ISSN (Print) : 2320 – 3765
ISSN (Online) : 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 9, September 2015

Design and Development of High Voltage Pulse Generator and Receiver Circuit for Ultrasonic Velocity Measurements in Binary Liquid Mixtures of Benzene with Alcohols

Dr. Shaik Abdul Jaffar

Research Scholar, Department of Instrumentation, Sri Krishnadevaraya University, Anantapuramu, India

ABSTRACT: This paper discusses the design and development of a single channel transceiver for broad bandwidth ultrasound applications.. The transceiver has the pulser as transmitter and a broad bandwidth receiver. A high requency ultrasound transducer is used both for the transmission of ultrasound pulse and for receiving the ultrasound echoes. The pulser circuit is a high voltage, high speed, switching circuit designed for 20 V pulse amplitude and pulse width as low as 10 ns. The preamp is a low noise, wide bandwidth amplifier and the time gain compensation circuit has a low noise figure and a bandwidth of 15 MHz. Custom, miniaturized PCB's have been fabricated and tested for the R.F. electronics. The performance characteristics of 2 MHz transducers are tested and calibrated.

KEYWORDS: Pulse generator, Pulser-Receiver, Ultrasonic velocity measurements

I.INTRODUCTION

Ultrasonic pulser-receivers are well suited to general purpose ultrasonic testing. Along with appropriate transducers and an oscilloscope, they can be used for flaw detection and thickness gauging in a wide variety of metals, plastics, ceramics, and composites. Ultrasonic pulser-receivers provide a unique, low-cost ultrasonic measurement capability The pulser section of the instrument generates short, large amplitude electric pulses of controlled energy, which are converted into short ultrasonic pulses when applied to an ultrasonic transducer. Most pulser sections have very low impedance outputs to better drive transducers. Control functions associated with the pulser circuit include:

- Pulse length or damping (The amount of time the pulse is applied to the transducer.)
- Pulse energy (The voltage applied to the transducer. Typical pulser circuits will apply from 100 volts to 800 volts to a transducer.)

In the receiver section the voltage signals produced by the transducer, which represent the received ultrasonic pulses, are amplified. The amplified radio frequency (RF) signal is available as an output for display or capture for signal processing. Control functions associated with the receiver circuit include

- Signal rectification (The RF signal can be viewed as positive half wave, negative half wave or full wave.)
- Filtering to shape and smooth return signals
- Gain, or signal amplification
- Reject control

The pulser-receiver is also used in material characterization work involving sound velocity or attenuation measurements, which can be correlated to material properties such as elastic modulus. In conjunction with a stepless gate and a spectrum analyzer, pulser-receivers are also used to study frequency dependent material properties or to characterize the performance of ultrasonic transducers. This work presents circuits that are developed to excite ultrasonic transducers transmitters and to receive the coming signals of ultrasonic transducers receivers [1-3]

II.DESIGN CONSIDERATIONS

(i) High frequency pulse generator:

The First part to be designed was the transmitter (Fig.1). It was decided to use an analog circuit to generate the driver frequency, mostly due to better accuracy and reliability. An LM555 timer constantly provides an square signal of the 5MHz frequency; this signal is connected to the monostable multivibrator which generates pulse width 3 us. The sample rate is 500 Hz. The output of 74121 is applied to the IRF530 Power MOSFET which utilize advanced processing techniques to achieve extremely low on-resistance per silicon area. This benefit of the IRF530, combined with the fast switching speed and ruggedized device design that HEXFET power MOSFETs are well known for, provides the designer with an extremely efficient and reliable device for use in a wide variety of applications. The amplitude of output pulse uses 60 V peak to peak; which is given to sender transducer (Tx). In the design of a practical pulse generator, parasitic capacitors associated with the MOSFETs and the coaxial cable connecting to the transducer have to be considered. These capacitors keep the pulse generator output at high voltage for a long period that could saturate the high-gain echo amplifier and also increase the leakage current that may create safety issues. Thus, at the end of each pulse train, discharging the parasitic capacitors to zero potential is essential

