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# Relay-based Coupling Scheme of High Speed Communication Data, High Voltage DC and High Power Pulsed AC for Coaxial Cable

Manoj G.[*], Eldho Jacob, and Sona O. Kundukulam.

*DRDO-Naval Physical and Oceanographic Laboratory, Cochin - 682 021, India*

[*]*E-mail: manojg@npol.drdo.in*

**ABSTRACT**

Coaxial cable telemetry is most commonly used in the field of underwater applications like data logging in oil rigs, underwater wireless modem, underwater acoustic measurements, borehole measurements, deep sea telemetry for sediment analysis, airborne sonars, imaging sonars. In all the above applications coaxial multicore cables are used. The design and development of relay based coupling scheme which helps to replace the multi-core cable with a single core coaxial cable for telemetry application is described. Single core cable is suitable for long distance data communication. Multi core cables are generally heavy and due to the size, may not meet space constraints in complex systems. They are not economical too. The relay based coupling scheme is used to mix or separate the high speed bi-directional communication data, high voltage DC and high power pulsed AC. In single relay scheme one relay is used to switch the centre core of single core coaxial cable. Here the ground is common for both high power AC transmission and high speed bi-directional data path. A dual relay scheme is discussed where two relays are used to switch both the centre core and ground of the single core coaxial cable. This provides more ground isolation and can avoid ground lifting issues while high power AC transmission occurs. The simulation of the coupling scheme was done using PSpice®. A prototype of the coupling scheme was also made for analysis. Filter responses were analysed for each coupling path. The DC coupling filter has 85 Hz cut-off frequency at -3 dB. The cut-off frequency of high speed data coupler is 500 KHz at -3 dB. A 4.3 KV peak to peak of 3 KHz and 7 KHz AC signals were transmitted and measurements were taken to analyse the effect of high voltage over different coupling paths. The 3 KHz signal has a peak of 61.88 dB and that of 7 KHz signal, the peak is 62.50 dB. The signal components of 3 KHz signal in the DC path has a voltage level of 9.375 dB and that of 7 KHz signal is 25.63 dB.

**Keywords:** Passive filters; Coupling schemes; Coaxial cable; Power line communication; Remote systems; Telemetry

## 1. INTRODUCTION

Coupling circuits are used in power line communications (PLC's) for impedance transformation which is realised using passive components[1]. Passive coupling circuitry is also used to replace the transformer coupling for PLC's to reduce the cost of PLC modems[2]. Passive filters have the ability to pass or block band of frequencies. For remotely operated vehicle (ROV) applications, cable signal separation filters were developed to separate the DC and information signal[3]. Filtering schemes for AC coupled systems have also been discussed. High voltage low valued capacitor in series with a coupling transformer[9] between the power line and the transmitter or receiver, are used in power line communication to couple the data signal to the transmission line. This will block any signal of frequencies lower than the cut off frequency and allow pass any signal having frequencies higher than the cut off frequency. A novel coupling/decoupling scheme for PLC in DC differential power buses employed on-board space vehicles has been proposed by Grassi[10], *et al.* In SABER[11] model of power line carrier communication (PLCC) system, coupling of data from a transmitter side and recovery of data at the receiver side over a power line is discussed. Another filtering schemes for the power line communication based on parallel resonant coupling technology has been proposed by Wang mao[17], *et al*.

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Underwater applications like ROV[3,15], underwater acoustic measurements[4], data logging in oil rigs, borehole measurements[5], deep sea telemetry for sediment analysis[6], wired drill pipe telemetry[13,16] airborne sonars[7], imaging sonar[8] etc. require remote unit and on-board platform unit which is connected using coaxial cable. All the above referenced applications uses multi core coaxial cables. The remote unit requires high voltage DC supply, high power pulsed AC transmission and bi-directional high speed communication data. Separate cables for each signal are not cost effective and have a multiplicity of engineering challenges in implementation. Single core coaxial cables are cheap and are commonly available. The coupling schemes discussed in the above referenced papers is for data signals and voltages. For handling all the three signals a proper coupling scheme is necessary to effectively operate the remote unit through single core coaxial cable. Coupling schemes reduces the complexity of multicore cables, handling of multicore cables, number of slip rings (if the systems have a winch), multi pin connectors, etc.

