Legal Time of the Republic of Colombia and its international traceability using the Cesium Atomic Clock – Time and Frequency National Standard

Liz Catherine Hernández Forero and Nelson Bahamón Cortés

Instituto Nacional de Metrología de Colombia, Avenida Carrera 50 No. 26 – 55 Int. 2, Bogotá D.C., Colombia.

lhernandez@inm.gov.co, nbahamon@inm.gov.co

Abstract. Around the world, there are different providers of timestamp (mobile, radio or television operators, satellites of the GPS network, astronomical measurements, etc.), however, the source of the legal time for a country is either the national metrology institute or another designated laboratory. This activity requires a time standard based on an atomic time scale. The International Bureau of Weights and Measures (BIPM) calculates a weighted average of the time kept in more than 60 nations and produces a single international time scale, called Coordinated Universal Time (UTC). This article presents the current time scale that generates Legal Time for the Republic of Colombia produced by the Instituto Nacional de Metrología (INM) using the time and frequency national standard, a cesium atomic oscillator. It also illustrates how important it is for the academic, scientific and industrial communities, as well as the general public, to be synchronized with this time scale, which is traceable to the International System (SI) of units, through international comparisons that are made in real time.

1. Introduction

The routine of a human being in a social context entails the dating of events and their punctual execution, for example, the time of birth or death, the due dates for bills for public services or banking entities, the deadline for enrollment in a study program or for submitting a bid, the starting time of a sporting event, the schedule of working hours, the celebration of Christmas or the New Year, are just a few of the many events that require identifying a numerical reference of time.

According to the Spanish language dictionary Real Academia Española © [1], the meaning of punctuality is: "care and diligence in arriving to or leaving a place at the conventional time." Grammatically, the object of this sentence is "conventional time". As such, if we frame this object in a metrological definition, the key words are "time" and its adjective "conventional," specifically associated with the word "convention." That is to say, a time agreed upon or settled on by people, organizations, or countries. One of the characteristics of metrology is the linking of the units of measurements of reference, in particular, to the International System of Units (SI), which was established by the General Conference on Weights and Measures (CGPM), in turn created by the Metre Convention in 1875 [2]. Therefore, within the metrological framework of the SI, a relationship was established for dating events by using a numerical value for time linked to a convention on references, itself internationally identified as a time scale. The scale of time in a country is tied to legislation, or the set of rules or laws by which the State governs. As such, the point of interest in this document is to detail

the legal and metrological context for maintaining, coordinating, and disseminating Legal Time in the Republic of Colombia.

2. Metrological context of time

On June 22, 1799 in the National Archives in Paris, when the French Revolution was concluding, the initial step in developing the present SI was to create the decimal metric system and to define standards for the meter and kilogram [2]. With the signing of the international treaty called the "Metre Convention" on May 20, 1875, three inter-governmental organizations were created: the International Bureau of Weights and Measures, the General Conference on Weights and Measures, and the International Committee for Weights and Measures, whose acronyms in French are, respectively: BIPM, CGPM, and CIPM. The CGPM is comprised of delegates from every member state who meet every four years. As a result of each meeting, the CGPM makes decisions with regard to metrology, mainly associated with the International System of Units (SI). Each meeting is identified by a consecutive number. The content of the section of the present document on metrological context, section 2, uses as a reference the prescriptions of the eighth edition of the SI Brochure [2].

2.1. International system of units (SI)

The seven SI base units were established at the tenth CGPM in 1954 and at the fourteenth CGPM in 1971. The definition of each of these units is modified insomuch as scientific and investigative developments advance [2].

2.1.1. First definition of the second.
The fraction 1/86 400 of the duration of a mean solar day: the exact definition of a "mean solar day" has an application for astronomers. It has been shown that this definition is inadequate due to irregularities in the earth's rotation. To have a more precise definition, during the eleventh CGPM in 1960, a definition provided by the International Astronomical Union was adopted based on the tropical year 1900 [2].

2.1.2. Second definition of the second.
Experiments have shown that an atomic time standard based on the transition between two energy levels of an atom or a molecule can be produced and reproduced with much greater accuracy [2]. Taking into account that a precise definition of the unit of time is indispensable for science and technology, the thirteenth CGPM in 1967 replaced the definition of the unit for second with the following:

A second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.

