Zeitschrift: Comtec : Informations- und Telekommunikationstechnologie = information and telecommunication technology

Herausgeber: Swisscom

Band: 79 (2001)

Heft: 11

Artikel: On the measurement of electric fields

Autor: Lehmann, Hugo / Fritschi, Peter

DOI: https://doi.org/10.5169/seals-876590

Exploration Programmes:
Corporate Technology Explores Future Telecommunications

On the Measurement of Electric Fields

In Switzerland the limits for the exposure of the general public to electromagnetic fields generated by mobile phone transmitters are based on the recommendations of the International Commission on Non-Ionising Radiation Protection (ICNIRP). For intensively used locations such as apartments and offices, however, the precautionary principle is applied. Therefore, so-called "installation limit values" – in the frequency range of interest a factor of ten lower than the ICNIRP values – have to be followed. These "installation limit values" are valid for each single transmitter station (using one or several frequency bands). The work presented here elaborates the scientific basis for the proposition of a reproducible and practicable measurement procedure for in-situ (indoor) measurements of electric fields near GSM base stations to verify the compliance with these precautionary limits.

The exploration Programme "Electromagnetic Effects" investigates the electromagnetic compatibility (EMC) aspects of emerging telecommunication technologies and the biological effects of electromagnetic radiation. Necessary actions and guidelines are elaborated allowing Swisscom to improve quality of service and minimise installation and troubleshooting cost.
With its Exploration Programmes, Corporate Technology is exploring telecommunication technologies and new service possibilities with a long-term view of 2–5 years. Further, the expertise built up in the course of this activity enables active support of business innovation projects.

From a theoretical point of view the electric and magnetic phenomenon found already in 1873 a unified theory in Maxwell's "Treatise on Electricity and Magnetism". On this theoretical basis electromagnetic waves are well described in the framework of electrodynamics. Quite soon ideas for important

HUGO LEHMANN AND PETER FRITSCHI

technological applications followed (for instance by Marconi some hundred years ago). Nevertheless, the precise experimental determination of high frequency electric fields in a complex environment is still a difficult task. This is mainly due to the interaction of three fundamental physical properties of electromagnetic waves or waves in general: reflection, absorption and interference. Under controlled conditions, for instance in an absorber hall, reproducible measurements should in principle be possible. In a more complicated environment, however, different measurements can lead to quite different results due to changing conditions. Thus, the physical properties of electromagnetic waves and the requirement of reproducibility are diametrically opposed.

Is a reproducible measurement of the electric field conditions possible in a real-life environment? What are the main physical properties of the system and how should a possible measurement method look? These are the crucial questions to which the present article tries to give answers and hints for the solution of the problem.

Nevertheless, local autorities, as well as the public, demand an experimental determination of the intensity of high frequency electric fields inside buildings. In order to ensure that these measurements rely on a sound scientific and technical basis Swisscom, as the major telecommunication operator in Switzerland, must possess and maintain a proper competence and know-how in this field. The key issue of the work presented here was thus the elaboration of the scientific basis for the determination of the electric field conditions in real-life environments. Our preliminary results allowed to propose a standard measurement procedure to verify the compliance of GSM base station installations with the limits set by Swiss legislation [1].
The scope of this article is to present these preliminary results, which are not the subject of an ongoing political discussion, but are interesting from a fundamentally scientific point of view.

Swisscom Competence Centre for Non-ionising Radiation

At Swisscom Corporate Technology know-how on the classical technical aspects of electromagnetic compatibility is maintained in a dedicated group of experts called EEC (Environment and Electromagnetic Compatibility), supported by an accredited EMC test laboratory. In addition, the implication of possible biological effects of electromagnetic radiation are followed up and studied in the same group.
In the emerging communication society, possible adverse health effects of electromagnetic waves are a public concern. In this context, measurements of the electric field inside rooms are of special interest and require exactly the skills described above. The expertise group EEC of Corporate Technology thus represents the competence centre for non-ionising radiation issues of Swisscom.

