NEW GENERATION OF MILLIMETER-WAVE COMMUNICATION SYSTEMS

Aleksandar Nešić[1], Veselin Branković[2], Ivana Radnović[1]
[1]Institut IMTEL, Beograd
[2] Telecommunication Research & Development Europe (TRDE); SONY International GmbH, Germany

Abstract - **The vision of future high data rate in-door communication systems is presented. The key technological requirements and possible solutions for RF technologies are outlined. Integration of front-end with antenna in the mm-wave range and incorporation of the dual frequency operation may provide a major step toward a low cost solution. The key technology features are verified by prototyping, showing encouraging results.**

I INTRODUCTION

The main goals in the development of new generation mobile communication systems operating in 60 GHz range with capacities up to 150 Mb/s are, among others, increase of capacity and great number of specific applications such as high resolution image transfer in medical, industrial and economic buildings, as well as in institutions dealing with informatics. One of the very important objectives is also compatibility with existing 3rd generation mobile communication systems.

Concepts, solutions and standards that are considered are:

- ☐ Internet Protocol (IP)
- ☐ Universal Mobile Telecommunication System (UMTS)
- ☐ Asynchronous Transfer Mode (ATM)
- ☐ Integrated Services Digital Network (ISDN)

These new systems will provide a broadband access to applications which will appear in the result of the converging business areas Telecommunications, Information technology, and mass MEdia - the so called TIME-Markets (see Figure 1). Future access technologies must support mobility - which is a clear indication for the growing importance of wireless systems (see Figure 2).

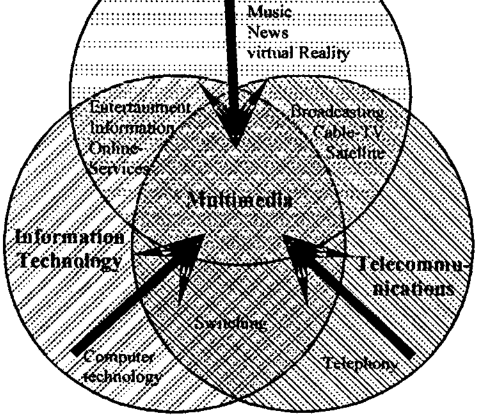


Figure 1. Convergence of the TIME-markets.

II CHOICE OF THE FREQUENCY RANGE

At the moment, mobile communication systems of the 2nd (GSM) and 3rd (UMTS - Universal Mobile Telecommunication System) generations are in use and they are not compatible. New wireless systems are considered in various world projects: RACE (European investigation project within which the UMTS is created) and ACTS (Advanced Communications Technologies and Services) which is the most remarkable European project in this field at the moment. Future systems conceived within these projects are:

- ☐ RACE MBS (Mobile Broadband System),
- ☐ ACTS MEDIAN (system at 60 GHz),
- ☐ ACTS SAMBA (High-data Communication System at 40 i 60 GHz),
- ☐ ANSIBLE (system that is being investigated and developed at the moment).

On the basis of previously mentioned considerations, key requirements for the ANSIBLE system are defined:

- ☐ Enhancement of the existing broadband wireless LAN concepts in 60 GHz range,
- ☐ Enabling of high data rates - up to 150 Mb/s,
- ☐ Compatibility with a new HIPERLAN 2 system operating in 5 GHz range, e.g. fast transition from 60 GHz system to a 5 GHz system and reverse.

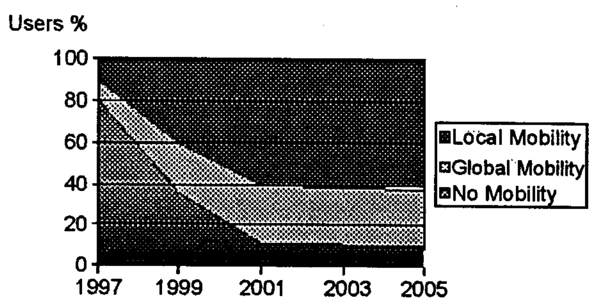


Figure 2 Requirement for mobility support.