The 1997 CIPM meeting confirmed that this definition refers to a cesium atom at rest at a temperature of zero kelvin (0 K) [2].

2.2. Symbols, derived units and units outside the SI

Table 1 includes a summary of the units used for time and frequency, which are explained in sections 2.2.1 to 2.2.3.

2.2.1. Symbols.
Writing the symbols of units correctly is mandatory. In the case of quantities of time, the symbol for the second in the SI is the letter "s" from the Latin alphabet. This is to say that the use of abbreviations such as "sec" or "sc" are not aligned with the stipulations of the SI.

Table 1. Units of time and frequency quantities.

Type of Unit	Quantity	Unit Name	Unit Symbol	Equivalences in terms of other units			
Basic	Time	second	s	1 s	0.017 min	0.00028 h	0.000012 d
Derived Coherent	Frequency	hertz	Hz	1 s^{-1}	Not apply.	Not apply.	Not apply.
Outside SI	Time	minute	min	60 s	1 min	0.017 h	0.00069 d
Outside SI	Time	hour	h	3 600 s	60 min	1 h	0.042 d
Outside SI	Time	day	d	86 400 s	1 440 min	24 h	1 d

2.2.2. Derived coherent unit. In the case of quantities of frequency, a coherent derived unit is used, given that the frequency is a power of the base unit of time that only includes a numerical factor equal to 1. This is to say that frequency is equal to the inverse of the period of oscillation (time). A special name and symbol was assigned to frequency: the name is "hertz" and the symbol is "Hz," which, when expressed in terms of the base units of the SI, is "s^{-1}" [2].

2.2.3. Units outside the SI. It is accepted that some units not belonging to the SI, such as the day, hour, and minute, still appear in scientific, technical, and commercial literature and will continue being used for the foreseeable future because they have historic significance and are profoundly rooted in the culture and daily life of the human race. Each one of these units has an equivalent in terms of the unit of the second. See Table 1 [2].

2.3. Time and frequency standards
For the metrological basics of time and frequency, it is highly important to identify the type of standard with which the unit of second can be reproduced. As is mentioned by Lombardi in [3]: "**all time and frequency standards** are based on a periodic event that repeats at a constant rate. The device that generates this event is called a **resonator**. In the simple example of pendulum clock, the pendulum is the resonator. Of course, a resonator requires an energy source to move backwards and forwards. Together, the energy source and resonator make up the **oscillator**. The oscillator operates at a rate known as the **resonance frequency**. For example, by design, a pendulum can swing once per second. The count of one complete swing of the pendulum produces a time interval of 1 s. By counting the total number of changes, a **time scale** is created which establishes the longest time intervals, such as minutes, hours, and days. The device that counts and visualizes or registers the results is called a clock".

2.3.1. Time bases. A time base is an oscillator within an electronic instrument. Its evolution is directly related to scientific advancements for achieving greater stability in a resonator, which results in a clock with greater accuracy. Table 2 provides a summary of the evolution of time and frequency standards and their uncertainty values (*U*) [3]. It is very important to elaborate on the order of magnitude of this evolution; from the 14th century to 1991 (approximately 700 years), the uncertainty of frequency started at 1×10^{-2} and evolved to 1×10^{-15}, that is to say, an improvement by 13 orders of magnitude. If we analyze the years 1921 to 1991 (approximately 100 years), the uncertainty of frequency started at 1×10^{-7}, meaning an improvement by 8 orders of magnitude.
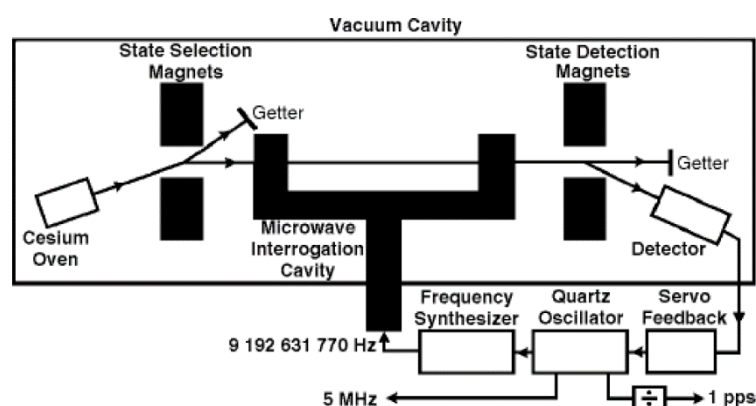
In the majority of electronic instruments such as hand watches, computers, timers, cellular phones, global positioning systems (GPS), telecommunications equipment, among other appliances, the time bases used are quartz oscillators (hexagonal crystal prism) because of their application of the piezoelectric effect as a technological foundation. However, depending on the application and the context of required accuracy, some GPS or network synchronization instruments are manufactured with rubidium oscillators as their time base [4].