The advantages of using relay based coupling scheme include replacement of multicore cable with single core coaxial cable, which leads to the reduction in cable diameter as well as weight of the cable. Coaxial cables are cheap and readily available. The coupling circuit is realised using passive components. The vacuum relay provides good isolation between the high speed data path and high power AC path.

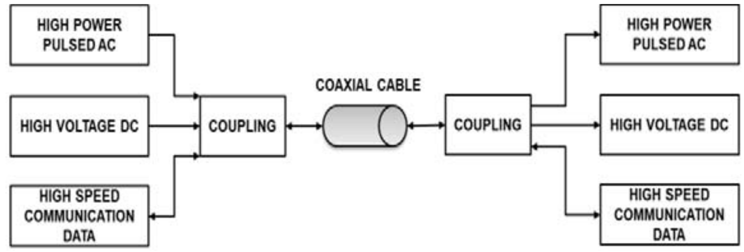


**Figure 1. Block diagram of single core coaxial cable coupling.**

Relay based scheme and passive filter based scheme are the two coupling schemes commonly used[12]. For data telemetry the coupling scheme is to be used at both the remote unit and on-board unit, which are connected through single core coaxial cable. The bi-directional high speed communication data, high voltage DC and high power pulsed AC are transmitted from one end of the cable. At the other end, the signals are separated out using coupling filters. Transmission of high power AC realised using a single relay scheme[12]has already been discussed. For coupling and retrieving these signals, proper filters are used thereby enabling inter-operation of all the above signals through the same single core coaxial cable.

The major challenges in the mixing schemes is the co-existence of low voltage communication signal along with the high voltage DC supply and high power pulsed AC. As the coupler is operated along with high power pulsed AC, protection and isolation[14] are essential for high power pulsed AC and high speed bi-directional communication data. The operation of relay is controlled by the high voltage DC and any failure in the operation of relay leads to the failure of the on-board electronics. To avoid this failure proper coupling filters for DC path is to be designed.

As the ground is common for high power AC path and high speed bi-directional data path, the single relay based coupling scheme has poor isolation while high power pulsed AC transmission occurs. This can be overcome by using dual relay based coupling scheme. This paper covers the design, simulation, development and analysis of a dual relay based coupling scheme. One relay is kept for the centre core and the other one is for ground (shield). This helps to provide full isolation of the high power AC signal from the high speed bi-directional data.

## 2. COUPLING SCHEMES

For the applications mentioned in the introduction, bi-directional telemetry is required to communicate between remote side and on-board side along with high power pulsed AC transmission and high voltage DC. To operate this over a single core coaxial cable, a properly designed coupling scheme is essential. These signals are operated at different band of frequencies. Fig. 1 shows the basic block diagram of a coupling scheme for a single core coaxial cable[12]. Vacuum relay based coupling chosen to provide better isolation for high power pulsed AC path and high speed bi-directional data path. The ground lifting issue due to lack of isolation may cause damage of electronics in the data path.

In the proposed design a two relay scheme is discussed, which will provide full isolation in both high voltage AC and high speed data. When high power pulsed AC transmission occurs, the relay connected to the high voltage AC signal and the one connected to the ground path is switched.

## 3. DESIGN OF DUAL RELAY BASED COUPLING SCHEME

For providing isolation of the data communication signal from the transmission signal, vacuum relay based coupling scheme is used. The Vacuum relay consists of three terminals, namely normally open (NO), normally close (NC) and common (COM).

Dual relay configuration provides a ground isolation when the high power pulsed AC signal transmission happens. Fig. 2 shows the block diagram of the coupling scheme with a dual relay based switching. The two relays fully isolate the high power AC path and high speed bi-directional data path. Hence the leakage of high power AC transmission to high speed bi-directional data path is close to zero.