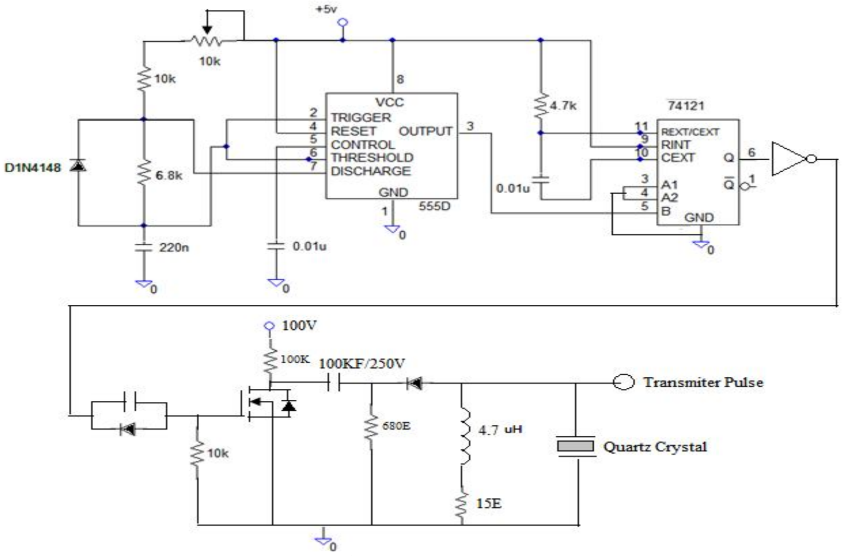

Fig. 1: High frequency pulse generator

(ii) Wide band Receiver

In practical situations, the received echo signal intensity can be less than 1% of that sending out from the transducer. A high gain amplifier is required to amplify the echo signal received from the transducer. The circuit diagram of wideband receiver is shown in figure 2. An amplifier consists of single stage, which is assembled by using the AD822 which is a dual precision, low power FET input op amp that can operate from a single supply of 5 V to 30 V or dual supplies of ±2.5 V to ±15 V. It has true single-supply capability with an input voltage range extending below the negative rail, allowing the AD822 to accommodate input signals below ground in the single-supply mode. Output voltage swing extends to within 10 mV of each rail, providing the maximum output dynamic range. Offset voltage of 800 µV maximum, offset voltage drift of 2 µV/°C, input bias currents below 25 pA, and low input voltage noise provide dc precision with source impedances up to a gigaohm. The 1.8 MHz unity-gain bandwidth, –93 dB THD at 10 kHz, and 3 V/µs slew rate are provided with a low supply current of 800 µA per amplifier. The output signal is then fed to LH0002 which is a general purpose buffer. Its features make it ideal to integrate with operational amplifiers inside a closed loop configuration to increase current output. The symmetrical output portion of the circuit also provides a low output impedance for both the positive and negative slopes of output pulses. The AD602 dual-channel, low noise, variable gain amplifiers are optimized for use in ultrasound imaging systems but are applicable to any application requiring precise gain, low noise and distortion, and wide bandwidth. Each independent channel provides a gain of 0 dB to +40 dB in the AD600 and −10 dB to +30 dB in the AD602. The lower gain of the AD602 results in an improved signal-to-noise ratio (SNR) at the output. However, both products have the same 1.4 nV/√Hz input noise spectral density. The decibel gain is directly proportional to the control voltage, accurately calibrated, and supply and temperature stable.

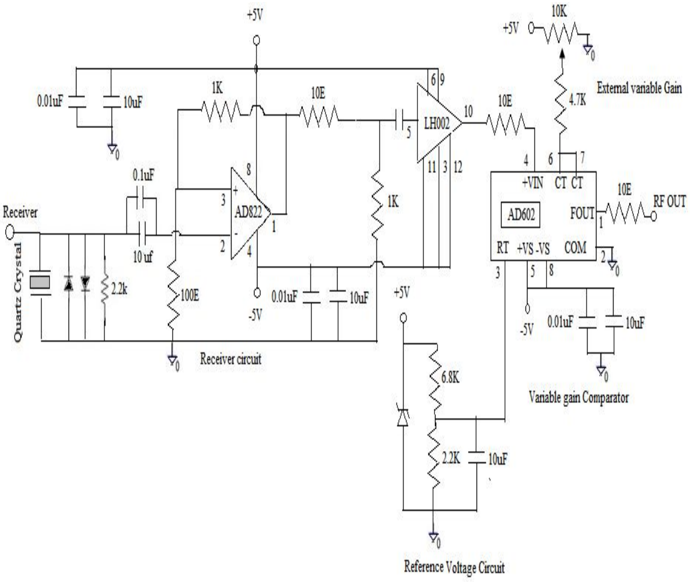

Fig.2 Wide band receiver

III.MEASURING TECHNIQUE

For the measurement of ultrasonic velocity and attenuation, the Sender Transducer(Tx) is firmly fixed at one end of the measuring cell, while Receiving Transducer(Rx) if fixed to movable scale having least count of 0.005cm.

