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Development of EM Wave Guide Amplifier Potentially used for Sea Bed Logging

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Abstract: Seabed logging is a new technology being implemented for deep target exploration. The technology uses electromagnetic (EM) wave where an antenna transmits EM wave into water layer underneath seabed and with resistivity characteristics of hydrocarbon reservoir, the wave is reflected and received by the detectors on the seafloor. However, the roughness of the sea caused by underwater sea current limits the transmission of EM wave. EM wave itself has its own attenuation in seawater that is 102 dBm and the underwater sea current has made it worst. In seabed logging technology, the vessel is towing the transmitter at a very slow speed (1.5 km h^{-1}) with high EM wave energy for transmitting the waves of ~1250 A cm^{-2}. Due to this large current more heat is generated. In this project, we propose an EM wave guide amplifier to be used to overcome these problems. The EM wave guide amplifier amplifies the wave without modifying the transmitter (antenna) circuit. Therefore lower energy is required for the transmitter and is sufficient for seabed logging technology. The thermionic cathode and molybdenum (Mo) anode with work function of 1 eV are selected to get higher amplification of EM wave. It is found that potential difference between the cathode and anode improves the electron acceleration in the wave guide amplifier. It has been observed that with the use of wave guide amplifier and with 20 Vpp supply to the transmitter at 5 MHz frequency, the wave received by receiver has been amplified up to 170%. The application of this new method in seabed logging shall reduce the heat generated and overcome the EM wave attenuation problems.

Key words: Sea bed logging, EM waves, transmitter, receiver, EM wave guide amplifier

INTRODUCTION

Hydrocarbon exploration is very expensive, not accurate and extensively harmful to marine life. A new technique of detecting oil reservoirs has been developed and is called "seabed logging". Seabed logging is an application that uses marine controlled source electromagnetic (CSEM) sounding technique to detect and characterize hydrocarbon bearing reservoirs in deep water areas (Eidesmo *et al.*, 2002). The system consists of three main components. The first component is the transmitter or the antenna. The transmitter is supplied with appropriate voltage and frequency and as it receives current, electromagnetic wave is produced. The energy of the electromagnetic wave depends on the voltage supplied to the transmitter. The second component is the receiver that is placed on the sea floor measure both the amplitude and the phase of the received signal that depends on the resistivity structure beneath the seabed. Different positions of the transmitter and receivers can be used to determine model of sub seafloor resistivity. A hydrocarbon reservoir can have resistivity perhaps 10-100 times greater than seawater and other sediments in sea. Basically transmitted EM wave is reflected due to the high resistivity of the hydrocarbon reservoir (Kong *et al.*, 2002). CSEM is a method of propagating low frequency electromagnetic wave. The lower frequency will generate higher wavelength and the distance it travels will have low attenuation. The wave must have sufficient energy when it is received by the receivers. When transmitter transmits the wave it is controlled by the source power generator. The electromagnetic wave generated by the transmitter will be reflected and guided by the reservoir because of its high resistance (Kong *et al.*, 2002). However there are many other constraints that need to be discussed and considered. The transmitter for instance produces EM wave in all directions. Three different types of waves (air waves, direct waves and deflected waves) are identified by the receivers after propagating from the transmitter. The air wave is wave generated on seawater interface and in shallow water exploration, this air wave is inevitably

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affects the reading of data collected by the receivers. The direct wave is the wave that is propagated from the transmitter and is directly received by the receivers. The other type of wave is the deflected wave that comes out after deflecting from high resistivity hydrocarbon reservoir (Kong *et al.*, 2002; Guru and Hiziroglu, 1998).

Dipole transmitter transmits very low frequency electromagnetic waves with frequency ranges from 0.25-10 Hz. Low frequency electromagnetic waves attenuate less in the resistance layers due to the skin depth and has more attenuation power in conductive medium. In seabed logging method, high resistive layers such as hydrocarbon reservoirs electromagnetic wave is guided back from the hydrocarbon to receivers on the sea floor (Sinha *et al.*, 1990).

Many authors have reported about the hydrocarbons detection using CSEM and propagation of EM waves in seawater environment (Tompkins, 2008; Al-Shamma *et al.*, 2004; Constable and Cox, 1996; Carazzone *et al.*, 2005; Cox *et al.*, 1986). A wave guide amplifier can be assembled using high density charge particle principle as discussed by researcher (Griffiths, 1999).