Available Methods

The first part of the work presented here consisted of an evaluation of the already available methods, as the measurement equipment should be existing in order to be applied immediately. The application of a yet to be developed measurement tool would delay too much the implementation of measurements for compliance verification of the limits.
Fundamentally, one can distinguish two different kinds of methods for high frequency measurements. Firstly, isotropic field sensors allow for a simple, non-selective measurement of the electric field. Secondly, more complicated, frequency selective measurements are possible by combining an antenna with a spectrum analyser or a test receiver. Both methods have their advantages and disadvantages (tab. 1).
The major drawback of the easy-to-use broadband probes is that the non-selectivity of this method is in contradiction to the frequency selective installation limits. For installations in different frequency ranges the limits are different, i.e. 4 V/m for the 900 MHz band, 6 V/m for 1800 MHz band, 5 V/m for combined mobile phone base stations and 3 V/m for broadcasting installations. These technical considerations on the available tools leads already to an important conclusion: the use of a frequency selective method is compulsory.

Standing Waves

What about the physical side of the problem? How does the electric field behave in a highly reflecting environment? When a reflected wave interferes with the ingoing wave a standing wave can build up. In some locations the intensity of the field is cancelled out, whereas at the maxima of the standing wave the electric field is doubled. The question whether and – if yes – to which extent such standing waves can build up under these conditions has to be answered. For this purpose a commercial mobile phone antenna was installed in our laboratory. The concrete walls, as well as several quite big metallic objects, make this lab a highly reflecting room. A schematic view of the experimental setup can be found on the left-hand side of fig. 1. As we worked at quite high intensities of the electromagnetic field, it was possible

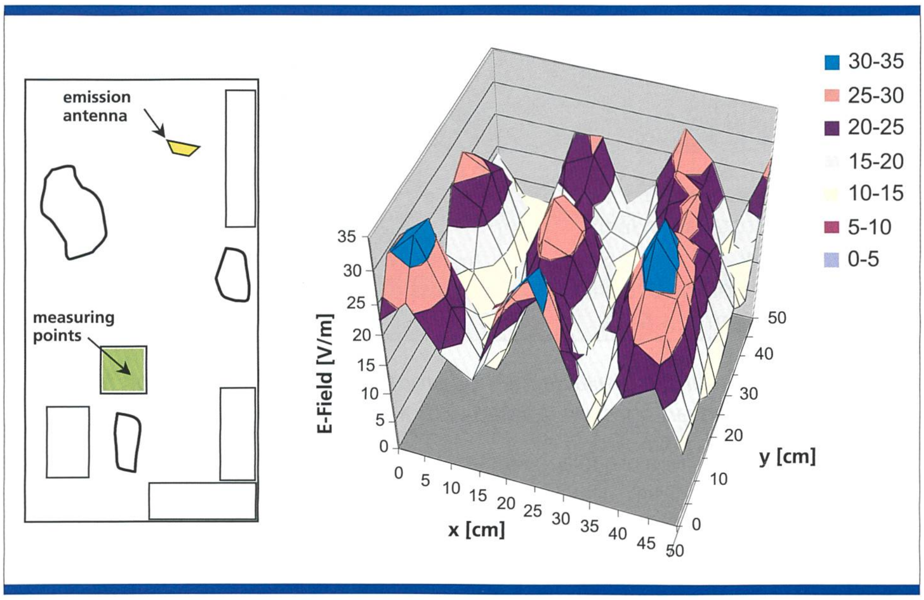

Fig. 1. Experimental setup in the laboratory (left-hand side) and the resulting standing wave pattern of the electric field intensity (right-hand side) in the presence of one single frequency of 920 MHz measured with the isotropic field sensor.