Table 2. Evolution of time and frequency standards [3].

Standard	Resonator	Date of Origin	U of time (24 h)	U of frequency (24 h)
Sundial	Apparent motion of the sun	3 500 B.C.	N/A	N/A
Verge escapement	Verge and Foliet mechanism	14th century	15 min	1×10^{-2}
Pendulum	Pendulum	1656	10 s	1×10^{-4}
Harrison chronometer (H4)	Spring and balance wheel	1759	350 ms	4×10^{-6}
Short pendulum	Two pendulums, slave and master	1921	10 ms	1×10^{-7}
Quartz crystal	Quartz crystal	1927	10 μs	1×10^{-10}
Rubidium gas cell	^{87}Rb resonance	1958	100 ns	1×10^{-12}
Cesium beam	^{133}Cs resonance	1952	1 ns	1×10^{-14}
Hydrogen maser	Hydrogen resonance	1960	1 ns	1×10^{-14}
Cesium fountain	^{133}Cs resonance	1991	100 ps	1×10^{-15}

2.3.2. Block diagram of a cesium atomic oscillator. Figure 1 shows a block diagram of a type of oscillator with a cesium beam, which is similar to the cesium oscillators that are sold commercially (cesium fountain devices are developed for research experiments in, for example, the United States and Germany). The internal operation of an atomic oscillator includes a quartz crystal; its position in the diagram is in the feedback loop. The theory on closed loop control systems [5] is used to explain the operation of the cesium oscillator with the objective of graphically representing the functions carried out by each component and representing the signal flow in figure 1. The definition of the functions is as follows:

- Process: Cesium beam technology and frequency standard outputs (5 MHz, 1 PPS).
- Reference: Resonance frequency of cesium atom (^{133}Cs), which is equal to 9 192 631 770 Hz.
- Sensor: Detects atoms whose energy status has changed while passing through the microwave oven cavity (vacuum cavity, getter and detector).
- Controller: Must continuously synchronize the quartz oscillator and synthesize resonance frequency (frequency synthesizer, quartz oscillator and servo feedback).
- Actuator: Cesium gas oven, status detection magnets and microwave oven cavity (cesium oven, state selection magnets and microwave interrogation cavity).

Figure 1. Block diagram of the cesium beam oscillator [3].

An explanation of the process of a cesium beam oscillator is provided by Lombardi in [3]: "The ^{133}Cs gas atoms are heated in an oven. Atoms from the gas leave the oven in a high-velocity beam that travels through a vacuum tube toward a pair of magnets. The magnets serve as a gate that allows only atoms of a particular magnetic energy state to pass into a microwave cavity, where they are exposed to a microwave frequency derived from a quartz oscillator. If the microwave frequency matches the

resonance frequency of cesium, the cesium atoms change their magnetic energy state. The atomic beam then passes through another magnetic gate near the end of the tube. Those atoms that changed their energy state while passing through the microwave cavity are allowed to proceed to a detector at the end of the tube. Atoms that did not change state are deflected away from the detector. The detector produces a feedback signal that continually tunes the quartz oscillator in a way that maximizes the number of state changes so that the greatest number of atoms reaches the detector. Standard output frequencies are derived from the locked quartz oscillator".

2.4. Time scales
A time scale depends on the oscillator of reference (time base) and the specific objective of the scientific or legal application. The time base of each scale has evolved from astronomical measures with reference to celestial bodies such as the moon (ephemeris time), the stars (sidereal time), the sun (solar time, Julian date, Greenwich time, universal time (UT) and adjustments to the UT to minimize the effect of inhomogeneities in the earth's rotation), even the current atomic scale (TAI, UTC). Table 3 has a summary of the main time scales.