In this method, for better amplification a wave of high frequency with high density electron beam will propagate through vacuum. The electron beam creates an active dielectric in the wave guide, slows down the input wave and amplifies it when the electron beam and wave that come from transmitter is synchronized. Figure 1 illustrates the behavior and process of the wave guide amplifier. When EM wave is slowed down inside wave guide, it acts like a capacitor. The wave guide will store the energy of the slow wave and upon reaching at the low density electron beam near the RF output, the wave will burst rapidly hence amplifies the EM wave energy. One could circulate the guided wave back into the input of the wave guide. Constant feeding of the wave energy into the wave guide will increase or boost up the power of wave in the wave guide (Griffiths, 1999). In wave guide amplifier,

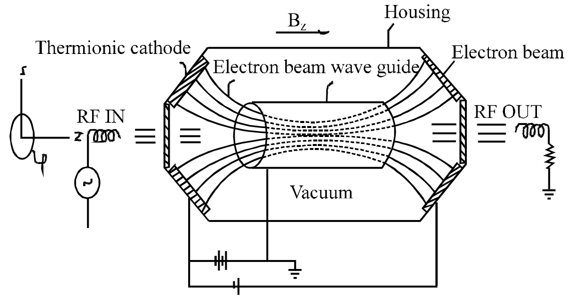

Fig. 1: Wave guide amplifier using high density charged particle (Griffiths, 1999)

thermionic converter consists of a hot electrode which thermionically emits electrons over a potential energy barrier to a cooler electrode, producing a useful electric power output. Caesium vapor is used to optimize the electrode work functions and to provide an ion supply (by surface contact ionization or electron impact ionization in a plasma) to neutralize the electron space charge. One major disadvantage of the electrode is, it works only for limited time, which is before electron is totally emitted from the material (Ji *et al.*, 2005).

The objective of this study is to design EM wave guide amplifier, create vacuum in the chamber and validating EM wave data after receiving at the detector with and with out wave guide amplifier.

MATERIALS AND METHODS

Design and fabrication of EM wave guide amplifier: The EM wave guide amplifier is designed by using Auto CAD software. The first stage of the experiment is to conduct wave guide by using aluminum, transmitter and receiver. Fabrication of EM wave guide amplifier is according to research experiment done by Arnold Shih from Naval Research Laboratory in Washington DC (Shih, 2001). In wave guide amplifier construction, thermionic cathode consists of strontium carbonate ($SrCo_3$), calcium carbonate ($CaCo_3$) and barium carbonate ($BaCo_3$) plated to nickel plate. The compositions are mixed and dissolved in the solvent. Table 1 shows the ASTM mixture of the compositions. The process of combining the compositions to the nickel plate is by spraying the compound solution to the nickel plate. The vacuum is created inside the chamber of amplifier for better electron acceleration. Molybdenum plate with 2.5 mm thickness is used as anode in EM wave guide amplifier. The design of the EM wave guide amplifier is shown in Fig. 2. The length of the EM wave guide amplifier is 12 and 10 cm in width. Figure 3 shows the nickel plate used in the EM wave guide amplifier.

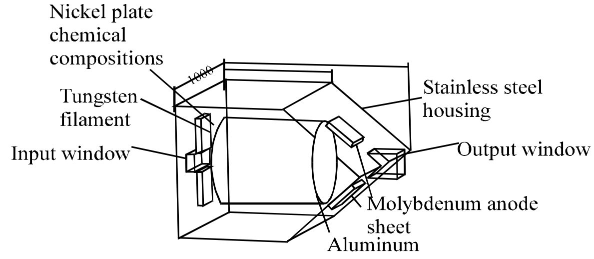

Fig. 2: EM wave guide amplifier AutoCAD design

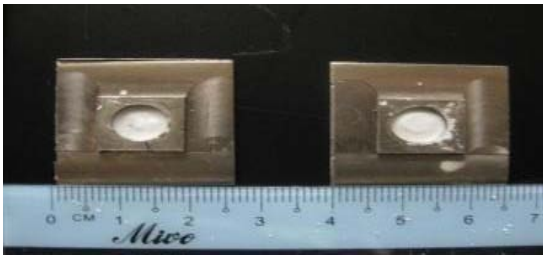

Fig. 3: Nickel plate with chemical compositions

Table 1: Mixtures of compounds and solvents

Compositions	Standard amount (%)	Mass (g)	Mole	Solvent volume (mL)
Barium carbonate	49	6.295	0.0319	31.9
Calcium carbonate	5	1.241	0.012	12.4
Strontium carbonate	44	6.29	0.0421	42.4