The vacuum relay is controlled by high voltage DC which is sent from on-board unit. At remote unit, the high voltage DC is to be separated out using DC coupling circuit. At the same time the high power AC signal has to be blocked. This area is challenging and coupling scheme for high voltage pulsed AC and high voltage DC has to be thoroughly studied. Once DC is available, the vacuum relay will switch from high power AC signal transmission mode to high speed data mode.

When relay is connected to the high speed bi-directional data communication signal, the high voltage DC generates the relay control to maintain continuous high speed bi-directional communication data. Once high power pulsed AC transmission starts, then the high voltage DC is not available at the remote side. This leads to the switching of relay at remote side for high power pulsed AC transmission. Once transmission is over the high voltage DC is available at remote unit, which leads to switching of the relay for bi-directional high speed communication. The high power pulsed AC signals is required for active mode of operations like imaging sonar, dunking

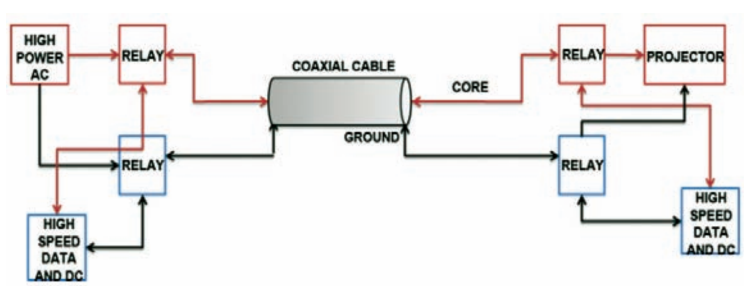


**Figure 2. Block diagram of dual relay based single core coaxial cable coupling.**

sonar underwater communication etc. The pulse length decides the vacuum relay operations and is usually called as 'mute'. During this time, on-board relay gets activated and high power pulsed AC signal transmission happens. Typical mute values vary in the range of 100 ms to 3000 ms with pulse repetition intervals of 8 s to 50 s. After mute time, on-board relay switch back to high speed data path and high voltage DC path, data will be immediately available from remote unit.

The high speed bi-directional communication data and high voltage DC is sent through the cable from the on-board unit and at the remote side of the cable.The high speed bi-directional communication data and high voltage DC has to be separated using passive filters. The design of the passive filters is critical as the high speed data is attenuated at the high voltage DC path.

The high speed bi-directional communication data and high voltage DC (250 V) is a well separated band. So the design of the coupling scheme for high speed bi-directional communication data of on-board and remote units is simple compared to that of the high voltage AC transmission path.

For designing a coupling scheme it is necessary to consider the attenuation characteristics of filters[2].

$$A = 10 Log[1 + (\frac{\omega}{\omega_c})]^{2n} \tag{1}$$

Equation (1) represents the attenuation for a low pass filter where $A$ represents the attenuation in decibels, $\omega$ is the frequency at which the attenuation is desired, $\omega_c$ is the cut-off frequency of the filter, and $n$ is the number of elements in the filter circuit. When designing high-pass, the equation is simply transformed by inverting the ratio $\frac{\omega}{\omega_c}$ for a high-pass filter. For the transmission path the coupling filter should drastically attenuate the high voltage AC signal in the high voltage DC path. Various filter designs are discussed by Mloyiswa[2], *et al.*

For realising the coupling schemes, three different types of filters have to be designed. A high pass filter for high power AC path, a low pass filter for high voltage DC and a high pass filter for high speed bi-directional data. The cut off frequencies for each filters are 7 KHz, 8 Hz and 3 Hz respectively.

Coupling filter response is selected based on the operating band of the signals. In this paper the signal used are well separated. For high voltage DC coupling, low pass filter response is suitable. High voltage pulsed AC coupler uses high pass filter response. High speed bi-directional communication signal operates at a band of frequencies (1 MHz to 10 MHz). So band pass or high pass filters are suitable. The high voltage DC coupler uses inductors and capacitor elements. The combination of $L_3$, $L_4$, $L_5$, $C_2$ and $C_3$ has a low pass filter response. The theoretical value of the attenuation of high voltage pulsed AC signal of 5 KHz frequency at the high voltage DC coupling filter is -148 dB.