2.4.1. UTC time scale. UTC is the atomic time scale that forms the base for the coordinated diffusion of standard frequencies and time signals [6]; it is generated and monitored by the BIPM. The importance of each country generating its own atomic scale is that the UTC is an average weighted from these atomic scales. This means that the indication of international time associated to the UTC is not generated by one cesium clock alone, as described in Section 2.3.2, but rather that the UTC is a scale derived from a mathematical algorithm and not from a physical clock.

Table 3. Evolution of time scales.

Time scale	Reference	Purpose
Solar time	Apparent motion of the sun over the horizon of a place.	Base of all calendars. The highest point in the sky signifies "noon".
Greenwich Time (GMT)	Mean solar day as observed at the Greenwich Meridian.	Definition of time zone. A count from 12:00 one day to 12:00 the following day.
Universal Time (UT)	GMT	A count from 00:00 one day to 00:00 the next day, in 1925.
Universal Time 0 (UT0)	1 tropical year (vernal point) $= 365\ d + 5\ h + 48\ min + 45.5\ s$	UT0 = Minimize the effects of the eccentricity and inclination of Earth's orbit.
Universal Time 1 (UT1)	1 second $= 1$ mean solar day / 86 400	UT1 = UT0 + True angular rotation movement of Earth.
International Atomic Time (TAI)	Readings from different atomic clocks.	Define a coordinated time reference in 1970 and adjusted in 1980.
Coordinated Universal Time (UTC)	Leap Seconds (N) are applied: UTC = TAI – N [7].	In the first half of 2017: $N = 37$ leap seconds.

Countries that participate in the creation of the UTC are those countries who have signed the "Metre Convention," the treaty that is now known as the CIPM MRA – CIPM Mutual Recognition Arrangement. It is important to emphasize that the CIPM MRA is the framework through which national metrology institutes (NMIs) can show international equivalence of their measurement standards and the calibration and measurement certificates that they issue. Proof of this international equivalence is realized through peer reviews and through the approval of CMC – Calibration and Measurement Capabilities. These CMC are published, so as to be available to the public, in the CIPM MRA database, called the "The BIPM key comparison database" (KCDB).

In 1875, there were 17 initial member countries in the Metre Convention. Currently (2016), the CIPM MRA has been signed by representatives of 102 institutes, distributed in 57 Member States, 41 Associates of the CGPM, and 4 international organizations. In addition, it covers 153 other institutes

designated by the signatory bodies [6]. This implies that the CIPM MRA provides the technical base for the negotiation of international commerce and regulatory matters in every country in the world.

This is how the BIPM creates two technical bases. First, it creates a scale called TAI – International Atomic Time, which is the strict average weighing the time scales of all signatory countries who send data from their clock signal to the BIPM, located in Sèvres, France. The TAI scale should be adjusted to ensure a scale of reference that is approximately in agreement with the time derived from the earth's rotation; the adjusted TAI is the aforementioned UTC.

3. Legal context of time

Every country establishes its use of a system of units for general purposes or for use in specific areas such as for commerce, health, public security, and education. In the specific case of the quantities of time and frequency, the technical base corresponds to the numerical indication of the legal time for the country and for the entity designated for disseminating that indication.

3.1. International context

Using for reference the countries that are currently member states in the CIPM MRA, Table 4 includes some examples of institutes whose function is broadcasting the legal time of the country and the website where the time is published for the citizenry.

Table 4. Examples of Institutes that disseminate the legal time of their country.

