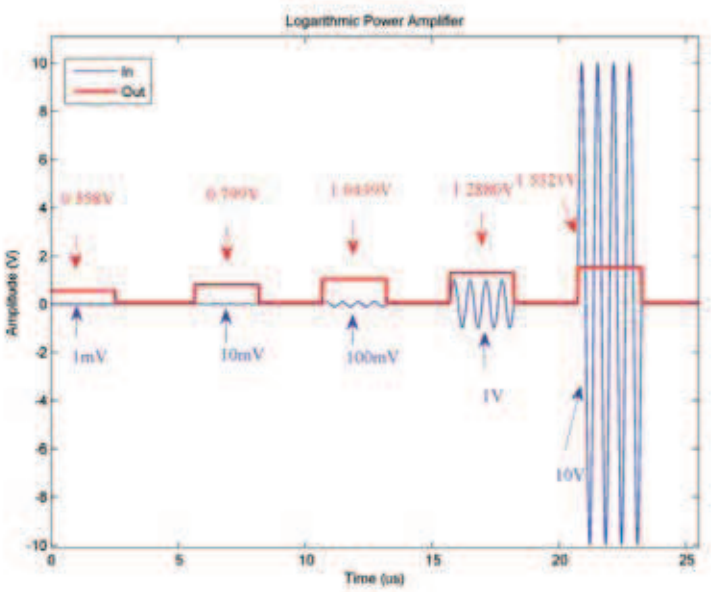


Figure 2: Potential power savings for different network standards

Amplitude Modulator Unit

In this work, an amplitude modulator was designed to modulate the logarithmic power amplifier output with the desired carrier frequency. Figure 4 shows the modulator simulation results. A 100kHz sinusoidal signal (red) is modulated by a 5MHz square wave (green) and an amplitude modulated signal is achieved (blue). In this circuit, Analog Devices's AD8036A low-distortion, wide-bandwidth, voltage feedback clamp amplifier was used as a modulator. The AD8036A input resistance is 150kΩ and output resistance is 0.3Ω. Its bandwidth is typically 240MHz and slew rate 1200V/µs. It is a very fast amplifier; its rise and fall times are 1.4ns for V_{out} = 0.5V step and 2.6ns for V_{out} = 4V step.

The modulator circuit schematic is shown in Figure 5. LTC1799 is an oscillator IC used for carrier frequency generation. This IC can generate square waves up to 33MHz. This is a sufficient range to generate ultrasonic waveforms, since 1, 2.5 and 5MHz are the preferred frequencies in the TT inspection method.

The LTC1799 is supplied in a +3.1V and -1.9V supply configuration, which helps produce a symmetric square wave in the 5V range. The positive supply voltage is larger than the negative one because the modulated signal logarithmic power amplifier output varies in the positive scale, and the amplifier's non-inverting input was used for modulation. Resistors R7 and R8 were chosen to be 274Ω since this configuration results in unity amplifier gain. Impedance matching is by resistor R9, because

Company	Device
Sofratest	SFT-4001H
Socomate	PC-RCPP7101
Ultrasonic Science	PM30
Mistras	ADIPR 1210
Us Ultratek	DSPUT 5000
Matec	TB 1000

Table 1: Some of PCI Plug pulser and receiver boards available on the market

Unit	Channel 1 (1MHz)	Price	Unit	Channel 2 (5MHz)	Price	Unit	Power Supply, Box and PCB	Price
1	AD8036A	9.99	1	AD8036A	9.99	1	24V to ±12V	40.19
1	LTC1799	4.99	1	LTC1799	4.99	1	LT1175	5.52
1	200kΩ Trimmer	4.94	1	200kΩ Trimmer	4.94	1	MIC5239-5	3.06
2	SMA Connector	4.80	2	SMA Connector	4.80	4	10uF 16V Tantal	0.75
1	1kΩ Trimmer	1.65	1	1kΩ Trimmer	1.65	2	100nF Capacitor	0.10
1	10uF 16V Tantal	0.75	1	10uF 16V Tantal	0.75	3	300Ω Bead	0.10
1	100nF Capacitor	0.10	1	100nF Capacitor	0.10	1	Aluminium Box	18.80
9	Resistors	0.10	9	Resistors	0.10	1	PCB	5.00
EACH UNIT		32.92			32.92			76.07
TOTAL								$ 141.91