The high voltage pulsed AC coupling filter requires a high voltage rating capacitor. This is realised using a capacitor $C_4$ and the diode $D_1$. $C_4$ blocks the DC component and $D_1$ is to bypass the negative cycle of the high voltage AC signal. The theoretical value of attenuation of high voltage DC at the high voltage AC coupling filter is -148dB.

Similarly for the high speed bi-directional data path, coupling filter needs a capacitor to block high voltage DC in the high speed bi-directional communication path. Attenuation of high speed communication signal (10 MHz) in the high voltage DC path is -490 dB.

The Transfer function of the simulated high voltage DC coupling circuit is as shown in Eqn. (2).

$$H(S) = \frac{s^2 L_5 C_3 + 1}{\begin{array}{c} s^4 C_2 C_3{}^2 L_4 + s^4 C_2 C_3{}^2 L_5 + s^2 C_2 C_3 \\ + s^2 C_3 L_5 + s^2 C_3 L_4 + s^2 C_3{}^2 + 1 \end{array}} \tag{2}$$

It is clear from the transfer function that the coupler has two zeros and four poles.The transfer function of simulated DC coupler circuit used at the on-board side is as shown in Eqn. (3). Here there are only two poles.

$$H(s) = \frac{1}{(s^2 L_6 C_{12}) + 1)} \tag{3}$$

For the simulated high speed data coupler, transfer function is computed and is as shown in Eqn. (4). From the equation it is clear that there are two zeros and two poles

$$H(s) = \frac{s^2 C_{10} L}{s^2 L C_{10} + s^2 L_7 C_{10} + 1} \tag{4}$$

## 4. SIMULATION STUDY USING PSPICE®

For the design of coupling scheme, two vacuum relay are used for isolation of high power signal transmission. Simulation study has been carried out for transmission path and for data path using PSpice® based on the cut off frequencies and frequency of operations mentioned in earler section.

Figure 3 shows the PSpice® model of coupling scheme of high power transmission path. As the DC is coupled from the single core cable at the remote unit, it is essential to study the effect of high voltage pulsed AC signal in the DC path at the remote side.

A coaxial cable model with resistance, capacitance, inductance and conductance are arranged in a manner to simulate the coaxial cable. The values [R(6Ω), L(0.1 uH), C(120 pF) and G(10 M)] of a 300 m single core coaxial cable are used to simulate single core coaxial cable.

At remote side the high voltage DC has been taken from the cable and not from the relay. So the operation of coupler and its circuit has been simulated along with the coupler of high voltage DC path. When the transmission happens at on-board side the relay is controlled by a transmission enable signal,

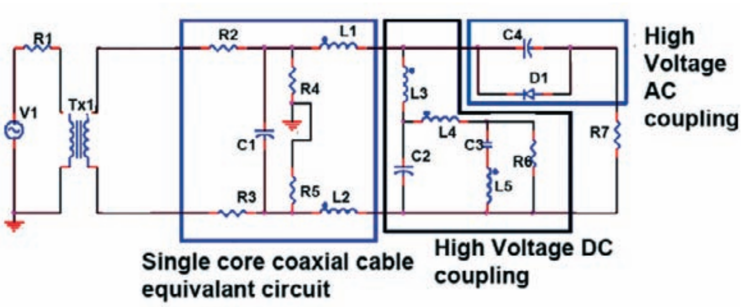


**Figure 3. PSpice® model of high transmission path.**

which switches the relay for high power pulsed AC.

Figure 4 plots the frequency response of the couplers in the high power pulsed AC path, ie.for high power AC and high voltage DC. Fig. 4(a) is the high pass response of the high power AC coupler and Fig. 4(b) is the low pass response of high voltage DC coupler at remote side. From the figure it is clear that there is no high power AC in the DC path as the coupler -3 dB point is 8.6 Hz. For high power AC coupler the -3 dB point is at 8.6 Hz.

