ROV AND REMOTE DATA GATHERING CONTROL, COMMUNICATIONS, AND POWER SUPPLY OVER A SINGLE INEXPENSIVE COAXIAL CABLE USING A LOW POWER MULTIPLEX SYSTEM.

A. P. Shefer
Naval Surface Warfare Center
Ft. Lauderdale Detachment
1650 S.W. 39th St.
Ft. Lauderdale, Fl. 33315

Abstract- A need exists for a compact, low power, maintainable method for operating remote data gathering and control devices using inexpensive cable. When acquiring data or controlling events from a remote site, a system is required to communicate pertinent signals between the controlling station and the remote site. Common signals are digital or analog sensor data, video and sonar. In addition to sending data back from the remote site, it must also be supplied power and signals to control the onboard package.

The use of multiconductor cable is common at this time. Often significant cross channel interference exists. On longer cables, the cost of this cable and the signal losses are often significant and prohibitive. Optic fiber is an alternative, but again the cost of cable and the specialized equipment used with optic fiber systems is often prohibitive. The system described in this paper was designed to be relatively inexpensive to build and maintain.

The paper shows how a Frequency Multiplexed System can be designed using low power CMOS integrated circuits which not only eliminate the need for multiconductor cable, but also increase the workable length of the cable. The design of frequency multiplexed systems and power supply are covered with particular attention to cable characteristics requirements, and correlation of these requirements to commonly available coaxial cables. The use of Super-Hetrodyne type receivers to carried underwater communications is covered in particular. The paper discusses the design and implementation of such a system to operate NSWCDD's TONGS (Televised Observed Nautical Grappling System), increasing its usable depth, while significantly reducing the systems electrical crosstalk and maintenance costs.

I. INTRODUCTION

This paper will outline a frequency multiplexed system designed for use with inexpensive RG-8 type coax cable. The heart of the system is a low-power digital telemetry link based upon Signetics' NE605A low-power CMOS FM receiver IC and Harris CD74HC4046 Low-power CMOS Phase Locked Loop demodulator. In addition, a transition detector of the authors design is used to reconstruct the digital signal. The basis for the system is multiplexing frequencies across a broadband on to the cable. Each frequency is used to communicate one type of information, in one direction. This type of system is thus called a Frequency Multiplexed System.

The system described in this paper was developed in order to reduce the cost of replacement cable and to improve the performance, of NSWC, Ft. Lauderdale Detachment's underwater recovery vehicle known as TONGS, Television Observed Nautical Grappling System. One of the Ft. Lauderdale Detachment mission tasks is to provide the capability to deploy and recover heavy loads in deep water. The TONGS system is the primary vehicle for recovery of these loads. As currently configured, loads of up to 10,000 pounds are handled by using separate mechanical and electrical lines, attaching an electrical tether to the mechanical load carrying wire, as the system is deployed and recovered. Using this method the electrical tether sees very little mechanical loading, thus the cost of the cable is reduced. Greater load handling capability is possible by simply increasing the strength of the mechanical wire.

The project was started to replace the electronics systems on TONGS with a new system which would allow the old multi-conductor cable to be replaced with a single coaxial cable. The coaxial cable would transfer all power and communications signals required to operate TONGS, with greatly reduced interference between sub-systems on TONGS. An additional benefit is that by using only a single coaxial cable, the TONGS system can be operated from an electro-mechanical cable on a single winch, as opposed to melding the electrical tether to the mechanical lifting wire.

II. FREQUENCY MULTIPLEX BASICS

To construct a system of this type, it is necessary to frequency multiplex onto the coaxial cable all signals required to operate a system, including system power. Frequency multiplexing is a technique in which each piece of information to be transferred is modulated at a different
carrier frequency and is then injected onto the cable. At the other end of the cable, each carrier signal is separated from unwanted signals by using filters designed to pass only the desired signal. The filtered signal is then demodulated to reconstruct the originally transmitted information.