The liquid sample was contained in a glass tube as shown in figure 3. A glass tube of height 160mm and outer diameter is 60.5mm and inner diameter is 53.5mm. The glass tube was inserted in an inner space of Double walled chamber which was made of brass tubes. Dimensions of double walled chamber are: height of double walled chamber is 145mm, outer diameter 82.7mm and inner diameter is 61.5mm. The Double walled chamber was provided with inlet and outlet for constant temperature water circulation. Water circulation arrangement was made through thermostat. The lower surface of the glass tube and double walled chamber were in the same plane. The lower portion of Glass tube is partially closed leaving an opening of 24mm diameter in which a gold plated X-cut Quartz crystal of natural frequency 2MHz and of approximately 20mm diameter is held firmly with a Silicon O-ring. The Crystal is kept pressed by a Silicon O-ring held in position by three screws and tightened with optimum pressure. The Crystal is in direct contact with the medium under investigation.

The Receiving Transducer Rx is kept in Crystal holder assembly and the Crystal is kept pressed by a Silicon O-ring and tightened with optimum pressure by using chuck nut. The Receiving Transducer Rx is coupled to micrometer via Crystal holder pipe and Dottle–Neck arrangement. The micrometer screw is having a pitch of 0.05mm and it is connected to Stepper motor via Universal Coupling. Knowing the distance and transit time , Ultrasonic velocity and attenuation measurements can be computed. The transmitting and received pulse is displayed on personal computer using ADC card.

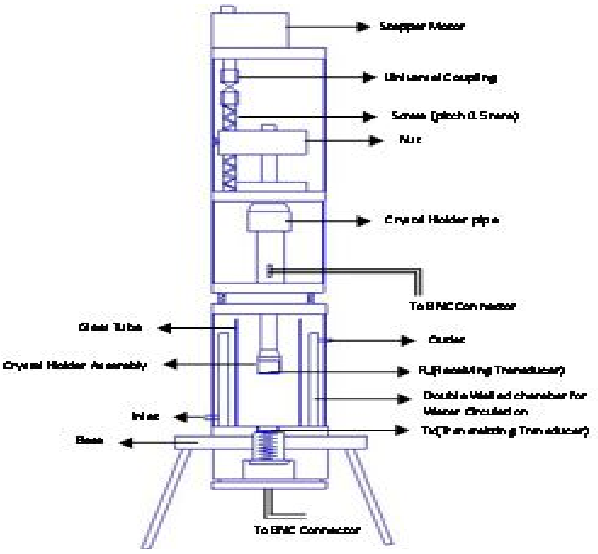

Fig. 3 : Measuring cell

IV. RESULT AND DISCUSSIONS

The liquids – benzene, n-hexane, methanol, n-proponal and n-butanol are chosen in the present study for investigation. The ultrasonic velocity for these pure liquids is measured at 30^{0}C. The measurements of these samples are presented in Table along with the literature values. The results of the measurements of ultrasonic velocity for pure liquids of the present study are in good agreement with the literature values.

ULTRASONIC VELOCITY
COMPARISON WITH LITERATURE VALUES AT 30^{0}C

S. No.	Sample	Ultrasonic velocity (m sec^{-1})		Reference
		Present study	Literature value	
1	Benzene	1286.52	1286.00	Takagi et al[4]
2	n-Hexane	1052.32	1052.00	N. Santhi et al[5]
3	Methanol	1087.46	1087.00	Plantier et al [6]
4	n-Propanol	1192.19	1192.80	N. Santhi et al [5]
5	n-Butanol	1225.51	1225.00	Plantier et al [6]

Binary liquid mixtures: Benzene + n-alcohols

Binary mixtures of each of benzene with three n-alcohols – methanol, n-proponal and n-butanol are chosen in the present study. The ultrasonic velocities of these binary mixtures at 30^0C and in the entire concentration range are studied.In the present study, the mole fraction of the alcohols in the concentration range 0 to 1 are chosen. The ultrasonic velocities, densities and adiabatic compressibility of the binary liquid mixtures : benzene + methanol, + n-proponal and + n-butanol are measured at 30^0C and at different concentrations.

