

An Overview on RF and Microwave Research in Latin America (Revised Version, Submitted on Jan. 19, 2023)

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We present in this article an up-to-date general and brief scan of the main research activities on RF and microwaves in Latin America. First, we geographically identify the main research and development clusters on RF and microwaves in this large region of the world. We next describe the most recent and representative research work developed in the most active Latin American countries in this technical field; namely, Argentina, Brazil, Chile, Colombia, Costa Rica, Ecuador, Mexico, Peru, and Puerto Rico. To develop this updated survey on RF and microwaves in Latin America, we started from considering previous similar reviews available in the literature [1],[2], including some of them focused on specific Latin American countries [3],[4]. In our review, we essentially focus on the last five or six years of scientific research production. Given the synergistic relationship between the IEEE MTT-S and the level of activities and maturity in RF and microwaves, we finalize our article by summarizing the status as well as the main challenges and opportunities for MTT-S in Latin America.



Figure 1. Geographical distribution of the main clusters of RF and microwaves activities in Latin America. Most relevant work in the field is realized in 9 countries (out of 26). Updated from [1].

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Main Clusters of RF and Microwave Activities in Latin America

Latin America encompasses all the countries of the American continent where the Romance languages are predominantly spoken (mainly Spanish, Portuguese, and French). It comprises 26 countries (20 sovereign states), with more than 656 million inhabitants distributed in a very large geographical zone with an area of almost 20×10^6 km². Less than half of those 26 Latin American countries concentrate the most advanced engineering and industrial development. More specifically, the main clusters of activities on RF and microwave engineering are geographical distributed as illustrated in **Figure 1**, where it is seen that only 9 countries in the region have significant activities in these technical fields. In the following sections we briefly mention the main RF and microwave research lines currently developed in those countries.

RF and Microwave Research in Argentina

Research activities on RF and microwaves in Argentina are mainly focused on satellite-based navigation systems [5],[6], multipoint modulators [7], sensors [8], radiometers [9],[10], metrology and calibrations [11]. These research activities are mainly conducted by the following organizations: the National University of La Plata [5]-[7], the National Technological University [8],[11], the National University of Cordova [10], and the National Commission of Space Activities [9].

RF and Microwave Research in Brazil

Brazil is the Latin American country with more research groups on RF and microwaves. Brazil also has the largest number of IEEE MTT-S chapters and members. Since 1985, Brazil organizes the biannual International Microwave and Optoelectronics Conference (IMOC), sponsored by the Brazilian Microwave and Optoelectronics Society (SBMO) and the MTT-S.

Excluding the areas of optics and optoelectronics, where Brazil has a strong research tradition, the research scope on RF and microwaves covered by Brazilian institutions is very broad. It includes antennas [12]-[16],[23], specific absorption rate (SAR) studies [17],[18], frequency selective surfaces [19]-[21], defected ground structures (DGS) [22], metamaterials [23],[24], wireless power transfer [16],[25],[26], power transmission lines monitoring [27],[28], low-cost radars for human movement detection [29],[30], CAD techniques [29]-[32], low-cost RFID technologies [33],[34], negative group delay circuits [35]-[38], EM field analysis and waveguide component design [39]-[43].

The main most active Brazilian institutions developing research on RF and microwaves are listed below in alphabetical order, citing some of their most recent and representative research contributions (see the previous paragraph to identify the corresponding technical areas):

- Federal Institute of Paraiba (IFPB), in João Pessoa [12],[15],[19]-[22].
- Federal Institute of Pernambuco (IFPE), in Recife [28].
- Federal Institute of Rio Grande do Sul (IFRS), in Canoas [17],[18].
- Federal Institute of Rio Grande do Norte (IFRN), in Parelhas [15].
- Federal Institute of Sao Paulo (IFSP), in São Paulo [12].
- Federal Rural University of Semi-Arido, in Mossoro [19].
- Federal University of Campina Grande (UFCG), in Campina Grande [12],[15],[35]-[38].