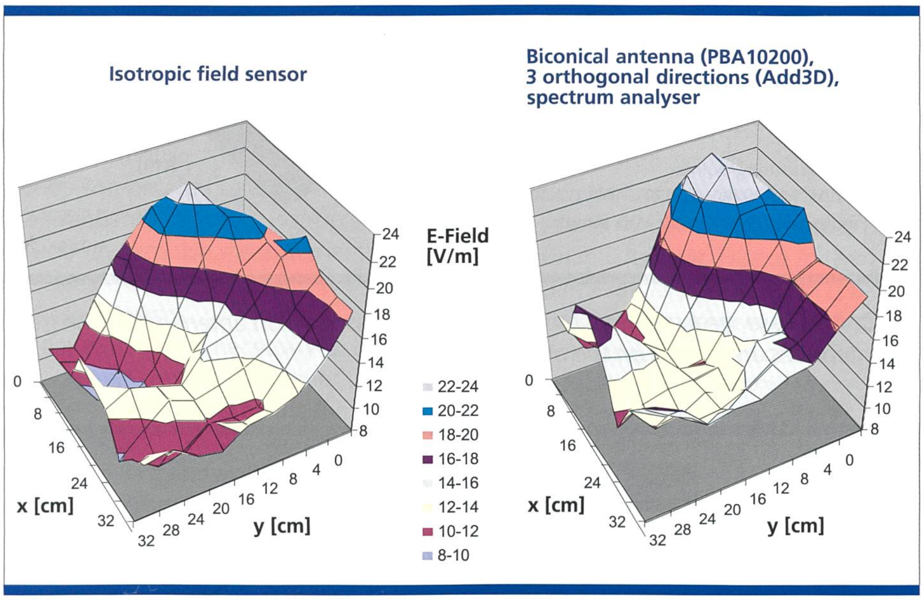

Fig. 2. Superposition of two frequencies (935 and 1850 MHz): Comparison of the measurements using the isotropic field sensor and a frequency selective measurement using a biconical antenna that was successively turned in three orthogonal directions.

to use an isotropic field sensor (W&G, EMR-300) in its specified intensity range for the measurement of the electric field. Furthermore, as only one frequency was present during the experiment, the non-selectivity of the probe was not problematic. The measurement points were distributed like the corners of a chessboard. The right-hand side of fig. 1 shows the results of this measurement. Indeed, the spatially well defined interference pattern of a standing wave having a wavelength of $\lambda/2$ was observed.

Superposition of two Frequencies

How does the system behave when a second electromagnetic wave of a different frequency is present? To address this question a second mobile phone antenna operating in the 1800 MHz frequency range was installed in the laboratory. The experimental setup was identical to the one in the first experiment. The two different frequencies had the same incident power in order to avoid predominant contribution of one component. In a first step we measured with the isotropic field probe. As can be seen on the left-hand side of fig. 2 the spatially well defined pattern is washed out by the superposition of the two frequencies. One has, however, to note that well localised, sharp maxima and minima remain present.

Isotropic, Frequency Selective Measurements

The review of the available methods evinced that for the compliance verification a frequency selective method is unavoidable. Moreover, in the complex situation encountered in highly reflecting environments, where contributions from all directions build up the total electric field at a given point, a measurement should be isotropic. As no high frequency antenna used in combination with a spectrum analyser has an isotropic characteristic, the solution consists in turning the antenna with a well-suited characteristic successively in three orthogonal room directions. By taking a biconical or a dipole antenna this requirement is approximately fulfilled. The total electric field is then given by the root mean square value of the three contributions. We used a biconical antenna and an ingenious system for the easy realisation of three orthogonal room directions, the so-called Add3D method developed in the Austrian research centre *Seibersdorf*. The results are shown on the right-hand side of fig. 2. A comparison with the measurement using the isotropic field sensor shows that the two methods compare quite well and are identical within the measurement errors. We thus conclude that by the successive measurement of three orthogonal directions a nearly isotropic, frequency selective and also sufficiently sensitive measurement is feasible.

By performing such type of measurements in a realistic situation an important amount of data has to be handled. By implementing automatic data recording and on-site analysis from the very beginning (using LabVIEW 5.0 from National Instruments) the efficiency was obviously increased. Furthermore, the possibility of errors in the process is thereby clearly reduced.