Table 2: List of electronic components and hardware costs

Figure 3: A water squirter system

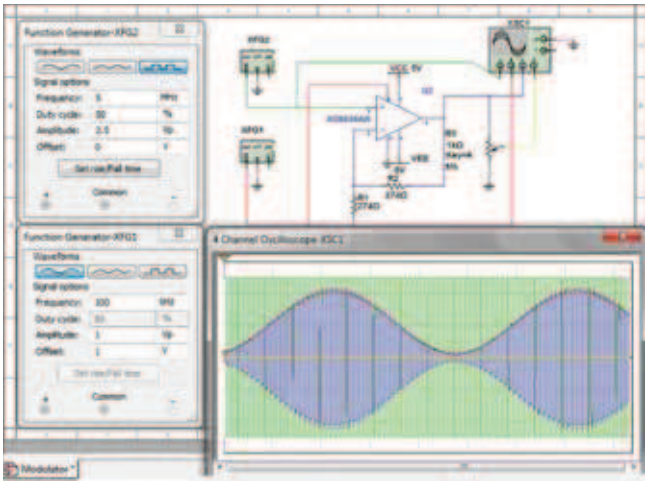


Figure 4: Modulator circuit simulation results

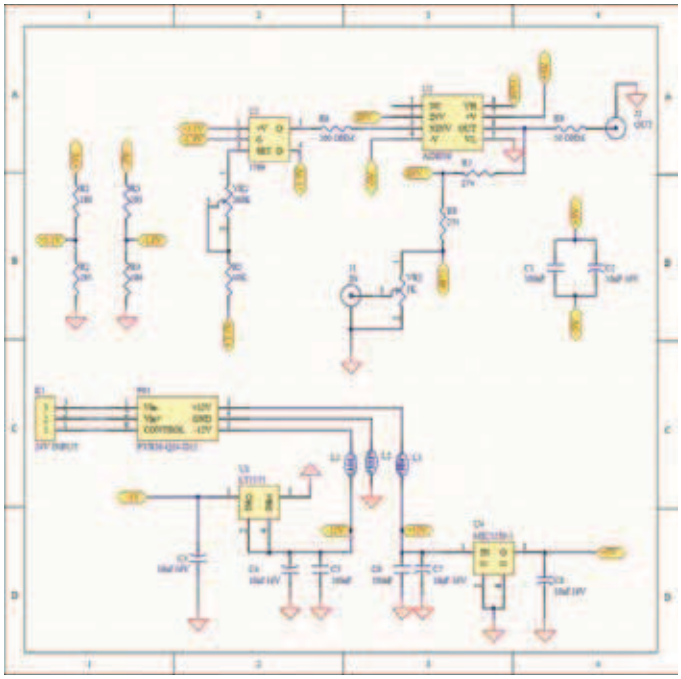


Figure 5: Modulator unit schematic diagram

this resistor should be the same as the digitizer input impedance, generally 50Ω. Resistors R1, R2, R3 and R4 are a voltage-divider tree. PS1 is a 24V to ±12V DC-to-DC converter that feeds two regulator units: MIC5239 (+5V LDO) and LT1175 (-5V LDO). The reason for selection of 24V input voltage is the availability of 24V in industrial areas.

Figure 6 shows the test setup of the modulator unit. The modulator input signal was produced by a signal generator. The input and output of the modulator unit were measured with a dual-channel 500MHz oscilloscope. The 200kHz sinusoidal signal was applied to the modulator unit, which then modulated this signal with a 5MHz square wave.

The input and output signal waveforms are shown in Figure 6. There are four oscilloscope screenshots in Figure 6; channel A shows the input and channel B shows the output of the modulator. The 200kHz sinusoidal, square wave and triangle input and output signal waveforms are shown in Figures 6a, b and c respectively. Figure 6d shows the logarithmic power amplifier output (red) and its modulated output (blue). The logarithmic power amplifier amplifies 1kHz signal bursts, and the modulator modulates the output of the amplifier with a 5MHz square-wave.

Results

The modulator circuit has been used for more than eighteen months without any issues at the Turkish Aerospace Industries inspection department on a 10-axis ultrasonic scanning system. The modulator is very reliable and has been used with the US Ultratek DSPUT 5000 PCI plug ultrasonic pulser and receiver board. This board and modulator have two channels: one for 1MHz and the other for 5MHz. Figure 7 shows the hardware test setup, while Figure 8 shows the modulator's PCB in its aluminum case.

