ICARUS connectivity test — December 2018

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Abstract

We present here the updated procedure and results of the connectivity tests done on the TPCs wire planes of the ICARUS detector on December 2018. The test verified the connection of the TPC wires up to the connectors to the readout boards just outside the cryostats. All wires were tested on all three planes, with the exception of the shorter wires in the second induction and in collection planes, that are read out from one of the eight chimneys at the end of the detector.

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1 Introduction

ICARUS detector comprises two twin modules, counting more than 50,000 wires[1], each one independently read out. The goal of a "connectivity test" is to verify the electric continuity from each wire to the readout boards. In fact, the aim is to diagnose major problems early enough that they can be immediately fixed, reduced or mitigated. In particular, we aim to detect and correct any complete failure on a cable, which carries 32 contiguous channels, to attempt the correction of failures involving a few contiguous channels, and to record isolated single channel failures.

A first test was performed starting on August 2018[3], where connectivity was verified between the wires and the cables bringing the signal to the chimneys. This report describes the test performed on December 2018, which extends the test to the decoupling and biasing boards (DBB) and the interface connector on the flanges. The relevant detector configuration is described in section 2 and the test methodology is described in section 3. A summary of some of the findings are reported in section 4.

Details of the operations are described in appendix A and appendix B.

Figure 1: Illustration of the termination of the wires at the top of the anode plane frame.

2 Detector description

To check:

- bias voltage levels on the wire planes
- grounding
- the general description of the connections

The ICARUS detector includes two modules (T300), each with two TPC's sharing the cathode, which will be kept at a potential of $-75\,\mathrm{kV}$. Each TPC anode is made of three wire planes, which are kept at a potential close to the ground. The first one, commonly called first induction plane, has horizontal wires, each about 10 meters long and spanning half of the detector, and kept at $-300\,\mathrm{V}$. Each half plane includes 1056 channels, all ending on the sides of the anode plane frame. Three millimeters away, the second plane ("second induction plane") is made of wires at an angle of $\pi/6$ from the vertical ($\pi/3$ from the horizontal wires) at ground ($0\,\mathrm{V}$). Its wires can be grouped in three sets: the longest ones, terminated on the top and on the bottom of the anode plane frame[1], the shorter ones that terminate on the bottom and on the side of the anode frame, and the shorter ones that terminate on the top and on the side of the frame. Located other $3\,\mathrm{mm}$ away, the third plane ("collection plane") is similar to the second induction plane, but with angle $\pi/6$ of the other side of the vertical, and at $300\,\mathrm{V}$. Its wires follow the same categories.
At the top termination, or at the side termination if no top one is present, the wires are pinned in groups of 32 on a card and their signal conveyed to a 68 pin connector (fig. 1). The card is about $11\,\mathrm{cm}$ long on the top frame. The connector hosts a twisted pair cable, with 34 pairs of wires, one connected to the wire and carrying the signal, and the other twisted around the former to shield it from interference. The shield wire is supposed to be at ground. It became evident in the previous connectivity test that, regardless the design intentions, some of the shield wires are actually grounded to the detector, while others are not grounded. In both cases grounding is ensured by the downstream connections. The highest two pairs (number 33 and 34) of the cable are not used. All the cables are cut to be of the same length, resulting into the ones to the closest wires having a lot of spare length, and into the ones to the farthest wires having little to none. At the other side, cables are generally grouped in sets of 18, half from the second induction and half from the collection plane, to pass through a "chimney" and be connected to decoupling and biasing boards[2] (DBB). Each

[1] The wires are spaced at $d = 3\,mm$, and their terminations are spaced at $2/\sqrt{3}\,d = 3.46\,mm$.

Figure 2: A decoupling and biasing board.

Figure 3: A flange assembled with nine DBB's.

of the nine boards serves a cable from the second induction plane and one from the collection plane. Its purpose is twofold: to translate the induced current into a potential for the front end to read (through a 10 nF capacitor) and to provide the bias voltage of the wire plane. The board (fig. 2) is split into two insulated halves, each serving a different plane and therefore at a different bias voltage. For its physical characteristics, the two halves are sometimes referred to as short and long (or tall); in the blueprints, they are called *left* (L) and *right* (R). The only difference between the left and the right part of the board is the bias voltage line, and beyond that they are identical, both functionally and component-wise. In addition to some circuitry common to all channels in a half, each channel has its own dedicated circuitry independent, and insulated, from the other channels. The DBB offers four connectors: two are 68-pin connectors with clips, which host the cables from the wires, one side for each plane. The others, also one per board side, plug directly into the flange. In addition, the board has two wires, also one per side, to be connected to the flange structure distributing the bias voltages. A flange is the interface between the cold environment inside the cryostat and the outside, warm environment, where the front end readout is. It exposes nine pairs of connectors (each backed by a single DBB), and four SMA connectors (wire female, shield male) on each of two sides. Of the two sets of four, the bottom one (defined as in fig. 4) hosts the distribution channel of bias voltage for the left side of the DBB's on the leftmost connector, and for the right side on the rightmost connector, while the central ones are unused. The set on the top of the flange hosts the four cables distributing the test pulses to the wires connected to the bottom of the anode frame, which we'll describe next.