Application to Real-life Situations

With this important methodical improvement the measurement procedure was applied to real-life cases. The geometrical situation at one measurement location is given on the left-hand side of fig. 3. In total six different BCCH frequencies were present and measured. The electric field values over the measured area are illustrated on the right-hand side of fig. 3. For 81 measurement points the intensity of all 6 frequencies were recorded for the three orthogonal directions. It can be seen that due to the superposition of the different frequency components the total electric field shows a quite complicated pattern with spatially well defined maxima still present. The intensity distribution in a realistic case is shown in fig. 4. The distribution – here best fitted with a Weibull distribution – is right skewed. For such asymmetric distributions the most probable value for the electric field is the one which can be found under the maximum of the distribution curve. However, for the sake of simplicity we still considered the average value of the field to be the best-suited parameter for the electric field conditions. This value will generally be found at higher electric field intensities than the highest probable field value. The consideration of the distribution shows also that the maximum field intensity is less probable to measure as it is at the low-probability end of the distribution. It is interesting to note that the property of right skewness seems to be systematic for the distribution of the electric field in such real-life environments. In more than 20 cases in which sufficiently high statistics, i.e. a high number of measuring points, was available, the experimental distribution of the intensity showed this property.

To verify this theoretical argumentation in an extended measurement campaign the stability of the average field value was compared to methods in which only the maximum field value is searched for (as proposed by the BUWAL, ref. [2]). Only one example is presented here (tab. 2). Three measurements carried out by different teams on different days are compared. Note that the variations of the maximum are bigger than the ones of the spatial average in the same volume. As can be seen in the last column, the stability of the average value is linked to the number of measured points. The results given in the last column have

Isotropic field probes	Frequency selective methods
+ isotropic + easy handling + mobile	+ frequency selective + high sensitivity + accurate
– not-frequency selective ↔ compliance installation limit – low sensitivity – designed for sinusoidal signals → measurement error > 41 %	– non-isotropic antenna characteristics – costly and complicated – less mobile

Tab. 1. Comparison of the available methods for the measurement of high frequency electric fields: the advantages are labelled with a plus sign whereas the disadvantages are indicated by a minus sign.

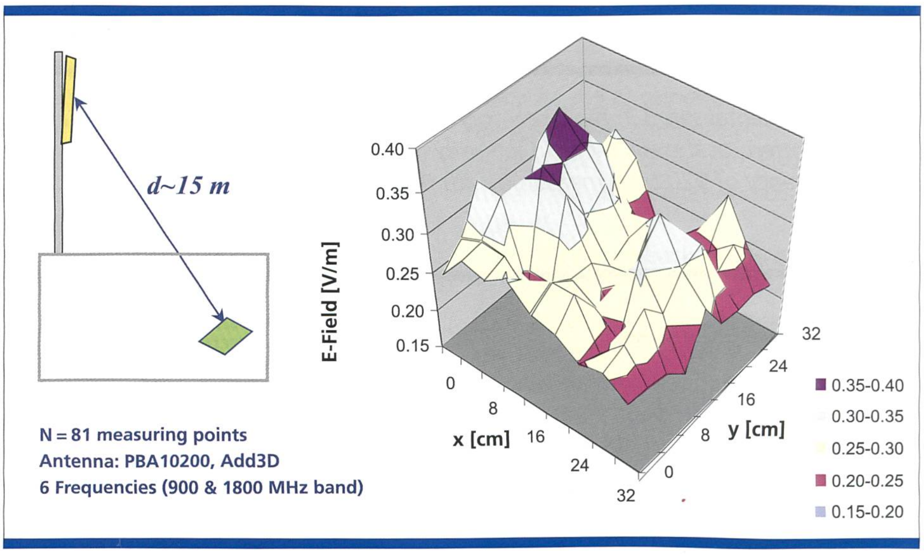

Fig. 3. Real-case measurement in a room below a base station antenna. The measured intensities are shown on the right-hand side.