The modulator's power consumption is 3.36W or 140mA current consumption at 24V input voltage. The cost of the modulator unit is given in Table 2. Two channel modulator unit costs $141.91 from DigiKey.

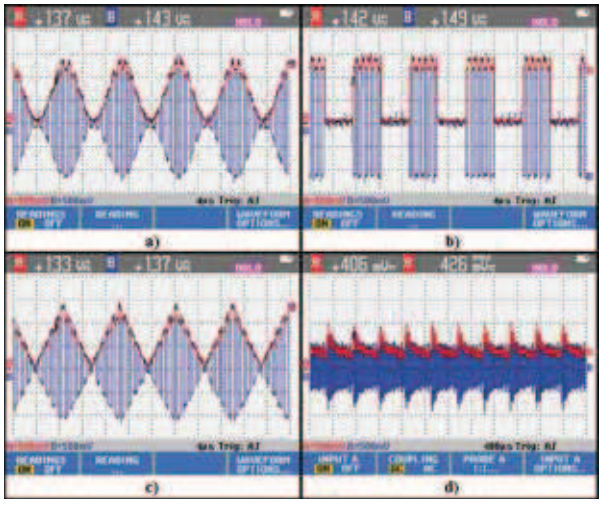
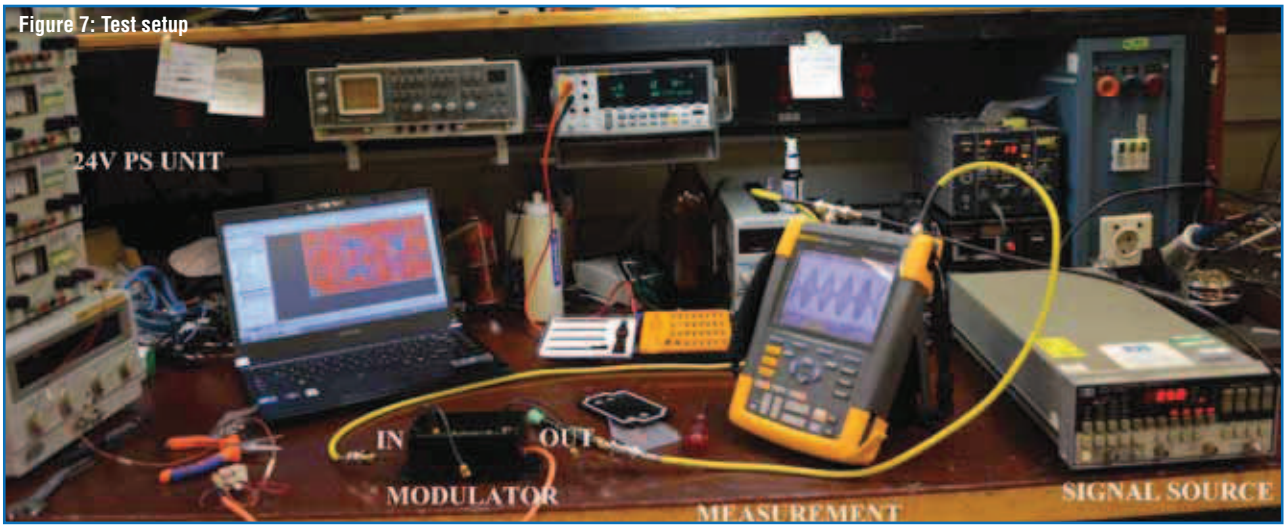


Figure 6: Oscilloscope screenshots

Figure 7: Test setup



In an ultrasonic inspection system, reliability is very important because 120dB signal attenuation is measured with a 2V ADC range. Therefore, the signal responses of all units must be stable, otherwise each inspection may not give results with the same characteristics. These inspection systems are certified each year, where the signal integrity is expected to be stable. Users must be aware of environmental noises, such as switch-mode power supplies, electric motors and large machines, that can interfere with ultrasonic signalling. Therefore, the scanning system and instrumentation hardware must be isolated from these noise sources, and calibration must be performed as soon as any hardware modification is made. ●

Figure 8: Modulator PCB