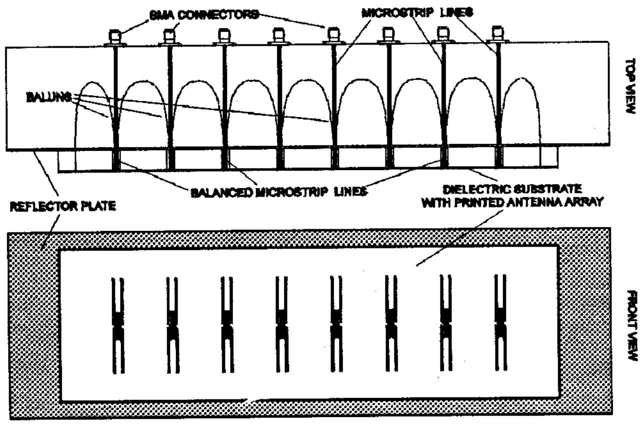


Figure 4 Array of 8 printed dipoles operating on third resonance.

	SYSTEM	DEMONSTRATOR
TECHNOLOGY	OFDM/TDMA/ ATDD	COFDM single link
RADIO FREQUENCY	5/ 24/ 60 GHz	5/ 24 GHz
CHANNEL BW	15 - 30 MHz	20 MHz
USER DATA RATE	up to 155 Mbit/s	up to 40 Mbit/s
SC MODULATION	(D)(4,8,16)PSK, 16 QAM	D4PSK, D8PSK (D16PSK)
FFT LENGTH	64 (128)	64 - 512
CODE RATE	1/2, 2/3	1/2, 2/3

Figure 3 Characteristics of the ANSIBLE system and of the demonstration model.

- ☐ Wide frequency range in order to enable high density of users and therefore services from a few kb/s to 150 Mb/s,
- ☐ Peer-to-peer mode (also called direct mode) terminals close enough to each other could communicate directly and not via the basestation that benefits in more efficient use of the system resources.
- ☐ Acceptable dimensions of terminal devices,
- ☐ Low-cost.

III MAIN ACTIVITIES DURING THE INVESTIGATION AND DEVELOPMENT

- ☐ Theoretical investigations,
- ☐ Simulation of the functional blocks and subsystems,
- ☐ Design, prototyping and measurements of the demonstration system operating at lower frequency (24 GHz),
- ☐ Design, prototyping and measurements of different key sub-parts of 60 GHz system,
- ☐ Integration of 60 GHz front-ends (with new MMIC components) with antennas.

The key problems in the theoretical investigation and design of a MW part are antennas of different types that have to be used in the ANSIBLE system [1], low noise amplifiers and high power amplifiers.

Expected characteristics of the ANSIBLE system, as well as those of the demonstration model are shown in the following table, Fig. 3, [2].

IV ANTENNAS IN THE ANSIBLE SYSTEM IN 5 GHZ, 24 GHZ AND 60 GHZ RANGES

The following types of antennas integrated with convenient microwave circuits are planned to be used:

- ☐ SMART antennas with digital beam-forming,,
- ☐ Space diversity antennas,
- ☐ Antennas with circular polarization,
- ☐ Antennas with circular polarization and conical beam,
- ☐ High-gain antennas for 24 GHz and 60 GHz ranges.

V ARRAY FOR SMART ANTENNA SYSTEM

SMART antenna system enables:

- ☐ Automatic adjustment of direction and shape of the antenna pattern,
- ☐ Tracking of receiving signals,
- ☐ Suppression of co-channel interference.

In the presented version of the array for SMART antenna system, 8 printed dipoles operating on third resonance are used and each of them is integrated with preamplifier and a mixer. After mixing, signal is being processed in the baseband in order to form desired antenna beam, [3]. The array is shown in Fig. 4.

VI SPACE DIVERSITY ANTENNA

This antenna is used for the 5-6 GHz range in cases when there is no line of sight and when direction of the incoming signal is uncertain.

