



Installation and Operation Manual

**TRZ® Analyzer - Ultrasonic transducer and horn analyzer G9
& TRZ® Software 6.1**



ATCP Physical Engineering

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& TRZ® Software 6.1

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1. Introduction

This installation and operation manual contain important and necessary information for the correct use and maintenance of the TRZ® Analyzer - Ultrasonic transducer and horn analyzer G9 and TRZ® Software 6.1.



***Read this manual carefully before using the equipment and software.
Improper use may compromise the performance and damage the product.***

The instructions herein refer to TRZ® Analyzer - Ultrasonic transducer and horn analyzer G9, which will be from now on named TRZ® Analyzer, and the TRZ® Software 6.1, which will be from now on named TRZ® Software.

The TRZ® Analyzer may be singlehanded or used together with TRZ® Software. The TRZ® Analyzer is normally singlehanded in basic applications, when the knowledge of frequencies and their respective impedances are enough (for example, when checking the effectiveness of preventive maintenance or inspecting for acceptance of new parts). It is used together with the TRZ® Software in advanced applications, and for the registry and comparison of results (for example, for maintenance and for ultrasonic elements tuning).

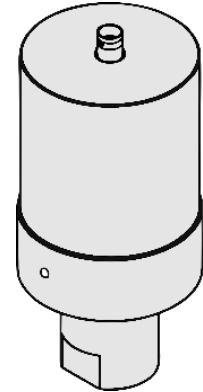
In addition to instructing the user on how to operate the TRZ® Analyzer and TRZ® Software, this manual also contributes to the understanding of basic concepts of ultrasonic engineering and to the usual maintenance and manufacturing procedures of ultrasonic elements and equipment.

2. Definitions and symbology

2.1 Definitions

Transducer or converter: Element used to convert alternate electric energy into ultrasonic vibration. "Transducer" is a general denomination; "converter" is a denomination for the ultrasonic welding area.

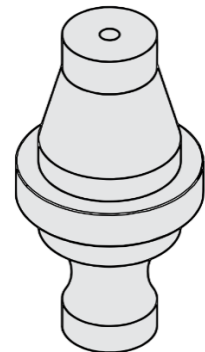
The transducer works based on the principle of the direct piezoelectric effect and consists of PZT ceramic rings compressed between metallic parts by a bolt; the electric contact is performed by electrodes. This type of transducer, also known as bolt-clamped and Langevin type [1], was originally developed for sonar applications having its use later expanded to industrial applications [2] for welding and cleaning.



Typical converter.

Acoustic transformer or booster: Element used in ultrasonic welding systems to change the ratio between force and vibration amplitude.

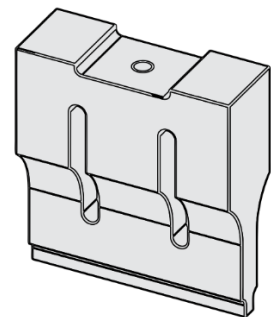
For a given power, the product between force and amplitude is constant; therefore, reducing one will proportionally increase the other. The acoustic transformer is specified in terms of this proportion, also defined as "gain", usually varying between 1:0.6 and 1:2.5. The higher the gain, the greater is the amplitude of vibration and the smaller is the force. The acoustic transformer also plays the part of support for the fixation of acoustic stacks, being the element in the middle. The acoustic transformer is built using a solid metal section, a metallic ring and internal O-rings working as cushions to allow freedom of vibration. The fixation metallic ring is positioned on the nodal region, where the amplitude of vibration is the lowest.



Typical acoustic transformer.

Sonotrode, tool or "horn": Element used in welding and sonochemistry systems to deliver the ultrasonic vibration according to the geometry and area required.

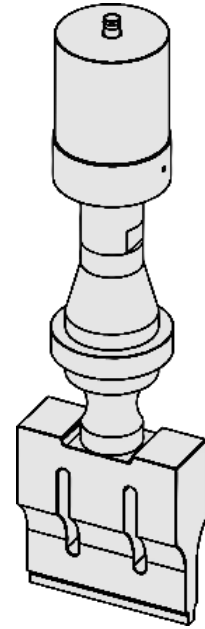
Sonotrodes are the main source of failures for ultrasonic equipment because they are prone to damages caused by impact and subjected to be worn off through abrasion during its use. Any dimensional change, even the smallest one, will change the sonotrode frequency and may compromise its efficiency and the acoustic stack operation.



Typical sonotrode.

Acoustic stack: This element is the “power train” of the ultrasonic welding equipment and usually comprise a converter + booster + horn, or only a converter + horn.

The acoustic stack elements must be well coupled and tuned with respect to each other so that the ultrasonic vibration generated by the transducer is efficiently transferred to the load. On the contrary, losses and reflections may happen and, therefore, heating and a probable cracking of the parts. The coupling is ensured by clean and smooth surfaces and a torque-controlled tightening during the assembly. Tuning is ensured when manufacturing or refurbishing the converter and acoustic transformer by employing the TRZ® Analyzer and TRZ® Software. In the case of the sonotrode, there may be a tuning loss caused by the wearing, generating the need for new tuning. The acoustic stack should be tuned and in agreement with the generator operation range of frequency and impedance.



Typical acoustic stack.

Electrical impedance (Z): It is the measure of opposition to electric current at a specific frequency.

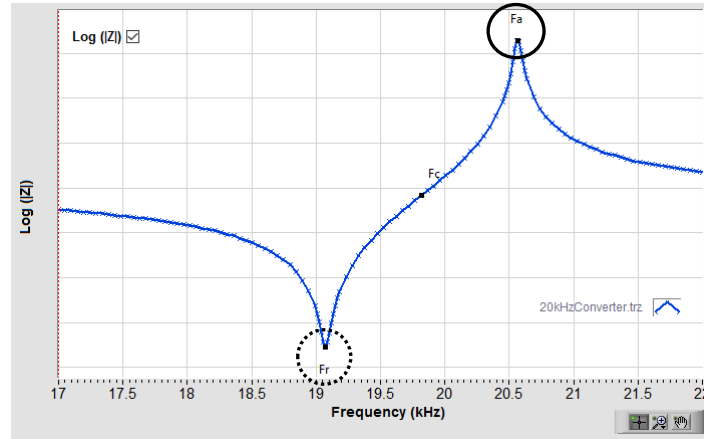
Electrical impedance is a vector quantity that varies according to the frequency in reactive components, for example, capacitors and inductors. In the particular case of resistors, which are not reactive, the electrical impedance is constant and equal to their resistance. For transducers and acoustic stacks, the impedance dependency on frequency is complex and related to the operational frequencies.

Impedance modulus ($|Z|$ e $|Z(f)|$): To ease the interpretation of electrical impedance measurements as a function of frequency, impedance may be reported in terms of its modulus ($|Z|$). The TRZ® Analyzer and TRZ® Software are capable of measuring, building graphs, and analyzing the impedance modulus as a function of frequency ($|Z(f)|$) ranging from 1 to 200 kHz and from 0.1 Ω a 999 k Ω .

Antiresonance (or parallel resonance): Operational basis where a transducer or acoustic stack operates at their maximum amplitude. It is typical of ultrasonic welding equipment (exceptions apart). Antiresonance occurs at the frequency at which the electrical impedance modulus is maximum and, therefore, the consumed current from the generator is minimum.

Resonance (or series resonance): Operational basis where a transducer or acoustic stack operates at their maximum force. It is typical of ultrasonic cleaning equipment. The resonance occurs at the frequency at which the electrical impedance modulus is minimum and, therefore, the consumed current from the generator is maximum.

Impedance modulus curve as a function of frequency ($|Z(f)|$ curve): This curve provides the basic information used by the TRZ® Analyzer and TRZ® Software to determine resonance and antiresonance frequencies for ultrasonic elements and other analyses. To obtain this curve, the impedance modulus ($|Z|$) is measured as a function of frequency (f) at the interval of interest, which must agree with the operation range of the element under test.

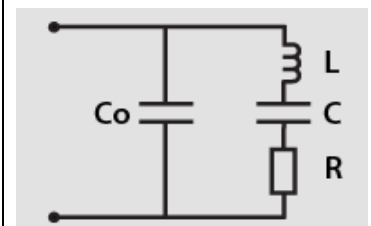


Typical curve of the impedance modulus as a function of frequency ($|Z(f)|$). The resonance frequency is highlighted by a dotted circle, and the antiresonance frequency by a continuous circle.

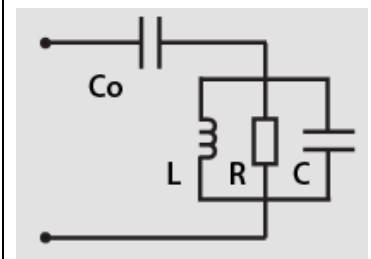
The antiresonance frequency may be considered as the frequency at which the electrical impedance modulus is maximum (continuous circle), and the resonance frequency as the one at which the impedance modulus is minimum (dotted circle).

Butterworth-Van Dyke equivalent circuit (BVD): Electrical circuit presenting an impedance curve as a function of frequency similar to the ultrasonic transducer or acoustic stack curves near the operating frequencies (resonance and antiresonance).

This circuit consists of two capacitors (C and C_0), an inductor (L) and a resistor (R) arranged in series or in parallel. The L and C components are associated with the piezoelectric effect, the R encompasses electrical losses, mechanical losses and the load. The parallel configuration C_0 capacitor is associated with the electrical capacitance of the transducer's piezoelectric ceramics at kHz range. The calculation of the components values is performed by a multi-parameter adjustment that maximizes the curve coincidence of the equivalent circuit with the element under test. At the series configuration, it is prioritized the curve adjustment around the resonance frequency, while at the parallel configuration it is prioritized the adjustment of the curve around the antiresonance frequency. The figures on the right represent the series configuration (top image), and the parallel configuration (bottom image). For more information, please, check the chapter 1 of the reference [3].



Series configuration (RLC/C_0) of the BVD equivalent circuit.



Parallel configuration ($R/L/C-C_0$) of the BVD equivalent circuit.

Mechanical quality factor Q_m : Parameter proportional to the element under test efficiency in vibrating, and inversely proportional to its damping or rate of energy loss. Q_m is equal to the average between the quality factor (Q) of the BDV circuit on the series configuration and the quality factor of the BVD circuit on the parallel configuration.

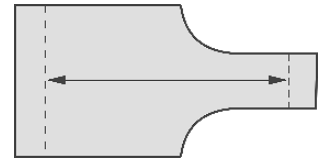
The knowledge of Q_m is useful for quality control and development because it is an absolute parameter and does not depend on the frequency of the element under test. Converters in good condition shall have the Q_m equal or greater than 250, and acoustic stacks the Q_m equal to or greater than 1000, regardless of frequency.

Tuning: It consists in altering the dimensions of an element to adjust its operation frequency to the desired value (this frequency may be the resonance or antiresonance). The reduction of length increases the frequency, while advancing the radius position, reducing the diameters and widening the slots, decreases the frequency [4]. The frequencies sensitivity to the dimensional changes is maximum for the length change (≈ 100 Hz/mm for 20 kHz cylindrical horns), being much easier to increase frequency by reducing the length than to decrease the frequency by advancing the radius position, reducing the diameters and widening the slots. The dimensional changes must be performed unhurriedly, gradually and with the measurement of frequencies by employing the TRZ® Software. The tuning is carried out on the manufacturing and on the recovery of worn elements, mainly horns.

The resonance and antiresonance frequencies of an element also depend on its materials properties, more specifically, on its density and elastic moduli (Young's modulus and shear modulus). Heating changes these properties and, as a consequence, the frequencies (heating decreases the frequency and cooling increases it). In the transducers' case, the assembling torque and the relaxation time after assembling also influence the frequency.

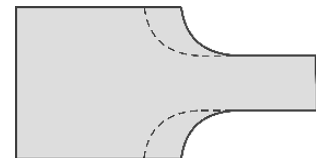
To increase the frequency:

- Reduce the length.

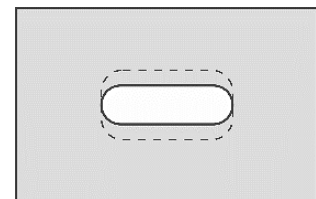


To reduce the frequency:



- Advance the radius position;



- Widen the slots.



2.2 Symbology

 USB port	 Attention! Danger!	Vac Volts alternating current
Vdc Volts direct current	I Switches on the equipment	O Switches off the equipment

3. Applications, connection, tests and testable elements

3.1 Applications

The TRZ® Analyzer and TRZ® Software constitute a robust and user-friendly solution for maintenance, manufacturing, and development of elements and power ultrasonic equipment that operates with frequencies up to 200 kHz. Their functions and characteristics were projected for the following areas and applications:

- **End-users of ultrasonic welding equipment and power ultrasonic equipment in general:**
 - Inspecting for the acceptance of newly purchased and refurbished parts.
 - Troubleshooting of acoustic stacks.
 - Evaluation of preventive maintenance and interfaces recovery effectiveness.
 - Sonotrode / ultrasonic horns recovery via re-tuning (note: wear and dimensional changes modify the operational frequency of sonotrodes).
 - Sonotrode manufacturing.
 - Testing piezoelectric ceramics to detect cracks and defects, including those invisible to the naked eye.
- **Manufacturers of ultrasonic equipment:**
 - Monitoring and systematic registration of the changes in frequency, impedance and mechanical quality factor (Q_m) as a function of dimensional changes for sonotrode and another ultrasonic element tuning.
 - Determination of nodal point for boosters and converters.
 - Quality control based on acceptance criteria with record in electronic files (".pdf" and ".TRZ") promptly identifiable and recoverable.
 - Comparison between characterizations and standard characterizations / references.
 - Piezoelectric ceramic testing for cracks detection, including those internals and invisible to the naked eye (observation: it is common to find new ceramics presenting internal cracks and/or delamination).
 - Validation of simulations by allowing comparison between the simulated impedance modulus curve and the experimental one.
 - Development and optimization of impedance matching circuits (*observation: the TRZ® Analyzer is capable of carrying out characterizations of transducers or acoustic stacks through impedance matching circuits*).
- **Research groups, educational institutions, P&D departments:**
 - Development and optimization of ultrasonic power transducers and resonant piezoelectric devices.
 - Experimental classes on reactance, resonant electric circuits, piezoelectric devices and equivalent circuits.
 - Simulations validation and optimization of impedance matching circuits.

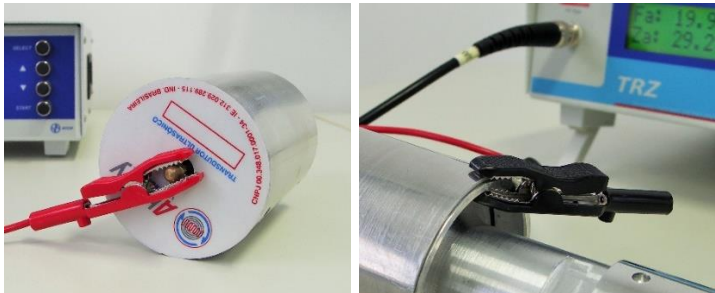

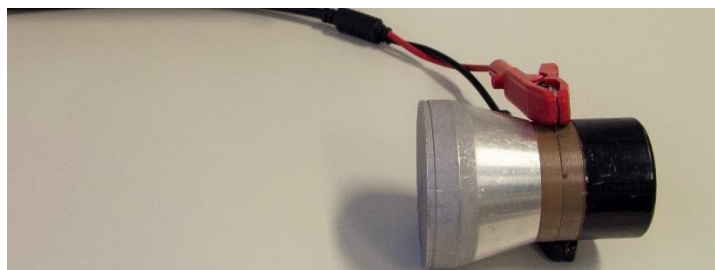

3.2 Connecting and performing tests

To carry out the tests, connect the TRZ® Analyzer to the element to be tested, select the suitable frequency range according to the frequency of the element and give the measuring command (or press the start button). The element must be lying horizontally. The earth wire of the TRZ® Analyzer (black alligator clip) must be connected to the ground wire or to the enclosure of the element, and the live wire (red alligator clip) to the live end of the element.



To protect the TRZ® Analyzer of a possible high voltage discharge, discharge the tested element with a short circuit between its terminals before connecting it to the analyzer.

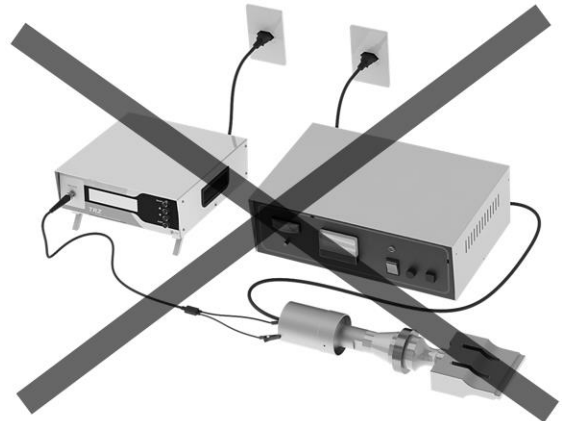
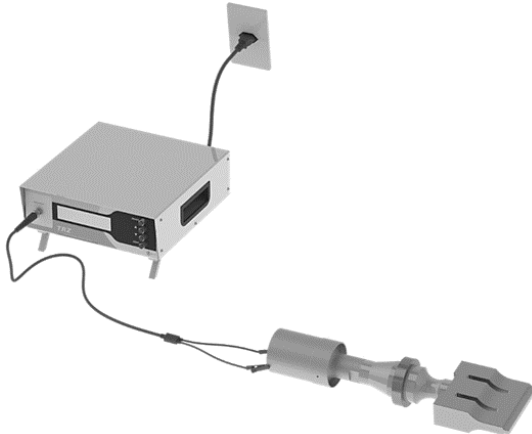
Table showing connection examples for typical applications of the TRZ® Analyzer.

<p>CJ-20 Branson converters and similar: The red alligator clip must be connected to the live terminal of the converter, and the black alligator clip to its enclosure. The converter must be on the horizontal position.</p>	
<p>Converters with connectors: It must be used a pigtail fitted with a compatible plug to make the earth and live ends of the converter available for the TRZ® Analyzer alligator clips. It is also possible to customize the testing probe by replacing the alligator clips for the compatible plug.</p>	
<p>Frame less transducer: Alligator clips must be connected to the transducer electrodes or wires. The red clip must be connected to the central electrode (live), and the black clip to the electrode making electric contact with the metallic parts (ground). The transducer must be placed horizontally.</p>	
<p>Piezoelectric ceramics: For the piezoelectric ceramics test, it is necessary to employ the accessory "Piezoholder". This accessory must be connected to the TRZ® Analyzer by a coaxial cable with BNC connectors. The ceramic polarity on the support is not relevant.</p>	

The previous table shows typical electrical connections. To ease the results comparison, it is advisable to carry out the test without acoustic load (without allowing that the end faces of the element touch surfaces or objects). It is also suggested to carry out the tests with the element on the horizontal position, on the top of a clear and smooth surface. Avoid touching it with the hands or move it during the measurement.



Do not connect the TRZ® Analyzer to ultrasonic generators or energized circuits because it will damage the equipment. The TRZ® Analyzer must be only connected to passive elements.



To perform the test, it is indispensable to have piezoelectric ceramics in the constitution of the element or stack under test. For that, it is necessary to couple the sonotrodes and boosters to a transducer/converter as detailed on the next topic.

3.3 Testable elements



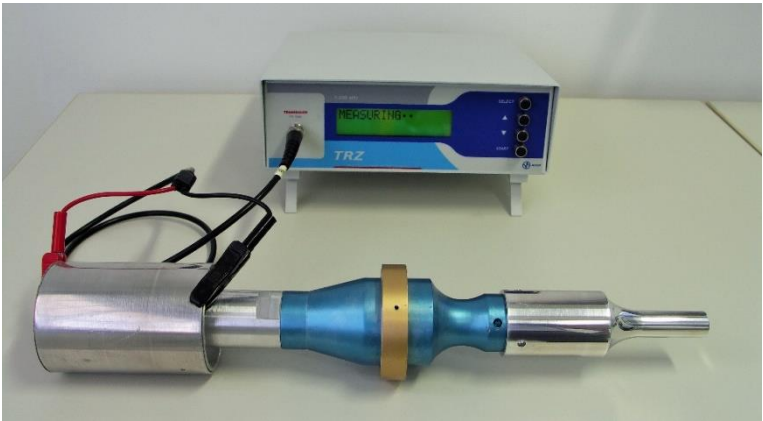
The TRZ® Analyzer and TRZ® Software are capable of testing any element or piezoelectric device operating at a frequency ranging from 1 to 200 kHz, such as:

- Transducers (converters), acoustic transformers (boosters) and sonotrodes (tools, horns) used in ultrasonic welding or power ultrasonic applications in general.
- Transducers and sonotrodes (horns) employed on dies polishing.
- Bolt clamped transducers (Langevin type) employed in ultrasonic cleaning equipment.
- Tubular transducers employed on sonoreactors, biodiesel processing and sonochemistry.
- Ultrasonic transducers used in dental equipment (prophylaxis), medical equipment (lithotripsy), and in aesthetic equipment (cavitation ultrasonic peeling).
- Piezoelectric ceramics (the TRZ® Analyzer allows checking new and used piezoelectric ceramics for internal cracks).