When information is modulated onto a carrier, the resulting signal contains not only the carrier frequency, but also many other frequencies adjacent to the carrier, known as side bands. It is the side bands of this communication signal which actually carry the information being transferred. The span of frequencies included in the side bands, from the lowest to highest required to replicate the signal which has been modulated, is known as the bandwidth of the signal. Each carrier frequency carrying a separate piece of information in its sidebands will be referred to as a CHANNEL. Ideally, this would indicate that an unlimited number of separate channels of information could be passed on the cable, but in fact the cable only has a finite amount of usable bandwidth, due to excessive attenuation at higher frequencies, which restricts the total number of channels which may be used.

III. CABLES AND POWER

The job of a cable is to pass power. When passing information, the cable is commonly used to transfer a voltage signal, while passing virtually no current. In this case the voltage level may be accurately passed, but very little power is conveyed since electrical power is the product of voltage and current. Necessarily, the cable will not yield the same amount of power at the terminating end as was supplied at the source end. These power losses at low frequencies are due to cable resistance (R) multiplied by the square of the current (I) carried, commonly known as IR losses. It is the IR losses that affect the transfer of system power to the remote unit or ROV.

At higher frequencies the losses, which affect the communications signals passed through the cable, are due to the capacitive, inductive and resistive properties of the cable. These properties determine the characteristic impedance of the cable, which is the most important parameter when designing communications equipment to be used with a particular cable. Fundamentally, the impedance of the cable indicates the most efficient load resistance which can be driven by the cable. A system in which both the driving impedance and the terminating load are matched to the impedance of the cable provides for the minimum signal attenuation possible at any given frequency. Restated, when a system is designed to transmit a signal at a particular frequency into a resistive load equal to the impedance of the cable being used, and that load is then used at the other end of the cable, power is most efficiently transferred through the cable.

The reason that system power can be transferred by the cable along with the information channels is that power is merely another piece of information being injected onto the cable at one end so that it may be received at the other end. Direct Current (DC) power has a frequency of 0 Hz, while Alternating Current (AC) typically has a frequency of 50, 60 or 400 Hz. Techniques for separating system power and communications channel signals from the cable involve the design of appropriate filtering systems at each end of the cable.

![Figure 1(a)](image)

*Figure 1(a) Cable Signal Separation Filtering For Use With DC Powered Systems.*

![Figure 1(b)](image)

*Figure 1(b) Cable Signal Separation Filtering For Use With AC Powered Systems.*

Figure 1.(a) shows such a system for use with DC system power, while figure 1.(b) is typical for AC system power. In fig. 1.(a) the capacitor passes the communications channels, which are at high frequencies, while blocking the low frequency power. The inductor prevents the very low impedance of power system from shorting the communications signals to ground. In figure 1. (b) an AC powered system operates in the same manner except it is not immediately obvious that the internal self inductance of the power transformer is sufficient to prevent the power system from shorting the communications signals to ground. In either case, the components chosen must be capable of
passing the required system power current.

Once the power and control signals are separated on both ends of the cable, additional filtering is used to separate each channel's carrier from the others. The transmitted and received signals are then injected onto or retrieved from the cable through the appropriate filter. The signals on the receiving end of the cable are then routed to tuned amplifiers or directly to the demodulators. Tuned amplifiers are only used to overcome cable attenuation when required.

Figure 2. shows the frequency attenuation characteristics for RG-8 type, 50 Ohm coaxial cable. At 5 MHz, the cable attenuates signals 3.5 dB per 1000 feet, or about 74 dB at 4 miles. If a 1 Vrms signal is transmitted, then a .2 mVrms signal is received at the other end of the cable. Since the receiver system described in section VI. has a sensitivity of less than .005 mVrms, this would be considered a very strong signal.

**Figure 2.** RG-8 Type Cable Attenuation vs. Frequency.

### IV. MECHANICAL AND ENVIRONMENTAL REQUIREMENTS OF CABLE

This paper is to outlines methods which will allow the use of a single coaxial cable in place of a larger more expensive multiconductor cable. The RG-8 type cable used in the discussions is one of the most common coaxial cables on the market. It was chosen primarily due the fact that it has lower resistive and high frequency losses than cable such as RG-58. Although these cables are not designed for underwater use, they can be used for limited durations as 'wet cables'.