- Federal University of Ceará (UFC), in Fortaleza [15].
- Federal University of Minas Gerais, in Belo Horizonte [13].
- Federal University of Pernambuco (UFPE), in Recife [27]-[32].
- Federal University of Rio Grande do Sul (UFRGS), in Porto Alegre [17]-
- Federal University of Rio Grande do Norte, in Natal [19],[20],[21].
- Federal University of Santa Catarina, in Florianópolis [25],[26].
- Fluminense Federal University (UFF), in Niteroi [33],[34].
- Pontifical Catholic University of Rio (PUC-Rio), in Rio de Janeiro [13],[24],[34],[39]-[43].
- São Paulo State University (UNESP), in São Paulo [13],[43].
- University of Brasilia, in Brasilia [35],[36].
- University of Campinas (UNICAMP), in Campinas-SP [14],[16],[23],[29],[30].

Making a more detailed description of the research work developed at each of the previous 17 Brazilian institutions falls beyond the scope and space limits of the present article. For the sake of brevity, we illustrate in **Figure 2** an example of the laboratory research resources available at the Pontifical Catholic University of Rio, in Brazil. **Figure 3** shows a microwave research lab facility at the Federal University of Campina Grande (UFCG).

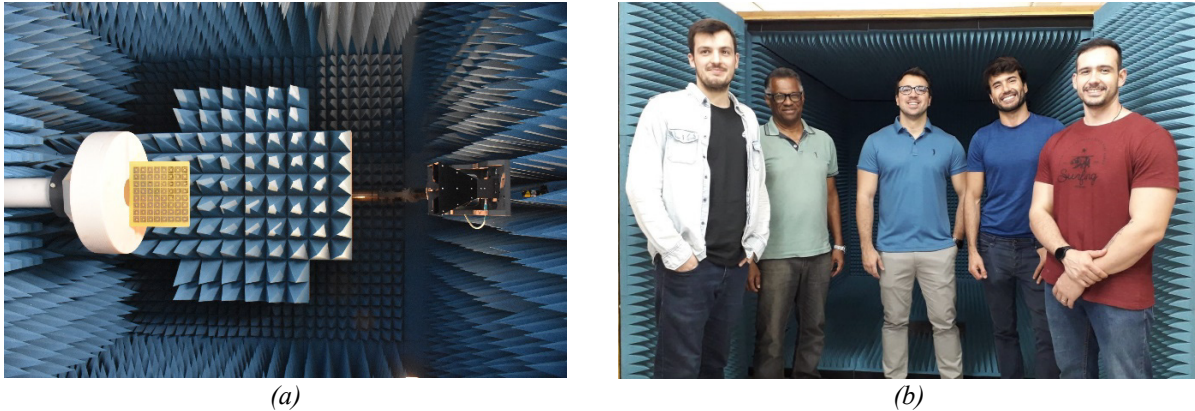


Figure 2. Illustrating some of the research lab facilities at the Pontifical Catholic University of Rio (PUC-Rio/CETUC), in Rio de Janeiro, Brazil: (a) planar antenna in anechoic chamber; (b) graduate students in front of the anechoic chamber. (Photos courtesy of Prof. Guilherme Simon da Rosa).



Figure 3. Setup for measurement of a magneto-dielectric antenna in an anechoic chamber at the Federal University of Campina Grande (UFCG), Brazil. (Photo courtesy of Prof. Glauco Fontgalland).

RF and Microwave Research in Chile

Chile has a well-established tradition on scientific activities related to astronomy. The most outstanding research on RF and microwaves in Chile is mainly focused on microwave integrated circuits for radio astronomy [44],[45], remote sensing [46], radio imaging [47], nanosatellite systems [48], and antennas [49]-[52].

The main Chilean institutions doing research on the previous topics include the University of Chile [44],[45],[48]-[50], the Pontifical Catholic University of Chile [47], the Pontifical Catholic University of Valparaiso [44],[51],[52], the University of *Concepción los Ángeles* [46], and the National Radio Astronomy Observatory [44],[49].