Antenna is cube-shaped with 6cm sides. On the four of them, there are triangular slots (complementary with bow-tie dipoles) behind which is a corner reflector plate. Bandwidth of this antenna is relatively wide and its

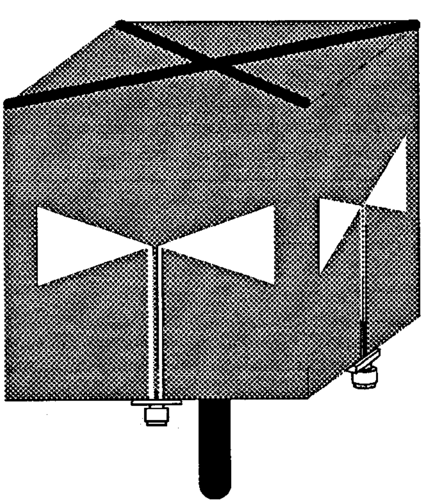


Figure 5 Space diversity antenna.

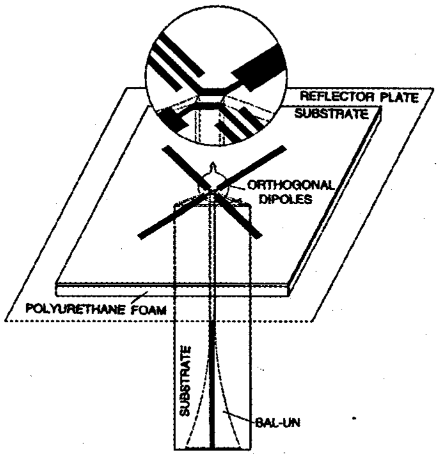


Figure 6 Two orthogonal dipoles fed by a symmetrical microstrip line.

radiation pattern is very suitable for above-mentioned application. Drawing of the antenna is given in Fig.5.

VII ANTENNAS WITH CIRCULAR POLARIZATION

Antennas with circular polarization are practically unavoidable in mobile communi-cations due to the fact that there is no need for the antenna orientation Beside this, the special advantage of the circularly polarized antennas is their feature of additional physical attenuation of reflected waves (due to polarization direction changing) which makes propagation channel much better and the overall system more resistant in the case of multipath propagation

Printed antenna realized in the IMTEL Institute has much wider bandwidth, better axial ratio and lesser VSWR comparing to conventional printed antennas with circular polarization, [4].

VIII ANTENNAS WITH CIRCULAR POLARIZATION AND CONICAL BEAM

These antennas will be used as base station antennas for in-door applications in order to achieve approximately uniform field in a whole room. Diagram that

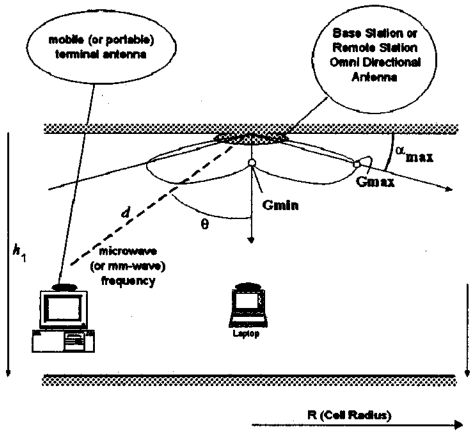


Figure 7 In-door application scenario for the antenna with circular polarization and conical beam.

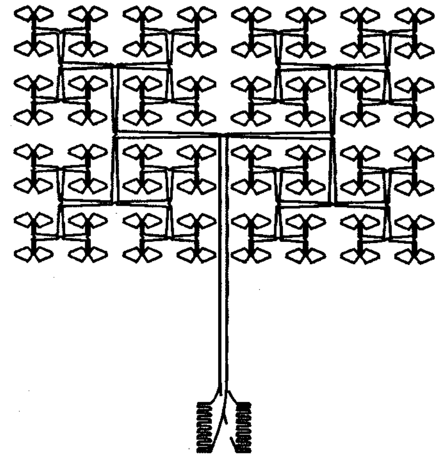


Figure 8 Printed array with 8x8 dipoles for 60 GHz range.

shows principle of use and radiation pattern of the antenna with circular polarization and conical beam is given in Fig. 7, [5].