In the case of resonant elements without piezoelectric materials within their constitution, such as the case of acoustic transformers (boosters) and sonotrodes (horns), it is necessary to couple them to a converter of reference (examples on the table below). This converter must be within the specifications and must be identical to the one used to operate the element under test because its characteristics and frequency may influence the result. The coupling between the converter of reference and the element(s) under test must be carried out with controlled torque and with the interfaces in good condition. For the 20 kHz ultrasonic welding machine

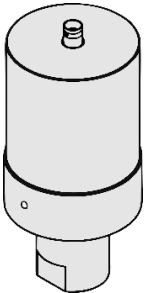
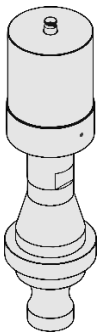
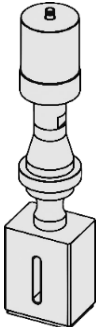
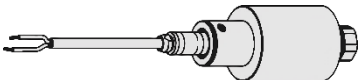

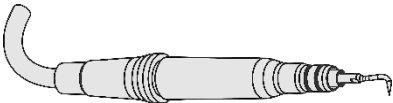
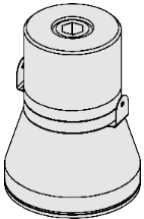
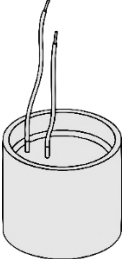
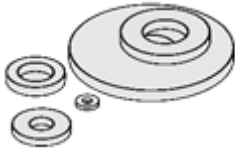
elements, the recommended coupling torque is 35 Nm, and for 40 kHz machines, it is 20 Nm (these values may change according to the bolt type).

Table showing images of typical configurations for testing boosters and sonotrodes.

<p>Converters and transducers: To be tested alone.</p> <p><i>Important: Always carry out the test by placing the element horizontally and keeping its end faces free (without touching anywhere).</i></p>	
<p>Boosters: Must be tested coupled to a converter in good conditions.</p> <p><i>Important: Always carry out the test by placing the element horizontally and keeping its end faces free (without touching anywhere).</i></p>	
<p>Sonotrodes (horns): Must be tested coupled to a converter and to a booster, both in good conditions. There will be cases where the sonotrode is directly coupled to the converter without a booster.</p> <p><i>Important: Always carry out the test by placing the element horizontally and keeping its end faces free (without touching anywhere).</i></p>	

The next table presents the illustrations of configurations and typical elements that are testable by TRZ® Analyzer and TRZ® Software. The transducers (converters) and the ceramics are tested alone (a, d, g, h, i); the acoustic transformers must be coupled to a converter (b); the sonotrodes to acoustic transformer or converter (c), or to converter only (e) according to the element actual use.

Table showing elements and typical configurations of tests carried out by TRZ® Analyzer and the TRZ® Software.

 <p>a) 20 kHz converter for ultrasonic welding</p>	 <p>b) 20kHz converter + acoustic transformer (booster)</p>	 <p>c) 20 kHz converter + acoustic transformer + square sonotrode (horn)</p>
 <p>d) 35 kHz converter for ultrasonic welding</p>	 <p>e) 35 kHz converter + sonotrode (horn)</p>	 <p>f) 35 kHz dental prophylaxis transducer + insert</p>
 <p>g) Bolt-clamped ultrasonic transducer (Langevin type) for ultrasonic cleaning</p>	 <p>h) Ultrasonic transducer employed in sonars and distance meters by echo-pulse.</p>	 <p>i) Piezoelectric ceramics shaped as rings and discs.</p>

Piezoelectric ceramics may be tested separately from the transducers for the detection of cracks because these defects create spurious resonances easily identifiable when employing the TRZ® Analyzer, TRZ® Software and PiezoHolder (PS: it is not rare to find new ceramic presenting internal cracks).

4. Characteristics and frequency range

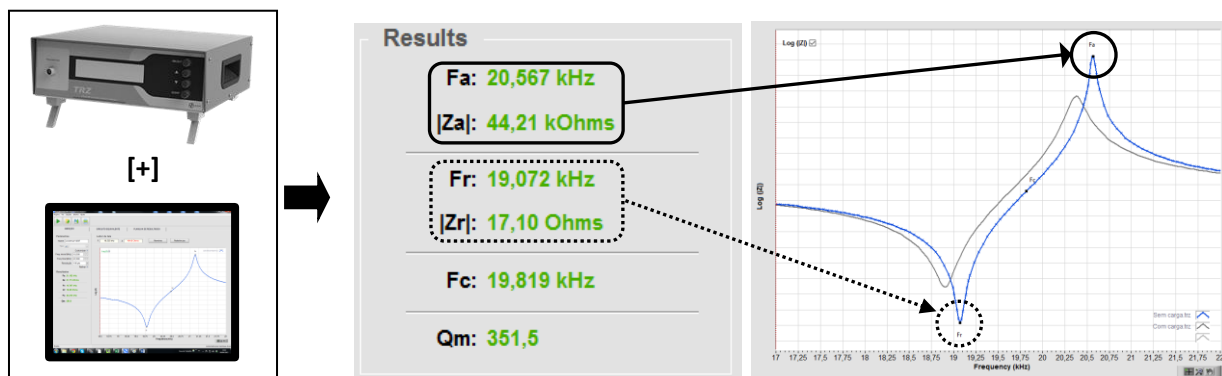
4.1 Characteristics

TRZ[®] Analyzer - The TRZ[®] Analyzer is an impedance analyzer that obtains the impedance modulus curve as a function of frequency ($|Z(f)|$) by performing a frequency sweep. Based on this information, the TRZ[®] Analyzer determines and reports on its display the resonance and antiresonance frequencies and their respective impedance modulus as illustrated on the example below.



Example of a presentation of results by the TRZ[®] Analyzer: frequencies and impedance moduli of a 50 kHz transducer (to change the result screen it is required to press a button).

TRZ[®] Software: The TRZ[®] Software is a graphic interface with tools that leverage the TRZ[®] Analyzer use. By using the TRZ[®] Software with the TRZ[®] Analyzer it is possible to visualize the curve $|Z(f)|$ and obtain additional parameters such as the central frequency (Fc) and the mechanical quality factor (Qm), as illustrated below. It is also possible to obtain the equivalent circuit BVD, apply acceptance criteria, save, recover and compare the measurements and results.



Example of a results presentation given by the TRZ[®] Software and of the curve visualization $|Z(f)|$. The grey curve is from the previous measurement. Curiosity: the ATCP Physical Engineering logo was inspired on the standard curve $|Z(f)|$, typical of ultrasonic transducers and piezoelectric resonant devices.

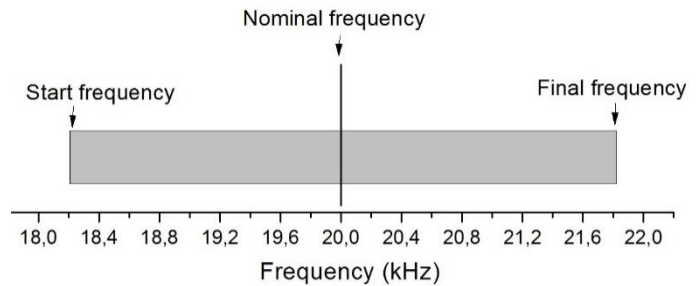
4.2 Frequency ranges

The TRZ[®] Analyzer has 30 options of frequency range and one option for calibration. The TRZ[®] Software also contains 30 frequency ranges plus an additional one for testing piezoelectric ceramics aiming the detection of internal cracks. In the TRZ[®] Software, the user may change the frequency ranges; in the TRZ[®] Analyzer, the frequency ranges are fixed. The nominal frequency corresponds to the central frequency in general and to the span to 18% of the nominal frequency.

Following are presented the frequency ranges and their respective start and final frequencies for the TRZ® Analyzer. These ranges are fixed.

TRZ® Analyzer frequency ranges table.

Nominal frequency (kHz)	Start frequency (kHz)	Final frequency (kHz)
15	13,7	16,3
16	15,0	18,0
19	17,2	20,6
20	18,2	21,8
21	19,1	22,9
22	20,1	24,1
25	22,8	27,2
28	25,5	30,5
30	27,3	32,7
33	30,0	36,0
35	31,9	38,1
37	33,7	40,3
40	38,2	45,8
45	41,0	49,0
50	45,5	54,5
55	50,1	59,9
60	54,6	65,4
65	59,2	70,8
70	63,7	76,3
80	72,8	87,2
90	81,9	98,1
100	91,1	109,0
110	100,2	119,8
120	109,3	130,7
130	118,4	141,6
140	127,5	152,5
150	136,6	163,4
160	145,7	174,3
170	154,8	185,2
180	163,9	196,1
Calibration	20,0	180,0



*TRZ® Analyzer frequency range example (20 kHz).
The sweep starts at 18.2 kHz and ends at 21.8 kHz;
the sweep width is 3.8 kHz (18 % of the nominal
frequency).*

To perform the measurement at the shortest time possible without compromising precision, the TRZ® Analyzer and TRZ® Software discretize the frequency interval in 100 or 200 points. After that, they perform additional refining measurements and a polynomial interpolation around the resonance and antiresonance frequencies. In the TRZ® Software, refining may be disabled and the resolution (number of points) changed.

The average measurement duration is 15 seconds for the TRZ® Analyzer alone, and 20 seconds for the TRZ® Analyzer operating with the TRZ® Software.

Following are presented the options of frequency range and their respective start and final frequencies for the TRZ® Software. The user can change these ranges.

Software TRZ® frequency ranges table.

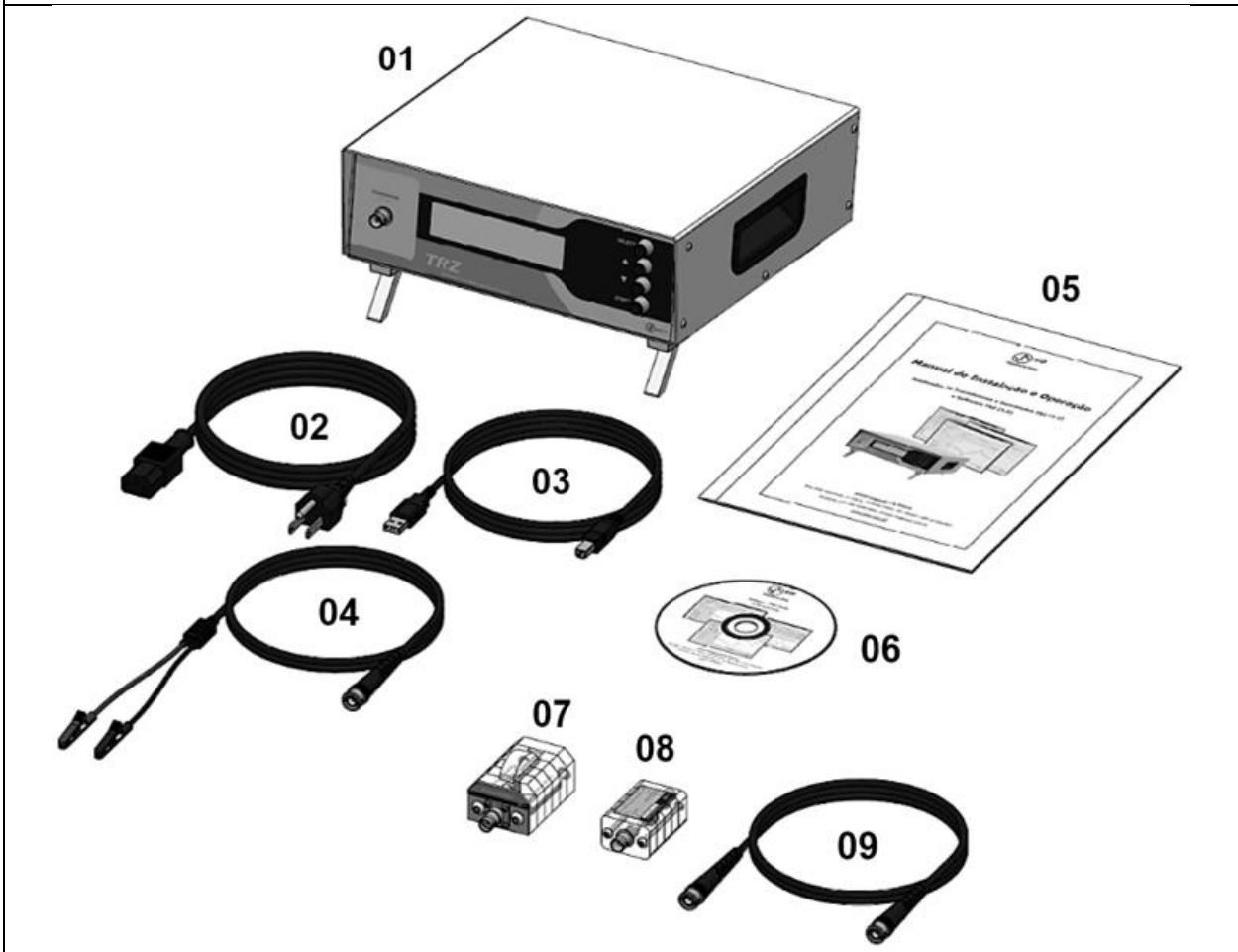
Nominal frequency (kHz)	Start frequency (kHz)	Final frequency (kHz)
15 kHz (C)	13,7	16,3
15 kHz (C+B)	13,7	16,3
15 kHz (C+B+H)	13,7	16,3
16 kHz	15,0	18,0
19 kHz	17,2	20,6
20 kHz (C)	18,2	21,8
20 kHz (C+B)	18,2	21,8
20 kHz (C+B+H)	18,2	21,8
21 kHz	19,1	22,9
25 kHz	22,8	27,2
28 kHz	25,5	30,5
30 kHz (C)	27,3	32,7
30 kHz (C+B)	27,3	32,7
30 kHz (C+B+C)	27,3	32,7
33 kHz	30,0	36,0
35 kHz (C)	31,8	38,1
35 kHz (C+B)	31,8	38,1
35 kHz (C+B+H)	31,8	38,1
37 kHz	33,7	40,3
40 kHz (C)	36,5	43,6
40 kHz (C+B)	36,5	43,6
40 kHz (C+B+H)	36,5	43,6
70 kHz (C)	63,6	76,2
70 kHz (C+B)	63,6	76,2
70 kHz (C+B+H)	63,6	76,2
80 kHz	72,8	87,2
100 kHz [TRZ CK]	89,0	107,0
120 kHz	109,3	130,7
150 kHz	136,6	163,4
170 kHz	154,8	185,2
Piezos	15,0	160,0

On the table above the acronyms mean: (C) range and judgment criteria for converters; (C+B) range and judgment criteria for the combination of converters + boosters; (C+B+H) range and judgment criteria for sets of converters + boosters + horns; [TRZCK] range and criteria for the TRZ® Analyzer and TRZ® Software functional test applying the accessory "TRZ® Calibration Kit".

5. Configurations, parts, accessories and optional items

The TRZ® Analyzer is supplied with the TRZ® Software in a standard configuration.

Available items in the standard configuration



Parts:

01 - TRZ® Ultrasonic Transducer and Horn Analyzer.

Accessories:

02 - 1.8 m tripolar power cable (NEMA 5-15P + IEC 320-C13).

03 - 1.8 m A/B 2.0 USB cable.

04 - 1.0 m probe with large alligator clips (10 mm opening).

05 - Installation and Operation Manual.

06 - TRZ® Software installation CD or flash memory drive.

Optional items:

07 - Holder "PiezoHolder" for testing piezo ceramics of thickness between 2 and 8 mm.

08 - Standard "TRZ® Calibration Kit" for the functional test of the TRZ® Analyzer.

09 - 0.3 m BNC-BNC cable to connect the PiezoHolder and the TRZ Calibration Kit to the TRZ® Analyzer.

6. TRZ® Analyzer

6.1 Technical specifications

Protection against electric shock	Class I
IP protection level	IP40
Operation mode	Continuous
Power supply	90-260 VAC
Frequency	50 or 60 Hz
Maximum consumption power (stand-by)	10 Watts rms
Maximum consumption power (operating)	25 Watts rms
Equipment dimensions (W x D x H)	260 x 250 x 100 mm
Packaging dimensions	370 x 330 x 140 mm
Equipment weight without packaging	3.8 kg
Equipment weight with packaging	4.4 kg
Working temperature range	-10 to +45 °C
Measuring ranges:	

	Minimum	Maximum	Uncertainty
Frequency (f)	1 kHz	200 kHz	± 0.03 %
Impedance modulus ($ Z $)	0.1 Ω	999.9 k Ω	± 3 % *

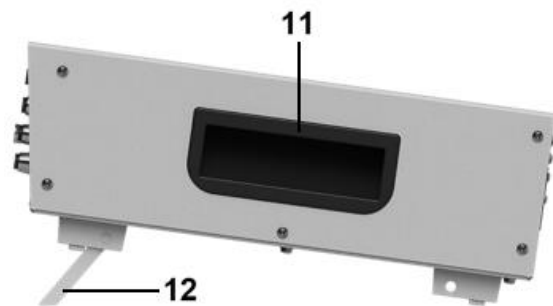
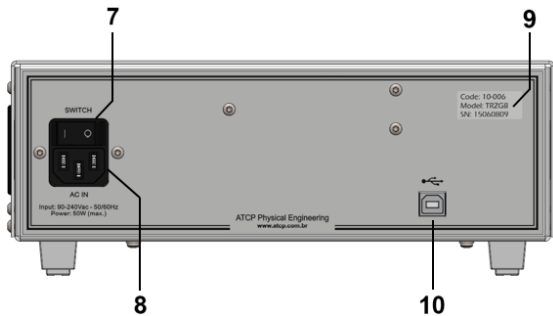
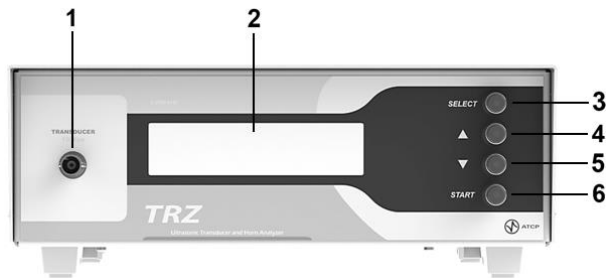
* Uncertainty at 20 kHz for the impedance range from 0.1 k Ω to 10 k Ω , purely resistive.

Notes:

- The average length of a measurement using the TRZ® Analyzer is 15 seconds, whilst it takes 20 seconds when using the TRZ® Analyzer and the TRZ® Software together (in both cases, for 100 points of measurement without refinement).
- The TRZ® Analyzer probe presents a stray capacitance of approximately 120 pF and a stray resistance of approximately 1.8 Ω , which are not compensated.

6.2 Components identification and installation

Components identification



[1] "TRANSDUCER" connector: BNC-type connector for connecting the element under test. Maximum output voltage is 10 Vpp.

[2] Display: LCD alphanumeric interface featuring backlight. It contains two lines for 16 characters.

[3] "SELECT" button: Push-button to change screens between "DEVICE FREQUENCY", "REMOTE MODE" and the results screen.

[4] e [5] "▲" and "▼" buttons: Push-button for scrolling the screens and to increase and decrease numbers. At the DEVICE FREQUENCY, it is possible to select the frequency range. At the results screen, between F_a and $|Z_a|$ or F_r and $|Z_r|$.

[6] "START" button: Push-button to start new measurement. This button does not work at the REMOTE MODE screen.

[7] "SWITCH" key: Key to switch the equipment ON and OFF.

[8] AC IN: Entry connector for the power cable (90-240 VAC automatic - 50/60 Hz).

[9] TAG: Code, model and the serial number of the equipment.

[10] USB port: Connector type B, female, for USB communication.

[11] Side handle: Handling and transportation holder.

[12] Tilting legs: Mobile legs located on the front feet for the optional lifting of the equipment panel.

Installation

Minimum requirements:

- Firm and flat bench large enough to place the TRZ® Analyzer, a computer with the TRZ® Software and to test elements on the horizontal position with the end faces free.
- An earth-wired VAC outlet (90-260 Vac - 50/60 Hz). If the outlet is not earth-wired, use an isolation transformer for safety.

Step-by-step:

- Step 01* Place the equipment on the bench and regulate the tilting legs so the position is adequate for the visualization of the display.
- Step 02* Connect the AC cable to the back-panel connector [AC IN] and to a suitable earth-wired outlet or isolation transformer.
- Step 03* Connect the probe BNC connector to the equipment connector [TRANSDUCER], which is located on the front panel.

6.3 Operation

Performing a measurement

- Step 01* Turn the equipment on using the SWITCH key on the back panel. The following message will be displayed for a few seconds, and then it will give place to the same screen showing when the equipment was switched off.



TRZ Analyser
www.atcp.com.br

- Step 02* Observing the polarities, connect the probe alligator clips to the terminals of the element under test (which must be placed horizontally on the bench with end faces free).
- Step 03* Find the DEVICE FREQUENCY screen by pressing the [SELECT] button. This screen will allow selecting the frequency range. On the example below the 50 kHz frequency range, which goes from 45,5 to 54,5 kHz, is selected.



DEVICE FREQUENCY
50 kHz

- Step 04* Use the [▲] and [▼] buttons to change the frequency range, if necessary. The new selection will be memorized by the TRZ® Analyzer for the next measurements.



To select the most suitable frequency range, the user must know the nominal frequency of the element under test.

Step 05 Press the [START] button to start measuring; the screen will show MEASURING. The dots showing after the word MEASURING will indicate the progress of the process. The typical duration is 12 seconds.



MEASURING..

After the measurement is taken, the following screen is presented. This screen informs that the refining stage of the measurement, considering the frequencies of resonance and antiresonance when these are identified, is being carried out. The typical duration of the refining stage is 8 seconds.




REFINING...

At the end of this process, the obtained values for frequency (top line) and impedance modulus (bottom line) are presented. These results can be related to resonance (Fr e |Zr|) or antiresonance (Fa e |Za|), depending on the last selection of the user.

Frequency → Fa: 50.368 kHz
Impedance → Za: 49.91 kOhm



Step 06 Change between the results for resonance and antiresonance by pressing [▲] or [▼]:



Fr: 49.724 kHz
Zr: 26.2 Ohm

[▲] or [▼]

Fa: 50.368 kHz
Za: 49.91 kOhm



The user must know the operation mode of the element under test to select the results to be displayed (resonance or antiresonance results).