RF and Microwave Research in Colombia

Colombia was the hosting country of the most recent edition of the IEEE MTT-S Latin America Microwave Conference (LAMC), celebrated in virtual format from the city of Cali, in May 2021. Most of the research work on RF and microwaves in this country is developed in four Colombian institutions, as briefly described next.

The Research Group GINTEL at the Pedagogical and Technological University of Colombia, at Sogamoso, develop research mainly on wideband RF and microwave power amplifiers and digital predistortion systems [53]-[56].

The National University of Colombia, in Bogota, mainly researches on tunable frequency selective surfaces (FSS), metamaterials, and antennas [57]-[59].

ICESI University, in Cali, and Francisco de Paula Santander University, in Santander, mainly focus on wireless sensor networks and on rural wireless broadband propagation models [60],[61] (see **Figure 4**).



Figure 4. Transmitter used to validate propagation models of TV White Spaces (TVWS) technology for wireless broadband in rural Colombian rain forest [60]. (Photo courtesy of Prof. Andrés Navarro-Cadavid).

RF and Microwave Research in Costa Rica

Costa Rica is an emerging country in the arena of RF and microwave engineering. Its research in this field mainly concentrates on antenna design [62],[63], microwave CAD techniques [64],[65], signal integrity and high-speed interconnects [65],[66], microwave plasma heating [67], solar radio bursts [68], and microwave virtual education [69]. The principal institutions making research on these fields are the Technological Institute of Costa Rica [63]-[67], the University of Costa Rica [62],[68], and the Distance State University of Costa Rica [69].

RF and Microwave Research in Ecuador

The University of the Armed Forces (ESPE), in Sangolqui, and the San Francisco University of Quito (USFQ), in Quito, are the two main institutions developing research on RF and microwaves in Ecuador. They mainly focus on passive waveguide components design [70], with emphasis on substrate integrated waveguides (SIW) technologies [71].

RF and Microwave Research in Mexico

Mexico was the hosting country of the first edition of the IEEE MTT-S Latin America Microwave Conference (LAMC), held in Puerto Vallarta, in December 2016 [72]. The main research groups on RF and microwaves in Mexico are located in four institutions: the Center for Scientific Research and Higher Education of Ensenada (CICESE), in Baja California; the Center for Research and Advanced Studies of the National Polytechnic Institute at Guadalajara (CINVESTAV-Guadalajara); the National Institute of Astrophysics, Optics, and Electronics (INAOE), in Puebla; and ITESO – The Jesuit University of Guadalajara.

CICESE is the Mexican institution with the longest tradition in RF and microwaves. It carries out research along two main lines: power amplifier characterization and microwave metrology [73]-[76], and planar sensors for materials monitoring and characterization [77]-[80]. **Figure 5** illustrates some of the measurement equipment available at the Laboratory of RF and Microwave located in the Applied Physics Division at CICESE. **Figure 6** shows an experimental setting for materials characterization.