Country	Entity	Type of institute	Website with the legal time
Colombia	Instituto Nacional de Metrología (INM)	National	horalegal.inm.gov.co
Germany	Physikalisch-Technische Bundesanstalt (PTB)	National	ptbtime1.ptb.de
Costa Rica	Instituto Costarricense de Electricidad (ICE)	Designated	www.grupoice.com/wps/portal/ICE/AcercadelGrupoICE/Laboratorios/LMVE
United States	National Institute of Standards and Technology (NIST)	National	nist.time.gov
Italy	L'Istituto nazionale di ricerca metrologica (INRiM)	National	www.inrim.it/ntp/webclock_i.shtml
México	Centro Nacional de Metrología (CENAM)	National	www.cenam.mx/hora_oficial

3.2. National context

Documents and Administrative Acts from the Colombian government are a tool for establishing the legal parameters that govern the country's citizenry. Table 5 is a summary of the implementation history of the international system of units, of the definition of legal time, and of the designation of national measurement standards. It is important to detail two aspects:

- Regarding the declaration of the national time standard: the difference between the resolutions issued in 2011 and 2013 stems from extricating a specific instrument brand, model, and serial number from the declaration, given that commercial cesium oscillators generally have a useful life span of 5 to 12 years. Therefore, it is reasonable that the declaration should mention the type of atomic isotope of cesium used to construct the primary standard clocks, which by the SI definition of the second, is isotope 133 (see Section 2.1.2).
- The current adoption of the UTC reduced by 5 hours as the legal time in the Republic of Colombia is directly related to the geographic location of the country. Colombia is located in the fifth time zone to the left of the Greenwich meridian (see Figure 3).

Table 5. State of the art related to the legislation on the Legal Time in the Republic of Colombia.

Year	Administrative Act	Issuing entity	Content
1853	Ley 8	Senado y cámara de representantes de la Nueva Granada.	Legal text adopting the French decimal metric system for all purposes in Colombia [8].
1982	Decreto 2707	Ministerio de comunicaciones	Legal time = UTC − 5 hours. Broadcasted by the Centro de Control de Calidad y Metrología of the Superintendencia de Industria y Comercio (SIC).
1992	Decreto 717	Ministerio de Desarrollo Económico	Legal time = UTC − 4 hours. Purpose: To achieve electric power saving through the use of sunlight. Broadcasted from 1992-05-01 until 1993-02-07.
2011	Decreto 4175	Ministerio de Comercio, Industria y Turismo (MINCIT)	The Instituto Nacional de Metrología (INM) is created. One of its functions: "Maintain, coordinate and broadcast the legal time of the Republic of Colombia".
2011	Resolución 6467	MINCIT and SIC	The national time standard is declared to be the following: Cesium atomic clock, Brand: Symmetricom, Model: Cs III 4310 B, Serial number: 0833008915.
2013	Resolución 41242	MINCIT and SIC	The national time standard is declared as follows: Name: Atomic clock. Description: set of cesium 133 atomic clocks.
2015	Decreto 1595	MINCIT	The businesses, entities, and bodies dedicated, among its services, to informing or using the legal time in some way, should disclose the legal time coordinated by the INM.

3.3. Written format

In the international context, the standard of reference is ISO 8601:2004, titled: "Data elements and interchange formats - Information interchange - Representation of dates and times". In Colombia this standard was adopted through Colombian technical standard NTC 1034:2014, titled "Elementos de datos y formatos de intercambio - Intercambio de información - Representación de fechas y horas". The former version of this standard was issued in 1994. The two main characteristics are:

- **Day of the year:** to write the time periods of day, month, and year numerically, the order used should be the time period which descends from the greatest to least duration and be separated by hyphens (year-month-day).
  Example: the date September 14, 2016 should be written as 2016-09-14.
- **Time of day:** to write the hour by taking into account the three elements that indicate the accumulation of seconds in a day—hours, minutes, and seconds— NTC 1034:2014 indicates that two digits should be written for each of the three elements, separated by the colon symbol and, that the 24-hour format be used, which is to say that the hour of the day be counted consecutively from the day's start to end, where the day's end coincides with the start of the next day. This moment is commonly known as "midnight". Due to the sexagesimal system, the count of the quantity of seconds in a minute and the quantity of minutes in an hour is an interval of 00 to 59 and the quantity of hours in a day is interval of 00 to 23.
  Example: the 57th second of the 19th minute of the 7th hour is 07:19:57.