Important observations:

- The impedance values |Zr| and |Za| are displayed without the modulus bars because of the limited number of characters.
- The unit of frequency shown in the results is kHz (10^3 Hertz) and of impedance is Ω (Ohms). For the impedance values that are bigger or equal to 1,000 Ω , the prefix "k" from the International System of Units (SI units) is used, "k Ω ".

Special cases:

After measuring and refining, if the resonance or the antiresonance frequency are not detected, a message showing "OUT OF RANGE" will be displayed, indicating that the selected frequency range is incompatible with the frequency of the element under test. This may occur for one or for both frequencies (resonance and antiresonance). The following table presents possible cases.

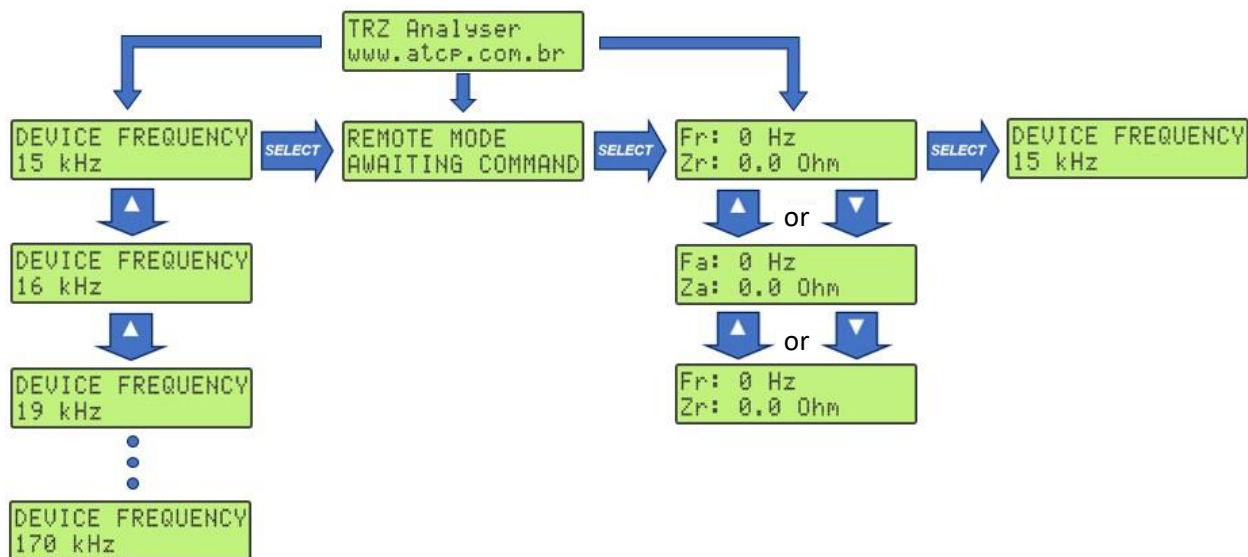
Table showing possible cases according to the found frequencies.

Case	Results screen
The two frequencies were found	<div>Fr: 49.724 kHz</div> <div>Zr: 26.2 Ohm</div> <div>↔ [▲] or [▼]</div> <div>Fa: 50.368 kHz</div> <div>Za: 49.91 kOhm</div>
Only the resonance frequency was found.	<div>Fr: 49.724 kHz</div> <div>Zr: 26.2 Ohm</div> <div>↔ [▲] or [▼]</div> <div>ANTI-RESONANCE</div> <div>OUT OF RANGE</div>
Only the antiresonance frequency was found.	<div>RESONANCE</div> <div>OUT OF RANGE</div> <div>↔ [▲] or [▼]</div> <div>Fa: 37.229 kHz</div> <div>Za: 48.71 kOhm</div>
None of the frequencies were found.	<div>RESONANCE</div> <div>OUT OF RANGE</div> <div>↔ [▲] or [▼]</div> <div>ANTI-RESONANCE</div> <div>OUT OF RANGE</div>

When the message OUT OF RANGE appears, it is necessary to change the measuring range so that the missed frequency can be read. There may be the case where there is no measuring range that allows taking both resonance and antiresonance frequency measurements. In that case, it will be necessary to take two measurements from distinct ranges or to use the TRZ® Analyzer together with the TRZ® Software (the TRZ® Software allows the customization of the frequency range).

General flowchart:

Next is presented the general flowchart for the menus and the TRZ® Analyzer screens. Menu changes happen by pressing the [SELECT] key on the front panel of the equipment. To go from screen to another, press the [▲] or [▼] keys.



When switching on the equipment, following the opening screen, the previous information showing at the time the equipment was last turned off will be once again displayed.

6.4 Troubleshooting

Problems	Possible causes	Solutions
- The TRZ® Analyzer does not turn on.	There is no electricity running through the AC outlet.	Find a working outlet.
	The power-supply cable is not connected to the outlet and/or the TRZ® Analyzer.	Connect the power-supply cable.
	The power-supply cable is damaged.	Replace the cable by a similar one in good working conditions.
	The I/O (on/off) switch is on the "off" position.	Move the switch on/off key to the "on" position.
- The TRZ® Analyzer cannot measure, or - The results are incoherent, or - The results cannot be reproduced.	The probe is not connected to the equipment.	Connect the probe to the TRANSDUCER connector.
	The probe has poor contact or some cable may be broken.	Fix or replace the probe.
	The probe is incorrectly connected to the element under test.	Check if the probe is connected to the correct pin or terminals.
	The selected frequency range is incorrect.	Select a compatible frequency range with the element.
	The TRZ® Analyzer is out of calibration.	Check the equipment (refer to item 6.5) and perform possible adjustments. If not possible, contact ATCP Physical Engineering.
- TRZ® Analyzer is not communicating with TRZ® Software	The USB cable is disconnected, the USB cable is damaged.	Connect or replace the USB cable.
	There is a problem with the driver.	Check the communication driver (instructions on page 38).

6.5 Calibration, adjustment and functional test

Frequency calibration

It is possible to calibrate the TRZ® Analyzer regarding the frequency generated to perform the measurements.

Requirements:

- Frequency meter capable of measuring the 20–180 kHz range with uncertainty equal to or below 0.5 Hz.
- Coaxial cable with BNC connectors on both ends.

Step-by-step:

Step 01 Adjust the frequency meter for the 20-180 kHz range and connect it to the TRZ® Analyzer (to the TRANSDUCER connector) using a BNC-BNC cable (as shown on Step 02 figure). Use the AC coupling and turn the Low Pass filter (LPF) on, if available (the cut-off frequency must be higher than 20 kHz).

Step 02 Switch the TRZ® Analyzer on and access the DEVICE FREQUENCY menu (press [SELECT] to choose between the menu options). Select CALIBRATION, as illustrated below (use [▼] and [▲] to move up and down the options).



Example of an experimental set-up for checking the TRZ® Analyzer frequency generation accuracy. The frequency measurement is performed by the frequency meter which is connected to the TRZ® Analyzer during the measurement under the CALIBRATION mode.

Step 03 Press the [START] button. The TRZ® Analyzer will generate the frequencies of 20,000, 50,000, 100,000 and 180,000 Hz, one after another, for about 5 seconds each whilst shows "MEASURING..." on the display followed by the frequency currently in progress, as shown below.

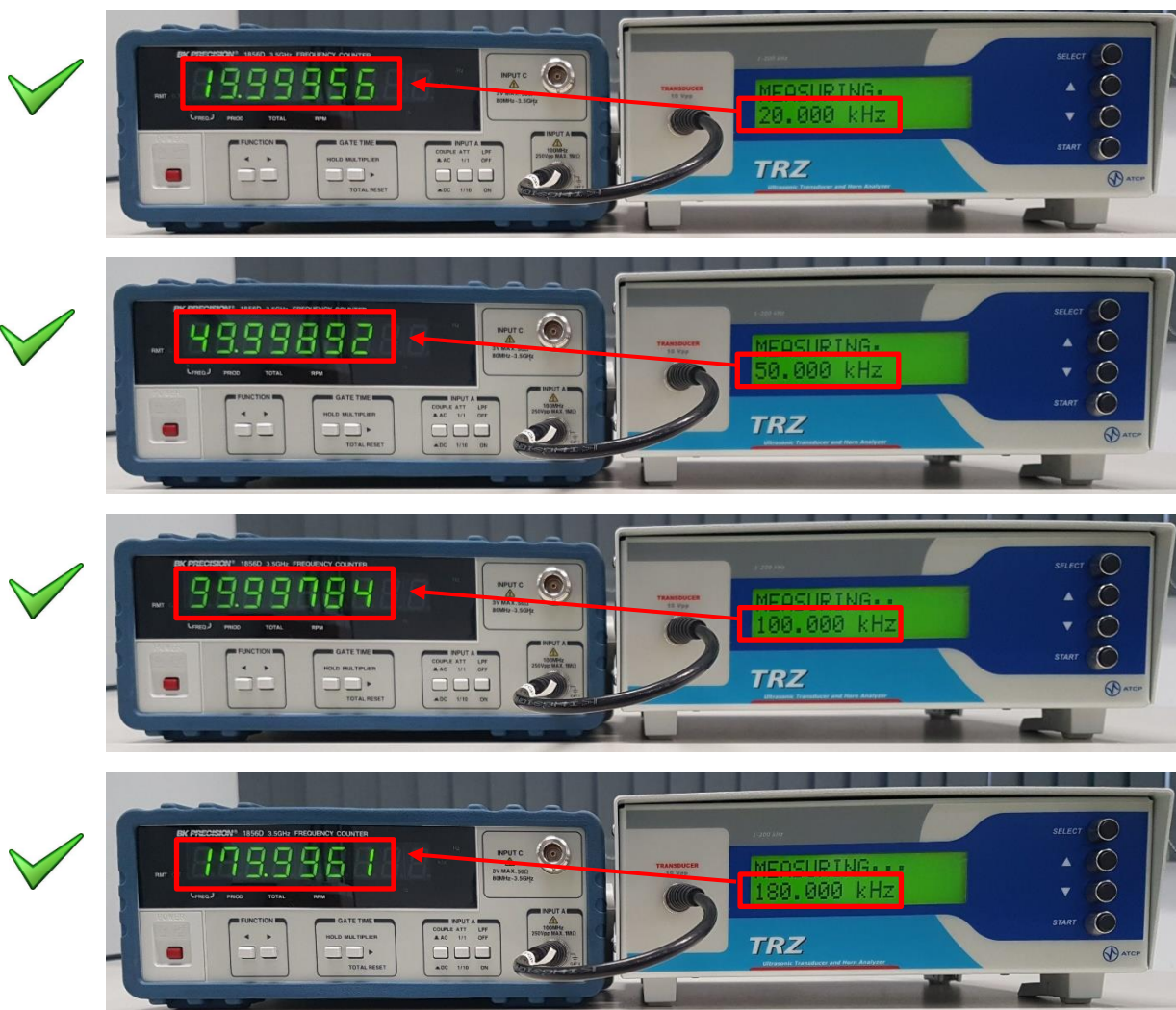


Step 04 Record the frequency meter readings for each nominal frequency and compare with the table below. The tolerance is $\pm 0.03\%$. If any of the readings are out of range, the TRZ[®] Analyzer must be send for maintenance.

Nominal frequency	Minimum	Maximum	uncertainty
20,000 Hz	19,994 Hz	20,006 Hz	$\pm 6 \text{ Hz } (\pm 0.03 \%)$
50,000 Hz	49,985 Hz	50,015 Hz	$\pm 15 \text{ Hz } (\pm 0.03 \%)$
100,000 Hz	99,970 Hz	100,030 Hz	$\pm 30 \text{ Hz } (\pm 0.03 \%)$
180,000 Hz	179,946 Hz	180,054 Hz	$\pm 54 \text{ Hz } (\pm 0.03 \%)$

Minimum and maximum frequencies acceptable in the calibration of the TRZ[®] Analyzer.

In the example below, all measurements are within the tolerance:



After generating the frequencies, the TRZ[®] Analyzer reports the impedance value measured at 20 kHz on the display, this information is necessary to calibrate the impedance module measurement (next topic).

Calibrating the impedance modulus measurement

It is possible to calibrate the TRZ® Analyzer regarding the measurement of the impedance modulus.

Requirements:

- "TRZ® Calibration Kit" or resistance decade box adjusted to 10 k Ω with uncertainty equal to or below $\pm 10 \Omega$ (Observation: the TRZ® Calibration Kit resistor uncertainty is $\pm 10 \Omega$).
- Short coaxial cable with BNC connectors on both ends to connect the "TRZ® Calibration Kit" to the TRZ® Analyzer or any type of connector needed in the case of using a resistance decade box.

Step-by-step:

Step 01 Connect the TRZ® Calibration Kit (10 k Ω side) or a resistance decade box adjusted to 10 k Ω to the TRZ® Analyzer (to the TRANSDUCER connector) as shown on Step 02 figure.

Step 02 Switch the equipment on and access the DEVICE FREQUENCY menu (press [SELECT] to choose between the menu options). Select CALIBRATION, as illustrated below (use [▼] and [▲] to move up and down the options).



Step 03 Press the [START] button. After 20 seconds, the display will show the impedance modulus measured at the frequency of 20 kHz (see the example below). The result must be between 9,700 and 10,300 Ω ($\pm 3\%$). If the result is outside this range, proceed with the adjustment (next item). In the example below, the deviation was of 250 Ω , therefore the equipment is within the acceptable range and does not require adjustments).



Adjusting the impedance modulus measurement

It is possible to adjust the TRZ® Analyzer regarding the measurement of the impedance modulus. This adjustment is necessary when the TRZ® Analyzer fails to calibrate the impedance modulus measurement (see previous item).

Requirements:

- TRZ® Calibration Kit or resistance decade box adjusted to 10 k Ω with uncertainty equal to or below $\pm 10 \Omega$ (Observation: the TRZ® Calibration Kit resistor uncertainty is $\pm 10 \Omega$).
- Short coaxial cable (≤ 20 cm) with BNC connectors on both ends to connect the TRZ® Calibration Kit to the TRZ® Analyzer or any type of connector needed in the case of using a resistance decade box.

Step-by-step:

Step 01 Access the adjustment menu by switching the TRZ® Analyzer on while keeping both the [SELECT] and [▲] keys pressed. Release them only when the equipment shows the "Z adjust" correction factor, as illustrated below (the value shown may be different / the second line shows the firmware version):



Step 02 Adjust the "Z adjust" correction factor using the [▼] and [▲] buttons. The "Z adjust" is a multiplicative factor of measured |Z| and it must be changed to be inversely proportional to the deviation observed when calibrating the impedance (see previous item **Calibrating the impedance modulus measurement**). The adjustment process must be interactive and interpolated with the repetition of the impedance calibration. If it is not possible to perform a satisfactory adjustment between the 0.950 and 1.050 intervals, the TRZ® Analyzer must be sent to service.

Step 03 To exit the adjustment mode, switch the analyzer off and on using the SWITCH key. The new "Z Adjust" value will be automatically saved.



It is advisable for the frequency meter and the TRZ® Calibration kit (or resistance decade box) to be calibrated.

Functional test

It is possible to perform a functional test on the TRZ® Analyzer and TRZ® Software by employing the TRZ® Calibration Kit, which has a resonator with known frequencies and impedances. This functional test is recommended to guarantee the reliability of quality control processes.

The approval of both the TRZ® Analyzer and TRZs Software on the functional test indicates, but does not guarantee, that the equipment is calibrated. For that, it is necessary to check the frequency and measurement of the impedance modulus, as described on previous items.

Requirements to perform the functional test:

- TRZ® Calibration Kit (100 kHz resonator side).
- Short coaxial cable with BNC connectors on both ends to connect the TRZ® Calibration Kit to the TRZ® Analyzer.

Step-by-step for the TRZ® Analyzer functional test:

Step 01 Switch on the equipment on and access the DEVICE FREQUENCY menu (press [SELECT] to choose between the menu options). Select the option 100 kHz, as illustrated below (use [▼] and [▲] to move up and down the options).



Step 02 Perform the resonator measurement by pressing [START]. After 20 seconds the display will show the resonance or antiresonance frequencies and their respective impedance moduli (use [▼] and [▲] to choose one or the other).

Fa: 101.37 kHz	/	Fr: 93.371 kHz
Za: 16.91 kOhm		Zr: 150.17 Ohm

Step 03 Check if the results match the specific ranges on the acceptance criteria table on next page. If any result is out of range, proceed calibrating impedance and frequency (check previous topics).

Acceptance criteria table for the functional test employing the "TRZ® Calibration Kit" 100 kHz resonator.

Antiresonance frequency (Fa)	100.5 kHz \pm 5.5 kHz
Impedance at the antiresonance ($ Z_{FA} $)	\geq 5,00 k Ω
Resonance frequency (Fr)	93.5 kHz \pm 3.5 kHz
Impedance at the resonance ($ Z_{FR} $)	\leq 500 Ω
Central frequency (Fc)*	98.9 kHz \pm 4.5 kHz
Mechanical quality factor (Qm)*	\geq 20

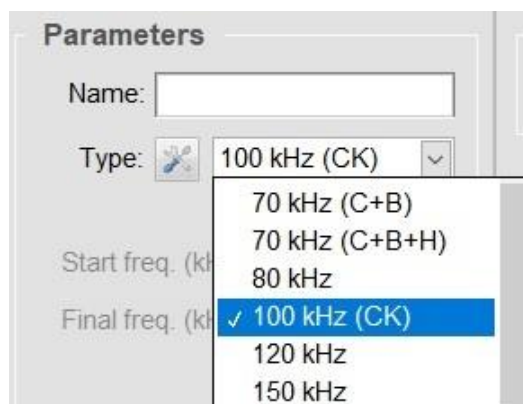
* Fc and Qm results are presented only when using the TRZ® Analyzer in partnership with the TRZ® Software.

Step-by-step functional test for the TRZ® Analyzer when used together with the TRZ® Software:

Step 01 Switch on the equipment and access the REMOTE MODE menu by pressing [SELECT] (this menu appears on the G9 version of the TRZ® Analyzer, on the versions prior to G9, the same menu is named COMMUNICATION).



Step 02 Connect the TRZ® Analyzer to the computer, run the TRZ® Software, choose "100 kHz (CK)" (see picture below) and perform the measurement by clicking on "PLAY". In doubt, check the item 7.6 (Typical measurement using the TRZ® Software) and other topics within chapter 7.




Choose the standard configuration "100 kHz" to perform the functional test.

Step 03 Check if the results are in agreement with the acceptance criteria (green color indicates the results agree). If any result is out of range, proceed with the impedance and frequency calibration (see previous topics).

Parameters

Name:

Type:  100 kHz (CK)

Customize ☐

Start freq. (kHz):

Final freq. (kHz):

Resolution:

Refine ☒

Results

Fa: 100,720 kHz

|Za|: 14,13 kOhms

Fr: 94,125 kHz

|Zr|: 191,36 Ohms

Fc: 97,423 kHz

Qm: 65,00



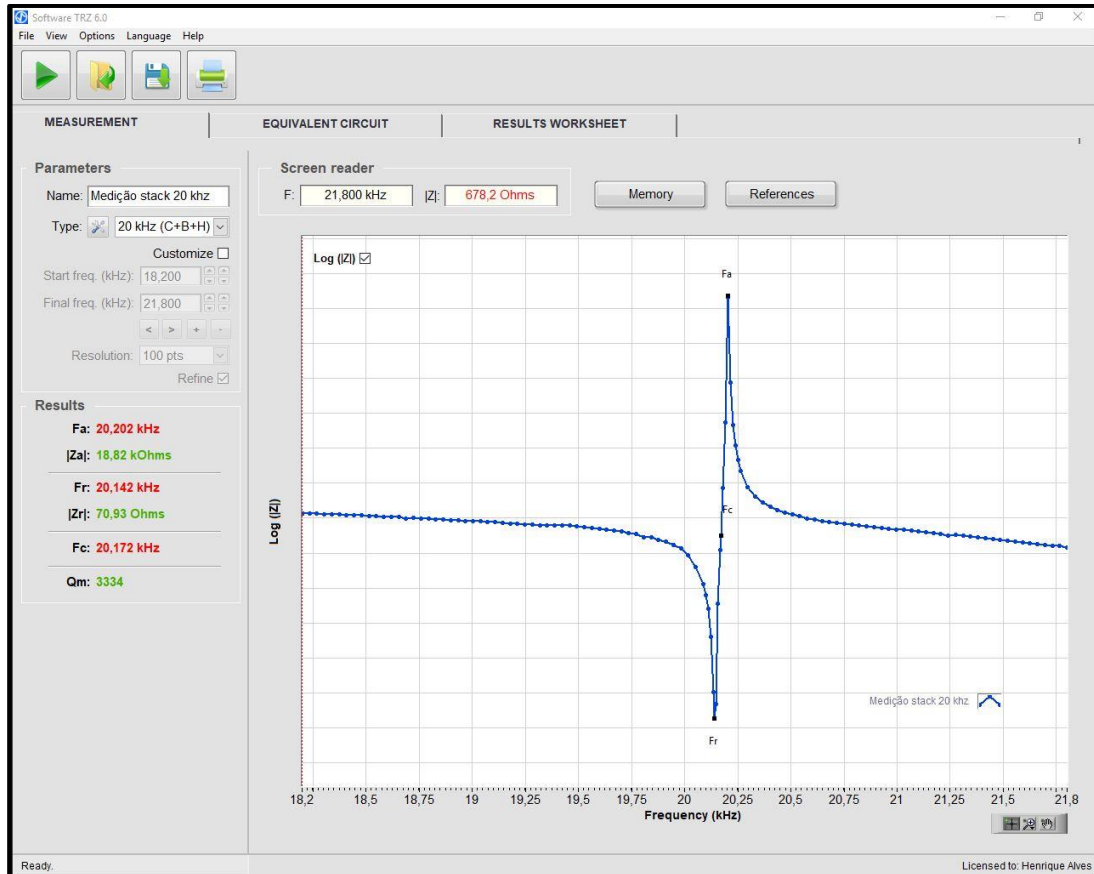
TRZ® Software results after measuring the "TRZ® Calibration Kit" 100 kHz resonator. None of the results should be red.