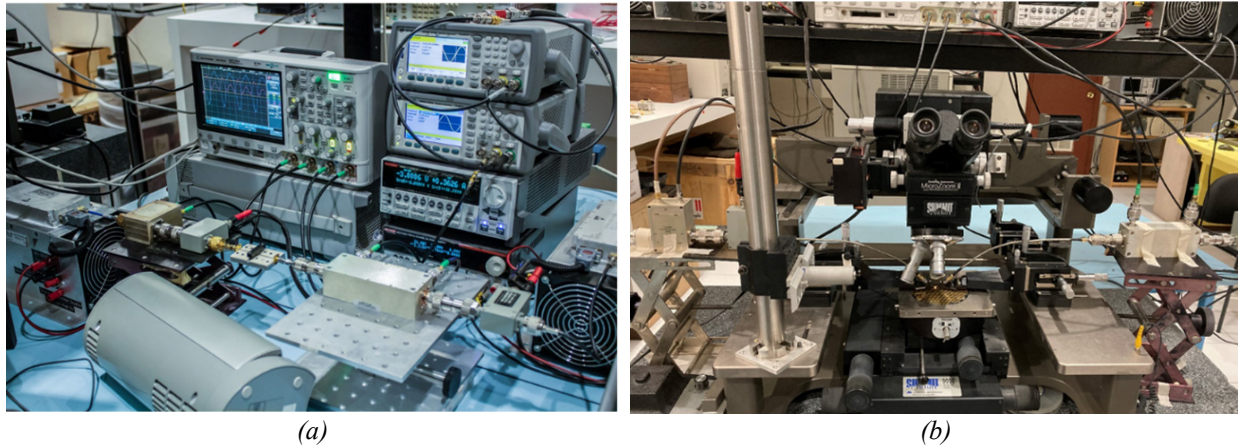


Figure 5. Some of the measurement equipment available at the Laboratory of RF and Microwave at CICESE; time-domain low-frequency active harmonic load-pull system for characterizing: (a) packaged power transistors; and (b) on wafer transistors. (Photos courtesy of Prof. Apolinar Reynoso-Hernández).

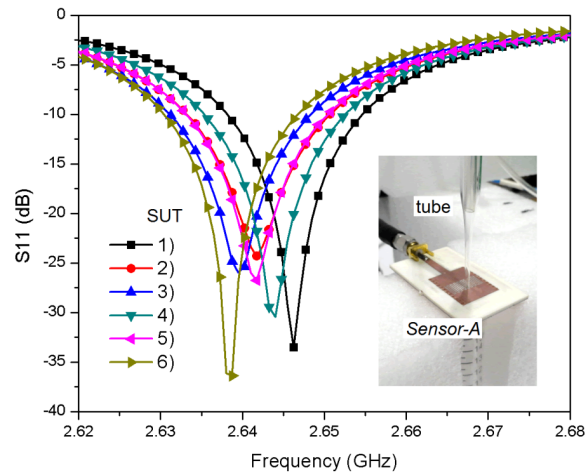
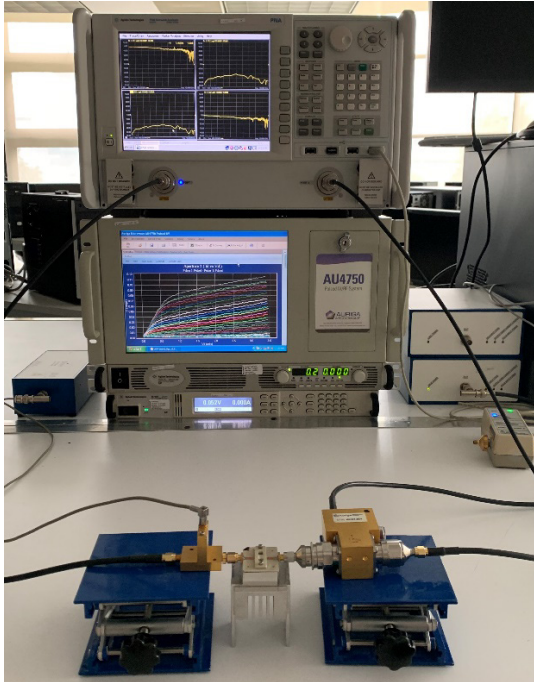
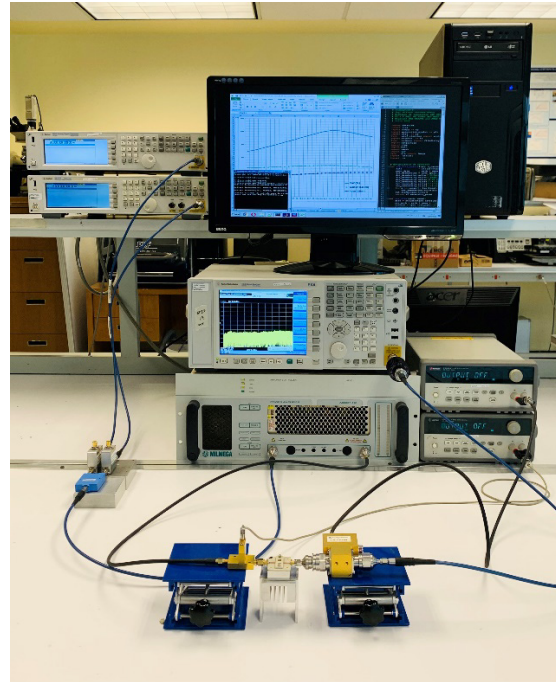