4. Metrological traceability

The INM establishes traceability of its own measurement standards to the SI by means of an uninterrupted chain of calibrations tying them to the definition of the respective primary standards of SI units of measurement. This link is accomplished by referring to the national measurement standards or to reference standards calibrated by other metrology institutes recognized in the MRA. In the case of

quantities of time and frequency, the national standard corresponds to a primary standard. As such, the cesium atomic oscillator designated as the national standard does not take into account the issuance of calibration certificates. Instead, its metrological assurance depends on international comparisons tying its traceability to the UTC time scale. Remembering what was described in Section 2.4.1 about the UTC time scale, it can be said that the BIPM maintains TAI and UTC time scales "on paper" [3]. Therefore, in order to estimate the uncertainty of the measurement processes of the Time and Frequency Laboratory at the INM, there are two international comparison options (see 4.1 and 4.2) that are executed in real time thanks to satellite communication.

4.1. INM traceability through the SIM

As is mentioned in Lopez et al [9], the Interamerican Metrology System Time Network (SIMTN) began operating in 2005 and continuously compares the time standards of the laboratories belonging to the SIM network. In 2011 there were 16 laboratories and currently there are 25 under comparison. The SIMTN reports results via the internet in real time every 10 minutes (http://tf.nist.gov/sim), making it easy to identify fluctuations in frequency and time in the short term and making possible the resolution of measurement problems. Since 2008, SIMTN data has been used to generate the SIM time scale (SIMT). Since the second half of 2009, the SIMT has been automatically generated with the results published in real time via the internet. Each time scale is denominated as SIMT(k) or UTC(k), with k as the acronym for the laboratory of the country participating in the comparisons. In Colombia's case, k is the INM. With the SIMTN system, the behavior of the local time scale of Colombia SIMT(INM) is registered, making it possible to estimate two parameters, the frequency offset, $(\Delta f / f)$, as well as its standard uncertainty, $u(\Delta f / f)$. The final result is an estimation of the best Calibration and Measurement Capabilities (CMC) of the INM, whose declared value is 6.0×10^{-13} [10]; during the estimation process, the time scale of the United States' NIST was used for reference. Thus, the time differences of interest are SIMT(NIST) – SIMT(INM), given that SIMT(NIST) is the most stable time scale of the participants in the SIMT scale and, of the most importance metrologically-speaking, it has traceability to the UTC through the UTC – UTC(NIST) time differences. Note that the declared value is between the two values of uncertainty in frequency of the rubidium and cesium beam from Table 2.

In the months of June and July of 2016, the contribution percentage to the SIMT(INM) was a maximum value of 4 % and in the months of August and September the contribution percentage increased to approximately 9 %. Meanwhile, the United States has maintained a percentage of support between 35 % and 40 % from June to September, thus showing that the SIMT(NIST) is a scale of great stability. In this period of time, the numerical value of the frequency offset parameter of the time differences SIMT (NIST) - SIMT (INM) was equal to 1.39×10^{-14}, which is directly associated with the accuracy of the clock with which the legal time of Colombia is produced, thus, the hour produced by the INM would advance one second with respect to the hour produced by the NIST in a period of time approximately equal to 2 million years; with the metrological assurance performed by the INM, this frequency offset value can be reduced up to about $\pm 7.0 \times 10^{-15}$, thus, the period of time could be extended up to about 5 million years to get to visualize the advance (due to the positive sign) or delay (due to the negative sign) of one second. If this type of comparison is performed using the time produced by a stopwatch made with quartz oscillator against the legal time, then the frequency offset would be approximately equal to a value between $\pm 1.0 \times 10^{-5}$ to $\pm 1.0 \times 10^{-6}$, which means that the time produced by the stopwatch would be advanced or delayed by one second with respect to the time produced by the INM in a period of approximately 1 day to 11 days.

4.2. Future work to contribute to the realization of the UTC

As a research project, the INM is studying the methods that facilitate the completion of two goals: increasing its percentage contribution to the SIMT scale and stably maintaining this percentage. Of the percentages described in Section 4.1, it is evident that the first goal has already been reached, using an objective framework of a contribution percentage of between 8 % and 10 %. However, it is necessary to maintain the stability of this percentage during a period of at least one hundred consecutive days. This

would constitute the first step for sending data from the INM clock signal to the BIPM. The final objective is to have the INM time scale included in the monthly publication called Circular T [6], which provides traceability to the UTC and with which the contribution percentage to the realization of the UTC through the time differences identified as UTC – UTC(INM) are documented.