The TRZ® Software contains the ranges of the acceptance criteria table already programmed to the standard configuration "100 kHz (CK)". Therefore, it is only necessary to perform the measurement and check if all the results are displayed under the green color. If they are, the TRZ® Analyzer functional test for the TRZ® Analyzer operating in partnership with the TRZ® Software has been successful.

Note: If the results are appearing in black color only, go to the **View** menu, and activate the **"Show evaluation results"** function.

7. Software TRZ®

The TRZ® Software was developed to be an extension of the TRZ® Analyzer and a friendly graphical interface. By using the TRZ® Software with the TRZ® Analyzer it is possible to visualize in depth the behavior of the transducer or acoustic stack thanks to the curves $|Z|$ versus frequency ($|Z(f)|$) analysis. It is also possible to obtain additional parameters, such as the central frequency (F_c) and the mechanical quality factor (Q_m), as illustrated on the picture below.



Main tab of the TRZ® Software after a 20 kHz converter characterization.

The Software TRZ® contains features to facilitate the testing and quality control processes. Under the MEAUREMENT tab it is possible to judge the results based on pre-established acceptance criteria. Under the EQUIVALENT CIRCUIT tab it is possible to obtain the Butterworth-van-Dyke (BVD) equivalent circuit of the element under test. Finally, under the RESULTS TABLE tab it is possible to compare the results of multiple measurements.

7.1 Requirements, installation, activation and communication

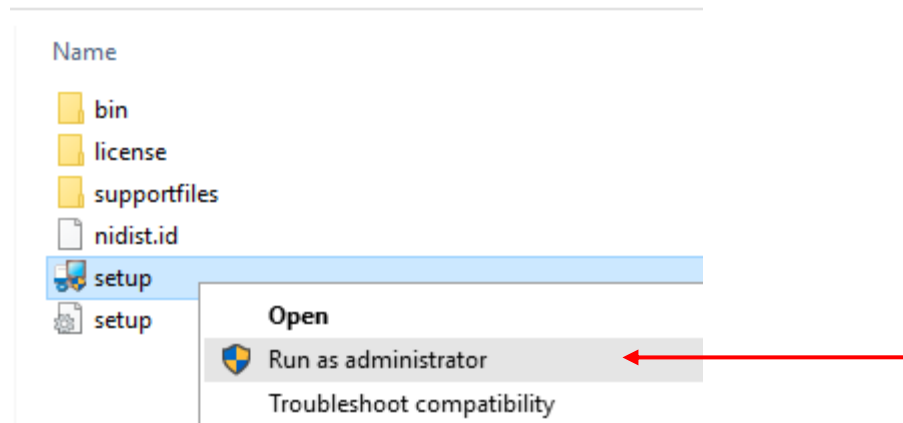
Computer requirements

Processor..... Pentium III or equivalent / superior.
RAM memory (minimum)..... 256 MB.
Screen resolution (minimum)..... 1024 x 768 pixels.
Space in disk (minimum)..... 2 GB.
Compatible operational system..... Windows 10, 8.1, 8, 7, Vista and XP (32 or 64 bits).
Connector..... 01 USB port available (2.0 or superior).

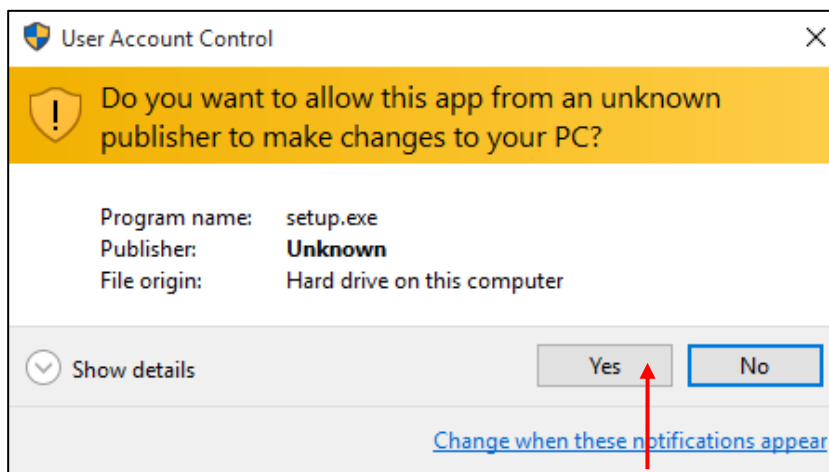
Installation

Users may perform the installation and configuration of the TRZ® Software by themselves. Next are presented the procedures step-by-step:

- Step 01** Run the installation DVD or flash drive or request the link to download the installer (write to ha@atcp.com.br).
- Step 02** Under the "1 - Installer Software TRZ®" folder, right-click on the "steup.exe" file and select "Run as administrator" option. Close all the open programs before initiating the installation process.

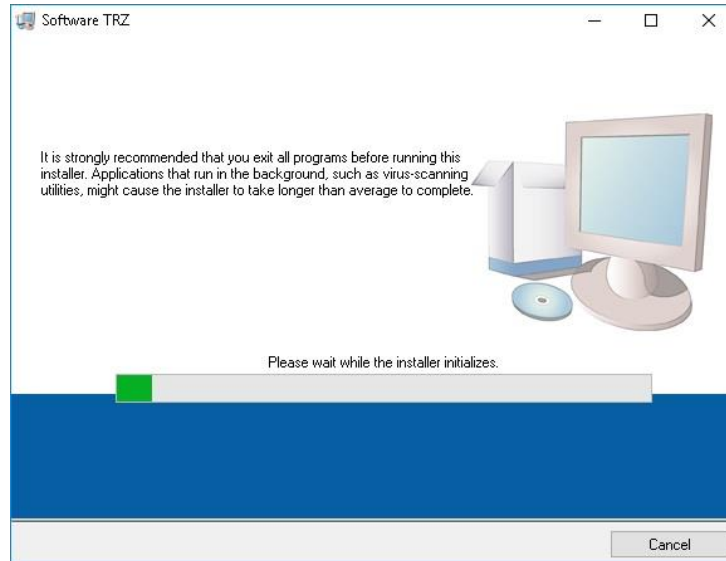


- Step 03** Click on the YES button of the User Account Control pop-up window to allow the installation of the program.



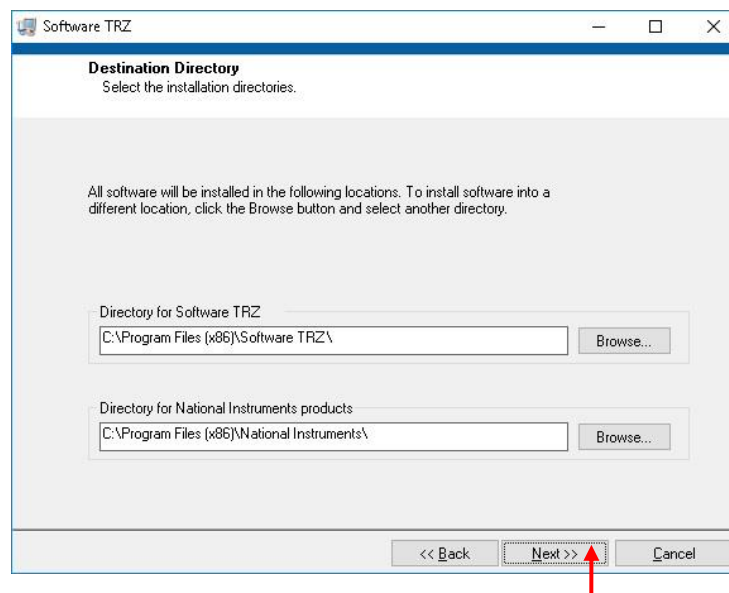
User Account Control window to allow the installation of the TRZ® Software. Important observation: The user must be logged on as the Administrator.

Step 04 Wait for the start window when the user will be advised to close all the programs before running the installer (see the picture below). Under this tab it also appears an alert advising the user about the possibility of the installation process to run for a while because of the antivirus action, which may be running in the background of the operation system.



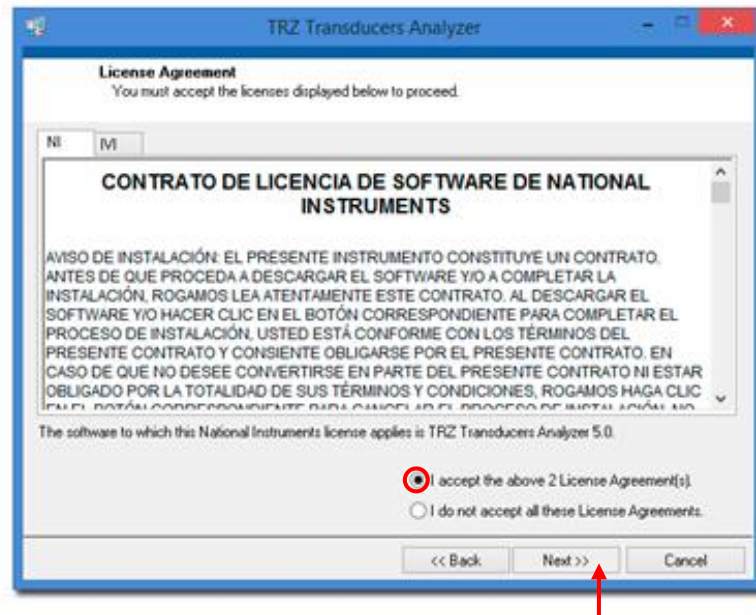
Window showing the beginning of the installation.

Step 05 Select the destination directory for the installation files and click on the NEXT button (it is not advisable to change the directories suggested by the installer).



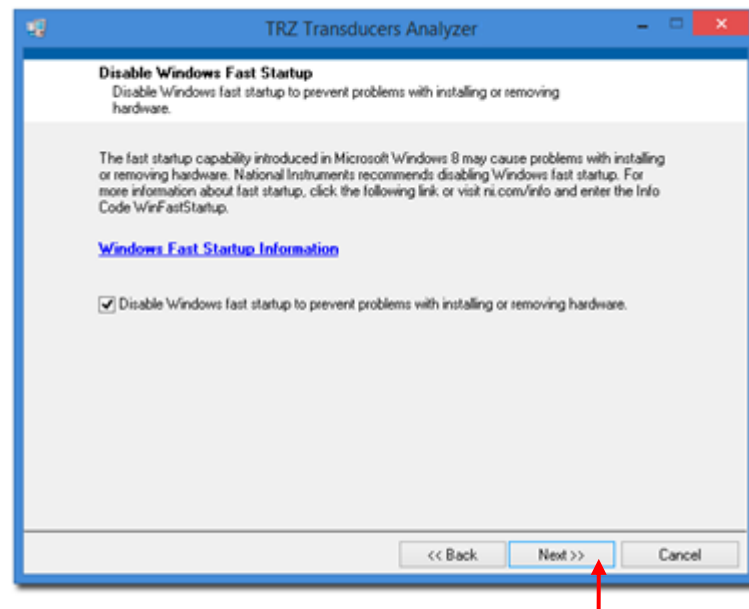
Window for selecting the destination directory of the installation.

Step 06 Accept the license agreement of the TRZ® Software and National Instruments. Proceed by clicking on the NEXT button.



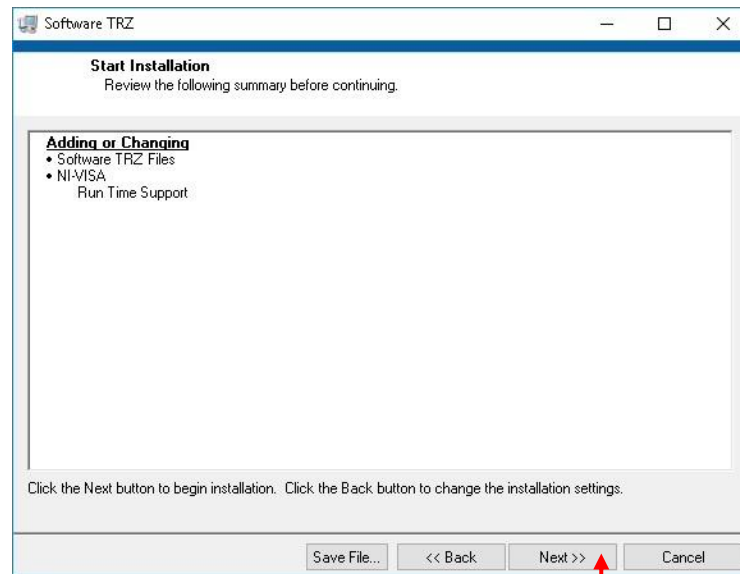
Window showing the license agreement.

Depending on the operational system of your computer, the installer may ask the user to disable the *Windows Fast Startup*. This is a feature incorporated to speed the system initiation, but it may cause inconveniences when installing the software.



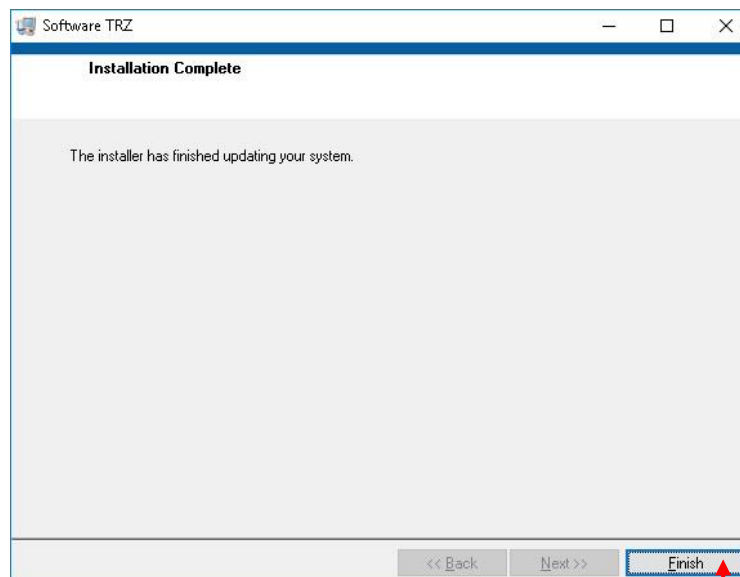
Window for disabling Windows Fast Startup.

Step 07 Installation summaries. This window presents a summary of the programs being installed on your computer. Clicking on NEXT will start the software installation.



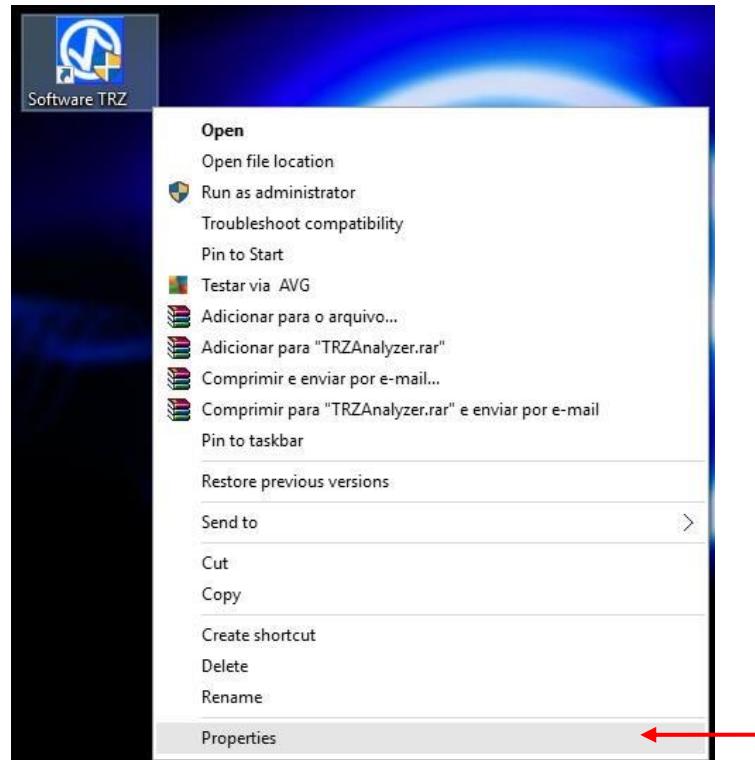
Summary window informing the files that will be installed on your computer.

Step 08 Wait for the conclusion of the files transference and finalize the installation process by clicking on the FINISH button.



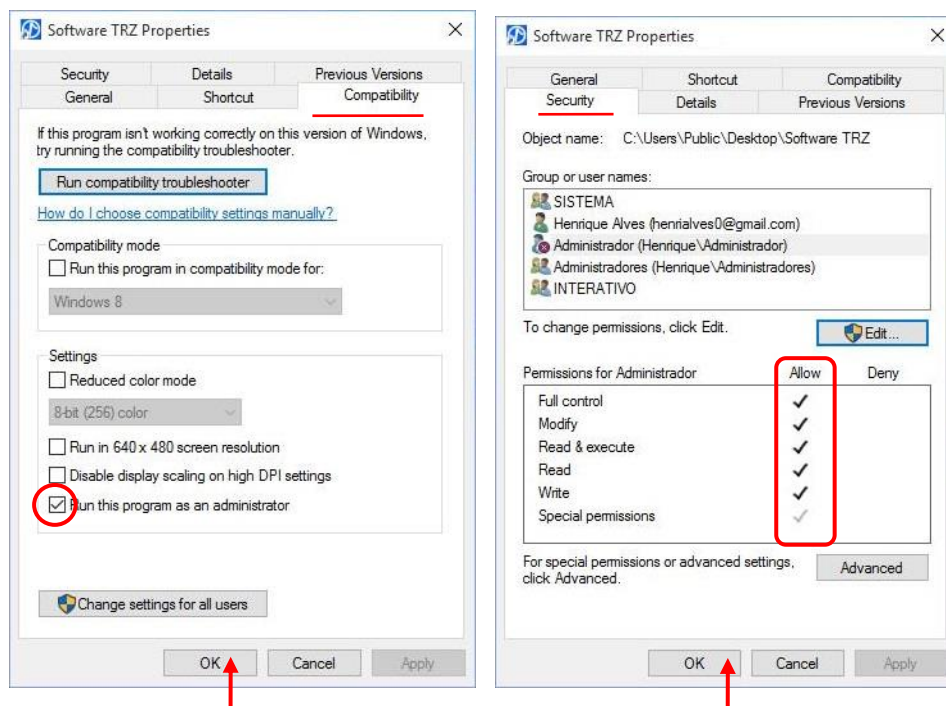
Final window of the TRZ® Software installer.

Ensure that the TRZ® Software is always run by users with administrative privileges. For that, once the installation process is concluded, click with the right button on the program icon, which will be shown on the desktop, and select under the menu the entry PROPERTIES, as shown next.



Window showing *PROPERTIES* on the drop-down menu.

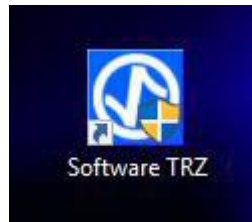
On the *PROPERTIES* window, select the *COMPATIBILITY* tab and mark the option "Run this software as an administrator", as shown below. Select the *SECURITY* option and activate the permissions for each user (use the *EDIT* button). Click on *OK* to confirm the changes.



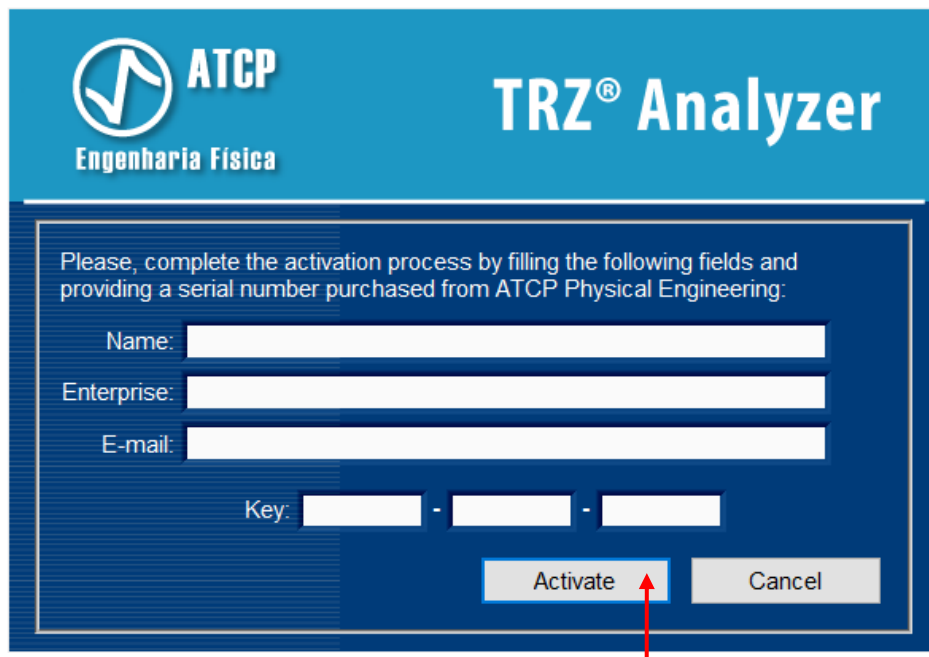
Window showing the properties of the TRZ® Software. *COMPATIBILITY* tab.

Activation

When the installation is concluded, the next step is to run the TRZ® Software. On the working area, double click on the icon of the TRZ® Software.



Because that will be the first time the software runs on your computer, it will be necessary to activate it using the key supplied by ATCP (check the sticker on CD or flash drive). Insert the data and click on ACTIVATE to conclude this form.