Figure 6. Experimental measurements using resonant sensor of solvent liquids and air (1-air, 2-ethanol, 3-methanol, 4-isobutanol, 5-isopropyl alcohol, 6-acetonitrile) (Courtesy of Prof. Humberto Lobato, CICESE).

CINVESTAV-Guadalajara focuses its research on microwave transistor modeling (linear and nonlinear) as applied to the design of power amplifiers [81],[82], including the development of behavioral models for power amplifiers [83]. It also carries out research on filters and diplexers [84] as well as on design of RF active circuits using X-parameters [85],[86]. **Figure 7** shows some of the equipment available at CINVESTAV Guadalajara to characterize microwave transistors.



(a)



(b)



(c)

Figure 7. Test benches to characterize RF and microwave FETs available at CINVESTAV Guadalajara: (a) pulsed I/V; (b) one- and two-tone tests; (c) load-pull. (Photos courtesy of Prof. Raúl Loo-Yau).

INAOE is another Mexican public research center with prominent activities on RF and microwaves for more than 30 years. Its research mainly focuses on the measurement, modelling, and characterization of semiconductor devices as well as passive components for integrated circuits [87]-[89], printed circuit boards [90]-[93], antennas [94], and microstrip filters [95]. INAOE's laboratory [96] is equipped with two advanced VNAs (see **Figure 8**), one capable of two-port measurements up to 67 GHz, and the other one able to perform four-port measurements in the 10 MHz to 70 GHz range, as well as two-port measurements up to 110 GHz.



Figure 8. Advanced VNAs available at INAOE, in Puebla, Mexico: one capable of two-port measurements up to 67 GHz, and the other one able to perform four-port measurements in the 10 MHz to 70 GHz range, as well as two-port measurements up to 110 GHz. (Photo courtesy of Prof. Roberto S. Murphy).

ITESO – The Jesuit University of Guadalajara, focuses its research on CAD techniques for RF and microwave modeling, design, and optimization of circuits and systems, most of it in close collaboration with local industry [97],[98]. More specifically, ITESO develops research on design optimization methods [99]-[101], surrogate-based approaches [102],[103], neuronal analog fault identification [104], and space mapping techniques [105]-[108], with emphasis on applications to signal-integrity and high-speed interconnects [109],[110], post-silicon validation of high-speed computer platforms,[111]-[113], power delivery networks and power integrity [114],[115].

RF and Microwave Research in Peru

The most active researchers on RF and microwaves in this country are at the Pontifical Catholic University of Peru [116],[117], in Lima, at the Catholic University San Pablo [118]-[120], in Arequipa, and at the National University of Saint Agustin [121], [122], also in Arequipa. Their research mainly focuses on microwave transistor modeling [121], power amplifiers [122], radar imaging and sensing [116],[117], as well as in antennas [118] and microwave sensors for materials characterization [119],[120] and cancer detection [123]. The second edition of the IEEE MTT-S Latin America Microwave Conference (LAMC) took place in Peru, at the Catholic University San Pablo, in December 2018 [124]; **Figure 9** illustrates some of the microwave laboratory resources at this university.