Table 2: Properties of EM wave guide amplifier

EM wave guide amplifier properties	Value
Wave guide	
Inner diameter	3.5 cm
Outer diameter	3.9 cm
Length	10 cm
Amplifier	
Length	12 cm
Wide	10 cm
Receiver opening angle	45°
Transmitter opening angle	90°
Weight	1 kg
Materials	
Wave guide	Aluminum
Amplifier housing	Stainless steel
Thermionic cathode	Nickel
Anode	Molybdenum
Filament	Tungsten wire (Gold plated)

Experimental setup: The method of adjusting thermionic cathode and the anode to the stainless steel housing is done by applying silicon paste. The silicon paste is able to support heat up to 600°C. Table 2 shows the properties of the EM wave guide amplifier. The housing of the EM wave guide amplifier is made of stainless steel because stainless steel will not stain, corrode, or rust as easily as ordinary steel. Stainless steel is corrosion resistance and is an important aspect in the amplifier as the thermionic emission produces carbon dioxide which contributes to corrosion. Stainless steel has melting point of 1500°C. This standard melting point is suitable when heat is transferred from the filament at an approximately 1000 K. The experiment has been conducted for the transmission of EM waves from transmitter to receiver with and without wave guide (3.5 cm diameter, 10 cm long). The transmitter used was a ring transmitter (3 cm diameter) with supply voltage of 20 Vpp at frequency of 5 MHz. A ferrite bar with 100 turns was used at receiver to improve the induction of the receiver. The experimental setup is shown in Fig. 4, where the distance between transmitter and receiver is 15 cm.

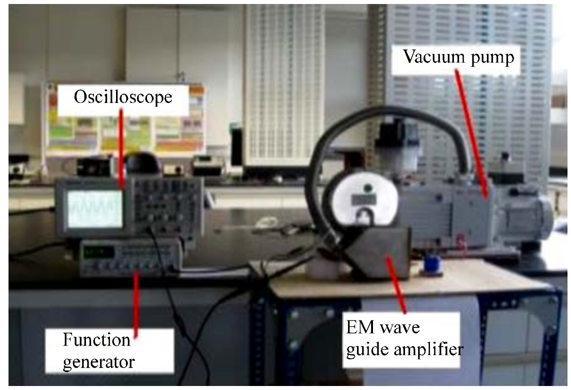

Fig. 4: Experimental setup of EM wave guide amplifier

RESULTS AND DISCUSSION

Table 3 shows the data collected at the receiver with and without the existence of the aluminum wave guide. From the results we can conclude that for single loop aluminum ring transmitter with 20 Vpp and 5 MHz, we can get higher value (with wave guide 19.36 mV) than without wave guide at the receiver. Similarly, with three loops aluminum ring transmitter higher value (65.28 mV) was achieved with wave guide than without wave guide at the receiver. It was observed that amplification of wave could achieved by increasing number of loops in transmitter and by placing wave guide in the path of EM waves with average increment of 82.6%. It was estimated that nickel could produce 1.5 eV energy and current density of 1 A cm^{-2} with this compositions plate (Ji *et al*., 2005). The anode used in this EM wave guide amplifier model is Molybdenum plate with 2.5 mm thickness and has the purity of 99.5% of metal basis. The Molybdenum metal would produce 1.85 eV energy (Loretto, 1994).

Figure 5 shows the waveforms of single loop aluminium wire at receiver with wave guide where as Fig. 6 shows wave form without wave guide collected by the oscilloscope. The resulted waveform shows less ripple voltage produced by applying the wave guide between the transmitter and the receiver. The reduced of ripple voltage is estimated around 45.6%. Wave form comparison with and without wave guide amplifier shows that EM wave guide has less distortion. This is because with the wave guide all the EM energy transmitted from the transmitter is guided in the wave guide and does not interfere with the noise from the surroundings. The wave guide focused all the EM wave energy directly to the receiver.