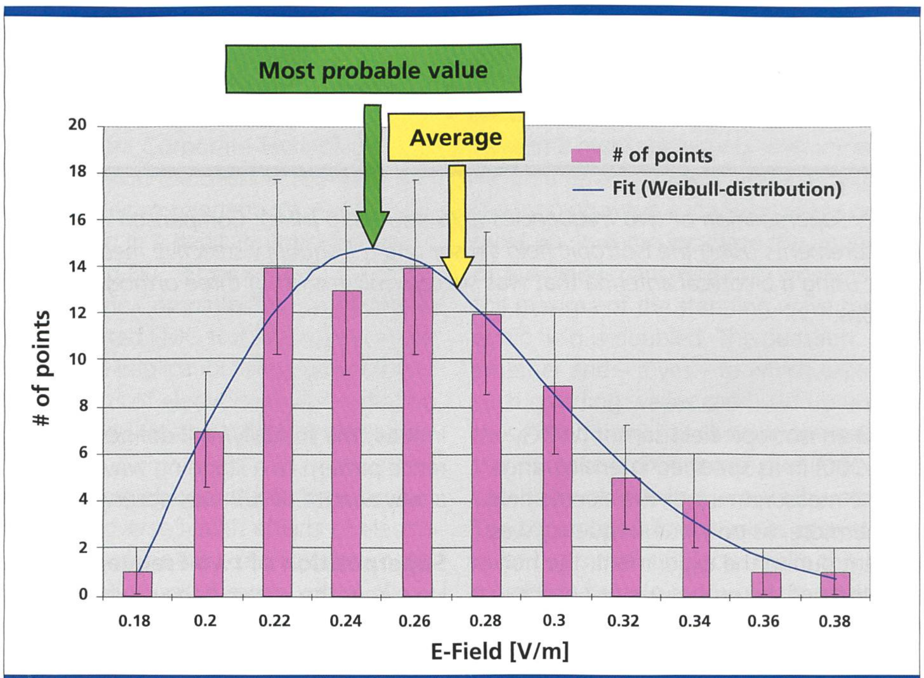

Fig. 4. Distribution of the electric field intensity for the n = 81 measuring points.

Measurement	E_{max}	E_{aver} (n = 63)	E_{aver} (n = 24)*
1 (team 1)	2.49	1.418	1.652
2 (team 2)	3.59	1.415	1.762
3 (team 3)	2.64	1.680	2.063
Δ_{max} [%]	**44**	**18**	**24**

*Points have been measured in slightly different geometry.

Tab. 2. Comparative field measurements: comparing maximum vs. spatial average.

been measured in a slightly different volume and geometry, which explains the difference in the absolute intensity value. This particular result is confirmed by the general trends shown by the measurement campaign. For further information on the results of the extended measurement campaign in which different methods – including spatial averaging as proposed here – are compared, and on similar findings based on a recent theoretical study, the interested reader is referred to Ref. [3] and [4], respectively.

Conclusions

The electric field conditions in realistic cases near mobile phone antennas show a quite complicated pattern. Nevertheless, frequency selective, isotropic and sufficiently sensitive measurements of the electric field inside rooms are feasible in these locations.

Spatial averaging is necessary to obtain reproducible results. The higher the number of measuring points the smaller the deviations from the average value for different measurements; i.e. the more stable the results.

The maximal field value happens to be less stable. An explanation of this result can be found considering the experimental distribution of the measurement points over the field values. From a statistical point of view, the average value is more probable than the maximum field value. This theoretical argument might explain the observed larger deviations of the maximal field intensity in the measurements.

The work discussed here delivered the scientific and technical basis for the proposition of a measurement procedure for in-situ (indoor) measurements of electric fields near GSM base stations, using on one hand spatial averaging and on the other hand a geometrical distribution of the measuring points in order to take into account the human body (see also ref. [3] for more detailed information).

The considerable interest of the international science community, authorities and industrial researchers in our results presented at international conferences [5] illustrates that the topic is of central interest.

Outlook

In the near future the distributions of the electric field intensities inside rooms will be further explored. The fundamental question why the measured distribution evokes generally a right skewed form will also be addressed.