The results of measurements are presented in Table 1 to Table 3 respectively. The corresponding data is shown graphically in fig1 to fig 6 at 30^0C. It is observed that at a given temperature the ultrasonic velocity varies as a function of concentration of n-alcohols.It is found that as the concentration of n-alcohols increases, the ultrasonic velocity decreases for all the systems.It is found that adiabatic compressibility curve has opposite trend to that of ultrasonic velocity curve for all the systems.

In Table 1 it shows the density (ρ), ultrasonic velocity (u), adiabatic compressibility (βad) of benzene(x_1) + methanol(x_2) at 30^0C. From the data it is clear that as the concentration of methanol increases the ultrasonic velocity decreases and the adiabatic compressibility increases.

TABLE 1

Mole fraction X_2	Density(ρ) (gm.cm^{-3})	Ultrasonic velocity(u) (m.sec^{-1})	Adiabatic compressibility(βad) (10^{-11} cm²/dyne)
0.0000	0.86829	1286.52	6.95
0.1952	0.85071	1259.90	7.40
0.3528	0.83823	1238.65	7.77
0.4833	0.82838	1223.45	8.06
0.5927	0.82011	1214.66	8.26
0.6856	0.81286	1198.64	8.56
0.7658	0.80635	1181.67	8.88
0.8359	0.80049	1162.72	9.24
0.8974	0.79489	1143.02	9.62
0.9516	0.78978	1116.70	10.15
1.0000	0.78501	1087.46	10.77

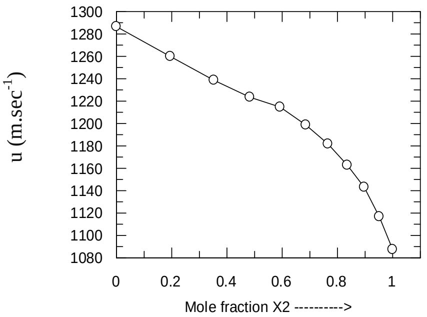

Fig1: Ultrasonic velocity of the binary mixture: benzene + methanol

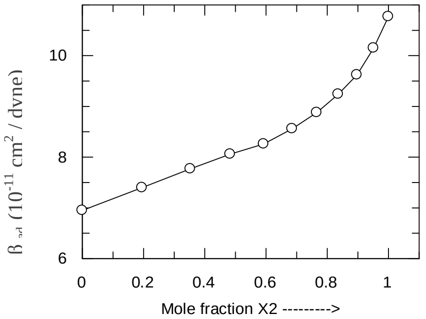

Fig 2: Adiabatic compressibility of the binary mixture: benzene + methanol

In Fig 1 it shows the graph of mole fraction Versus ultrasonic velocity. From figure it is found that as the concentration of methanol increases the ultrasonic velocity decreases.

In Fig 2 it shows the graph of mole fraction Versus adiabatic compressibility. From figure it is found that as the concentration of methanol increases the adiabatic compressibility increases.

TABLE 2

In Table 2 it shows the density (ρ), ultrasonic velocity (u), adiabatic compressibility (βad) of benzene(x_1) + propanol(x_2) at 30^0C. From the data it is clear that as the concentration of propanol increases the ultrasonic velocity decreases and the adiabatic compressibility increases.

TABLE 2

Mole fraction	Density(ρ) (gm.cm⁻³)	Ultrasonic velocity(u)	Adiabatic compressibility(βad)
0.0000	0.86829	1286.52	6.95
0.1176	0.86611	1265.42	7.25
0.2312	0.85754	1251.35	7.50
0.3402	0.84641	1238.54	7.74
0.4449	0.83530	1226.50	7.97
0.5458	0.82556	1218.14	8.16
0.6433	0.81770	1210.31	8.34
0.7372	0.81159	1205.28	8.48
0.8279	0.80668	1200.22	8.60
0.9155	0.80215	1196.66	8.70
1.0000	0.79771	1192.19	8.81

