1. Objectives

This note describes the hardware software and the required setup in order to measure the applied tension on each wire in a TRT module. Stringing of wires at a high tension establishes better wire positioning, mechanical and electrical stability. The wires are strung by fixing one end and applying a weight of 80 g to the other end. Friction and the fixing procedure that secures the tightened wires can result in lower tension.

The acceptable values of tension are between 50 and 80g (assuming an applied tensioning weight of 80 g). The upper value was chosen to be comfortably away from the breaking tension while the lower value is high enough to allow good operation of the cell even with a few grams of tensioning slippage.

2. Principle of Operation

The strung wire is composed of two electrically isolated segments. Under the presence of high voltage (550 volts) on the straw an electric field is present. Audio waves can impose wire vibrations on the wire. The mechanical vibrations of the wire in the electrical field act as a variable capacitance at high voltage that induces current. The amplitude of this current is maximized at resonance.

The 16-channel tension setup typically scans the amplitude of the induced signal in steps of 1 Hz between 100 and 180 Hz. The maximum amplitude is detected through a peak-sensing algorithm. The corresponding frequency is translated to applied wire tension through the formula:

\[ T = 4 l^2 f^2 \left( \frac{\rho}{g} \right) \]

where \( l \) is wire length in cm, \( f \) is detected resonant frequency in Hz, \( \rho \) is the unit weight in g/cm (typical value is 0.0001475 g/cm) and \( g \) is the gravitation constant (g = 980 cm/s^2).

Uncertainties in the measured tension arise from variations in the wire diameter, the length of the vibrating wire segments, the presence and positioning of the wire joint, and local deformations of straw tubes. The minimum uncertainty that arises just from the scanning step of 1 Hz is 0.8 g.

A sinusoidal wave generator with a frequency range of at least 50-500 Hz and remote control ability is used in the setup. The generator output frequency is determined by a set voltage send from a PC. A commercial audio amplifier IC embedded in a custom made board, amplifies the audio signal and feeds it to a 12-inch woofer.
The induced signals on the wires will be amplified with a 16-channel custom made amplifier that has high input impedance and an input signal threshold of 1.5 mV. Signals are forwarded to a PC based A/D board that has additional capabilities of D/A conversion for setting the applied frequency and high voltage. The maximum data-scanning rate will be 150 kHz. A PC based counter board is used to monitor and calibrate the frequency.

The program controlling the devices will scan the frequency range in predefined steps, record the amplified detected amplitudes, extract the resonant frequency and display online all the information to the user. The user will be prompted to switch to the next set of 16 channels at the end of the loop. All recorded data will carry a date and time stamp for later extrapolation of wire tension changes as a function of time.

The wire tension measurements will be performed in production assembly immediately after the module stringing, before and after shipping and in regular time intervals while the module is in storage, and before final installation into the detector. For comparison of measurements and detection of small tension changes it is important to maintain the same value on the applied HV (preferable at about 550V). A typical tension vs. applied HV dependence is shown in Figure 1.

\[ y = -0.0039x + 56.224 \]

![Figure 1. The measured tension as a function of the applied High Voltage.](image)

3. Hardware Description

3.1 PC Boards

Two rather inexpensive PC boards are employed in the tension measurement setup. Our current experience involves boards from Computer Boards Inc.
(www.computerboards.com):

PCI DAS-1001 (Manual)
16 Single ended Channels, 150KHz sampling rate, 12-Bit A/D resolution, Programmable gains of 1, 10, 100, 1000, two D/As, 3 counters and 24 digital I/O. Cost $549.
5 counter channels at 16-bit resolution, 8 digital inputs, and 8 digital outputs.

### 3.2 Instrumentation

K-Precision 3010 Function Generation Dynascant. The unit is used as a wave generator to produce a sinusoidal wave of predefined frequency according to the supplied voltage. A simple calibration of the unit is performed in every instance the software is initialized. Protek Multifunction Counter. This unit is redundant since the frequency can be read and stored through the PC boards and software. However, a visual confirmation of the used frequency can prevail potential software or equipment failures and of course can be valuable tool in case of further software development as a debugging tool.

### 3.3 Signal Amplification PCB

The induced AC signal on the wire is small (typically few mV); therefore the use of an amplification stage is necessary. A custom made board provides a preset amplification of 500 for a set of 16 channels. With appropriate cabling the 16 channels corresponding to an ASDBLR socket will be fed to the amplifier board and then to the PC embedded A/D converter. For the values shown in Table 1 and used in the prototype, the ratio of R5/R4 defines the amplification to 470. Further adjustment can be performed with the PCI-DAS 1000 programmable gain if desired.

![Figure 2. Schematics of the amplification stage. The values of components are shown in Table 1.](image)

The actual layout of the amplification board is shown in Figures 2 and 3. There is a repeatable pattern on the amplification board. This facilitates also the production of single channel units that are currently used during the stringing process. The schematics that correspond for one channel is shown in figure 1. The corresponding layout of the parts on the board is shown in figure 4.
There are 5 BNC connectors on the front of the Tension box, and two cables coming in to a 50 pin IDC connector and a 37 pin D-Sub receptacle. The 50-pin IDC cable carries the 16 amplified signals from the straws and the two D/A channels that control the High Voltage and the frequency. The two D/A channels are directly fed to the two right-most BNC connectors. The produced sinusoidal wave is fed back to the tension box for amplification and through a remotely control switch. Both the amplified signal and raw signal are sent to the remaining BNC connectors.

