33RD INTERNATIONAL COSMIC RAY CONFERENCE, RIO DE JANEIRO 2013
THE ASTROPARTICLE PHYSICS CONFERENCE

HV Cable Manufacture and Testing for the HAWC observatory

S. ADAMS[1], A. S. BARBER*[1], A. FULLMER[1], D. KIEDA[1], M. D. NEWBOLD[1], I. SOHL[1], R. W. SPRINGER[1], FOR THE HAWC COLLABORATION[2].

[1] *Department of Physics and Astronomy, University of Utah*
[2] *For a complete author list, see the special section of these proceedings*

ahron.barber@utah.edu

Abstract: HAWC, the High Altitude Water Cherenkov gamma- and cosmic-ray observatory is being constructed on Sierra Negra in the Pico de Orizaba National Park in Mexico. HAWC is an array of 300 water Cherenkov detectors spread over 22,000 m^2. Each detector has four photo multiplier tubes (PMTs). Individual high voltage power to each PMT is supplied from the central electronics facility, and travels to each PMT through 149-meter long RG-59 cables. Signals from each PMT travel back to the facility through the same high voltage cable, and the PMT signal is picked off the HV signal by the front-end board electronics for amplification, triggering, and event reconstruction. Reliable operation of HAWC requires testing of individual cables for the ability to handle the required PMT high voltages. Accurate reconstruction of extensive air shower direction and energy require the equalization of cable time delays as well as the accurate measurement of cable attenuation characteristics, including cable rise time and fall time. In this poster, we describe the fabrication, construction, and deployment of the HAWC cabling system. We outline the cable fabrication procedure used to equalize cable delays to ensure similar attenuation between cables, and describe the automated testing procedures used to certify individual cable high voltage and bandwidth performance. We summarize the characteristics of the cables produced for HAWC, including the average and standard deviation of the cable delays, rise and fall times, and cable attenuation for fast pulses.

Keywords: HAWC, HV Cables

1 Introduction

The High Altitude Water Cherenkov Observatory [1] is currently being built in central Mexico near Puebla within the Pico de Orizaba National Park. This is the second generation of water Cherenkov style detectors for gamma and cosmic rays. HAWC is composed of 300 water Cherenkov detectors built over an area of 22,000 m^2. Each of these detectors will be instrumented with one 25.5 cm photo multiplier tube (PMT) and three 20.3 cm PMTs. A total of 1200 PMTs will be instrumented and cabled to the central electronics facility. The electronics are centrally located to minimize the cable length to the most distant PMTs. Each PMT will have a single cable; the high voltage and the PMT signals propagate along the same coaxial cable. The PMT signal is isolated by the high voltage section of the front-end-board electronics, and is recorded using a multi-level discriminator and multi-hit TDC. The dual use of the cable for both high voltage and signal measurement requires properly prepared cables.

HAWC uses the RG-59 Belden 8241 coaxial cable, which is purchased in spools of $\sim$150 m in length. The core is solid-core copper coated steel with polyethylene insulator and copper braided shield with an outer PVC covering. This cable is designed to operate at a maximum voltage of 1700V RMS with no more than 470 watts at 50 MHz. However, our cables are subjected to 3100V DC in testing. This cable type was successfully used for the outriggers in the MILAGRO experiment, HAWCs predecessor. Each cable costs $\sim$ 150 USD.

It is important for the cables to be made as electrically identical to each other as possible because HAWC requires accurate timing and similar attenuation for all the cables. On-site timing calibrations will be performed periodically with a laser calibration system to account for the electronics pathways in addition to the cables [2]. The accurate reconstruction of the extensive air showers requires precise timing and charge measurements from the PMT signals. Small changes in the manufacturing conditions at the cable manufacturing factory can affect the electrical properties of the cable. To fabricate cables with consistent electrical properties, each cable is time matched to a standard reference (the "Golden Cable"). The standard Golden Cable was fabricated for constructing the first batch of cables for the first deployment phase of the HAWC detector: the first 30 detectors [3].

The raw cables are purchased in batches of $\sim$300 spools of 150m length each, and then processed at the University of Utah before being shipped to the HAWC site in Mexico for installation. In section 2, the fabrication of the cables is discussed. Section 3 discusses the methods used to test and verify the electrical performance of the cables. Distributions of various electrical parameters for the cables, such as time delay, rise and fall times are presented in section 4.