IX HIGH-GAIN ANTENNAS FOR 24 GHZ AND 60 GHZ RANGES

These antennas will be used for terminal devices, mostly in 60 GHz range. Novel and inventive solutions are implemented and obtained charac- teristics are much better than those of known printed antennas operating in millimeter range, [6]. Main advantages are: extremely wide bandwidth, relatively low losses and miniature dimensions. Layouts of printed antennas for 60 GHz range with 64 and 256 radiating elements and with gains of 20 dBi and 25 dBi, respectively are shown in Figs. 8 and 9.

X REALIZATION OF THE DEMONSTRATION MODEL AT 5GHZ AND 24GHZ

The main requirement which have to fulfill future systems is to simultaneously exploit advantages of lower and higher frequency bands. In order to prove the system concept, dual-frequency demonstrator working at 24 GHz (ISM band) and 5 GHz (Non-licensed band) is

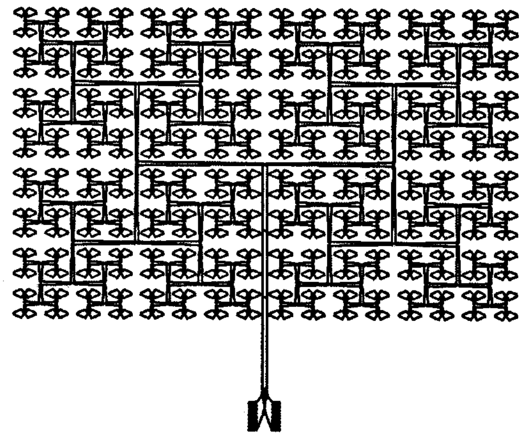


Figure 9 Printed array with 16x16 dipoles for 60 GHz range.

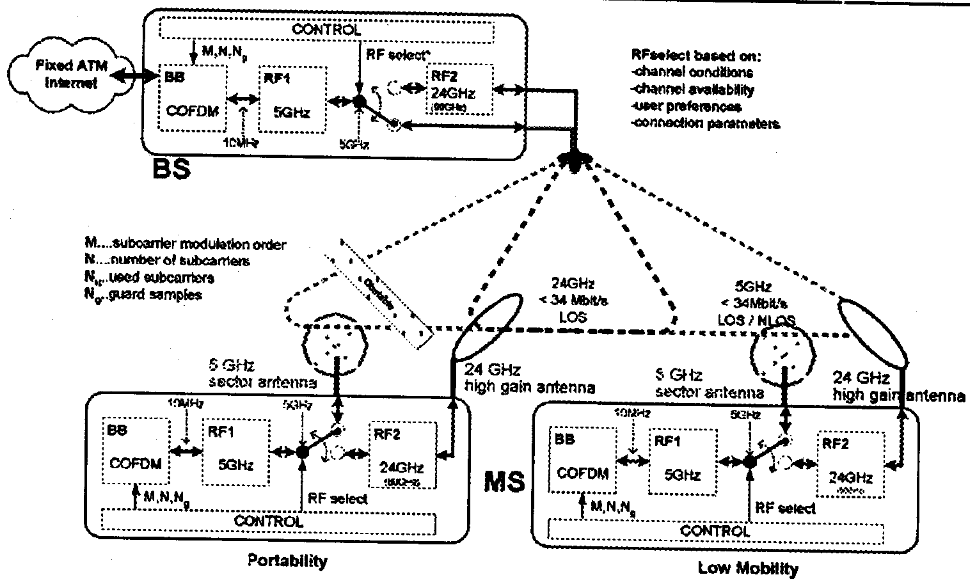


Figure 10 Block diagram of the communication system on 5 GHz and 24 GHz.

being under development. Modulation solution is OFDM based, followed by features of adaptive change of spectral efficiency. Full integration of the antenna assembly with up/down converters from 5 to 24 GHz band is achieved in low cost way. High data rate system for in-door communication in MM-wave range is the main objective of the work, where presented up/down converters are playing an important role. The proposed system functions at two frequencies, having the priority at 24 GHz (ISM band).