Furthermore, it is planned to study the discussed phenomena in collaboration with international research laboratories and/or universities from an academic and also more theory based approach.

For new technologies like UMTS, WLAN and WLL using broad band techniques, the problems concerning the analysis of the signal are still to be solved. Furthermore, such techniques, due to their quite different signal structure, will have the potential to generate fields with different physical properties which have to be understood in order to propose a scientifically sound measurement method. 8

Hugo Lehmann, *Dr. rer. nat, physicist, studies of experimental physics at the University of Fribourg (Switzerland). After a dissertation in nuclear structure physics he was responsible for the high-resolution gamma ray spectrometer at the research reactor of the Institute Laue Langevin in Grenoble, France for two years. Since January 2000 Hugo Lehmann has been working in the domain of electromagnetic effects of non-ionising radiation concentrating on biological effects on one hand and measurement techniques on the other.*

Peter Fritschi, *El'ing. HTL (bachelor of electrical engineering), has a five year experience in professional and broadcasting audio and video electronics, three years as responsible in an EMC-lab and four years in a start-up lab for electrical safety tests. He is at presence in a postgraduate MBA study. For two years Peter Fritschi has been working in the domain of electromag-netic compatibility including standard-isation work and measurement techniques for the compliance verification of non-ionising radiation limits.*

References

[1] Ordinance on non-ionising radiation (in German, but also available in French and Italian): http://www.admin.ch/ch/d/sr/8/814.710.de.pdf

[2] The draft of the Swiss federal institute for environment, forest and landscape for a measurement procedure for mobile phone base stations:http://www.umwelt-schweiz.ch/imperia/md/content/buwal_pdf/22.pdf

[3] http://www.sicta.ch/focus/fcs_antennas/fcs_antennas.htm. On this web page the final proposition of the Swiss operators, in reaction to the proposition of the BUWAL, can be found as well.

[4] IEEE transactions on microwave theory and techniques, vol. 48, 11, 2000, p. 1996-2002).

[5] H. Lehmann, P. Fritschi, B. Eicher and U. Knafl, Measurements of the electric field in rooms near mobile phone base stations, Proceedings of the 5th International Congress of the European BioElectromagnetics Association (EBEA), 6–8 September 2001, Helsinki.

Abbreviations

BCCH	BroadCasting CHannel
BUWAL	Bundesamt für Umwelt, Wald und Landschaft (Swiss federal institute for environment, forest and landscape)
EEC	Environment and Electromagnetic Compatibility (experts group at Corporate Technology)
EMC	ElectroMagnetic Compatibility
ICNIRP	International Commission on Non-Ionising Radiation Protection
UMTS	Universal Mobile Telephone System
V/m	Volts per metre, unit for the electric field
WLAN	Wireless Local Area Network
WLL	Wireless Local Loop