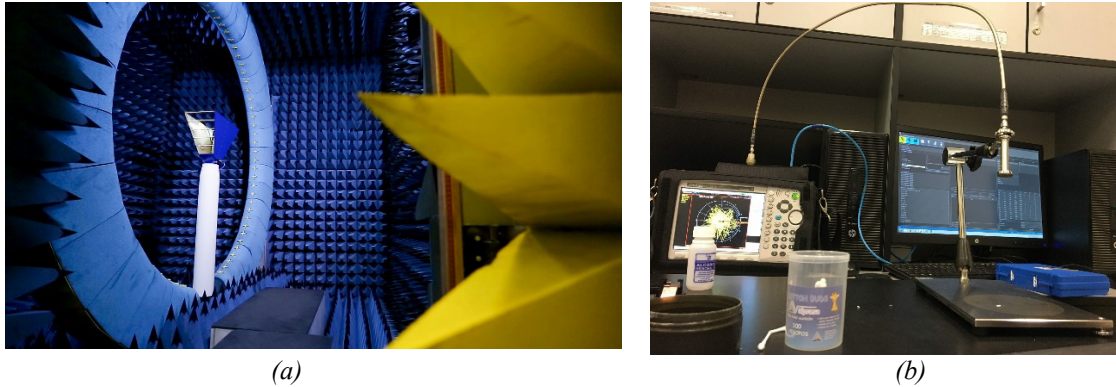


Figure 9. Some of the laboratory facilities available at the Catholic University San Pablo, in Arequipa, Peru: (a) anechoic chamber, (b) characterization system for dielectric samples. (Photos courtesy of Prof. Patricia Castillo-Aranibar).

RF and Microwave Research in Puerto Rico

The University of Puerto Rico at Mayagüez (UPRM) is the Puerto Rican institution with the most prominent research activities on RF and microwaves. They do research mainly on antennas and radar systems, as well as on small radiometers for unmanned aerial vehicles (UAVs) remote sensing (see **Figure 10**), with applications to weather forecasting, agriculture, and water resource management, among others [125]-[127].



Figure 10. Microwave remote sensing in Puerto Rico: (a) UAV carrying microwave radiometer flying over Magueyes Island; (b) brightness temperature measured with radiometer during field campaign at Magueyes Island [125], the circle size represents the antenna footprint. (Photos courtesy of Prof. Raúl Rodríguez-Solis).

Status, Challenges, and Opportunities for MTT-S in Latin America

The current MTT-S Chapters located in Region 9 are shown in **Figure 11**. We have a total of 15 MTT Chapters in Latin America, located in four countries: Argentina, Brazil, Mexico, and Peru. From those 14 MTT Chapters, 5 are Student Branch Chapters and 3 are joint chapters with other technical societies (see **Figure 11**). Their geographical distribution is indicated in **Figure 12**.

Chapter Name	Technical Societies	Country	Main Cities
Argentina Section	MTT	Argentina	Buenos Aires
Centro-Norte I Section	MTT/C/COM/PE/SP	Brazil	Belem
Centro-Norte II Section	MTT/ED/EMB	Brazil	Brasilia
Guadalajara Section	MTT	Mexico	Guadalajara
Mexico Section	MTT	Mexico	Mexico City/Ensenada
Northeast Brazil Section	MTT	Brazil	Recife
Northeast Brazil – UFCG	MTT (Student)	Brazil	Campina Grande
Northeast Brazil – IFBA	MTT (Student)	Brazil	Bahia
Northeast Brazil – UFERSA	MTT (Student)	Brazil	Mossoro
Peru Section	MTT	Peru	Arequipa/Lima
Peru Section – UNSA	MTT (Student)	Peru	Arequipa
Puebla Section – BUAP	MTT (Student)	Mexico	Puebla
Rio de Janeiro Section	MTT/AP/ED	Brazil	Rio de Janeiro
South Brazil Section	MTT	Brazil	Sao Paulo

Figure 11. Current IEEE MTT-S Chapters in Region 9; located in four Latin American countries: Argentina, Brazil, Mexico, and Peru.