The termination cards on the bottom of the anode frame feature a test capacitor of sorts, where the dielectric material is the card itself, and the electrodes are the terminating wire on one side, and a band of deposited conductor on the other, which spans all 32 wires. This band can be connected to a cable for injecting test pulses. When doing so, a signal, differentiation of the test pulse, is induced on all the wires, from which it can be read via readout or via a specific testing setup. There are four test pulse cables departing from each flange to serve the 18 cables (576 wires) the flange connects to (fig. 5). Two cables are connected to the second induction plane, while the other two are connected to

Figure 4: Illustration of the external connections of a flange. The triangular marking sets the orientation. The test pulse cables used to be referred to with color tags, and we'll keep that tradition for consistency (see section 3.2).

Figure 5: Illustration of the path for the test pulses from the flange to the wires.

Figure 6: Illustration of the external connections of the flanges serving horizontal wires. The triangular marking sets the orientation. Due to the relative orientation, the "left" and "right" labeling becomes confusing, and we resort to an arbitrary color coding instead.

the collection plane. The general rule is that one of the two cables is connected to a daisy chain of eight termination cards, while the remaining one serves a single card. This rule has been observed to have quite some exceptions. The cables themselves have been color-tagged, but that tag is not visible from the outer side of the flange: instead, a convention is followed as illustrated in fig. 4. While swapping bias voltage cables would have catastrophic effects, swapping test pulse cables has little to no effect except adding some confusion, since the colors are purely conventional. These flanges are spread across the length of the detector, one per chimney, in four columns each roughly above one of the anodes, with the exception which will be described shortly. On top of the flange, a minicrate with VME bus will be mounted, hosting nine readout boards into as many slots, with each one matching a single DBB.
The description above reflects the installation of wires terminated at the top of the anode frame. That includes all the full length wires from second induction and from collection planes, plus the half among the shorter ones which are terminated at top, and it leaves out the other half of the shorter wires on those planes, plus all the wires from the first induction plane, which are all terminated on the sides of the frame. To read out these wires, their cables (with different length) are brought up to the chimneys at the end of the detector (rows 1 and 20). These chimneys are special in that they stack three flanges instead of hosting just one: the top two serve the first induction plane (fig. 6), and the bottom one serves the shorter wires[2] and they have no connection to test pulse cables. They still have two bias voltage lines, which may be connected to any of the four SMA connectors. None of these wires is provided with a test capacitor, therefore the test pulse connectors are disconnected. The number of wires on first induction plane, 1054, requires 33 connectors with 32 channels each. Since all the flanges are standard, they have 18 connectors each. As a consequence, of the two flanges dedicated to that plane, one has three connectors not connected to any wire. Due to readout bus requirements, a "master" board always needs to be plugged into the first "slot", and for this reason it was chosen to always have a fully connected DBB in the first slot of each flange.
Most of the components are physically keyed to prevent mounting them in any but the right way. That includes the minicrates (with different step on the top

[2] These wires all belong to the same plane, either second induction or collection. The shorter wires from the other plane terminate on the top and they are served by a different chimney.

and bottom screw holes), the slots (with a shorter and a longer side), the 68 pin connectors, and also the connectors on the flange to the readout board (each split into a shorter and a longer side). The SMA connectors, instead, are not keyed nor marked in any way, and conventions need to be followed to identify each of them.

3 Test methodology

This test follows broadly the same principles as the one performed in September 2018. To test the electrical continuity, a test pulse is send, and a response is read, this time from the connectors to the readout.

We perform two tests, by probing two different paths. The first path is equivalent to the one used in September 2018: a test pulse is sent through the test pulse cables at the bottom of the anode frame, where it is distributed typically to 32 or 256 wires (for the single termination card and for the eight daisy chained ones, respectively). The pulse propagates through the wires, the termination card at the top of the anode frame, the 68 pin cables, the DBB and finally though the interface connector on the flange, where it is picked up by our test apparatus. The path within the DBB can be appreciated from [2], where it enters through a "WIRE" port (e.g. `WIRE9_L`) and through the 10 nF capacitor induces onto the front end (e.g. `FE9_L`).