The image shows the "TRZ® Analyzer" activation window. The title bar is blue with the ATCP logo and "Engenharia Física" on the left, and "TRZ® Analyzer" on the right. The main area has a dark blue background with a white border. Inside, it says "Please, complete the activation process by filling the following fields and providing a serial number purchased from ATCP Physical Engineering:". There are four input fields: "Name:", "Enterprise:", "E-mail:", and "Key:". The "Key:" field is divided into three boxes by hyphens. At the bottom right, there are two buttons: "Activate" (highlighted with a red arrow) and "Cancel".

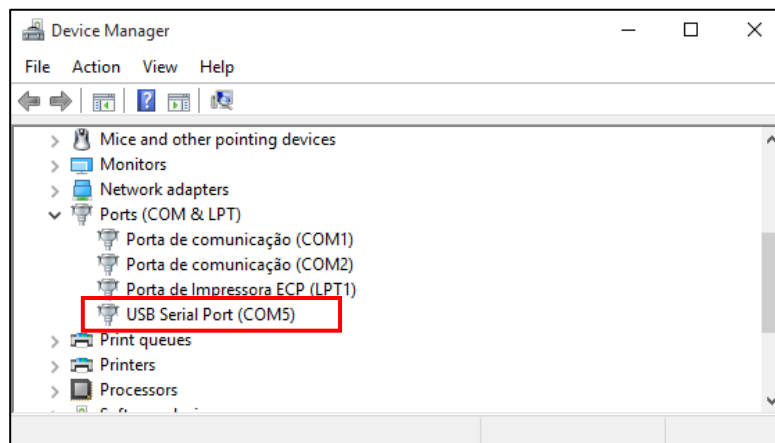
The TRZ® Software activation window.

Restart the software after clicking on activate. When restarting, if once again pops-up the activation window instead of the software window, ensure that you are running the software as the administrator (observation: it is not necessary to be connected to the Internet for the activation). It is also required for the TRZ® Software to be authorized to save files onto your computer so it can save the activation file.

Communicating with the TRZ® Analyzer:

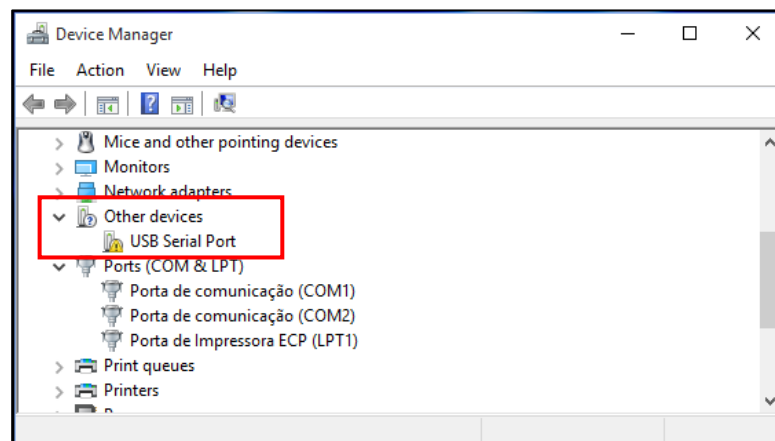
The next step after installing the TRZ® Software is to connect it to the TRZ® Analyzer so they can communicate with each other. In order to do that, keep the TRZ® Analyzer off and connect it to the computer using the A/B USB cable, which is one of the accessories.

A driver is required for the communication with the TRZ® Analyzer. Normally this drive is already included in the Windows package, however, in some cases, it may be necessary to install it manually. To verify whether the Windows already has this driver, access the Device Manager (Control Panel / Hardware and Sounds / Device Manager). At this window, under Ports (COM & LPT), there should be a new port to connect the TRZ® Analyzer, such as highlighted on the example bellow (the number of ports showing might be different).



Windows Device Manager interface.

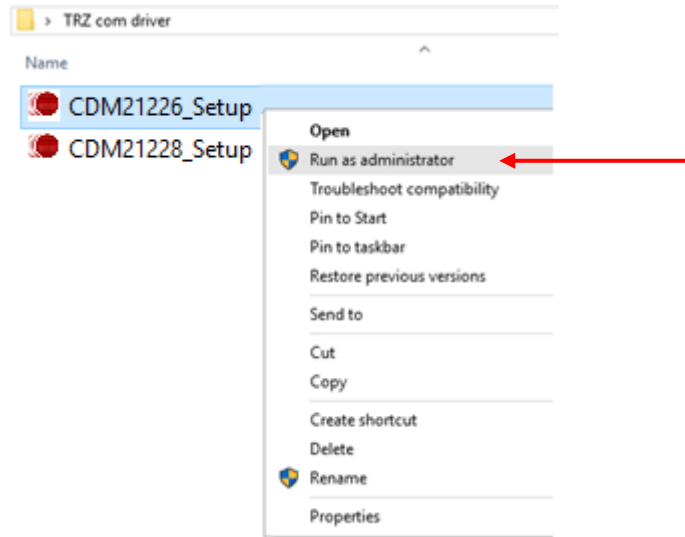
If the port does not appear as pictured above and in its place a message showing "Unknown device" with an exclamation mark is pictured next to the controller name, it means the driver was not automatically found by the system or that some mistake took place during the installation process. In those cases, the user must install the USB driver manually.



Driver identification problems may occur and are shown by an exclamation mark.

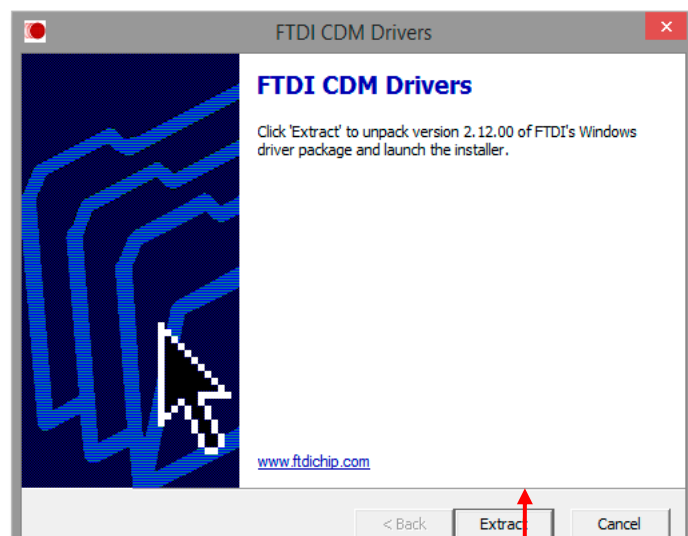
Manual installation for the TRZ® Analyzer communication driver:

Step 01 Run the file "CDM21226_Setup.exe" (or a superior version like CDM21228_Setup.exe) as the administrator (right-click the file and select "Run as administrator"). This file will be found on the computer desktop folder "TRZ with driver", created during the TRZ® Software installation. This driver is made available by the manufacturer of the chip used on the USB interface of the equipment ([FTDI](#)).



Manual installation of the TRZ® Analyzer communication driver.

Step 02 Click on the EXTRACT button of the new window to initiate the installation. Wait for the completion of the extraction process and the installation of the driver, which will occur automatically.



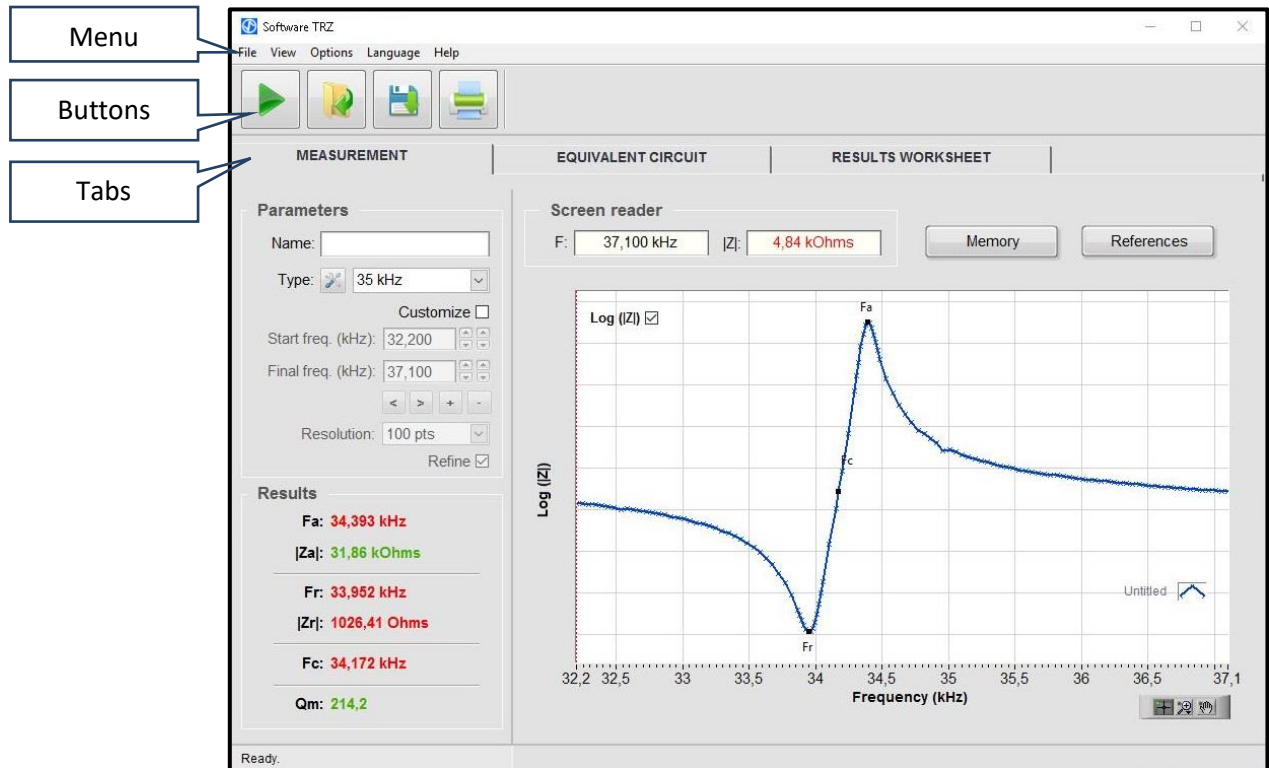
Window to initiate the installation.

Step 03 Go to Device Manager to confirm if the USB Serial Port driver was correctly installed (*Control Panel / Hardware and Sounds / Device Manager*).

7.2 Interface and menus

Interface

The TRZ® Software has a clean and user-friendly interface and the menu is easily identified, as well as the quick access buttons and the MEASUREMENT, EQUIVALENT CIRCUIT, and RESULTS WORKSHEET tabs. These elements are described in depth throughout the next paragraphs.



Interface of the TRZ® software.

Menus

The TRZ® Software menus are divided into five main areas that are familiar to the Windows users.

Under **File** there will be the functions for handling the files generated by the TRZ® Software and their respective keyboard shortcuts, besides the two functions of initiating a **New Measurement** and **Close**.

File	View	Options	Language	Help
New measurement				Ctrl+N
Open				Ctrl+O
Save				Ctrl+S
Print				Ctrl+P
Exit				Ctrl+X

File menu.

Detailed functions of the **File** menu:

New measurement: It initiates a new measurement following the parameters defined at the MEASUREMENT tab (start frequency, final frequency, number of points, refinement). This function is associated with the shortcut "Ctrl+N" and the quick access button:



Open: It loads the measurement files saved by the software. These files are identified by the extension ".TRZ®". This function is associated with the shortcut "Ctrl+O" and the quick access button:



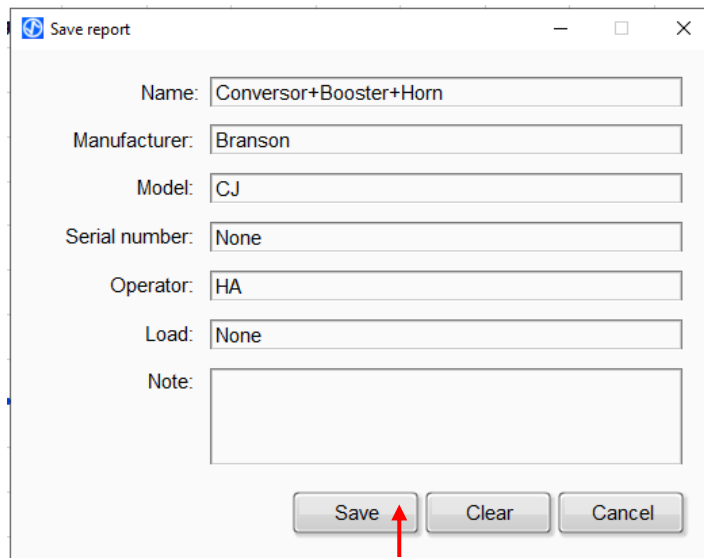
Save: It saves measurement data under a file so it can be recovered later. It is associated with the shortcut "Ctrl+S" and the quick access button:



Print: It prints results reports from the last measurement. It is associated with the shortcut "Ctrl+P" and the quick access button:



When activating the **print** function, a pop-up window will appear requesting information (filling it is optional) to save report. Once this step is concluded, select the printer and click on "Save".



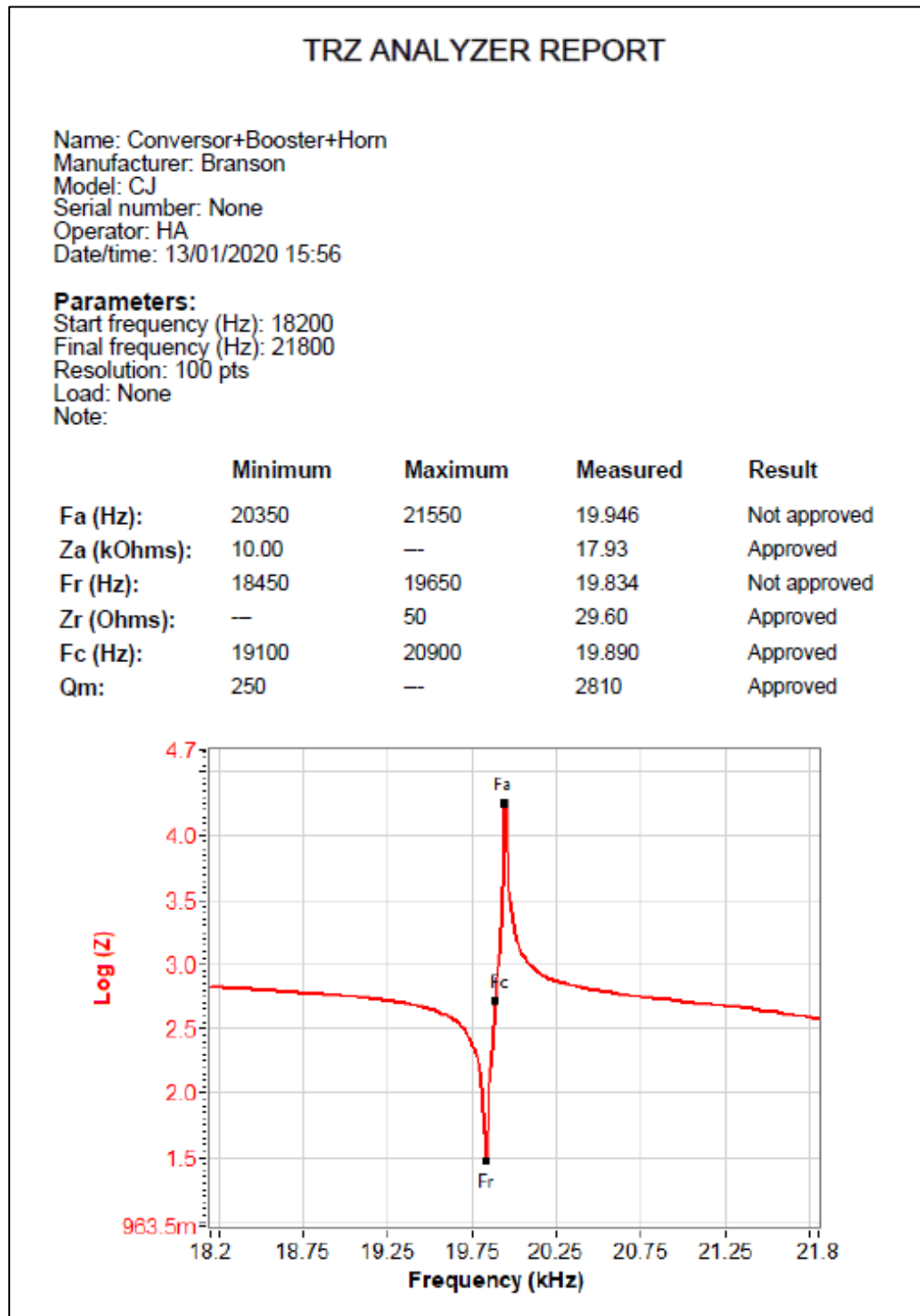
The 'Save report' dialog box contains the following fields and values:

Field	Value
Name	Conversor+Booster+Horn
Manufacturer	Branson
Model	CJ
Serial number	None
Operator	HA
Load	None
Note	

At the bottom, there are three buttons: 'Save', 'Clear', and 'Cancel'. A red arrow points to the 'Save' button.

Print menu window.

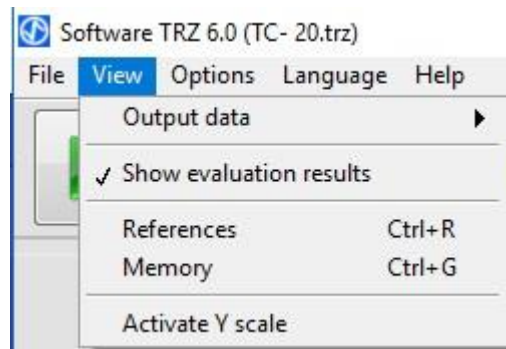
The **Print** function will create a PDF file. A report in PDF format will be saved at the end of this process as shown in the example below:



Example of a TRZ® Analyzer report.

Close: this function finishes the execution of the software.

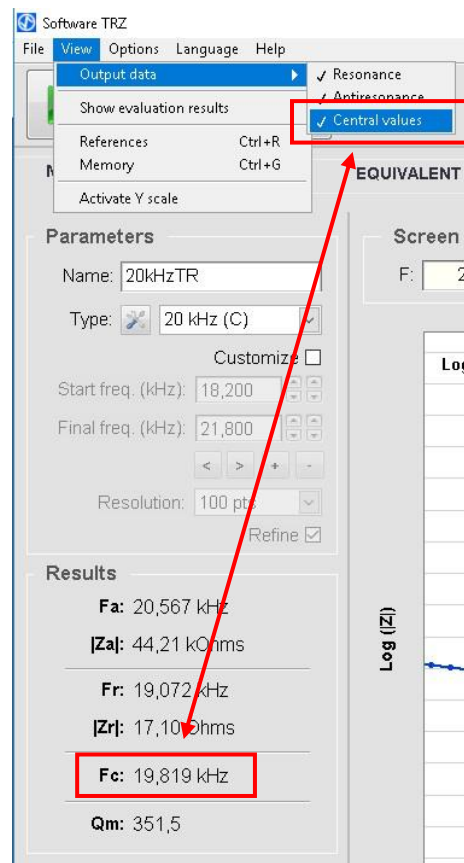
Under the **View** menu, it is possible to select the results that will be shown by the MEASUREMENT tab, turn the results evaluation on and off (all black if evaluation is off, green if approved / red if failed when evaluation is on), show the graph's Y scale and control the **References** and **Memory** functions.



View menu.

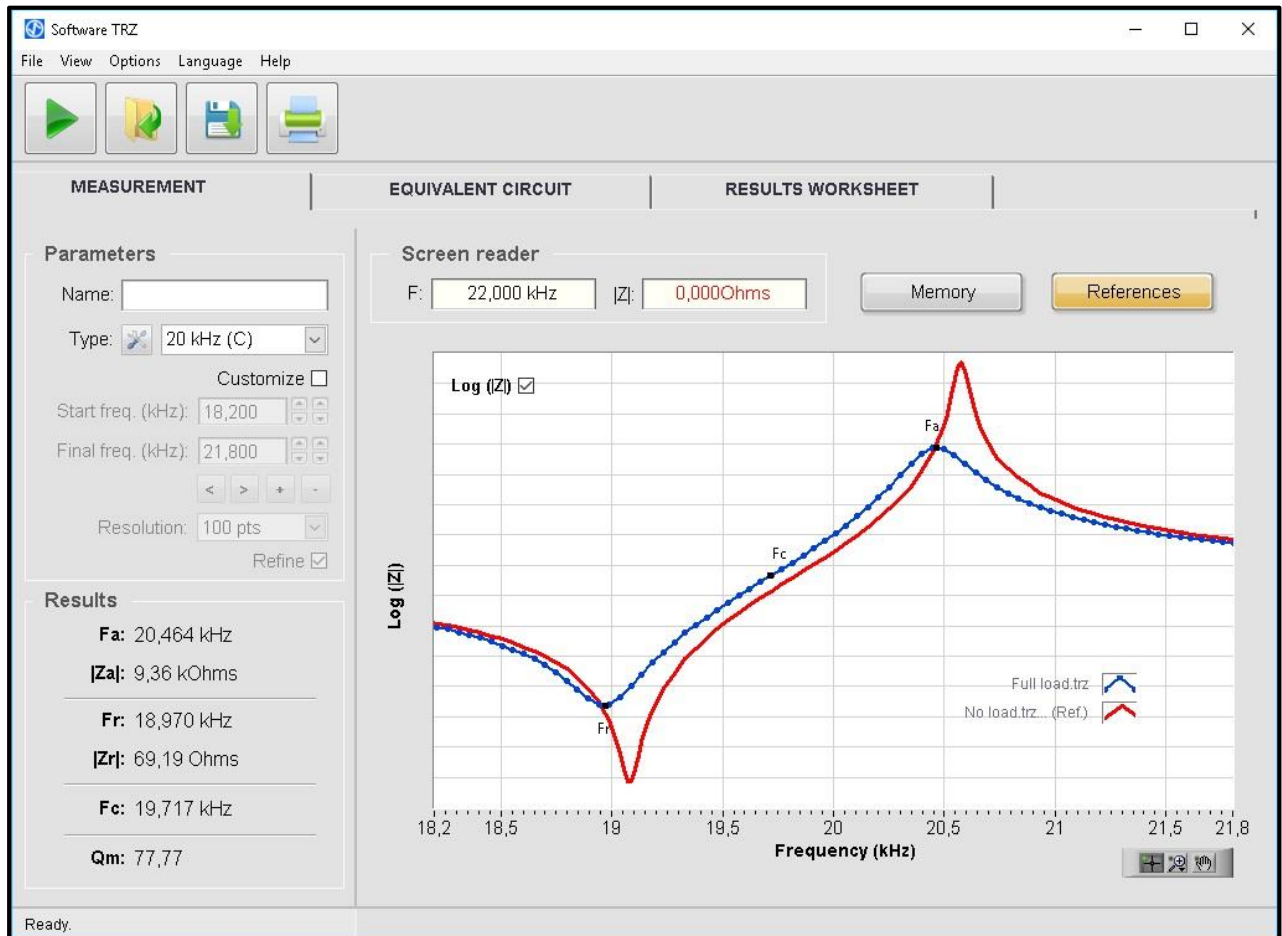
Details of the sub-menu and of the functions of the **View** menu:

Output data sub-menu allows controlling the presentation of the resonance frequency (F_r), antiresonance frequency (F_a) and their respective impedances ($|Z_r|$ and $|Z_a|$), as well as the central frequency (F_c) on the result table of the MEASUREMENT tab.