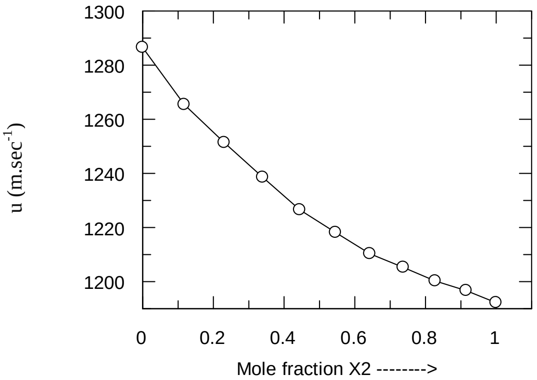

Fig 3: Ultrasonic velocity of the binary mixture: benzene + n-proponal

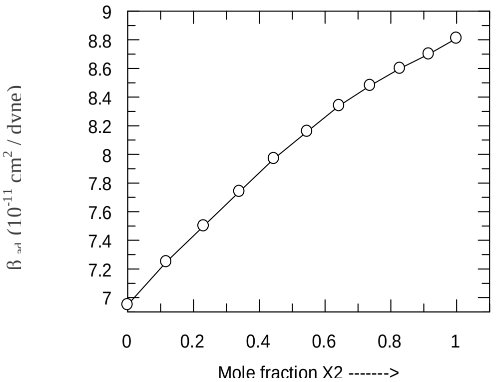

Fig3: Adiabatic compressibility of the binary mixture: benzene + n-proponal

In Fig 3 it shows the graph of mole fraction Versus ultrasonic velocity. From figure it is found that as the concentration of n- propanol increases the ultrasonic velocity decreases. In Fig 4 it shows the graph of mole fraction Versus adiabatic compressibility. From figure it is found that as the concentration of n- propanol increases the adiabatic compressibility increases. In Table 3 it shows the density (ρ), ultrasonic velocity (u), adiabatic compressibility (βad) of benzene(x_1) + butanol(x_2) at 30^0C. From the data it is clear that as the concentration of butanol increases the ultrasonic velocity decreases and the adiabatic compressibility increases.

TABLE 3

Mole fraction	Density(ρ) $(gm.cm^{-3})$	Ultrasonic velocity(u)	Adiabatic compressibility(βad)
0.0000	0.86829	1286.52	6.95
0.0981	0.85712	1274.36	7.18
0.1964	0.84882	1265.18	7.36
0.2956	0.84180	1257.36	7.51
0.3949	0.83577	1250.31	7.65
0.4945	0.83040	1244.33	7.77
0.5949	0.82537	1238.84	7.89
0.6955	0.82036	1235.52	7.98
0.7966	0.81503	1232.44	8.07
0.8982	0.80903	1229.16	8.18
1.0000	0.80221	1225.51	8.30

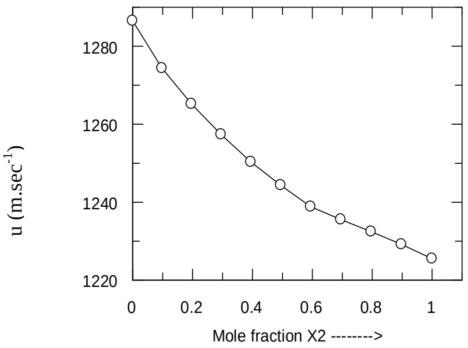

Fig 5: Ultrasonic velocity of the binary mixture: benzene + n-butanol

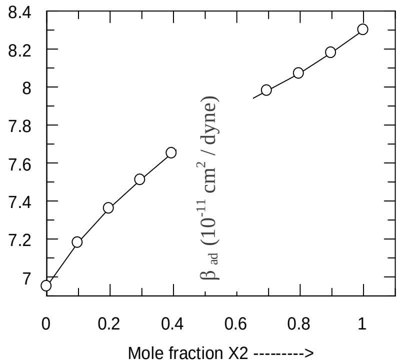

Fig 6: Adiabatic compressibility of the binary mixture: benzene + n-butanol

In Fig 3 it shows the graph of mole fraction Versus ultrasonic velocity. From figure it is found that as the concentration of n-butanol increases the ultrasonic velocity decreases.

In Fig 4 it shows the graph of mole fraction Versus adiabatic compressibility. From figure it is found that as the concentration of n-butanol increases the adiabatic compressibility increases.

V.CONCLUSION

The stability, accuracy and sensitivity of the system can be seen from the tables, It is observed that the experimental values of ultrasonic velocity at 2 MHz are found to be in good agreement with literature values. It is observed that at a given temperature the ultrasonic velocity varies as a function of concentration. It is found that as the concentration of n-alcohols increases the ultrasonic velocity decreases. It is found that adiabatic compressibility curve has opposite trend to that of ultrasonic velocity curve for all the systems.Thus the proposed design shows good performance.

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