Figure 5 shows the PSpice® model of coupling scheme of high speed bi-directional data along with high voltage DC. The high voltage DC path is common for both high voltage pulsed AC and high speed bi-directional data. When transmission enable issued by on-board unit, the flow of high voltage DC supply to remote unit is stopped. The high voltage DC supply will be received at remote unit once transmission is disabled at on-board unit. So the high voltage DC is used to control the vacuum relay for transmission and reception.

Figure 6(a) shows the effect of high speed data at the high voltage DC coupler and Fig. 6(b) is the band pass response of the high speed data coupler at on-board side. The -3 dB point of the band pass filter with lower cut off is 4.6 Hz and upper cut off is 41 MHz Similarly the -3 dB point of the high voltage DC coupler at on-board side with respect to the high speed data input is 9.6 Hz.

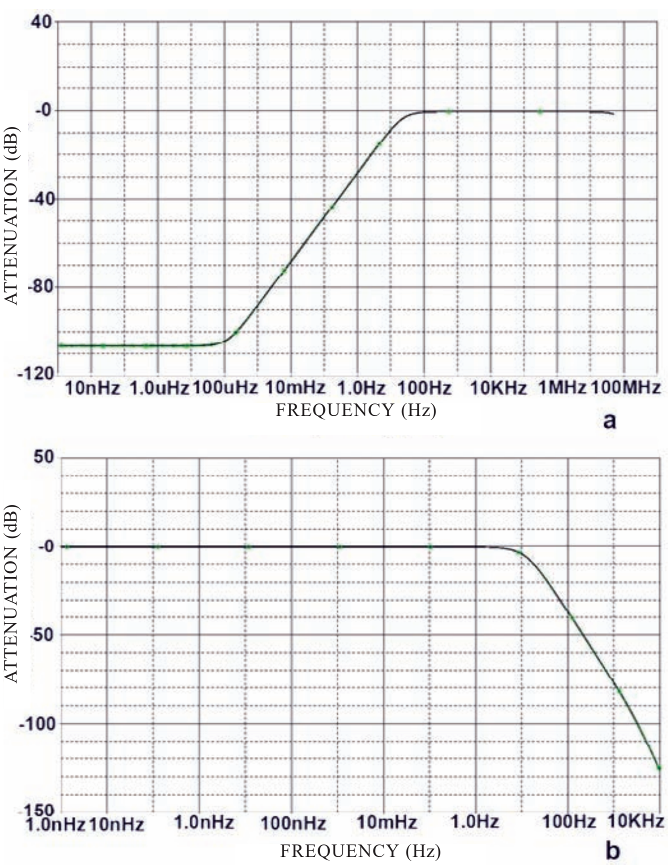


**Figure 4. Frequency response of the filters in the high power pulsed AC path: (a) is the response of high power pulsed AC coupling circuit and (b) is the response of high voltage DC coupling circuit.**