On the picture above, the central frequency is being shown only when the “Central values” option under the **output data** sub-menu is selected.

References: This function allows loading 01 reference file. It is associated with the shortcut "Ctrl+R" and with the "References" button of the MEASUREMENT tab. The reference measurement is displayed on the screen until this function is deactivated or the software is closed. By allowing the comparison between the results and standards, the **References** function speeds up and increases the reliability of the tuning and quality control processes.

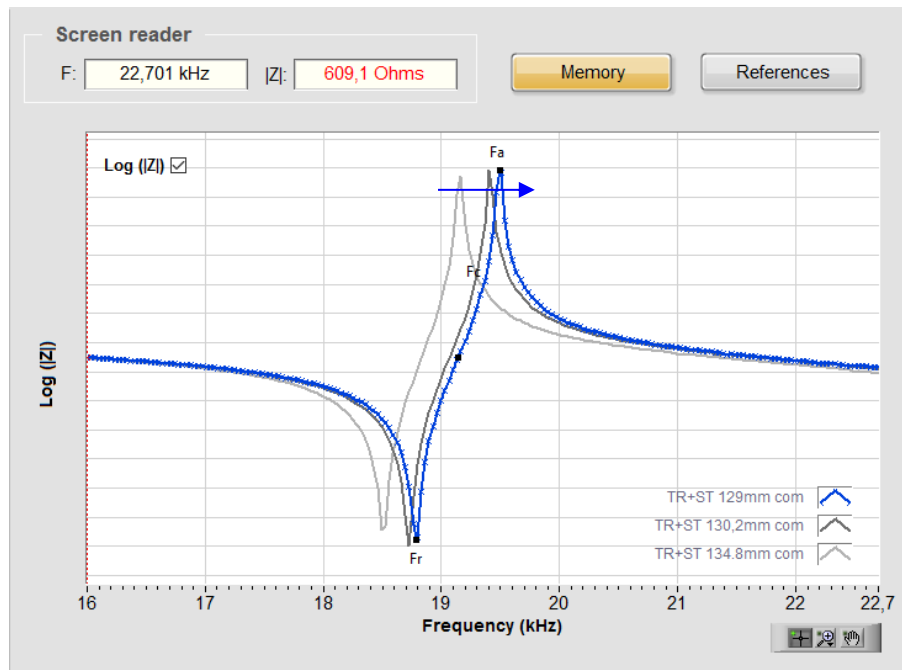


Example of use of the "References" function (reference curve is shown in red).

Memory: This function allows keeping the graph of the last two measurements and load files in the background. As new measurements are taken and new files are loaded, the oldest measurement is excluded. The last measurement is written in blue, the one before the last in dark grey, and the one before that in light grey. The **Memory** function is associated with the shortcut "Ctrl+G" and with the "Memory" button of the MEASUREMENT tab.

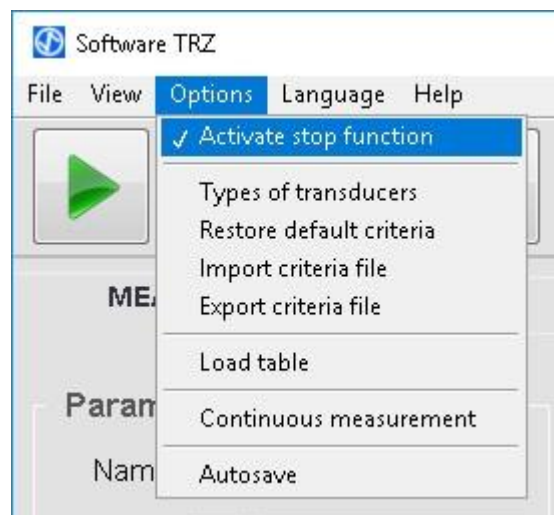
This function is useful for tuning processes because it allows keeping a visual track of frequency and impedance variations as a function of machining. The next example shows the curve of a sonotrode as its length decreases with the aim of increasing its antiresonance frequency.

Observation: It is possible to activate the **Memory** function and the **References** function simultaneously.



Example of the **Memory** function use. The curves shown belong to the same characterized sonotrode presenting different lengths along the tuning processes. At the light grey curve, the length was 134.8 mm, at the dark grey it was 130.2 mm, and at the blue, 129.0 mm (as the length decreases the frequency increases, as shown by the blue arrow).


On the **Options** menu it is possible to configure advanced features of the TRZ® Software, as shown next:

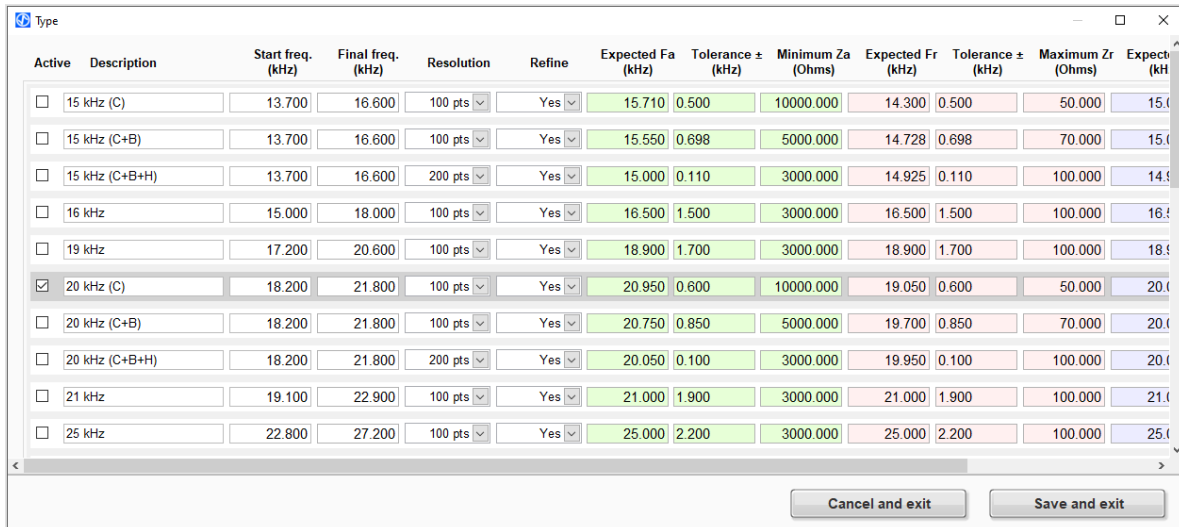


Options Menu.

Detailing the **Options** menu functions:

Activating the STOP function: This function activates the STOP button allowing the cancellation of a measurement that is being taken by the TRZ® Analyzer (Hardware previous versions to 8.1 do not obey to the Stop command, which is automatically deactivated).

Types of transducers: the TRZ® Software allows applying measurement parameters and pre-configured acceptance criteria to facilitate the measurement and quality control processes (these parameters and criteria may be changed by the user). By accessing the **Types of transducers** function or clicking on the button  of the MEASUREMENT tab, it is possible to access the configuration window as shown next:



Active	Description	Start freq. (kHz)	Final freq. (kHz)	Resolution	Refine	Expected Fa (kHz)	Tolerance ± (kHz)	Minimum Za (Ohms)	Expected Fr (kHz)	Tolerance ± (kHz)	Maximum Zr (Ohms)	Expected Fc (kHz)
<input type="checkbox"/>	15 kHz (C)	13.700	16.600	100 pts	Yes	15.710	0.500	10000.000	14.300	0.500	50.000	15.000
<input type="checkbox"/>	15 kHz (C+B)	13.700	16.600	100 pts	Yes	15.550	0.698	5000.000	14.728	0.698	70.000	15.000
<input type="checkbox"/>	15 kHz (C+B+H)	13.700	16.600	200 pts	Yes	15.000	0.110	3000.000	14.925	0.110	100.000	14.000
<input type="checkbox"/>	16 kHz	15.000	18.000	100 pts	Yes	16.500	1.500	3000.000	16.500	1.500	100.000	16.000
<input type="checkbox"/>	19 kHz	17.200	20.600	100 pts	Yes	18.900	1.700	3000.000	18.900	1.700	100.000	18.000
<input checked="" type="checkbox"/>	20 kHz (C)	18.200	21.800	100 pts	Yes	20.950	0.600	10000.000	19.050	0.600	50.000	20.000
<input type="checkbox"/>	20 kHz (C+B)	18.200	21.800	100 pts	Yes	20.750	0.850	5000.000	19.700	0.850	70.000	20.000
<input type="checkbox"/>	20 kHz (C+B+H)	18.200	21.800	200 pts	Yes	20.050	0.100	3000.000	19.950	0.100	100.000	20.000
<input type="checkbox"/>	21 kHz	19.100	22.900	100 pts	Yes	21.000	1.900	3000.000	21.000	1.900	100.000	21.000
<input type="checkbox"/>	25 kHz	22.800	27.200	100 pts	Yes	25.000	2.200	3000.000	25.000	2.200	100.000	25.000

Buttons: Cancel and exit, Save and exit

Measurement parameters and acceptance criteria window of configuration.

Each line shown on this window is a nominal frequency which is specified on the DESCRIPTION column (2°). The active option is shown on the first column with a check mark. The parameters and criteria may be set on this window:

- Start frequency: Initial frequency of the frequency sweep.
- Final Frequency: Final frequency of the frequency sweep.
- Resolution: Number of points between the start and final frequencies.
- Refinement: By activating this function, the hardware will refine the measurement surrounding the resonance and antiresonance frequencies, which will increase the resolution at these regions without extending much the measurement duration.
- Expected Fa and tolerance: Establish the value and its respective tolerance for the antiresonance frequency. These values define an acceptance criterion.
- Minimum Za: Establishes the minimum value for the impedance at the antiresonance. Low values are not approved.
- Expected Fr and tolerance: Establish the expected value and tolerance for the resonance frequency. These values define an acceptance criterion.
- Maximum Zr: Sets up the maximum value for the impedance at the resonance frequency. Greater values are not approved.
- Expected Fc and tolerance: Establish the expected value and tolerance for the central frequency. These values define an approval criterion.
- Minimum Qm: Minimum value for the quality factor. Smaller values are not approved.

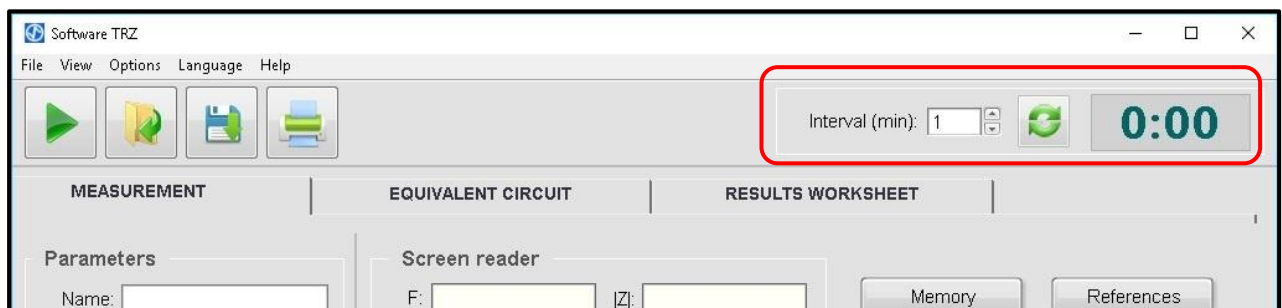
Restoring original criteria: This function allows reestablishing the original TRZ® Software values accordingly to the parameters and acceptance criteria. Observation: it must be taken into consideration that all the changes made will be lost when the user gives the **Restoring original criteria** command.

Import criteria: This function allows to load files previously saved by the user (see the following function **Export criteria**) with parameters and custom criteria. This function allows the use of more than one set of parameters and acceptance criteria. The TRZ® Software installer creates a folder in "C:\Program Files (x86)\Software TRZ\Transducers" in which there are two parameter files and criteria, the "Transducers_Standard" and the "Transducers_Welding". "Transducers_Welding" matches the original criteria of TRZ® 6.1 Software with types and frequency ranges equal to those in the table on page 21, "Transducers_Standard" corresponds to the types and ranges of the TRZ® Analyzer and frequency bands of Software 5.0 version.

Export criteria: This function allows you to export to file the current parameters and acceptance criteria.

Loading a table: This function allows loading the values measured by the TRZ® Analyzer at its last singlehanded use.

Continuous measurement: This function allows performing automatic sequential measurements with pre-defined time intervals. By activating the **Continuous measurement** function, there will be three new controls at the top right corner of the interface (see picture). "Interval", defines the Software waiting time between the end of a measurement and the beginning of another (this field is adjustable between 1 and 60 minutes and does not include the measurement length of time). "Play continuously" starts and ends the process of continuous measurement. The third element is a time indicator presenting the countdown of the time between two consecutive measurements. As the measurements are taken, the results are exported to a RESULTS SPREASHEET table.



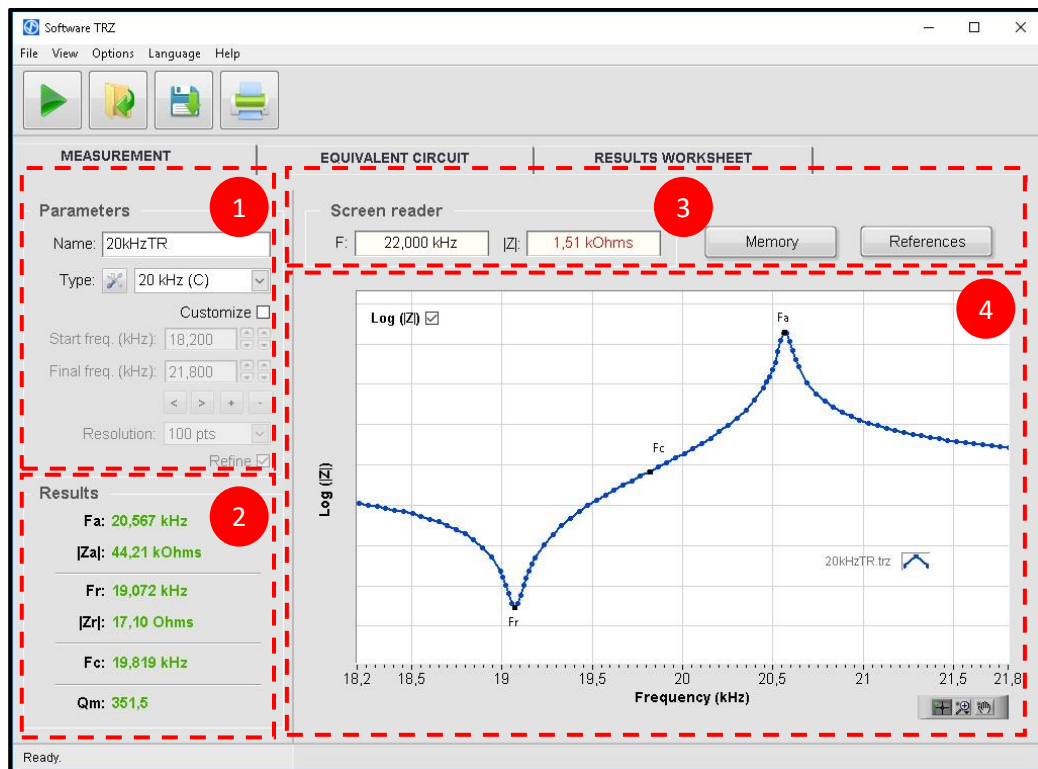
TRZ® Software showing its **Continuous measurement** function activated.

Autosave: This function allows the measurements made by the TRZ® Software to be automatically saved to file. The files name comprises the contents of the "Name" field with the measurement date and time

At the **Language** menu, the user may select one of the three options *English*, *Portuguese*, and *Spanish*. Once the language is chosen, the software will memorize the preference.

7.3 MEASUREMENT tab

The measurement tab may be divided into four sections as detailed next:

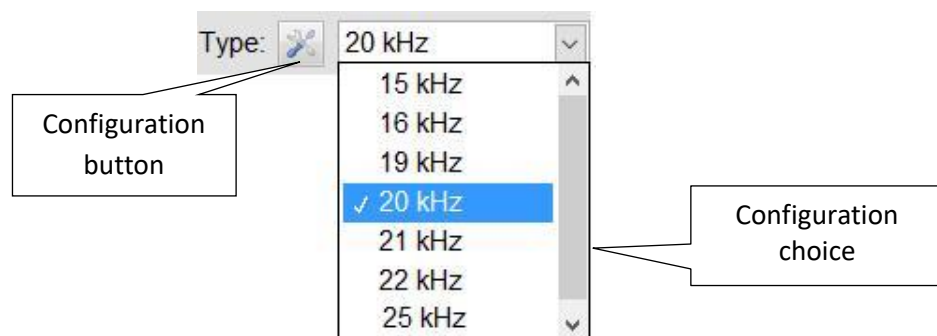


MEASUREMENT tab with highlighted and numbered sections.

Section 1: This is the “Parameters” section and it holds the measurement configuration fields, as detailed below:

Name: This field allows the association of a name with the measurement result. The software suggests a name when saving the file and when saving measurement reports. The same is also used on the graph’s captions and as an identifier on the table of the RESULTS SPREADSHEET tab.

Type: This control allows choosing between varied measurement parameters and acceptance criteria, which are pre-configured according to the nominal frequency of the element under test. The configuration button, which allows opening a configuration table for parameters and criteria, is associated with this control.



Control for choosing the pre-configured measurement parameters and acceptance criteria.

Customize: This control allows changing between the pre-configured values and the manual insertion of start and final frequencies, resolution and the refinement function control.

Start frequency: Initial frequency for the frequency sweep. It may be manually inserted or loaded from pre-configured parameters.

Final frequency: The final frequency for the frequency sweep. It may be manually inserted or loaded from pre-configured parameters.



Buttons: Allow increasing or decreasing the start and the final frequencies simultaneously.



Buttons: Allow increasing or decreasing the difference between the start and the final frequencies.

Resolution: The number of points of the interval of discretization between the start and the final frequencies. Under the customized mode the user may select between the values of 100, 200 and 500 points. The higher the number of points, the greater is the resolution and the slower will be the measurement.

Refine: This control activates the refinement function regarding the resonance and antiresonance frequencies. It allows increasing the resolution from the interest areas without extending much the duration of the measurement. Observation: even when this function is off, there is an interpolation around the frequencies to increase the resolution.

Section 2: This is the "Results" section where are reported the results for the resonance and antiresonance frequencies, their respective impedances, the central frequency and the average mechanical quality factor. The detail of each result is presented next. To find a detailed explanation of the meaning of each result, please go to Chapter 2 (Definitions and Symbology).

Fa: Antiresonance frequency.

|Za|: Electrical impedance modulus at the antiresonance.

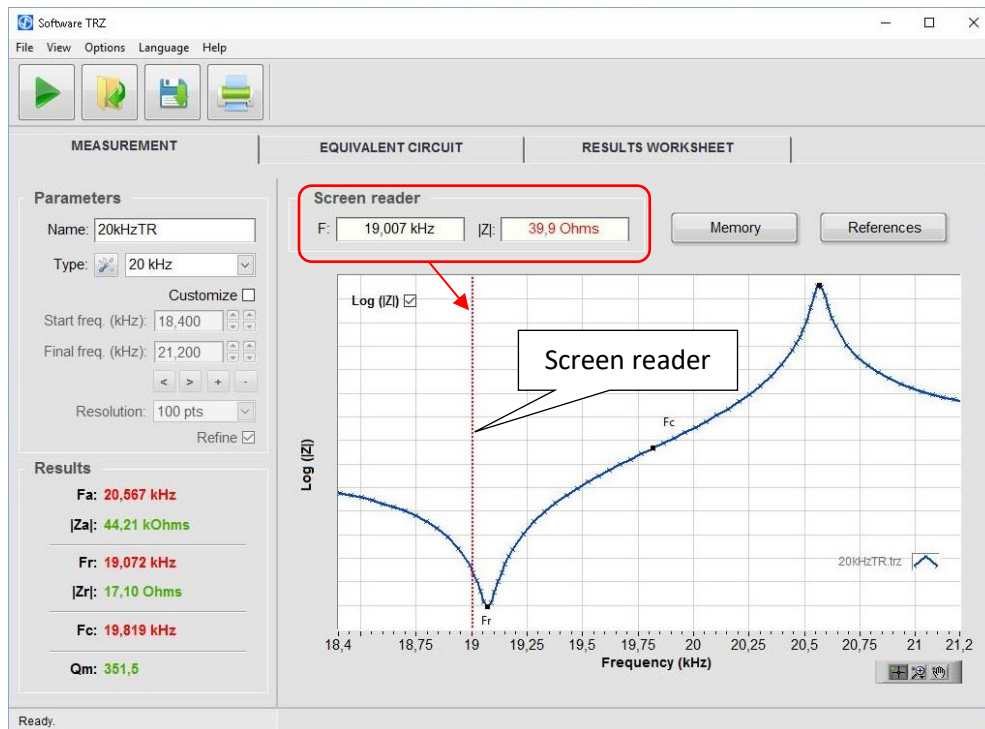
Fr: Resonance frequency.

|Zr|: Electrical impedance modulus at resonance.

