ISSN 2229-5518

Miniature Guided Wave Radar for Precise level Measurement using Time Domain Reflectrometry (TDR) Principle.

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Abstract-The aim of paper is to achieve a precise level measurement in the field of industrial tank. The principle of measurement is based on Time Domain Reflectrometry (TDR), which is well known measurement technique in telecommunication industries for evaluating electric and dielectric property of various material. Despite all advancement made within last few years, there is still lack of low cost, small TDR meter equipment in market. This paper proposes a design leads to development of low cost TDR meter with high resolution. In order to achieve high resolution, an extremely small time of incident and reflection pulse is thus required to be precisely measured. The key techniques of pulse generation and time measurement are introduce with the selection of Guided Radar Probe (GWR) for accuracy even when the measurement within a highly unstable environment. The measurement is accomplished with the Charge Time Measurement Unit (CTMU), which is responsible to measure time with 3.5 ps resolution. Hardware design were discuss with the various parameter. Due to low cost and get rid of complex laboratory setup, the TDR meter can be used in field of chemical, petroleum, shipbuilding and geoscience industries.

Index Terms— Time Domain Reflectometry (TDR), Charge Time Measurement Unit (CTMU), Transit Time, waveguide, Pulse Generation, Signal Processing And Calibration.

I. INTRODUCTION

In sensor Instrumentation Industries, for high precision level measurement the pulse radar techniques are commonly used [3]. Other than military and aeronautical sectors, level measurement meter using radar techniques gained more interest in petrochemical, Oil tanks, Shipbuilding and chemical mixing station of different dielectric constant materials. Comparing with traditional radar measurements techniques, the guided radar meter is widely used to dynamically monitor the level. Guided radar level based on the principle of TDR, measured the transit time between incident (send) wave and reflected (received) wave from surface of material under test [2]. TDR measurement is commonly based on the transmission and reflection and well-known method for obtaining frequency-dependent electric and dielectric properties of materials and substances [1], [5]. In this paper we are focus on the waveguide selection along with its calculation under different consequences of materials under test and development of signal generator and signal processing for high resolution. Generally we are trying to build high precise, low cost, simple equipped, high reliable, miniature TDR meter, which is used in field of petrochemical, shipbuilding, chemical mixing station and oil tanks.

II. SYSTEM PRINCIPLE

The measurement process utilized the periodic narrow pulses generally rectangular square wave pulses with sharp rising and fast falling edges. The signal is transmitting along the application based waveguide probe such as open ended co-axial lines or metal rod or ribbon cable or stainless steel tube. When pulse wave hit the surface of material under test, depends on dielectric constant the sudden change in characteristic impedance take place hence pulse wave reflected and received at the input end again. The resulting waveform of rectangular pulse is captured with high resolution, which used to calculate the transit time ΔT and corresponding height of material as

$$H = \frac{\Delta T \text{ X } V}{2} \tag{1}$$

Where, H is height of material, V is propagation velocity of rectangular pulse inside the co-axial stainless tube, ΔT is transit time.

Fig 1. 2m Stainless steel waveguide testing with characteristic impedance of 50 Ω.

ISSN 2229-5518

To get fast measurement, the ΔT should be in nanosecond (ns) range. In real time, it is impossible to measure the nanosecond range ΔT by using direct measurement technique. To get precise measurement of level, the time measurement capacity should be in picosecond (ps) range. The goal of new TDR meter is to capture waveform with high resolution is explain in IV and the architectural design in III.

III. SYSTEM DESIGN

The architecture of guided wave radar meter is shown as Fig 2. Which consists of charge time measurement unit (CTMU), signal generation, signal processing, microcontroller unit, display, USB connector and waveguide.

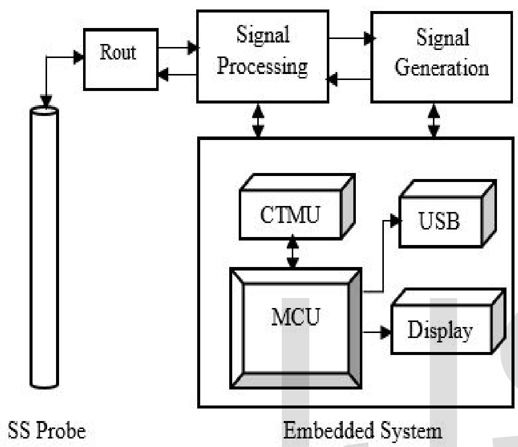


Fig 2 Architectural design of guided wave radar meter

The pulse generation is accomplished with microcontroller, a fast falling edge is generated. This fast falling edge pulse is driven into the waveguide. When it reaches the surface of impedance mismatch, a reflection is get back at the input end and is measured. To get measurement in the resolution of picosecond (ps), calibration is needed. This is accomplished using signal processing unit. The key component of TDR is charge time measurement unit (CTMU), which is responsible to capture time of output waveform with 3.5 ps resolution.