The second path starts by pulsing a bias voltage inlet. From there, the pulse is propagated to one side of the nine DBB (labelled "Cable AWG20" in [2]) through the common and the channel-specific circuitry before reaching the front end readout. It should be noted that the bias voltage circuitry is designed for a constant, large voltage (300 V), while the test pulse is small (a few volt) and rapidly changing. Therefore, features observed in this test may be not significant for the regular operation of the detector.

These two paths test different paths of the circuitry. The first path, pulsing the wire, tests the full signal path, and barely grazes the DBB circuitry. The second one instead skips the wire but goes through the whole set of DBB components. While the flanges have been tested for bias voltage distribution, that test is not sensitive enough to pin down a failure on a single channel. Also, as will be described in the result section (section 4), having a test including the wire and one excluding it allowed to pin down very precisely a faulty installation where a 68 pin cable was not correctly connected.

Both the paths we use for testing are necessarily *discontiguous*: both include a 10 nF capacitor on the DBB just in front of the front end outlet, and in addition the wire path an uncalibrated, picofarad-level capacitance on the bottom termination card. As a consequence, the test can't verify the continuity of the paths, but it has rather to interpret a response.

In addition, for a few flanges the test on the bias voltage path was performed also before the flange being mounted on the detector. That configuration is effectively almost identical to the one on the detector, with the exception that the wire is not connected at all and, for example, does not contribute to pick up noise.

3.1 Test setup

The test pulse is generated with a "test box" designed by Mark Convery (fig. 7), which includes a pulse generator and also provides amplification of the response to the pulse. After amplification, the responses are digitised by a four-channel

Figure 7: The box used for generating the test pulse and selecting and amplifying the response to it.

Figure 8: The box used for generating the test pulse and selecting and amplifying the response to it.

oscilloscope (Tektronix TDS3000C) and sent to a program running on a laptop, which can record them as waveforms (fig. 8).

The path followed by the test pulse is illustrated in the following paragraphs.

The test boxes are the same used in the testing of September 2018, including the dead channels (channel 2 in one of the boxes, channel 18 in the other), with some upgrade. The boxes are powered by three 1.5 V AA batteries, and they now include a voltage regulator that stabilizes the output at about 3.3 V. The test pulses are emitted at a rate of 100 Hz, each one a positive square wave of 3.3 V with a duration of about 100 μs. Each test box includes two outlets for the same pulse. One is sent directly to the oscilloscope to work as a trigger. The other is sent to the detector via a lemo to SMA cable: it will be plugged either to the test pulse cable or to the bias voltage distribution, to implement one of the two test paths described in section 3. The response to these pulses is read from the front end connectors on the flange. The standard setup includes the installation of an empty readout minicrate, its only purpose to provide mechanical support, and in it a board shaped as a readout board, which is in effect just an adapter from the front end connector to a 68 pin cable: each of these "fake" readout boards includes two such adapters, converting at once both the left and the right side connectors, and allowing for two different 68 pin cables. At a time, the correct one of the two cables (for example, the left one if the test is currently pulsing the left bias voltage distribution path) is plugged back into the test box, conveying the 32 channels from the DBB side it is connected to. The test box contains a eight position switch that selects four contiguous channels among the 32 from the cable. Signals from the four channels are amplified and offered each on an independent outlet. These four channels are sent to the oscilloscope for digitization and visual inspection. The oscilloscope can be driven by commands sent via Ethernet from a laptop, where a simple data acquisition program drives the readout and recording of the digitized waveforms. One of the test boxes also offers "direct", non-amplified versions of the signal.

Grounding has been an issue in the previous session of tests. Depending on the grounding of the shield wires, they do actually act as shield, or they rather act as antennas picking up noise. The upgraded test box allows the option of connecting all the shield wires to the ground (which is effectively the oscilloscope ground). This option was regularly used in the December 2018 testing session. It results into reduced noise and also in reduced signal response, allegedly because of reduction of cross talk from other cables. In addition, we grounded the oscilloscope chassis to the detector.

3.2 Labelling

4 Test results

A Operative details

B Test software

C Glossary and abbreviations

DBB *Decoupling and Biasing Board*,

T300 each of the two modules of the ICARUS detector, including its own cryostat, two drift volumes (TPC), for a reference argon mass of 300 tonnes

TPC (*Time Projection Chamber*) is defined as a unit including a single uniform drift volume, a cathode and a (composite) anode. In ICARUS, each cathode is shared by two TPCs. This is also the definition of TPC used in the official simulation and reconstruction software (LArSoft)

References

[1] To do: reference to article describing the tpc with complete information about wires.

[2] To do: Schematics of icarus decoupling and biasing board.

[3] Mark Convery, Angela Fava, Brenda Gómez, Gianluca Petrillo, Yun-Tse Tsai, and Somebody else. Icarus connectivity test. 2018.