2 Processing

The cable fabrication is performed in four steps:

1. Re-spool the raw cable.
2. Crimp on first SHV connector
3. Cut the cable length to time match the new cable to the Golden Cable
4. Crimp the second connector

Re-spooling the cables is done for two reasons: to identify any physical damage such as damage to the outer PVC jacket, and to expose a 9 m segment of cable to affix an SHV[1] connector and allow electrical testing. The rate of defective cables, physical damage, is found to be $\sim$1%. Most defects appear as an abrasion to the PVC outer jacket, or the outer PVC jacket is split lengthwise. It is important to identify defects in the outer PVC jacket as the cables are routed between the detectors in drainage pipes buried deep enough to avoid night to day temperature variations. These pipes occasionally fill with water, and so these cables must be able to carry the required high voltage even when submerged.

The cables must have the similar lengths to provide identical time delays, but the distance from the central electronics facility to each tank is different. For shorter distances, the excess PMT cable will be stored near its specific water tank, wound on their original spool. The exposed short 9m cable segment connects to the inner windings of the cable on the spool, and therefore allows the electrical connection to be made to this end of the cable without having to fully unwind the cable off the spool.

Once a cable has been checked for physical defects and rewound onto the spool with the exposed 9m cable segment from the inner windings, a Kings 1705-1 SHV connector is crimped to the end of the exposed 9m cable segment. The other end of the cable is then cut to give precisely the same time delay as the Golden Cable, using a reflection-cancellation technique.

The reflection-cancellation technique employs a fast pulse generator to send a signal through both the Golden Cable and the cable under fabrication (figure 1). A coaxial 4-way junction is used to split the pulse generator signal and pass it to one end of the Golden Cable, one end of the cable being fabricated, and channel 1 of a Tektronix TDS 580D Oscilloscope. The other end of the Golden Cable has the coaxial cable terminated to a zero Ohm short circuit. The pulse will therefore reflect off the short circuit and return to the oscilloscope with inverted polarity. The other end of the cable under fabrication is left open circuit so the reflected pulse will return without inversion. The sum of the two reflected pulses are observed to exactly cancel when both cables have the same time delay. This process has the advantage that it is very robust with respect to recalibration or temperature drift of the oscilloscope time base. After the cables are time matched, a second Kings 1705-1 SHV connector is crimped onto the open end of the cable being fabricated. . The cable is then assigned a cable serial number, and a PMT and tank label.

3 Testing

After attaching the second SHV connector, the cables are tested and the electrical properties of the cable are stored in an excel spreadsheet. The first test is a simple continuity test, which ensures the connectors have been attached properly and are making contact with the coaxial cable. The test is performed with a digital ohmmeter, and the range of acceptable values is listed in table 1.

The second test involves the measurement of the cable performance while subjected to high voltage. The cables are tested at a high voltage of 3100 V. This voltage substantially exceeds the normal high voltage used for the HAWC PMTs (by approximately a factor of two). This test employs a Bertan 375x, $\pm$5 kV supply with a current limit set to 1 mA. The power supply is configured for positive high voltage. The high voltage supply is connected through a 10 kOhm inline resistor to one end of the fabricated cable; the other end of the fabricated cable is left open circuit. The voltage across the inline resistor is divided by the 10 kOhm resistance in order to determine the current being supplied by the power supply to the coaxial cable. The high voltage is ramped to 3100V and the voltage across the inline resistor is measured by a handheld voltmeter in order to estimate the current being supplied to the coaxial cable. Cables which pull less than 140 microamps at 3100 V bias are considered acceptable for use in HAWC.

Measurement	Acceptable values
Core to Core	$23 \pm 1\Omega$
Shield to Shield	$1.4 \pm 0.2\Omega$
Core to Shield	∞

Table 1: The three continuity checks with acceptance bounds.

Measurement	High bound	Low bound
Rise Time (ns)	46	48.5
Fall Time (ns)	46	49.8
Delay Time (ns)	760	762.5
Area (ns·V)	181	191

Table 2: The acceptance bounds for the pass or failure for all cables.

The final test stage is the electrical characterization test. This test uses a BNC6040 pulse generator to send a calibrated square pulse into the cable. The other end of the cable is terminated to 75 Ohms at channel 1 of a LeCroy LC534A digitizing oscilloscope. The LeCroy LC534A oscilloscope measures the various electrical properties of the cable, including rise time, fall time, time delay , and pulse area. These values are then read into the LabView program to apply the acceptance cuts shown in table 2. This program displays all the data for a batch of cables and an indicator whether the cables passed or failed. The resulting values for each cable are stored in an Excel spreadsheet.