Fc: Arithmetic average of the resonance and antiresonance frequencies.

Qm: Average between the mechanical quality factor Q obtained from the series equivalent circuit and the mechanical quality factor Q obtained from the parallel equivalent circuit.

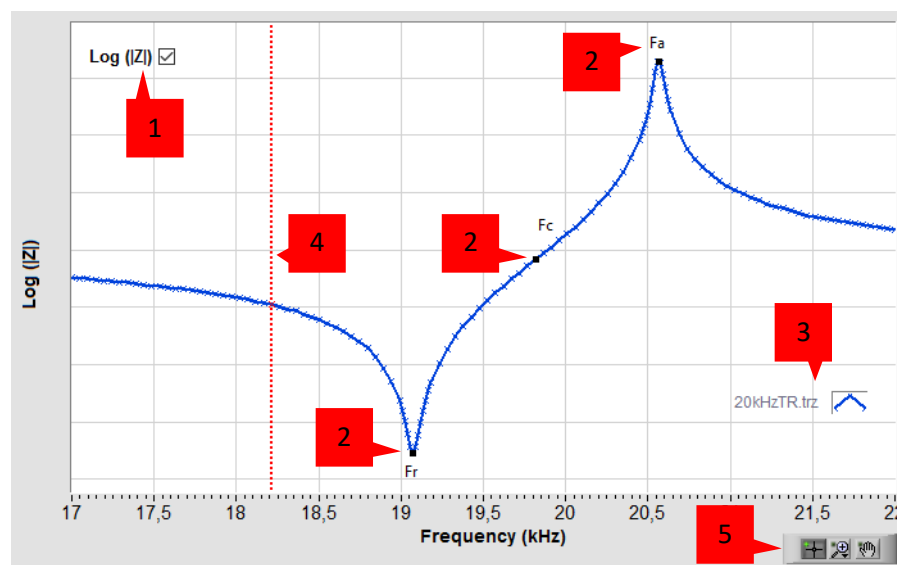
Section 3: This is the section for control and point-to-point reading of the graphs presented by Section 4. Both fields to the left, directly below "Screen reader", show the value of frequency and impedance modulus at the position of the curve $|Z(f)|$ where the screen reader is (dotted vertical line of the Section 4 graph).



Frequency and impedance modulus ($|Z|$) at the position of the screen reader.

Under Section 3, it can be also found the **Memory** and **Reference** buttons, whose features are described on the Chapter 7.2 (Interfaces and menus / View menu).

Section 4: This section includes the $|Z(f)|$ graph or $\log |Z(f)|$ as well as the visualization tools.



Log($|Z|$) graph as a function of frequency with the main elements numbered.

Detailing of the graph elements as numbered on the previous picture:

1: Selection box which allows showing on the Y axis the impedance modulus ($|Z|$) or impedance modulus logarithm ($\log(|Z|)$). This function eases the visualization of resonance and antiresonance points simultaneously. Note: You can display the Y-axis scale by turning the **Active Y scale** function on the **View** menu.

2: Tags identifying the points where the antiresonance (F_a), resonance (F_c) and central (F_c) frequencies occur.

3: Graph's caption showing the names of the active graphs on the screen and the colors identified with them. This information is especially necessary when the **Memory** and **Reference** functions are activated.

4: Screen reader. It allows Reading values of frequency and impedance modulus of the measuring curve. These values are shown on the top left corner of the Section 3 screen.

5: Auxiliary graph controls. Buttons included allow choosing from the following commands:



Pointer: tool for moving the graph's cursor.



Drag: allows dragging the graph by clicking on it.

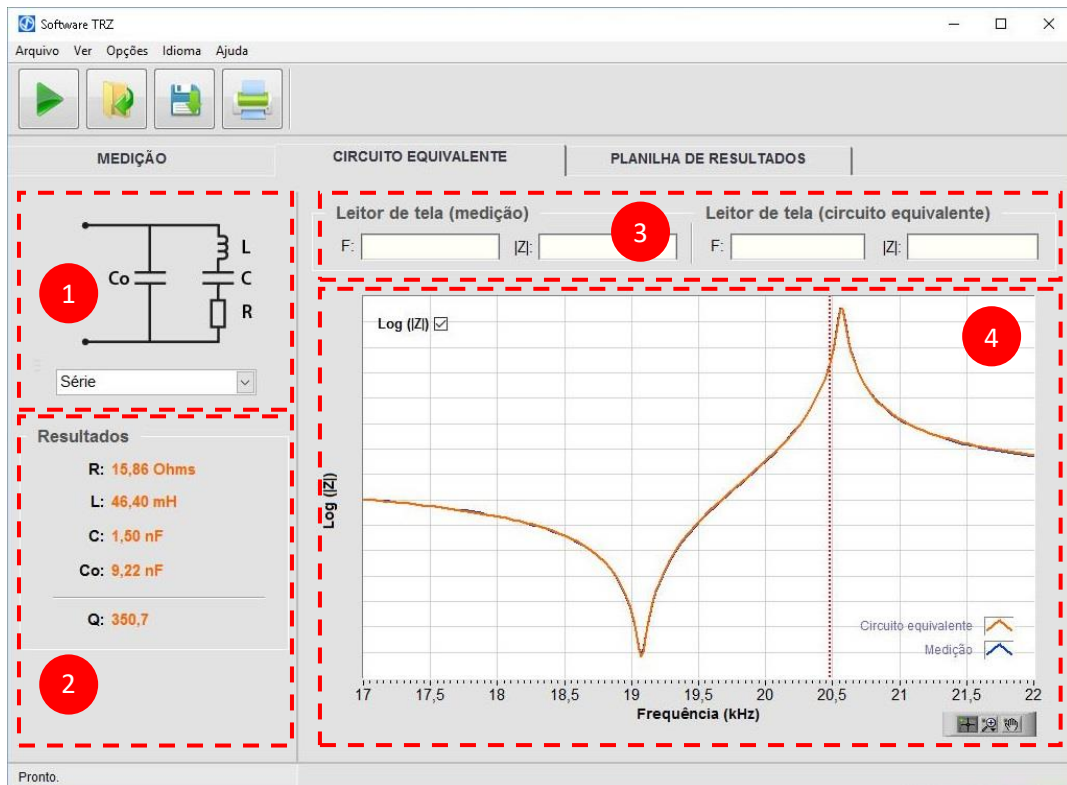


Zoom: allows zooming in or out of the graph. Use the drop-down menu that appears when clicking on the edge to select a magnification method.

The description of these function finalizes the MEASUREMENT tab details. Next, find the details of the next tab.

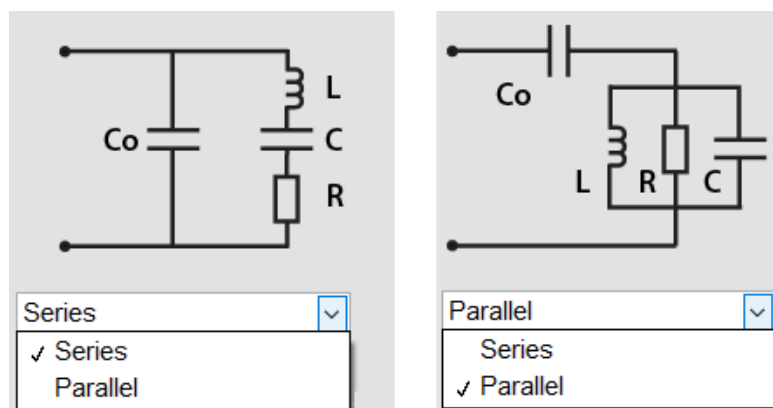
7.4 EQUIVALENT CIRCUIT tab

The EQUIVALENT CIRCUIT tab may be divided into four sections, as detailed next.



EQUIVALENT CIRCUIT tab with its sections highlighted and numbered.

Section 1: This is the section of the equivalent circuit configuration **selector** (series or parallel circuit).



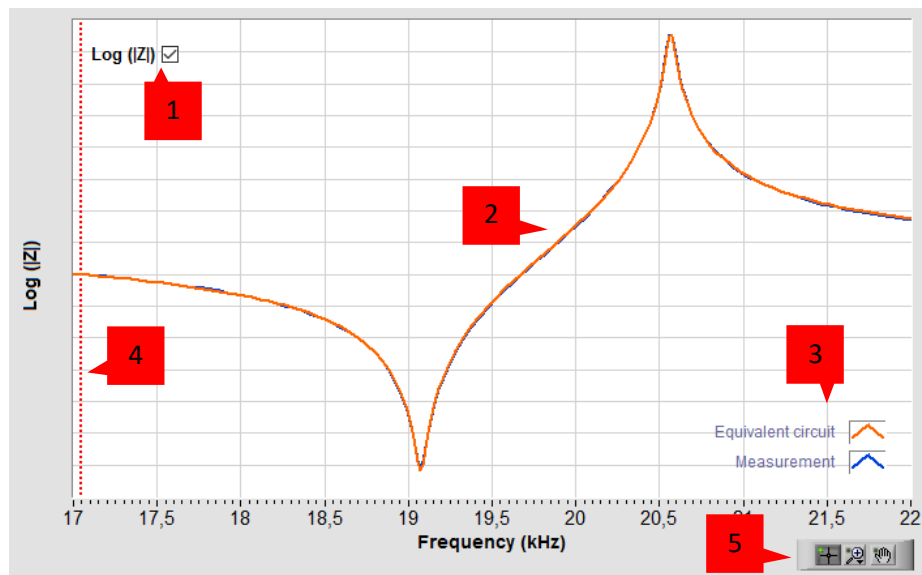
Equivalent circuit configuration selector.

Section 2: The values of resistance (R), inductance (L) and capacitance (C and Co) of the equivalent circuit are reported in this "Results" section. The quality factor (Q) is also shown therein.

Section 3: This is the section for the point-to-point reading of the graphs presented on Section 4. The reading is performed at the position of the curve where the screen reader is (dotted vertical line of the Section 4 graph). The two fields to the left show the values of frequency and




impedance modulus at the measured curve. The fields to the right display the values of frequency and impedance modulus at the equivalent circuit curve.

Section 4: This section comprehends the measurement (in orange) and equivalent circuit (in blue) $\log(|Z(f)|)$ graphs. In the case of the equivalent circuit, the graph may be related to a series or parallel configuration, depending on the **Selector** of Section 1. The better is the equivalent circuit adjustment, the greater is the curves fitting. Visualization tools are also displayed on this section.



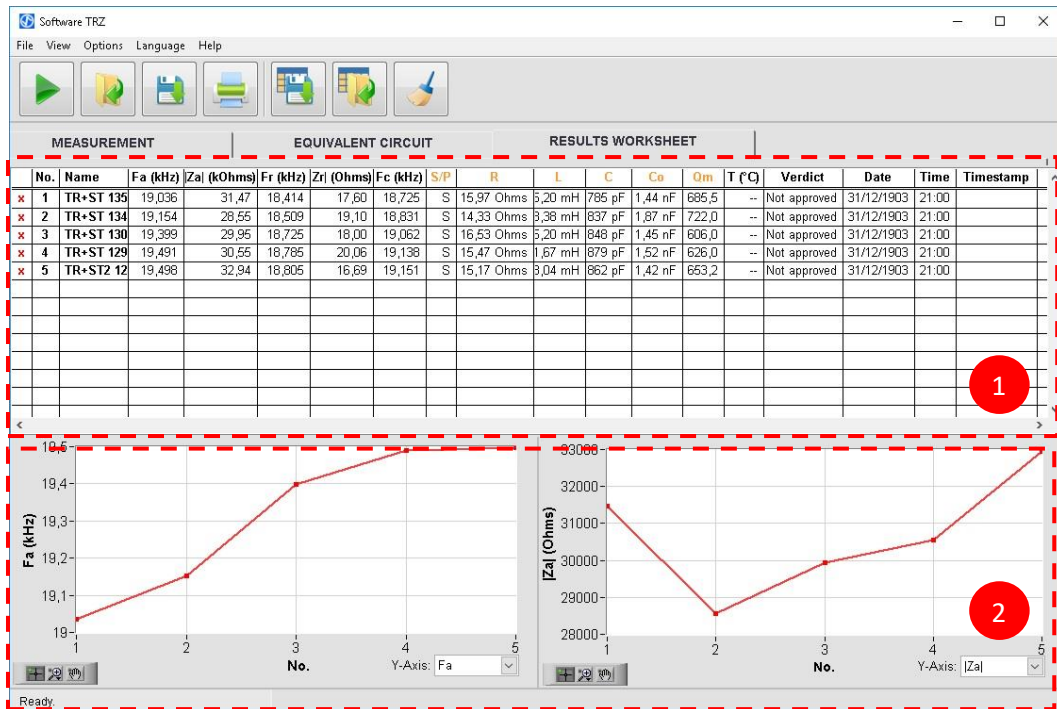
Measurement and equivalent circuit graph of Section 4.

Detailing the graph elements as numbered on the previous picture:

- 1:** Selection box which allows showing on the Y axis the impedance modulus ($|Z|$) or impedance modulus logarithm ($\log(|Z|)$).
- 2:** Measurement and equivalent circuit graphs selected on **Section 1**.
- 3:** Graph's caption showing the color codes used to differentiate the measurement graph from the equivalent circuit graph.
- 4:** Screen reader. It allows reading values of frequency and impedance modulus of the measurement and equivalent circuit curve. The respective screen readers of Section 3 show the values.
- 5:** Auxiliary graph controls. Buttons included allow choosing from the following commands:
 -  Pointer: tool for moving the graph's cursor.
 -  Drag: allows dragging the graph by clicking on it.
 -  Zoom: allows zooming in or out of the graph.

7.5 RESULTS WORKSHEET tab

The RESULTS WORKSHEET tab holds the results of measurements and loaded files, allowing a comparative analysis and a systematic follow-up of the tuning and quality control processes. This tab has two sections, as detailed next:



The RESULTS WORKSHEET tab with its highlighted and numbered sections.

Section 1: This section shows the results table. At each measurement or file loaded, a new line is added to the end of the table.

No.	Name	Fa (kHz)	Za (kOhms)	Fr (kHz)	Zr (Ohms)	Fc (kHz)	S/P	R	L	C	Co	Qm	T (°C)	Verdict	Date	Time	Timestamp
x 1	TR+ST 135	19,036	31,47	18,414	17,60	18,725	S	15,97 Ohms	5,20 mH	785 pF	1,44 nF	685,5	--	Not approved	31/12/1903	21:00	
x 2	TR+ST 134	19,154	28,55	18,509	19,10	18,831	S	14,33 Ohms	3,38 mH	837 pF	1,87 nF	722,0	--	Not approved	31/12/1903	21:00	
x 3	TR+ST 130	19,399	29,95	18,725	18,00	19,062	S	16,53 Ohms	5,20 mH	848 pF	1,45 nF	606,0	--	Not approved	31/12/1903	21:00	
x 4	TR+ST 129	19,491	30,55	18,785	20,06	19,138	S	15,47 Ohms	1,67 mH	879 pF	1,52 nF	626,0	--	Not approved	31/12/1903	21:00	
x 5	TR+ST2 12	19,498	32,94	18,805	16,69	19,151	S	15,17 Ohms	3,04 mH	862 pF	1,42 nF	653,2	--	Not approved	31/12/1903	21:00	

Results table image of Section 1.

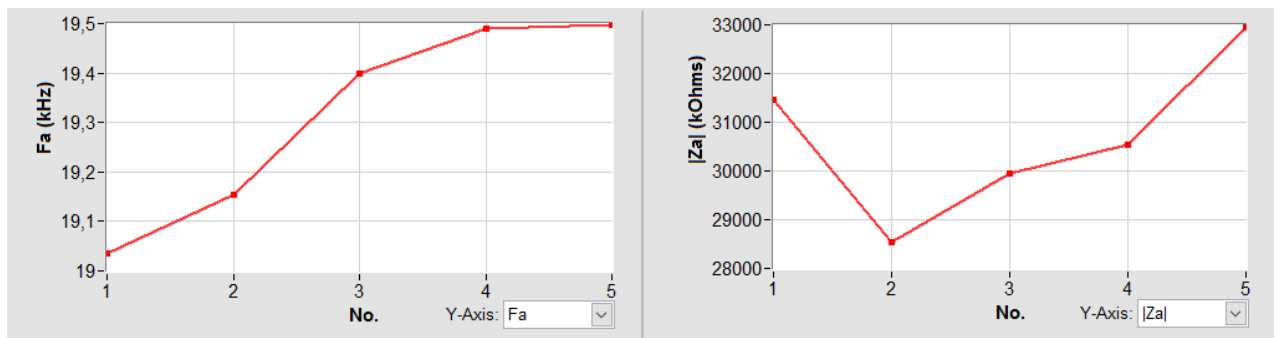
Column 1 (without a heading and showing a red "x") allows excluding the respective line just by clicking on the "x". Once the line is excluded, the corresponding value disappears from the graphs of **Section 2** and column 2 is re-calculated. Columns 3 and 8 (Name, Fa, |Za|, Fr, |Zr|, Fc) hold the name and measurement or loaded files results. Column 15 presents the "verdict" from the results judgment (*Approved* or *Not approved*) according to the acceptance criteria already configured at the *Options/Types of transducers* menu.

Columns 9 and 14 (S/P, R, L, C, Co e Qm), showing headings in orange, are correlated to the EQUIVALENT CIRCUIT tab. The S/P column indicates the configuration of the used equivalent

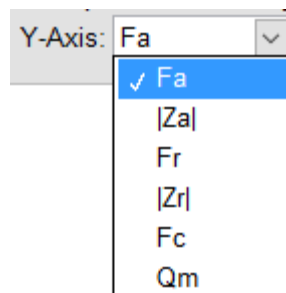
circuit (series or parallel); R , L , C and C_o represent the equivalent circuit result; and the Q_m column the average mechanical quality factor between the series and parallel configurations ($Q_m = \frac{(Q_{Série} + Q_{Paralelo})}{2}$).

The TRZ® Software is capable of performing the temperature acquisition as an auxiliary variable because the acquired license includes this feature and a NI USB-TC01 device (National Instruments) is connected to the computer. Once this device is connected, at each measurement the temperature is read and displayed on the column 16 ($T(^{\circ}C)$). On the contrary, this column will be blank and the temperature replaced by a dotted line "—".

Section 2: This is section of graphs allows visualizing the results evolution (F_a , $|Z_a|$, F_r , $|Z_r|$, F_c e Q_m) as a function of the number of measurements (column 2, N°). At the bottom right corner of the graphs, the Y-axis selector allows choosing the parameter to be shown. These graphs are especially useful for the tuning process.



Graphs of Section 2.



Selector of the parameter to be shown on the graph as a function of the n° of the measurement.

Another characteristic of the RESULTS WORKSHEET tab is the appearance of three new quick access buttons. These are linked to functions of handling the data table:

Saving data: Saves the data shown on the table in .csv files (comma-separated values), which may be imported by Microsoft Excel and similar software.



Loading data: Allows loading files of previously saved data tables.



Clear table: Excludes all data shown on the table.



The results shown on the results table of the RESULTS SPREADSHEET tab are not automatically saved in files, it is always necessary to use the quick access key **Save data** to be able to do that.

7.6 Typical measurement using the TRZ® Software

This item presents actions for a typical measurement employing the TRZ® Software in partnership with the TRZ® Analyzer.

Action 01 Prepare the TRZ® Analyzer for communication: Considering that the TRZ® Analyzer is switched on and correctly connected to the USB port of a computer where the TRZ® Software is installed, press the SEL button of the TRZ® Analyzer until the screen below is displayed.

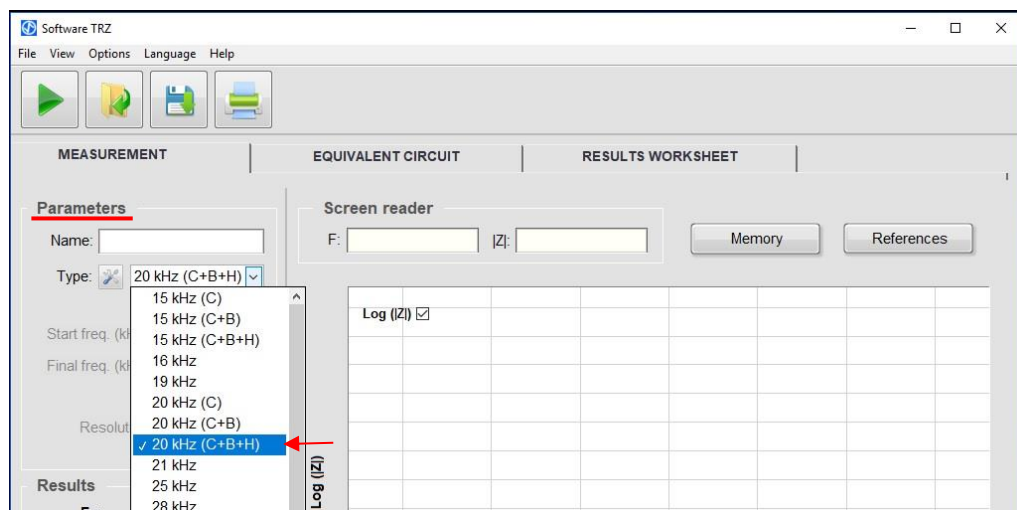


Or the next screen, if the TRZ® Analyzer version is previous to the 8.1 version.