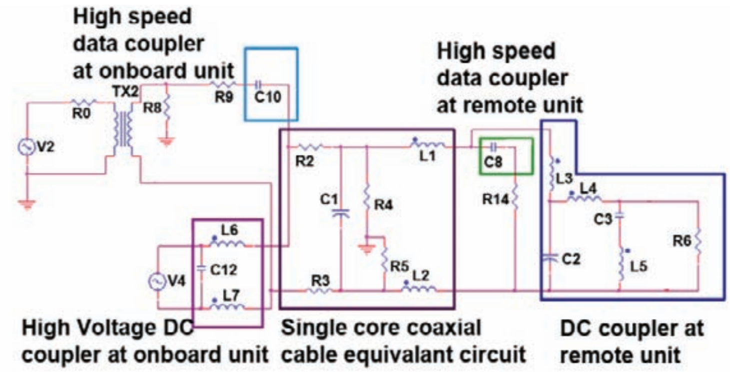


**Figure 5. PSpice® simulation coupler circuit for high speed data and high voltage DC path.**

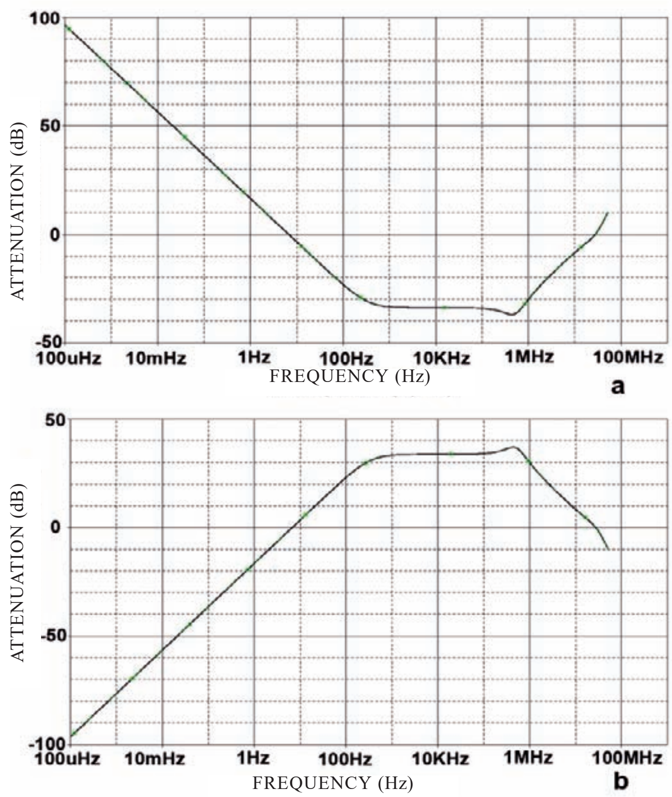


**Figure 6. Filter response at on-board side: (a) Effect of high voltage DC coupler circuit and (b) Effect of high speed data coupler circuit.**

The frequency response of the high speed data coupler used in the high speed data path at remote side is as shown in Fig. 7. The -3 dB point of the high speed data coupler is 62.85 KHz.

The designs of the couplers are optimised based on the operating band of frequency. The values of R, L and C are decided based on cut off frequency of coupling section. The attenuation of the frequency components is the only parameter to be checked while optimising the coupler design.

From the simulation it is concluded that the cut off frequency is around 10 Hz for low pass filter for DC coupling, 500 KHz for high pass filter for high frequency data coupling and 2.5 Hz for high pass filter for high power AC signal coupling.

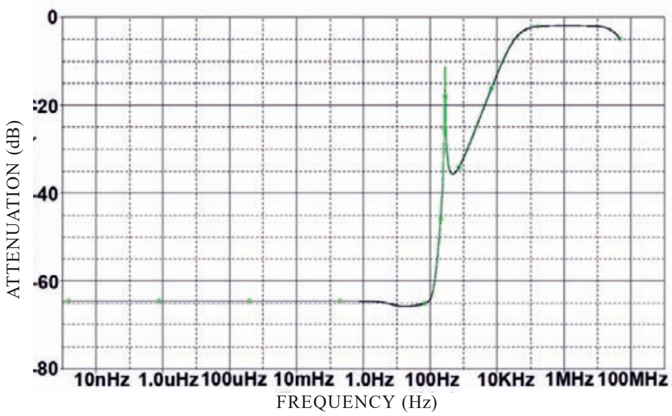


**Figure 7. Frequency response of high speed data coupler with respect to high speed data input at remote side.**

## 5. MEASUREMENT AND ANALYSIS OF DUAL RELAY BASED COUPLING SCHEME

Based on the above inferences, a prototype PCB has been fabricated and assembled foron-board and remote unit. Measurements were carried out for the transmission of high power AC signal, reception of high speed bi-directional communication data and high voltage DC separately. By impulse response of the each filter were plotted and the analysis to verify the effect of filter in high power AC coupling, high voltage DC and high speed bi-directional data coupling paths were carried out.