IV. WAVEGUIDE AND ITS IMPEDANCE

We are using 2 m stainless steel (SS) probe as transmission line. As compared to float system, SS probe is immune to mechanical shock and more resistant to corrosion. The probe consist inner conductor, an outer conductor and an insulator provides electrical isolation between them. The general impedance equation of a coax cable is:

$$Zs = \frac{1}{2\pi}\frac{\sqrt{\mu o \mu r}}{\sqrt{\varepsilon o \varepsilon r}} \times \ln\frac{Do}{Di} \qquad (2)$$

Where,

μo is the free space magnetic permeability
μr is the relative permeability of the conductors
εo is the free space dielectric permeability
εr is the relative dielectric of the insulating material
D_o is the outer conductor diameter, D_i is the inner conductor diameter.

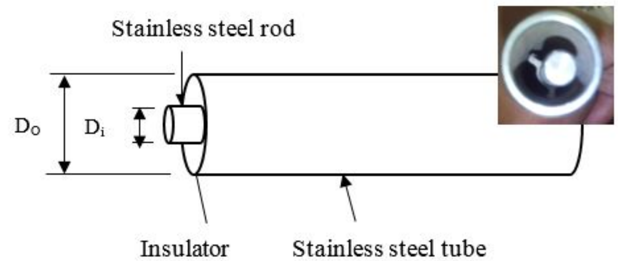


Fig 3 Stainless steel probe with a characteristic impedance of approximately 50 Ω in air as waveguide

μo, μr and εo are taken as constant and their values are known, hence the equation 2 becomes

$$Zs = \frac{59.87}{\sqrt{\varepsilon r}} \times \ln\frac{Do}{Di} \qquad (3)$$

According to mathematical measurement, the outer diameter of Stainless steel (SS) tube of length 78.74″ is 0.455″. This is generated using a total diameter of 0.62992″ and with a 0.08745″ wall thickness of SS tube. The SS probe is constructed with inner diameter of 0.1968 and air as the insulator, where εr is 1. Using all parameters of equation 2, we get:

$$Zs = \frac{50.25}{\sqrt{\varepsilon r}} \approx 50\Omega \qquad (4)$$

TABLE 1-Design parameter of SS probe

Parameter	Description	Optimal Value
D_o	Outer SS tube diameter	0.455″
D_i	Inner SS rod diameter	0.1968″
L	Length of a SS probe	78.74″
Z_s	Impedance of SS probe	50.25 Ω

The further change in impedance Z_s will be depends on the dielectric of material. Table 2 shows change in impedance Z_s due to change in dielectric constant will be defined by equation 3.

TABLE 2-Dielectric constant and their impedance for various fluid

Material	Dielectric constant	Impedance (Ω)
Petroleum	2.0-2.2	35.53-33.87
Acetic Acid (36° F)	4.1	24.82
Cement, Powder	5-10	22.47-15.89
Diesel	1.8	37.45
Water	68	6.09

V. SIGNAL GENERATION AND SIGNAL PROCESSING

The most important and critical part of guided radar level meter measurement is signal generation and signal processing for precise distance measurement with high accuracy. The signal generator must be generated a pulse with fast rise and fast fall time. If the wave will propagate about 4 inches in 1ns and if we use rise time of 1 ns then any reflection between 4 inches will gives attenuation in the edge of the pulse.

Same with the fall time, increase in rise and fall time produce less resolution and we can't figure out the sending and reflected pulse as a separate pulse. Hence the minimum distance measurement will drop to 4 inches, to neglect such consequence, we need to generate fast falling pulse. This pulse is fed down a SS probe with output pulse amplitude of V_P, output resistance of R_o and a terminal resistance of R_L.