4.3. Traceability of Colombian citizens with the INM

The legal time is published for all citizens at URL http://horalegal.inm.gov.co/. Businesses and entities can synchronize their equipment with the INM server. The same can be done with personal computers and devices through different applications that are available; more details can be found on the webpage: http://www.inm.gov.co/index.php/servicios-inm/hora-legal. The services provided by the Time and Frequency Laboratory can be consulted in the link: http://www.inm.gov.co/images/Docs/CMCs/Tiempo_y_Frecuencia_Espanol_2016-v1.pdf. Figure 2 shows the traceability chain.
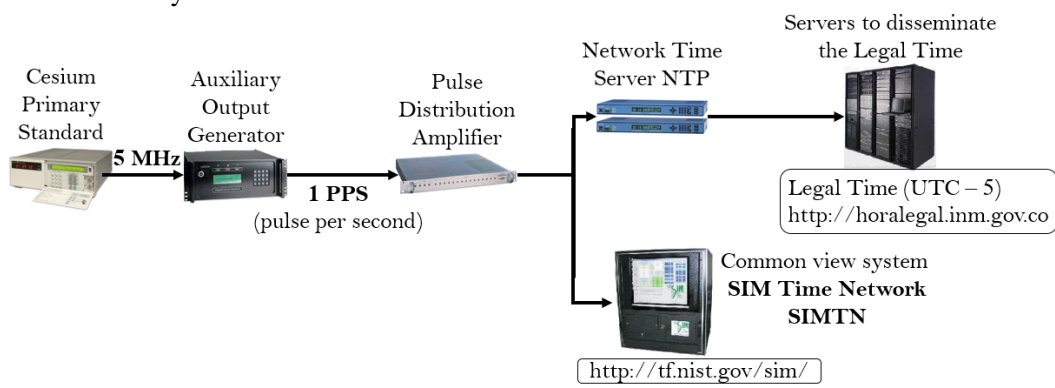

Figure 2. Traceability chain of the legal time of the INM time and frequency laboratory.

The INM systems technology department can monitor the different users that connect to reference the time by using a web analysis tool called "Google Analytics". The global information is summarized in Figure 3. As demonstrated, almost all of the countries in the world have connected at some time to reference the legal time in Colombia. This information is from a one-year period (Figure 3 shows specifically the log-on sessions from Russia). Table 6 shows the ten countries with the greatest number of log-ons to consult the legal time in the last year.
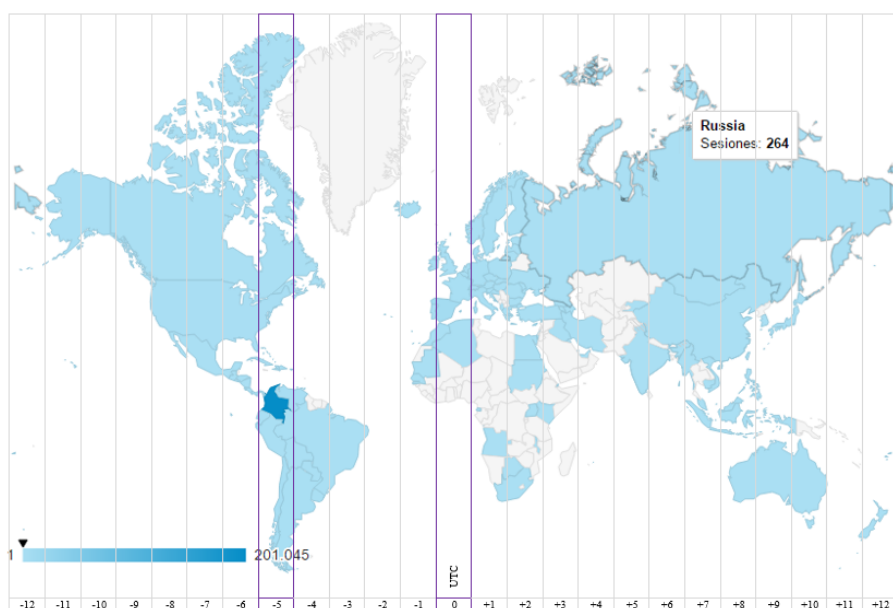
Figure 3. Users of the legal time issued by the INM and geographic location of UTC – 5 hours.