### 5.1 Transmission Path

The coupling circuits were tested with an input of 10 Vpp, half sinusoid, given from a signal generator. Fig. 8 shows the filter response of high voltage AC coupling filter. The high power pulsed AC coupling circuit has a high pass filter profile with an attenuation of -8 dB at 1 Hz.

High power pulsed AC signals were transmitted through the coupling filters. Measurements were carried out for two frequencies 3 KHz and 7 KHz at 4.3 KV peak to peak voltage.

From the analysis, it is observed that the 3 KHz signal has a peak of 61.88 dB and that of the 7 KHz signal is 62.50 dB. The component of 3 KHz and 7 KHz in DC path has a voltage level of 9.375 dB and 25.63 dB, respectively. This can be suppressed by using sufficient protection in the high voltage DC power supply side.

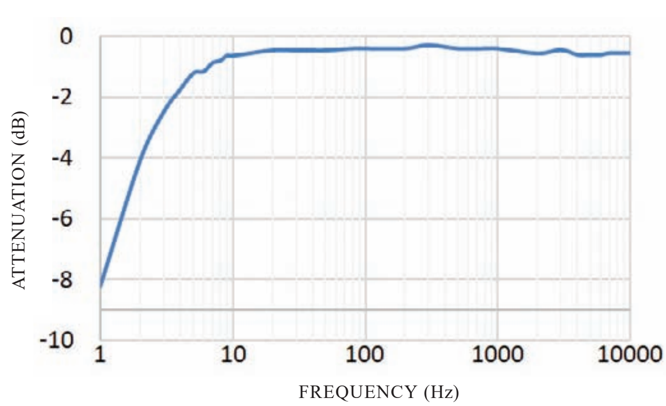


**Figure 8. High voltage AC coupling filter response.**

A Zener diode in back to back mode and a transient voltage suppresser (TVS) connected between the coupling filter outputs in the DC path provides protection over leakage of high power AC signal. When the vacuum relay is in the transmit mode, the cable along with the coupling filters are connected to the high power amplifier and the senor. In order to achieve the maximum power transmission, impedance matching has to be done at the power amplifier or sensor side.

### 5.2 Data Path

Once the vacuum relay switches to the data path, it will completely isolate the high power AC signal. This time the single core coaxial cable carries the high voltage DC and high speed data. This high speed communication data and high voltage DC is coupled through filters.

Figure 9 is the low pass filter response, for the high voltage DC coupler, with a cut off frequency of 85 Hz at -3 dB point. Fig. 10 is the filter response of a high speed data coupler which is a high pass filter response with cut off frequency of 500 KHz at -3 dB.

Additional protections have to be provided at the electronics side. Some of the protections suggestion is using metal oxide varistor (MOV) after the coupling filters. Addition of RF transformers in the data path provides isolation and also protects the transceiver circuits. RF transformer also helps for impedance matching between the transceiver chip and the coupling filters.