Sending one pulse through SS probe will result in one reflection from air-liquid interface. Drive (send) pulse with time sequence is shown as Fig 4, which has pulse amplitude (V_P) of 5 V, output resistance (R_o) of 50 Ω and transmission line impedance (Z_s) of 50 Ω. If T is time required by pulse to travel from start point to terminal point of SS probe. Then at time A (0 ns), the pulse generate output with amplitude of V_A and the equation is:

$$V_A = V_P * (Z_s / (R_o + Z_s))$$

(5)

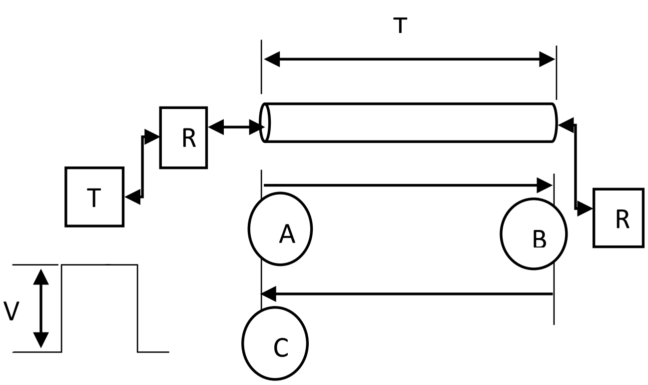


Fig 4 Drive (send) pulse of TDR

If $R_o = Z_s = 50$ Ω then V_A will be $V_P/2$. At time B (T ns), the pulse will arrive at the end of SS probe and get reflected back because of open impedance i.e. $R_L = 0$ Ω. But yet not return to input end, hence the voltage at input end will be still at $V_P/2$. At time C (2T), the pulse wave return to input end of transmission probe. In this case, the load resistance R_L will form a voltage divider with the output resistance R_o and the equation for voltage at input end is:

$$V_A = V_P * (R_L / (R_o + R_L))$$

(6)

The return pulse will provide output with zero amplitude, since R_L is 0 Ω. The propagation velocity is calculate from length of probe 78.74" and the transit time as,

$$L = \frac{\Delta T \ X \ V}{2}$$

(7)

The general concept using laboratory setup based on excitation of pulse signal, which is fed into an open ended SS probe and Oscilloscope is used for capturing the waveform of measurement signal. The typical waveform at beginning and the resulting reflected waveform at end and at air-liquid interface is shown in Fig 5 (a) and 5 (b). Resulting measurement waveform consist two reflection; one from end of probe, and another from testing material. The measurement will be made by sending pulse through transmission probe and when the reflection from the material under test returns. As the speed of light in free space is 0.0118"/psec and the velocity factor of SS probe is 0.5084, the speed of pulse travel down SS probe is 0.0059"/pec.

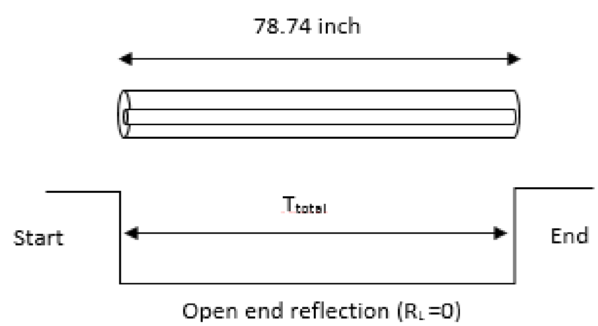


Fig 5 (a) Reflection due to change in impedance at the end of the probe.

ISSN 2229-5518

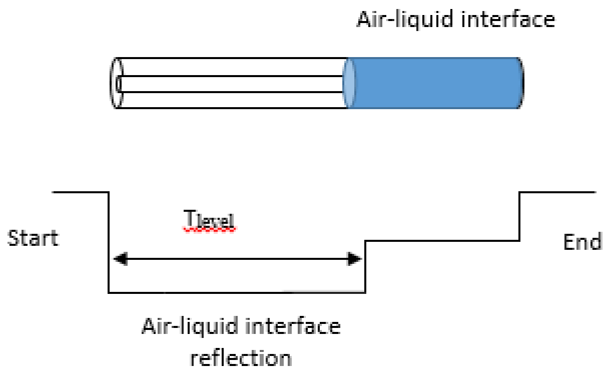


Fig 5 (b) First Reflection due to air-liquid interface and second reflection due to change in impedance at the end of the probe