The term 'wet cable' refers to the assumption that the outer shield conductor is assumed to be either wet or in contact with sea water. This assumption is made because the outer poly vinyl chloride jacket is not guaranteed to be free of pin holes and other microscopic faults which will allow sea water to infiltrate the coaxial shield. The polyethylene used to insulate the inner conductor of the coax from the shield is a much denser plastic and will isolate the center conductor from the sea water. Little change in cable characteristics is seen when the outer conductor becomes wet, as long as the insulation of the inner conductor is intact.

These are observations made from working with cables of similar construction for many years. Even though the cables were actually designed for underwater use, to keep the conductors dry, when they become damaged the substantial pressure of the depth forces sea water into the air gaps of the cable's conductors. It has been our experience that even though the sea water migrates through out the shield and inner conductors of the cable, as long as these two conductors stay insulated from one another, the cable will operate properly.

When AC or DC power is applied to a wet cable, galvanic corrosion will take place if the system's power is grounded or in any other way referenced to earth ground at either end of the cable. This fact requires a design in which the cable is completely isolated from the the equipment at both ends of the cable. At the top side end of the cable, DC power provided to the system must be allowed to 'Float', that is neither the positive or negative terminal of the supply can be connected to ground. The use of linear type power supplies is suggested since the internal transformer provides the isolation required. Caution must be taken when using switching type DC power supplies because an internal ground connection sometimes exists. For AC power, an isolation transformer is all that is needed.

At the sea end of the cable, the supplied DC power is isolated from it loads, and converted to the various voltage levels required by using DC/DC power converters. If AC power is required for a system powered by DC, power inverters are required. Both power inverter and DC/DC power convertors internally contain transformers which actually provide the isolation required.

### V. DATA TRANSMITTER/ MODULATOR DESIGN

The general design of the circuitry used is covered within texts on the design of radio communications equipment. A full discussion of both amplitude and frequency modulation is beyond the scope of this paper, thus it is assumed the reader is familiar with these basics. Only special techniques used with synthesised FM carriers for data communications will be covered in this section.

The data transmission technique most commonly used for data communications is known as FSK (Frequency Shift
Keying). This technique involves shifting the carrier between two known frequencies, one representing a mark, a digital 1, and the other representing a space, a digital 0. A variation of this technique developed by the author is termed Frequency Varying FSK (FVFSK). In this modulation scheme, although the actual frequencies of mark and space vary about the nominal center frequency, the relative frequency shifts between the mark and space remains the same. This technique was developed to allow FSK type transmission to be achieved while still having the stability of a crystal controlled frequency synthesizer.

For reliability, the system requires accurate and stable frequency generation, this is because small deviations in either transmitter carrier frequency or receiver local oscillator frequency will cause a much greater frequency shift in the intermediate stages of the superheterodyne receiver circuitry, causing signal loss. In order to minimize frequency drift, crystals are used to set these frequencies. This is a simple task for the receiver’s local oscillator, a simple crystal oscillator with sinusoidal output can be used. The transmitter, on the other hand, is not quite as simple since the crystal’s achievable frequency variation is on the order of 50 to 100 ppm, which provides inadequate frequency deviation for the generation of the required FSK signal, at frequencies in the 1 to 10 MHz range. The author’s solution to this problem involves the use of a Frequency Locked Loop design using the CD74HC4046, a low power CMOS phase/frequency locked loop.

The Frequency Locked Loop (FLL) is designed to lock to the transmitter’s nominal center frequency, which is supplied by a crystal oscillator or crystal based synthesiser. Within the loop’s feedback circuitry a modulation signal is added allowing for frequency modulation of the VCO. The loop’s filter and associated tracking characteristics are designed such that at the channel’s bit transmission rate, the loop has insufficient time to make any noticeable correction toward the reference frequency. During periods of no transmission, the loop will force the transmitters output to the reference frequency. The most critical portion of the system’s design is the transition from the inactive state to the active state, at which time an improperly designed loop filter will cause the transmitter to deviate outside of its allotted frequency band. Figure 3. shows a block diagram of a FVFSK transmitter.