The system tries at first to approach users in one room (one communication cell) at the higher frequency -24 GHz. This frequency may allow to use also sector antenna with medium gain (small size, also with tracking option) resulting in better communication channel. On the other hand, good propagation conditions allow higher spectrum efficiency and peak user data rates. At the same time, if the channel conditions are becoming worse or the user prefers that, lower frequency (non licensed 5 GHz band) is switched, allowing wall penetration of severe NLOS communication. This lower frequency is at the same time intermediate frequency of the RF system, so that the chip sets for 5 GHz system may also be used for 24 GHz system. The main idea standing behind proposed approach is that in both operational cases the same baseband hardware may be utilized. The channel bandwidth may remain the same.

Major blocks in the system are up converter (5GHz/24GHz) with integrated sector antenna in the transmitter and down converter (24GHz/5GHz) with integrated highly directed antenna, having relatively high gain, in the receiver. Block diagram of the communication system operating at 5 GHz and 24 GHz is shown in Fig. 10.

XI UP CONVERTER 5 GHZ - 24 GHZ

Signal at the first intermediate frequency is brought to the input of up converter (this signal is also used as a transmitting signal when the system operates in 5 GHz range). LO signal at 19 GHz is brought from a synthesizer whose oscillator has a dielectric resonator (DRO) at the working frequency in order to generate signal with low phase noise.

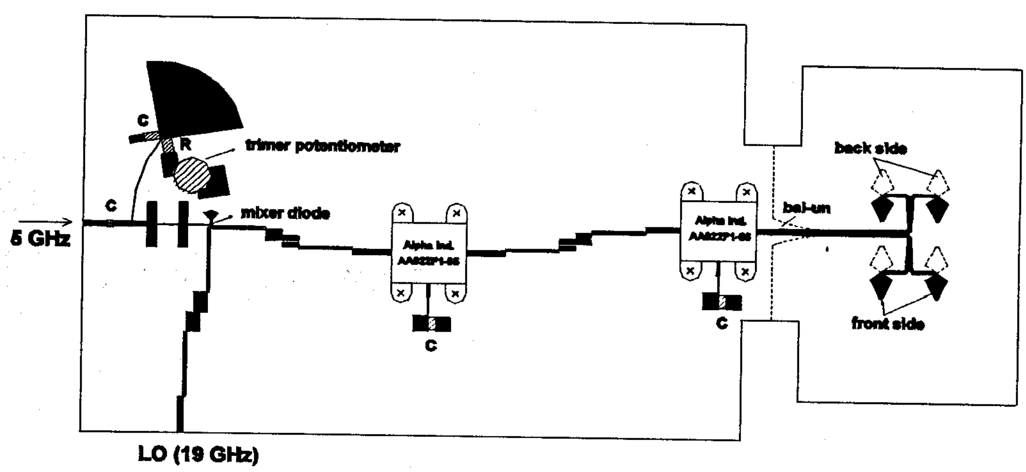


Figure 11 Layout of the up converter (5GHz/24GHz).