4 Results

The objective of this work is to create a very uniform set of cables for the HAWC experiment. This objective has been achieved, as shown in the table 3 along with the figures 2 through 5. Of the final production of cables, we find that there is a failure rate of 3%. If a cable fails any of the final test value ranges, it is rechecked for manufacturing errors (e.g. a bad SHV crimp). If it still fails, then it is reserved as a spare. Of the failures, 19 cables are found to have too short a time delay and are therefore kept as spares, meaning they do not receive a tank and PMT location until necessary. The obviously short cables are found early in the processing pipeline, as the physical length is found to be shorter than the Golden Cable during the re-spooling. Others are found when the cable is time matched; the reflected pulse is observed to be less than the Golden Cable's nominal time.

1. Secure High Voltage

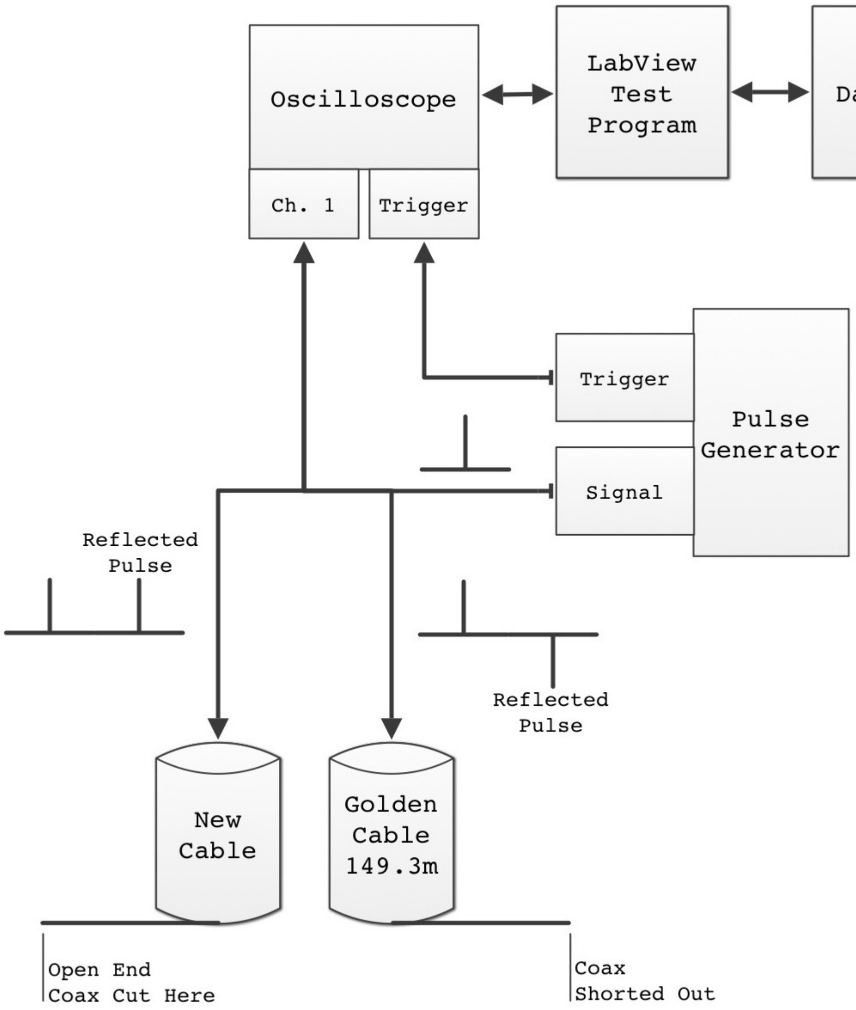

Figure 1: This figure illustrates the connections for the Pulse Generator (PG) which the signal is then split 3 ways, to the Golden Cable (GC) and the Cable (C) and the Oscilloscope (OS). This circuit is a simple 4-way junction containing equidistant paths for the two cables being compared.

These not so obvious short cables are then set aside to be spare cables and then processed after all other cables.

In figure 3, there are a few cables that are observed below the lower acceptance bound from table 2. However, as one can see in the figure, the distribution is continuous. Only two of the cables with a delay time less than 760 ns have a rise time faster than 47 ns. The limits set for the cables are arbitrary, and were chosen to highlight those cables falling on the extremes of a predicted distribution. We conclude that for any cable that falls outside the set limits (except for the delay time measurement) and are found to belong within the continuous distribution are acceptable. The fall time and the area both have a few outlying cables, but are within the chosen acceptable range or deemed acceptable.