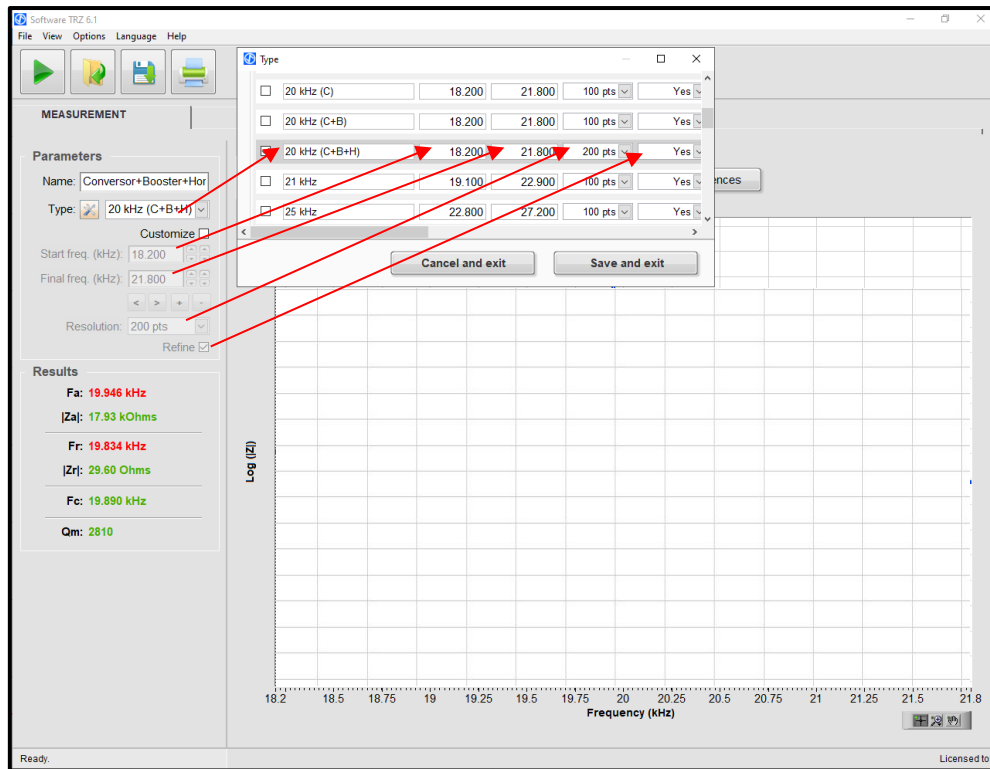
Only these two screens allow the communication between the TRZ® Software and the TRZ® Analyzer.

Action 02 Set the measurement parameters: Before measuring, configure the measurement parameters according to the characteristics of the element that will be tested. This configuration may be easily carried out by selecting TYPE with the closest frequency to the nominal frequency of the element. In addition to the frequency, choose the setting (C: Converter, C+B: Converter + Booster, C+B+H: Converter + Booster + Horn).



Choose the standard configuration for elements with central frequency around of 20 kHz for the C+B+H setting (Converter + Booster + Horn).

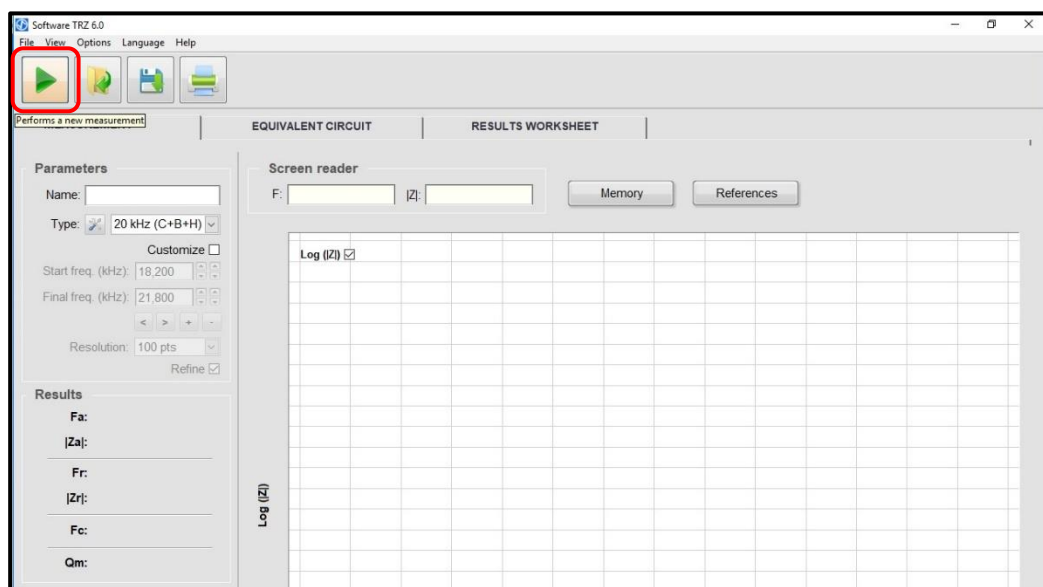
On the example of the previous picture, by selecting the 20 kHz (C+B+H) Type, the pre-configurations corresponding to the *Start frequency*, *Final frequency*, *Resolution* and *Refinement* are automatically loaded. The next figure represents the correspondence between the loaded files and the files kept by the transducers table.



Correspondence between the values loaded on the parameters and the ones on the transducers table.

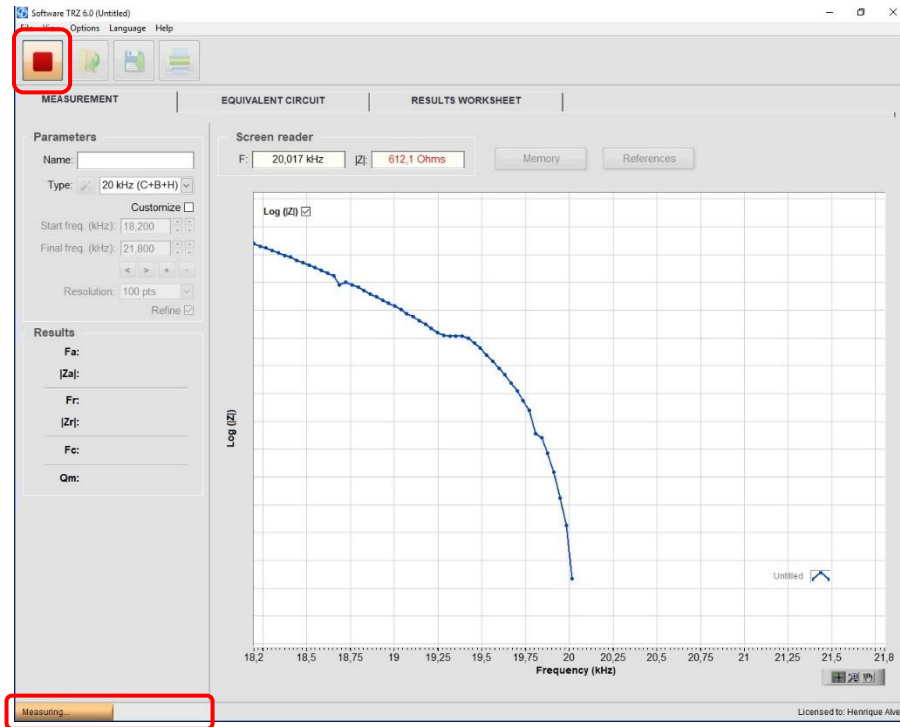
The measurement parameters can also be adjusted manually. In that case, it is only necessary to mark CUTOMIZE on the checkbox to allow access to entry this information.

Action 03 Carry out the measurement: Click on PLAY or use the shortcut Ctrl+N to initiate the measurement. Whilst the TRZ® Software establishes the communication with the TRZ® Analyzer, the message "Searching port..." will appear on the bottom left corner.



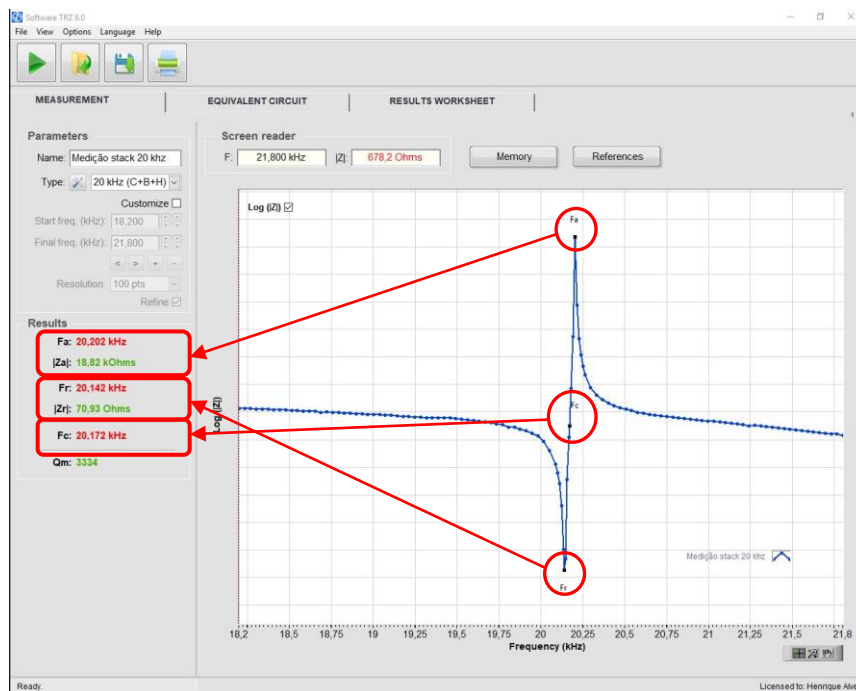
Begin measuring by clicking on the PLAY button.

During the measurement, the PLAY button will change to STOP (allowing the interruption of the measurement) and a status indicator bar will appear on the left bottom part of the measurement, as exemplified next:



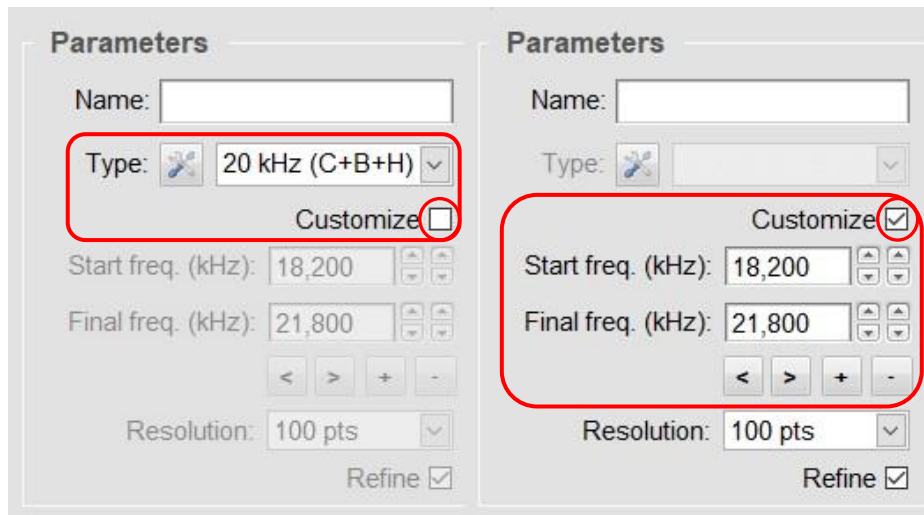
Screen of an ongoing measurement showing the STOP button and a highlighted status bar

After concluding the measurement and refinement, results will be presented and their respective positions will be indicated on the graph.



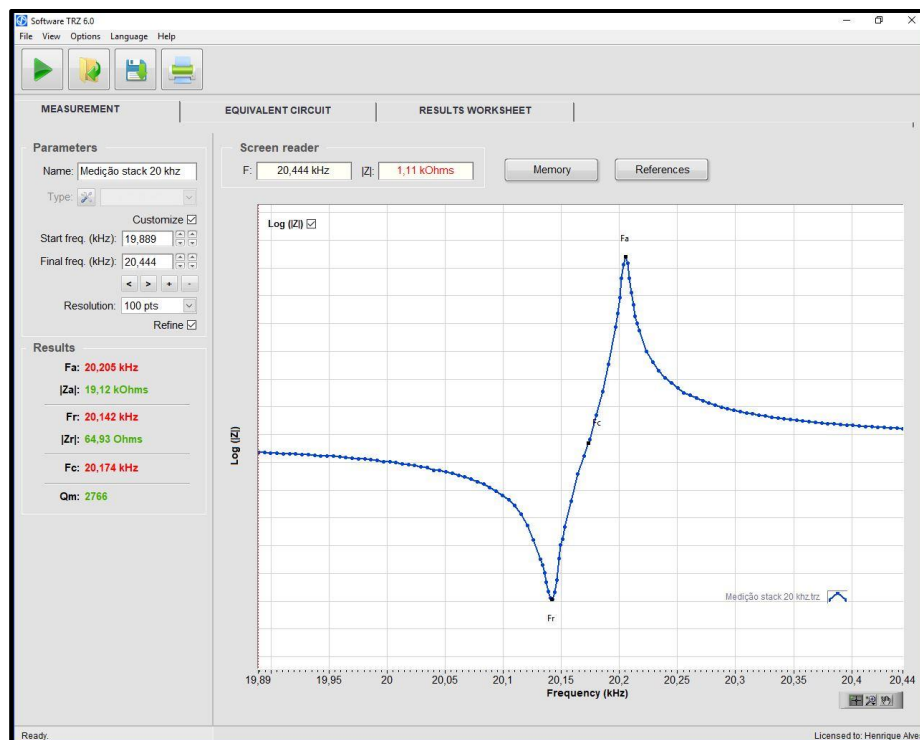
Screen showing the measurement results and their respective positions on the graph.

Action 04 Optimize the frequency range: Mark the "Customize" checkbox to allow access to the manual configuration of the measurement parameters, set up the frequencies to centralize and adjust the curve on the graphs, and give the command for a new measurement by clicking on PLAY.



Marking the "Customize" checkbox gives access to the manual configuration of the measurement parameters; when this checkbox is unmarked, pre-configurations of the Type selector will be applied.

For detailed information regarding the functions and controls permitted by the "Customize" checkbox, please refer to item 7.3 (MEASUREMENT tab).



Result of a new measurement with optimized frequency range (reduced and dislocated to the right).

Optimizing the frequency range is optional; however, it is very relevant for the cases in which the quality factor (Q_m) of the element under test is high. The high-quality factor makes the fraction of the graph occupied by a resonance much lower

than the interval of frequency of the pre-configured, also increasing the results uncertainty.

Action 05 Data analysis: Verify the frequency, impedance and mechanical quality factor values on the RESULTS field.



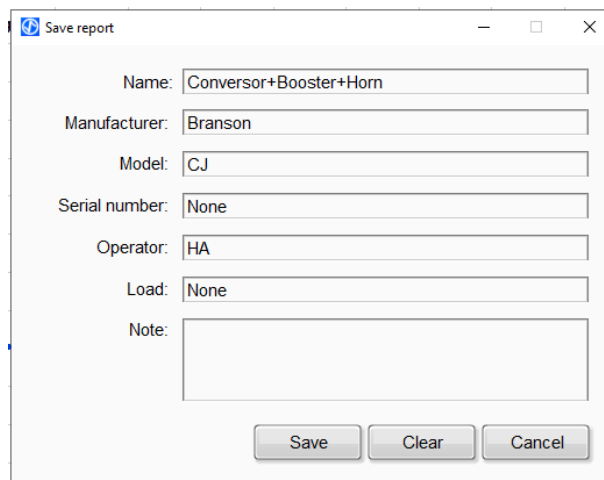
Results	
Fa:	20,205 kHz
Za :	19,12 kOhms
Fr:	20,142 kHz
Zr :	64,93 Ohms
Fc:	20,174 kHz
Qm:	2766

Obtained results judged according to the acceptance criteria of the Transducers table (green = approved, red = not approved).

Results will be judge according to the pre-configured criteria of acceptance green = approved, red = not approved). For this judgment to be meaningful, the user must adjust the acceptance criteria according to the specification of the element under test. To adjust them, access the Option/Transducer menu.

During the tuning process, check also the graphs of the RESULTS WORKSHEET tab to follow-up the evolution and the sensitivity of the frequency.

Action 06 Saving the results and generating reports: Click on SAVE or use the Ctrl+S shortcut. A new name for the file will be requested with the option to use the name already inserted on the PARAMETER field. The saved file will be a ".TRZ" and may be loaded later for comparisons. Another form of registering the results is generating a report by clicking on the PRINT button (Ctrl+P). A dialog box will appear and it may be filled with additional information (optional).



Save report

Name:

Manufacturer:

Model:

Serial number:

Operator:

Load:

Note:

Measurement report pop-up window.

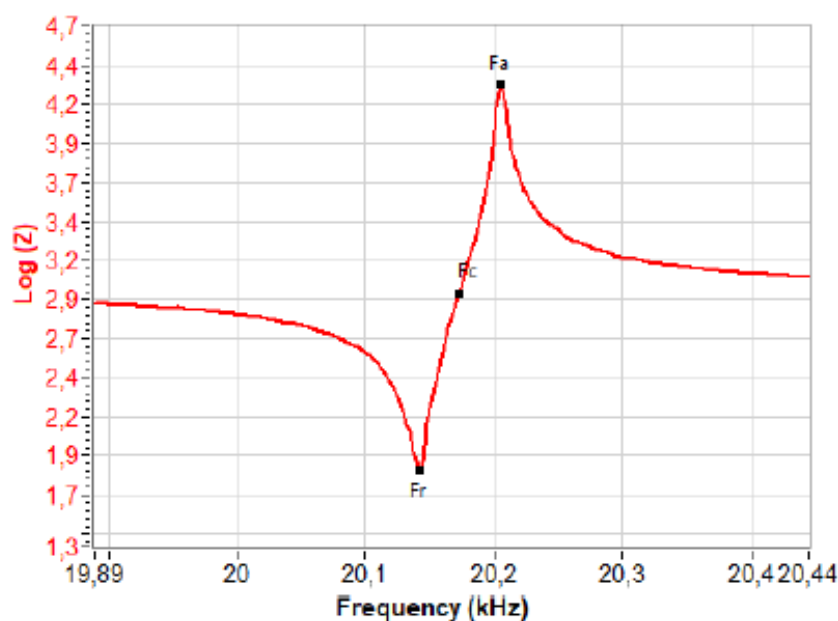
TRANSDUCERS ANALYZER REPORT

Name: Stack 20 khz
Manufacturer:
Model:
Serial number:
Operator: HA
Date/time: 05/10/2017 10:32

Parameters:

Start frequency (Hz): 19889
Final frequency (Hz): 20444
Resolution: 100 pts
Load: None

Observations:



	Minimum	Maximum	Measured	Result
Fa (Hz):	19950	20150	20,205	Not approved
Za (kOhms):	3,00	—	19,12	Approved
Fr (Hz):	19850	20050	20,142	Not approved
Zr (Ohms):	—	100	64,93	Approved
Fc (Hz):	19850	20150	20,174	Not approved
Qm:	1000	—	2766	Approved

Example of a measurement report saved in PDF.

This report, printed or in a .pdf file, may be used as an evidence of the quality control of the element tested.

8. Technical support, warranty terms and statement of responsibility

If the equipment presents a defect or malfunction, check if the problem is linked to any of those mentioned on the table of Item 6.4 (Troubleshooting). If the user still cannot find a solution, get in touch with ATCP Physical Engineering for analysis and possible repairs.

ATCP Physical Engineering offers two-year warranty for the TRZ® Analyzer from the purchase data. The warranty covers material and/or manufacturing defects. After the end of the warranty period, services, parts and other expenses will be charged. Factors that may invalidate the warranty:

- Lack of the care recommended by this manual in what regards the installation and operation of the equipment.
- Accident, fall, inadequate installation or any other damaged caused by incorrect use or action of natural agents.
- Violation, repair or any other modification or alteration performed in the equipment or in its parts by ATCP Physical Engineering non-authorized personnel.

ATCP Physical Engineering takes full technical and legal responsibility for the TRZ® Analyzer and TRZ® Software and guarantees that all the information contained in this Installation and Operation Manual is true.

▲ Reading all the information contained in this installation and operation manual is indispensable for the correct use of the equipment.

▲ Do not use the equipment for any other purposes other than the ones that have been indicated by this manual.

9. References

[1] LANGEVIN, P.; Procédé et appareils d'émission et de réception des ondes élastiques sous-marines à l'aide des propriétés piézo-électriques du quartz Procédé et appareils d'émission et de réception des ondes élastiques sous-marines à l'aide des propriétés piézo-électriques du quartz, French Patent 505.703, 1920.

[2] FREDERICK, J.; Ultrasonic Engineering: John Wiley & Sons, Inc. - 1965.

[3] PROKIC, M.; Piezoelectric Converters Modeling and Characterization, 2° edition, MPI Interconsulting, August 2004.

[4] DERKS, P.L.L.M.; The design of ultrasonic resonators with wide output cross-sections. Eindhoven Technische Hogeschool Eindhoven DOI: 10.6100/IR34306. 1984.

Link: <https://pure.tue.nl/ws/portalfiles/portal/3292148/34306.pdf>