If the time of incident and reflection is 15.76 nanosecond then the level of material under test can be calculated using following formula.

$$Measurement\ \ level = Delay \times Speed \times \frac{(1)}{(2)} \times \frac{(1)}{(12)}$$

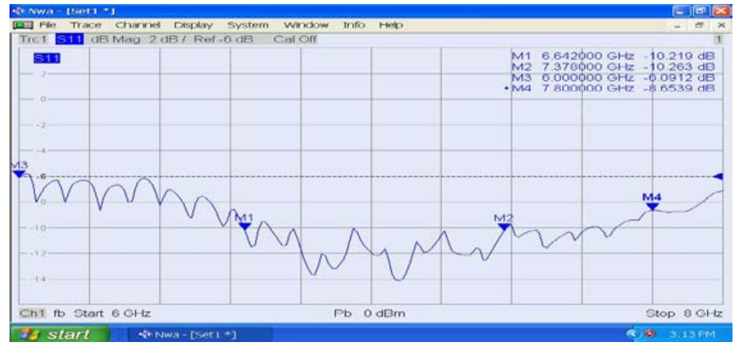
$$= 15.76 \times 5.9 \times \frac{(1)}{(2)} \times \frac{(1)}{(12)}$$

$$= 3.87 \text{ ft}$$

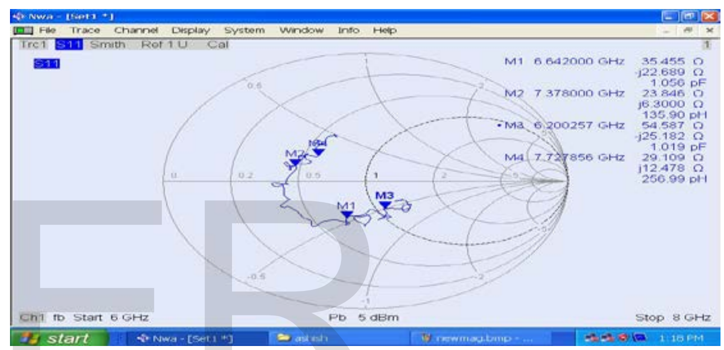
To get the precise measurement of the level height, extremely small time interval between incident and reflected pulse is thus required to be precisely measured, which is the key and the most difficult part of the level meter design. To capture such extremely small interval we will use charge time measurement unit (CTMU). The CTMU works by charging a capacitor with a constant current from a start event to a stop event, and measures the resulting voltage on the capacitor which is discussed in V section. The CTMU measures the time between two events. In this case, event 1 is the falling edge of the *Stop Pulse* and event 2 is the rising edge of the *Stop Pulse.*

VI. LABORATORY EXPERIMENT

In laboratory experiment, the goal of the experiment is to test the return loss of the SS probe at different excitation signal frequencies and the calculation of characteristic impedance. At the beginning of the experiment, an open-ended 50-Ω SS probe with a length of 2 m is connected to the vector network analyzer (VNA). The output resistor *R*out is set to 50 Ω, which allows for comparing the device to other standard laboratory equipment having 50-Ω outputs. In addition, it allows for connecting a 50-Ω coaxial cable for defined and reproducible measurements. We are investigating the system behaviour at 6GHz and 7 GHz and 7.3 and 8 GHz. Lower frequencies lead to extremely long acquisition times and are not acceptable in our target applications. The frequency response shows the considerable return loss of 10dB and the characteristic impedance is near to 50-Ω.



(a)



(b)

Fig 6 (a) Measured return loss of open ended 50-Ω SS probe at different frequencies (b) Smith chart for the calculation of characteristic impedance.

VII. CONCLUSION

This paper introduced an implementation miniature low cost GWR meter for high resolution level measurement based on the principle of TDR, namely radar, utilizing CTMU techniques. It will provide self-calibration and independence from fluid type. The construction of stainless steel as a waveguide means no corrosion, more immune to mechanical shock and less cost as compare to ultrasonic sensor in unguided system. The laboratory experiments results provide flexibility in frequency, use for pulse generation and also generate same impedance. The next step will be the development of control system with CTMU unit to achieve 3.5 ps resolution and further improvements on connection of SS probe with embedded system to boost the performance.

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