Acknowledgment: US National Science Foundation (NSF); US Department of Energy Office of High-Energy Physics; The Laboratory Directed Research and Development (LDRD) program of Los Alamos National Laboratory; Consejo Nacional de Ciencia y Tecnología (CONACyT), México; Red de Física de Altas Energías, México; DGAPA-UNAM, México; and the University of Wisconsin Alumni Research Foundation.

Measurement	Average	Standard Deviation
Rise Time (ns)	47.9	1.2
Fall Time (ns)	47.5	0.5
Delay Time (ns)	761.2	0.8
Area (ns·V)	184.8	4.5

Table 3: This is the end result for the 300 cables in the second and third batches of cables.

References

[1] M. Mostafa, Session HL of ICRC 2013
[2] H. Zhao and H. Ayala, Session GA-IN Poster 651 of ICRC 2013
[3] I. Torres, Session GA-IN Poster 824 of ICRC 2013

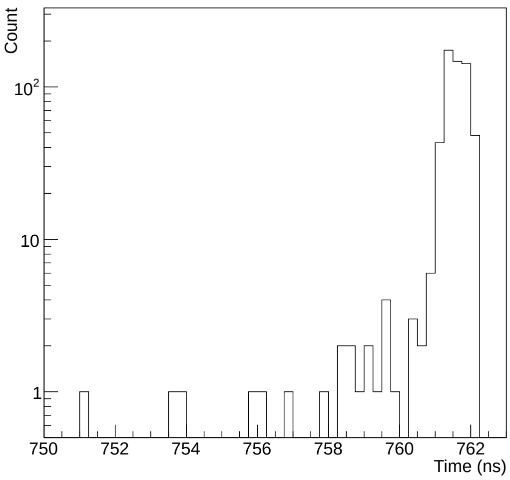

Figure 2: The observed distribution of delay times for 585 Cables.

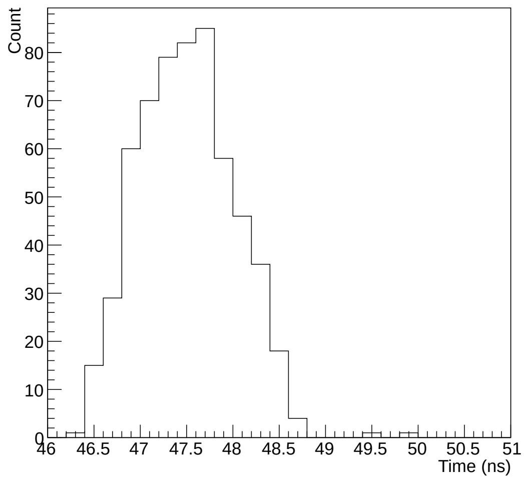

Figure 4: The observed distribution of fall time distribution for the 585 cables.

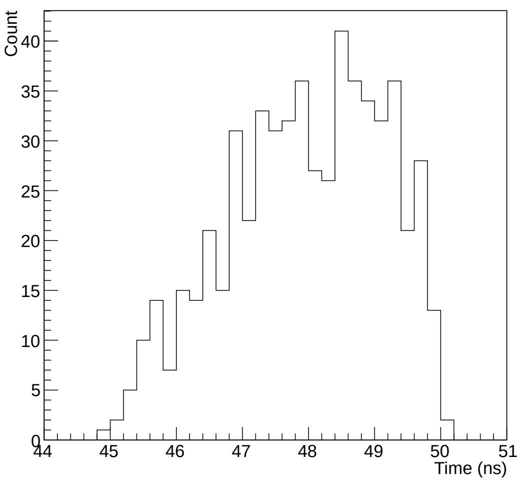

Figure 3: The observed distribution of rise time distribution for 585 cables.

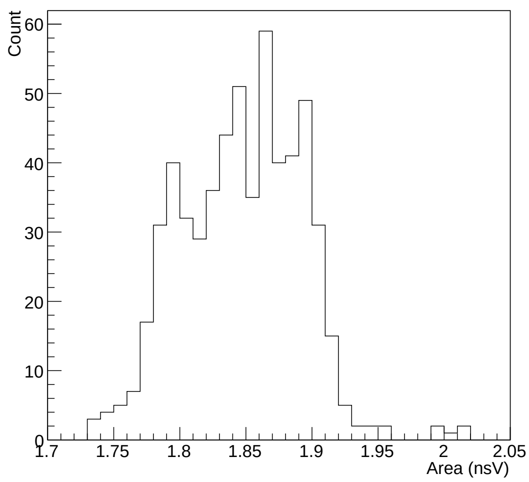

Figure 5: The observed distribution of Area distribution for 585 cables.