### 3.4 Audio Amplifier

An audio amplifier is used to amplify the signal in the few cases the speaker module coupling is weak. The detailed circuit used is shown inside the technical specification of
the amplifier IC (ST, TDA2006V) attached. A voltage of +15V provides the required power.

3.5 Power Supply
A SOLA GLT power supply is employed to provide +5V, +15V, and -15V up to a total of 65 W. The specification of the power supply is in appendix B.

4 Software Description

4.1 Flow Diagram
Figure 3 shows the tension measurement setup and how control signals and data transfer across the hardware components. The software through the D/A channel 0 of the PCIDAS1000 sets the appropriate frequency in the wave generator, and then the signal is amplified and sent to a speaker. During the initialization of the data taking process different values of frequency are requested and through the counter board (CTR-05) the signal is measured for consistency. The measured values are used online to make simple calibration adjustments.

Before the signal reaches the speaker a remote-controlled switch exists. The switch is turned on from the software in the beginning of the data taking sequence and it is turned off at the end. This guarantees that the speaker will not keep vibrating the module for longer periods than necessary. However, the user should be aware that absurd termination of the data taking software would leave the speaker on.

During the initialization the High Voltage is turned on to a value of 550 Volts. The software then starts the data-taking loop. Starting at frequency of 100 Hz (the user can change this value), the frequency is raised in steps of 1 Hz; wait for the wires to “settle” and data are retrieved simultaneously for all 16 channels. The amplitude of the signal is plotted online and a primitive algorithm is employed to extract the frequency at the peak amplitude.

5 Users Manual

5.1 Initial Hardware Setup
The speaker should be placed underneath the module at about ¼ of the module length away from the side the signal will be collected. Although audio waves should be sufficient to carry the vibration to the wire actual contact of the speaker and module will ease the transfer of vibrations.
The PCB amplification board, the remote switchboard, the audio amplifier and the power supply are bundled together in a box (Tension Box) with all the appropriate connections made internally. The box on the front side has 5 BNC connectors, on one side a card edge connector, on another side a 37 contact D-sub connector and on top a 50 contact IDC connector. The user needs to connect the Box to the PCI-DAS1000 board, the High Voltage unit, the wave generator, the CTR-05 counter board the speaker and the module.

The PCI-DAS1000 board is connected to the 50-contact IDC connector on the top of the box. The CTR-05 counter board is connected to the D-Sub connector. The card edge connector is connected through a special coaxial cable to the module the signal-inputs are located on the top of the card edge connector. The speaker needs to be connected to the Audio Output (BNC and/or RF connector) on the front. The BNC connector labeled HV-SET has to be connected to the remote control input of the HV power supply. The rest of the connectors are connected to the wave generator; the connector labeled “FREQ” is connected to the output of the wave generator, the one labeled TTL/CMOS to the
TTL/CMOS connector on the wave generator (it provides a TTL signal with the same frequency as the output signal) and the FREQ-SET BNC plug to the VGG-INPUT.

The High Voltage unit should be placed to remote control and set from the front panel to 0 Volts. The later is a precaution to be taken in case the unit is switched to local mode when the front panel set value with immediately applied to the output. The output of the HV unit should be connected to the module through a “fuse-box” (a HV distribution box with fuses, an HF filter and a 1MΩ current limiting resistor). The power on the Box and the PCB board (top switch) can be finally turned on.

Before starting the program make sure that the wave generator is set to the 0-500 Hz scale, the output is attenuated (dB button is pressed) and the frequency set dials on the front panel are set all the way to the right. This is important in order the self-calibration of the device to succeed.

6 Description of Software

The provided software is written in Visual C++ (version 6.0). The source code file is called Tension16.c Parameters can be passed only through the following header files: io_modules.h and io_userset.h. Besides these files the following files are required: cbw.h, cbw.lib, cbw.dll, io_version.h and a set of mapping files called StrawMap-N.dat and SokPcbRdo.dat. The StrawMap-N.dat files hold information about the mapping of readout channel to straw id and the second file defines the relation between the socket id to readout channel. All the files that provide input to the program are saved in the Input directory. Output files as the tension measurements and the amplitude vs. frequency data are saved to the Output directory under the name Tension<MOD>.csv and scan<MOD>.<STRAW>.dat respectively.

The data are saved in a comma separated ASCII format with the following sequence: <MODTAG> <SIDE> <STRAW ID> <READOUT CHN> <ASDBLR ID> <SOCKET ID> <ROW> <COLUMN> <TENSION> <FREQUENCY> <MAX. AMPLITUDE> <DATE> <TIME>. The READOUT CHN is the same as the plot id the user sees on the display. SIDE is the readout side (1=Front, 2=Back), (ROW, COLUMN) is the coordinate of the straw on the tension plate, STRAW ID is the straw no as reported on the tension plate, FREQUENCY the resonance frequency, TENSION the corresponding tension in weight grams and MAX. AMPLITUDE the amplitude found at resonance.

To start the Tension16 program double click on the Tension16.dsw file. From the Menu bar choose Build > Build All. Now on the left window choose File View and on the File Dependencies choose the io_userset.h

Modify any parameters you wish as: frequency range, module identification ASDBLR the signal cable is connected and so on. When you finished click Ctrl+F5 to recompile and run the program. A typical screen from the 16-channel program is shown in Figure 4.

7 Summary of Wire Tension Monitor Setup Parameters

High Voltage: 550 Volts on straws
Ramp up/down HV rate: 100 V/sec
Signal Amplification: 470
Readout Channels: 16
Scan frequency range: 100-180 Hz
Typical Frequency Resolution: 1 Hz