VI. DATA RECEIVER/DEMODULATOR DESIGN

The job of the FM receiver is to receive the transmitted signal, in as noise free a form as is possible and then pass this signal to the demodulator to reconstruct the transmitted digital signal. The receiver circuitry used is a super-heterodyne type receiver, similar to the type used in modern radio and television receivers. It’s job is to down convert the FSK signal from the carrier frequency to the Intermediate Frequency (IF), which in this case is 500 KHz. This type of receiver exhibits excellent frequency selectivity, signal-to-noise ratio and gain. After the IF frequency is amplified and limited, the signal is actually demodulated to recover the data transmitted using a Phase Locked Loop (PLL). Figure 4. shows a block diagram of the receiver/demodulator system.

The data channel receiver uses a crystal based Local Oscillator (LO) for stability. The LO is mixed (multiplied electronically) with the carrier to be received, resulting in a signal at 500 Khz. A two stage IF amplifier, with each stage having a bandwidth of 80 Khz, stagger tuned to yield an effective bandwidth of 120 Khz, is used to both amplify and filter the signal. The NE605 FM receiver system integrated circuit includes all the circuitry required to receive the signal, with the exception of a few capacitors and tunable inductors. The NE605 is a low power CMOS circuit designed for use in cellular phones and other battery powered applications, which makes it ideal for use with ROV’s and remote testing equipment.
To demodulate the IF signal, still a FSK signal, a PLL is required since the signal contains a DC component. It is the nature of the PLL that it can detect and maintain a DC component while tracking a frequency. The output of the PLL will be considered the raw demodulated signal, which is then passed to additional circuitry to reconstruct the digital data stream.

With a FSK signal, digital signal reconstruction is straightforward. The raw demodulated signal is compared with a set threshold level to switch the raw demodulated signal to digital states, as is shown in figure 5. When receiving FVFSK, the demodulated signals varies to such an extent that a simple threshold can not be used to detect the transmitted digital signal, as is shown in figure 6. To get around this problem, the author designed a transition based detection scheme, since the one stable characteristic of the transmitted signal is its well defined and almost instantaneous frequency shift at a digital level transition. The circuitry takes the raw demodulated signal and high-passes the signal at a frequency well above the natural frequency of variation of the transmitter's FLL. This causes positive and negative going transition spikes to be generated, which are then fed into a schmitt trigger, where the hysteresis is set for reliable detection with the greatest possible noise immunity, as is shown in figure 7.

VII. TONGS ON BOARD EQUIPMENT AND POWER REQUIREMENTS

The TONGS system consists of the mechanical structure, two thrusters for maneuvering the vehicle, a camera, a light, an obstacle avoidance/search sonar, pan and tilt, compass, and a listening hydrophone. The thrusters are only used to maneuver the vehicle while hooking a recovery bail. The compass, sonar, camera and light are all mounted onto the pan and tilt, so that the operator of the system has a coordinated view of the situation on the ocean's floor. The compass always indicates the direction that the camera is pointing. The sonar is used primarily to search for the object to be recovered, although it is also used to measure distances between objects on the ocean floor.

With this type of system it is safest to only supply power at one frequency. This then requires that the common power supplied be converted to the various types of power needed by the subsystems on board. The Power Distribution to the sub-system on board TONGS is one of the simpler tasks associated with this project. TONGS power will be supplied at 60 Hz. Table 1. shows the voltage levels, current types, current capacities and conversion method to be used, such that the 220 VAC power supplied to TONGS may be cause the system to exhibit poor noise immunity. Equally important is the fact that over modulation will result in reduced signal strength within the receiver due to the limited bandwidth of the intermediate frequency filters. Once the frequency deviation has been determined and the circuitry has been designed, the receiver system will exhibit greatly reduced receiver dynamic range and will often not work properly unless the transmitted signal has correct modulation level. The receiver design shown in figure 4. typically has over 80 Db. of receiver dynamic range, but when modulation is reduced by 20%, dynamic range is reduced by 30 Db.