Table 6. Quantity of log-ons of ten countries.

Country	Quantity of log-ons	Percentage of consultations
Colombia	201 045	90.33 %
Spain	7 128	3.20 %
Venezuela	1 891	0.85 %
Chile	1 849	0.83 %
United States	1 402	0.63 %
France	915	0.41 %
Argentina	813	0.37 %
Germany	614	0.28 %
Italy	574	0.26 %
Panamá	542	0.24 %
Total	216 773	97.4 %

5. Examples of the use of time

The INM uses a 24-hour format to issue the legal time; the advantage of this is avoiding ambiguity. It is common to ask if 12 p.m. is 12 noon or midnight. The answer can be found at: http://www.inm.gov.co/index.php/serviciociudadano/informacion-para-el-ciudadano/preguntas-frecuentes

6. Conclusions

Just as every country has its national anthem, every country designates which entity in the national territory provides the time used for activities associated with legal compliance. The Legal Time of the Republic of Colombia depends on a cesium oscillator which is a primary standard because the SI second is defined according to the resonance frequency of the 133 cesium atom. This oscillator was designated as a national standard by means of an Administrative Act of the Colombian government. Metrological assurance results from comparisons of real time across different time scales: SIMT(NIST) – SIMT(INM) and UTC – UTC(NIST). The numerical result of these comparisons indicates that legal time is produced with an accuracy level of 1 second of advance or delay that would be displayed in a period of time ranging from 2 million to 5 million years, thus evidencing the reliability of synchronizing any clock with the Legal Hour broadcasted by the INM.

References

[1]   Real Academia Española © (RAE) 2014 *Spanish Language Dictionary 23rd edition Tercentenary Edition* [Consulted in August 2016] Available at: http://dle.rae.es/

[2]   Bureau international des poids et mesures BIPM 2006 *SI Brochure: The International System of Units (SI)* (Paris: STEDI Media) **8** pp 95-177

[3]   Lombardi M 2002 *Chapter 17, Fundamentals of Time and Frequency (The Mechatronics Handbook)* (Austin, Texas: CRC Press LLC) pp 341-358

[4]   National Institute of Standards and Technology (NIST) Time and Frequency Division, Popular links 2015 *Time and Frequency from A to Z: An illustrated glossary* [Consulted in August 2016] Available at: http://www.nist.gov/pml/div688/grp40/glossary.cfm

[5]   Ogata K 2010 *Ingeniería de control moderna* (Madrid, España: PEARSON) pp 17-22

[6]   Bureau international des poids et mesures BIPM 2016 *International reference time scales, BIPM services* [Consulted in September 2016] Available at:
         http://www.bipm.org/en/bipm-services/timescales/
         International equivalence of measurements : the CIPM MRA, International equivalences [Consulted in September 2016] Available at:
         http://www.bipm.org/en/cipm-mra/

[7]   International Earth Rotation and Reference Systems Service IERS *Bulletin C 52 Observatoire de paris* [Consulted in September 2016] Available at:
         ftp://hpiers.obspm.fr/iers/bul/bulc/bulletinc.dat

[8]   Banco de la República 1853 and Biblioteca Luis Ángel Arango *Virtual library Miscellany 635* [Consulted in September 2016] Available at:
         http://www.banrepcultural.org/blaavirtual/derecho/lei-de-8-de-junio-de-1853

[9]   Lopez J, Lombardi M, Novick A, Jimenez F, Diaz N, Lopez E, Boulanger J, Pelletier R, Carvalho R, Solis R, Sanchez H, Hernández L, Gordon J, Perez D, Bances E, Trigo L, Masi V, Postigo H, Questelles A, Gittens A and Ramos R 2011 *Real-Time Generation of the SIM Time Scale (SIMT) from International Clock Comparisons Proc. XXXth Gen. Assem. URSI.* p 4

[10]   Hernández L and Chaparro G 2014 *Trazabilidad en tiempo y frecuencia usando método de calibración por diferencia de fase (Memorias de Simposio de Metrología 2014)* (Querétaro, México: Centro Nacional de Metrología CENAM) ISBN 978-607-96162-9-8 pp 681-686