The filament is heated with 6 V supply by changing voltage of the transmitter, a change in voltage were also detected by the receiver shown in Table 4. It has also been observed that wave guide amplifier cathode is

Table 3: Results with and with out EM wave guide with single loop transmitter and three loop transmitter

	Output voltage (Vpp)			
	With single loop Al wire		With three loop Al wire	
Input voltage	Without wave guide	With wave guide	Without wave guide	With wave guide
20	10.18 mv	19.36 mv	43.8 mv	65.26 mv

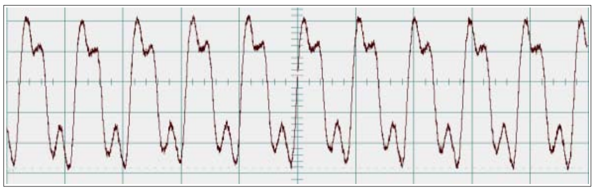

Fig. 5: Waveform result of single loop without wave guide

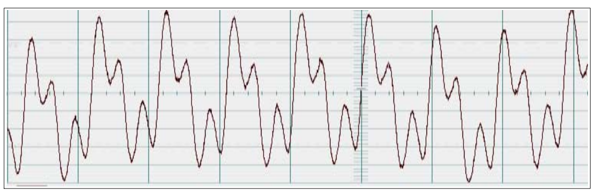

Fig. 6: Waveform result of single loop with wave guide

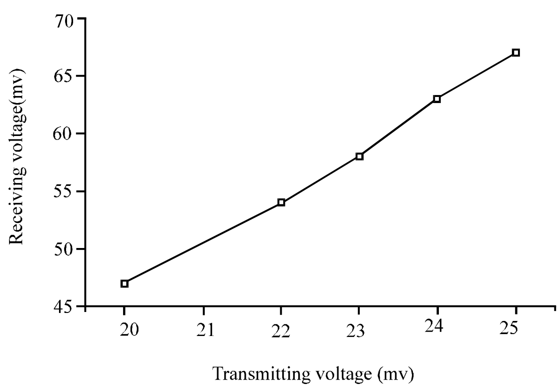

Fig. 7: Transmitter and Receiver voltage with wave guide amplifier

placed in parallel to the wave guide opening and the anode is 45° outwards the wave guide Fig. 3 to avoid the anode being induced by EM wave generated from the transmitter. However, the distance between the cathode and anode is 12 cm and this short distance could reduce the energy dissipation of the accelerating electrons gives better output.

When synchronism between the EM wave and beam is met, amplification is obtained. EM wave guide produced amplification of EM wave ranges from 150-170%. This amplification is inconsistent with the theory that says when thermionic cathode releases electron it slows down

Table 4: Results from experiment with EM wave guide amplifier

Transmitter (Vpp) mV	Receiver (Vpp) mV	Amplification (%)
20	47	135
22	54	146
23	58	152
24	63	162
25	67	168

the EM wave inside the wave guide hence releasing higher energy to the receiver (De Santis, 1983). Figure 7 shows the transmitting and receiving voltage with wave guide amplifier. It also shows that receiving voltage increases as the transmitting voltage increases at the transmitter.

CONCLUSIONS

The amplification in EM wave energy achieved from the experiment conducted was approximately 82.6% and it has reduced the ripple voltage up to 45.6% by using 20 Vpp of 5 MHz transmitter. This vast improvement in EM wave energy is useful in seabed logging application. The EM wave data was collected by using ferrite bar with 100 turns of copper winding. This shows the sensitivity of the ferrite improves the data collection at the receiver. By applying this EM wave guide amplifier it could reduce the energy use at the transmitter hence reducing the heat generation. This would save many living marine organism below the sea. EM wave guide amplifier has capability to amplify waves up to 150 to 170% easily, due to simple, portable and small design of EM wave guide amplifier. This characteristic is a huge advantage for future engineers in designing the amplifier suitable for seabed logging system.

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