MTT-S membership in Region 9 is relatively small, however, it has been consistently growing over the last three years, as confirmed in Figure 13.

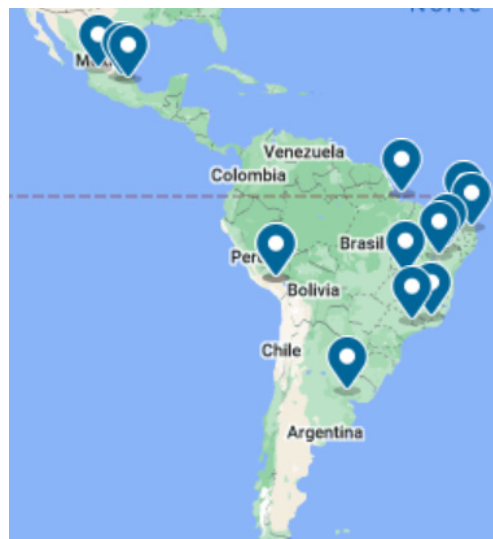


Figure 12. Geographical distribution of IEEE MTT-S Chapters in Region 9. Most of the chapters are located in Brazil and Mexico. From <https://www.mtt.org/chapters-by-region/?region=Latin+America#>.

Query Date	Active Members	Changes		
June 15, 2020	134	+17.9%	+10.7%	+30.6%
June 2, 2021	158			
June 5, 2022	175	+15.2%	+7.8%	+24.1%
Sept. 20, 2020	145			
Sept. 19, 2021	167			
Sept. 19, 2022	180			

Figure 13. Evolution of the IEEE MTT-S membership in Region 9 over the last three years. Data obtained from IEEE OU Analytics.

A key regional initiative that was approved by the MTT-S Administrative Committee in 2015 was the establishment of the IEEE MTT-S Latin America Microwave Conference (LAMC). This is a biennial conference that normally takes place in the second week of December, moving around to different locations in Latin American countries. It has a general scope on RF and microwave engineering and technologies, and it is technically and financially sponsored by IEEE MTT-S (see Figure 14). LAMC has significantly motivated the development of local RF and microwave research activities as well as to increase MTT-S membership in Latin America.



Figure 14. Official logo of the flagship MTT-S Region 9 conference on RF and microwaves: LAMC.

Among the main challenges and opportunities identified for MTT-S in Region 9, the following can be highlighted:

- ✓ We still have significant opportunities for MTT-S membership growth in specific areas of Latin America.
- ✓ Given the level of RF and microwave related activities observed in Colombia, Costa Rica, Chile, and Puerto Rico, new MTT-S Chapters could be created in the future in those countries.
- ✓ Strategic steps should be taken to consolidate LAMC as our flagship regional conference in RF and microwaves, keeping it as a catalyzer to stimulate further development in these technical fields in Latin American countries.
- ✓ Significant collaboration opportunities with Region 9 Young Professionals (YP) are identified to implement more technical talks and other similar activities in MTT-S Latin American Chapters at a regional level.

Conclusion

An updated overall survey of the main research activities on RF and microwaves in Latin America has been presented in this article. The special sessions that have been implemented in prior IEEE MTT-S International Microwave Symposia and European Microwave Conferences, along with the previous editions of the IEEE MTT-S Latin American Microwave Conferences (LAMC), were instrumental for getting to know among us and for identifying our own research efforts in the region. The information provided in this article confirms a notable progress in the level of research activities on RF and microwave engineering in Latin America over the last decade, both in terms of quantity and quality. We hope that the present article promotes higher visibility of the research efforts undertaken in this geographical region, as well as further collaborations not only between Latin American institutions but also worldwide. We firmly believe that progressing in education, research, and industrial development on RF and microwaves in the region will promote a more harmonized economic development in our Latin American countries.

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