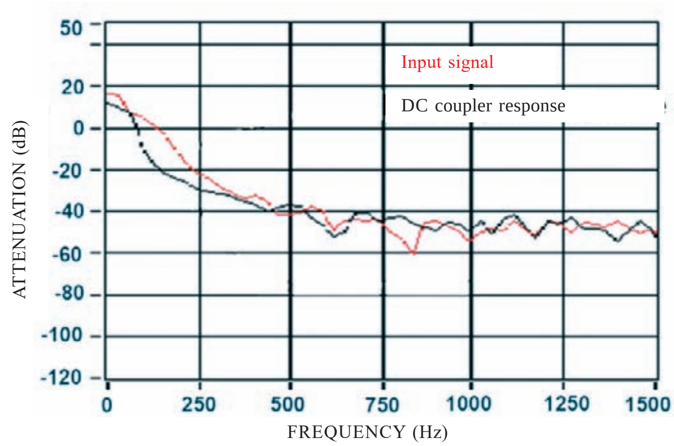


**Figure 9. High voltage DC coupling filter response.**

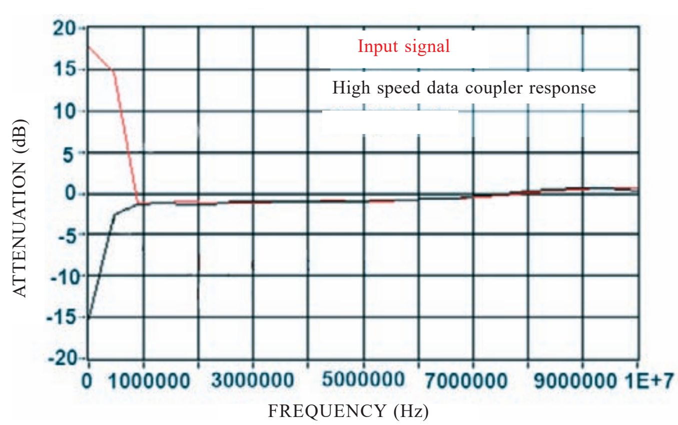


**Figure 10. High speed data coupling filter response.**

High speed data is sent from the remote unit with coupler circuit to the on-board unit through coaxial cable of 500 m. The voltage level at the input of the coupler at remote unit is 5 Vpp. At the output of the on-board high speed data coupler, the voltage level is dropped to 200 mVpp (-28 dB).This can be easily recovered using the on-board transceiver chip.

## 6. CONCLUSIONS

This paper introduces a dual relay coupling scheme, which will fully isolate the high power AC. The signals transmitted through the single core coaxial cable are well separated band of frequencies. The dual relay coupling scheme provides good isolation compared to that of the single relay coupling scheme. When high power pulsed AC transmission occurs, both the centre core and shield of the cable is switched to high voltage pulsed AC path. To realise this dual relay coupling scheme, simulation studies were carried out using PSpice®. Measurements were done to verify the filter response separately for high power AC signal coupling, high voltage DC coupling and high speed bi-directional data coupling. A high power pulsed AC signal of 4.3 KV peak to peak is transmitted and measurements were taken to study the effect of high power pulsed AC. Unlike the single relay mechanism, this scheme provides ground isolation. As the relay separates the high power AC path and high speed bi-directional path, leakage is zero. So this can be used in applications where high power signal handling is required along with high speed data communication and high voltage DC supply. Applications include imaging sonar and airborne sonar telemetry.

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## CONTRIBUTORS

**Mr Manoj G.** received MSc in Physics from Kerala University Campus, Karyavattom in 2001. Currently working as a Scientist at DRDO-Naval Physical and Oceanographic Laboratory, Kochi. His current research interests include, design and development of front end hardware and Telemetry development for Airborne Sonar, front end hardware design and Telemetry development of imaging sonar’s, near field acoustic characterization system, stepper motor controls. He has published papers related to challenges in Airborne Sonar’s, Sigma Delta Audio Cards, sensor less stepper motor controls, low noise amplifiers, linear power amplifiers for imaging sonars, simulink modelling etc.
In the current study, he has done the simulation using simulink and PSpice®, hardware prototyping and manuscript writing.

**Mr Eldho Jacob** received his ME (Power Electronics and Drives) from PSG College of Technology, Coimbatore, in 2015. Currently working as Scientist at DRDO-Naval Physical & Oceanographic Laboratory, Kochi in the field of acoustic signal conditioning, data acquisition, power line communication and networking. He is currently working in the design of airborne sonar telemetry and data acquisition, at Navel Physical and Oceanographic Laboratory.
In the current study, he helped for the selection of vacuum relay for enhancing isolation.

**Dr Sona O. Kundukulam** received the MSc (Electronics Science), in 1998 and PhD (Microwave Electronics), in 2003 from Cochin University of Science & Technology, India. Currently working as Scientist at DRDO-Naval Physical & Oceanographic Laboratory, Kochi. Presently she is working in the design and development of RF Systems for airborne Sonars. She has published more than 30 research paper in international and national journals and conferences.
In the current study, she is mainly involved in monitoring and verifying the results on a periodic basis. Her role in typesetting and bringing the paper in the present form is worth mentioning.