III-240
converted to power suitable for the various sub-systems on board TONGS.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Type</th>
<th>Current</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
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<td>AC</td>
<td>2</td>
<td>Isolation Trans.</td>
</tr>
<tr>
<td>110</td>
<td>AC</td>
<td>2</td>
<td>Step Down Trans.</td>
</tr>
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<td>DC</td>
<td>3</td>
<td>Power Supply</td>
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</tr>
<tr>
<td>24</td>
<td>DC</td>
<td>15</td>
<td>Power Supply</td>
</tr>
</tbody>
</table>

Table 1. Power Distribution Voltages, types, Capacities and Sources.

VIII. OVERALL FREQUENCY ALLOCATION FOR TONGS MULTIPLEXER

The frequency multiplexed system for TONGS was designed with the following frequency allocations. Power is provided to the TONGS at 220 VAC, at 60 Hz. Acoustic listening signals in the 500 Hz to 100KHz base band are transmitted to the TONGS control pod on an AM carrier at 1 Mhz, signal bandwidth will be 200 Khz. There are two high speed bi-directional digital data links between TONGS and the pod. Each link consists of an uplink and a downlink, for a total of 4 data channels. The data link channels designed use FVFSK carriers with 25 Khz deviation and data throughputs of 50 Kbits per second, with bandwidths of 150 Khz. Data uplinks (TONGS to control pod) are at 3.5 and 7.0 Mhz. Data downlinks (control pod to TONGS) are at 4.0 and 6.5 Mhz. For proper operation it was assured that no significant energy is injected onto the cable at 3.0, 4.5, 6.0 or 7.5 Mhz. These constraints are put on the system to limit image signal interference in the superhetrodyne receivers.

Wideband video, capable of transmitting high quality color video is modulated at 28 Mhz. This video signal is Amplitude Modulated (AM) with a bandwidth of 8 Mhz. A secondary video carrier is being reserved at 16 Mhz for either Color or Monochrome video signals, again AM modulated, but with only a 3.6 Mhz bandwidth. The frequency band from 1.3 Mhz to 2.8 Mhz is reserved for specialized auxiliary control signals on an as required basis. At the present time this band is only used for remote hardware reset of the on board CPU. All circuitry is crystal controlled to maintain frequency accuracy and reliable operation.

Control information is sent to TONGS using one of the two downlinks available. This control information includes Pan and Tilt commands, Thruster Motor commands, Camera Focus commands, Sub-System power control and Auxiliary System control. Control circuitry on board TONGS consists of serial to parallel convertor, mutually exclusive command lock-out logic and solid state relay drivers. The relay driver circuits directly drive the existing motor control box, another solid state relay bank (power MOSFET’s), having 200 amp switching capability, which in turn actually switch the thruster motor loads. Another solid state relay bank was installed to switch power for the pan and tilt, the light, the camera and the sonar, since these functions had previously been direct wired.

The remaining sub-systems currently on board TONGS have been implemented in the following fashion. The compass sends its bearing information to the control pod using one of the two uplinks available. The remaining uplink and downlink will be used by the digitally based optical avoidance sonar. The gas plasma light which has previously been used on TONGS was replaced with a filament bulb of identical mechanical design. This eliminates the need for a ballast, while retaining the current mechanical mounting system.

IX. SUMMARY

Modern underwater environmental, acoustic and device performance measuring and testing systems generally function under micro-computer control. These types of systems have typically used RS-422 differential serial communications, which require a separate twisted pair for each communications channel. This transmission method severely restricts the maximum length of a cable at high data rates, due to the high capacitive and resistive losses of the twisted pair. Typically, 19.2 Kbaud data transmission would be limited to under 1 mile.

The data transmission and reception system, along with the power separation systems, described in this paper overcomes this problem. The techniques can easily be applied to remote measuring and testing tasks, whether underwater or on land, allowing inexpensive coax costing approximately $0.50 per foot to be used in place of cables costing as much as $20.00 per foot. Systems with multiple channels operating at 19.2 Kbaud are possible well beyond 4 miles, the extent of our testing. At this test distance, the test system (3.5 Mhz FVFSK Carrier) could still handle another 33 db of loss, at which time the data transmission becomes unreliable. With higher transmission power, or a tuned preamp in the receiver section, the systems useful range may be extended significantly.