Zusammenfassung

Die messtechnische Überprüfung der Schweizerischen Anlagegrenzwerte, die seit 1. Februar 2000 in Kraft getreten sind, erfordert eine möglichst genaue und reproduzierbare Erfassung der elektrischen Feldstärke in Räumen bei Mobilfunkbasisstationen. Die hier präsentierten Untersuchungen erarbeiten wichtige wissenschaftlich-technische Grundlagen zur Messung von elektrischen Feldern in Innenräumen.
In Räumen mit hochreflektierenden Eigenschaften entstehen bei einer einzigen ausgesandten Frequenz räumlich klar definierte und ausgeprägte stehende Wellen mit der zu erwartenden Wellenlänge von $\lambda/2$. Die räumliche Ausprägung dieser stehenden Welle verringert sich, sobald mehrere Frequenzen (z. B. 900 und 1800 MHz) überlagert werden. Auch Streuung und Absorption, wie sie in einer realen Messsituation (in einer Wohnung oder einem Büroraum) auftreten können, verhindern die räumliche Entstehung dieser ausgeprägten Interferenzmuster. Die Grösse der Feldüberhöhungen bleibt jedoch bei den bisher angetroffenen realen Situationen in annähernd gleichem Masse vorhanden. Maxima sind zwar nicht mehr regelmässig vorhanden, sind aber dennoch örtlich relativ scharf ausgeprägt.
Die Kombination eines Spektrumanalystors mit einer geeigneten Messantenne, welche sukzessive in drei orthogonale Raumrichtungen gedreht wird, erlaubt eine isotrope, frequenzselektive und auch genügend empfindliche Messung des elektrischen Feldes an einem Raumpunkt.
Die räumliche Mittelwertbildung liefert die stabilsten und somit die reproduzierbarsten Resultate. Die Abweichung der Mittelwerte verschiedener Messungen nimmt mit steigender Anzahl Stützstellen grundsätzlich ab. Maximumsuchmethoden zeigen die grösseren Abweichungen als die Mittelwertmethoden.
Die im Rahmen dieses Explorationprogramms erarbeiteten Grundlagen stellten die wissenschaftliche Basis für den Vorschlag der Mobilfunkbetreiber für eine Messempfehlung zur Bestimmung der elektrischen Feldstärke bei Mobilfunkbasisstationen dar. Weitere Informationen über diese Aspekte können unter Ref. [3] nachgelesen werden.
Die Präsentation der hier vorgestellten Resultate an internationalen Konferenzen (siehe etwa [5]) sind sowohl bei Wissenschaftlern als auch bei Behörden- und Industrievertretern auf reges Interesse gestossen. Es ist denn auch geplant, die aufgezeigten Zusammenhänge in Zusammenarbeit mit Forschungsinstituten und/oder Universitäten genauer zu untersuchen.

Millimeterwellen im Vormarsch

300 GHz ist eine magische Frequenzmarke: Sie entspricht im freien Raum genau 1 mm Wellenlänge. Die technische Nutzung des Millimeterwellenbereichs liegt noch in der Ferne, die praktisch nutzbaren Frequenzbereiche sind heute um den Faktor 5 bis 100 niedriger. Die Frage, wie man solche kleinen Wellenlängen stabil und reproduzierbar herstellt, beschäftigt die Wissenschaftler auf der Welt. Von den NTT Photonics Laboratories und dem National Astronomical Observatory of Japan (NAOJ) kommt jetzt die Nachricht, dass man zwei Laserstrahlen mit verschiedenen Wellenlängen in einem Photomixer zusammengeführt und durch Mischung die Differenzfrequenz erhalten hat. Der Photomixer ist etwa so gross wie ein kleiner Personal Digital Assistant (PDA). Er lieferte Wellenlängen zwischen 75 und 110 GHz mit einer Ausgangsleistung von 1 mW. Man will innerhalb nur eines Jahres in den Sub-Millimeterwellenbereich hineinkommen und einen Photomixer für 350 GHz realisieren.

NTT Communications Corp.
1-1-6 Uchisaiwaicho
Chiyoda-ku
Tokyo 106-8019
Japan

Hoffnungsvoller Blauzahn

Trotz Produktverzögerungen und technischer Pannen – der drahtlosen Bluetooth-Technologie wird in einer neuen Studie von Frost & Sullivan weiterhin grosses Wachstumspotenzial bescheinigt. Das allerdings auf mittlere Sicht. Nach Untersuchungen des Marktforschungsunternehmens werden in diesem Jahr gut vier Millionen Geräte mit Bluetooth-Technologie verkauft. Für das Jahr 2006 soll erstmals die Marke von einer Milliarde Bluetooth-Geräten überschritten werden. Das läuft auf ein Wachstum von 300% pro Jahr für die nächsten fünf Jahre hinaus. Und das ist Mengenwachstum – da sollte bei fallenden Preisen noch ein Geschäft zu machen sein.

Frost & Sullivan
7550 West Interstate 10
Suite 910
San Antonio TX 78229-5616
USA
Tel. +1-210-348 1000
Fax +1-210-348 1003
Homepage: www.frost.com