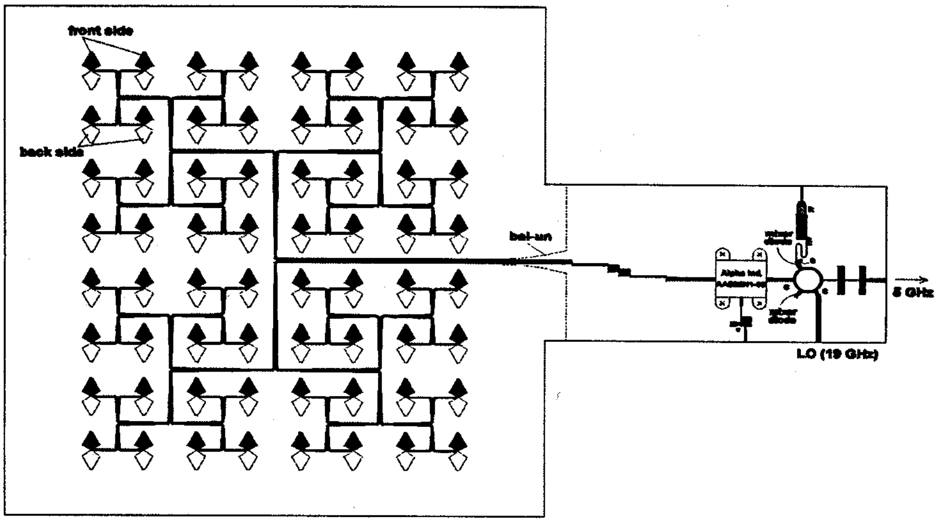


Figure 12 Layout of the down converter (24 GHz/5 GHz)

DRO is stabilized by a referent quartz oscillator (TCXO) through a phase locked loop (PLL). The same TCXO is also used as a reference in synthesizer in the 5 GHz range. Layout of the up converter 5/24 GHz is shown in Fig. 11. As it can be seen, the converter is realized on the same dielectric substrate with active printed antenna.

Incoming signal in 5 GHz range passes through a band-pass filter which attenuates LO- and converted RF-signal. Signal from the transmitter in 5 GHz range is led through a low-pass filter providing satisfactory attenuation of LO- and RF- signal (24 GHz) at the input.

Signal is then brought to a single-diode mixer with GaAs Schottky barrier diode (DMK 2790, Alpha Ind.) in flip-chip package. Diode biasing is performed so as to obtain optimal mixing performance i.e. to minimize conversion loss.

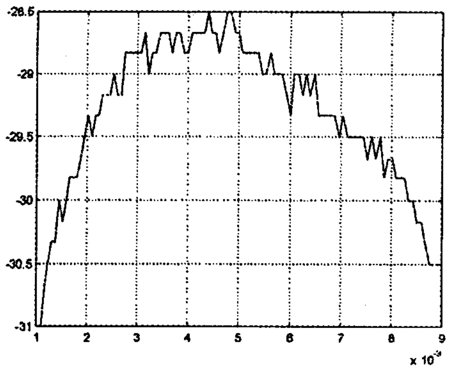
Outgoing signal is from the mixer led to a band-pass filter and to the first MMIC power amplifier (Alpha Ind. AA022P1-65). After that, it is being led to the second band-pass filter and another power amplifier (same as the first one) in whose output circuit there is an active printed antenna array. The array is realized with four wideband dipoles behind which is a reflector plate at the distance of about 0.275λ. Between the antenna and the reflector plate, there is a polyurethane foam with $\varepsilon_r=1.03$. All units of the presented up converter with integrated antenna are realized on the same dielectric substrate - teflon-fiberglass ($\varepsilon_r=2.17$, h=0.254mm), Fig. 11, [7].

XII DOWN CONVERTER 24 GHZ 5 GHZ

Down converter is shown in Fig. 12. Printed wideband receiving antenna with 64 dipoles is integrated with converter. Signal from the antenna is brought to a band-pass filter (24 GHz) and afterwards to a low-noise MMIC amplifier (AA022N1-65, Alpha Ind.). The signal is then led to a rat-race balanced mixer with two GaAs Schottky barrier diodes in flip-chip package (DMK 2790, Alpha Ind.). Diodes are biased (through a chock) with 4.5 mA current in order to optimize mixing performance, Fig. 13, [7].

XIII REALIZATION OF THE DEMONSTRATION MODEL AT 24 GHZ AND OBTAINED RESULTS

Both converters are realized on teflon-fiberglass dielectric substrate ($\varepsilon_r=2.17$, h=0.254mm). Realized up converter is shown on the photograph, Fig. 15. Diagram



.Figure 13 Influence of diode biasing on received IF power measured in the system with up/down converters.

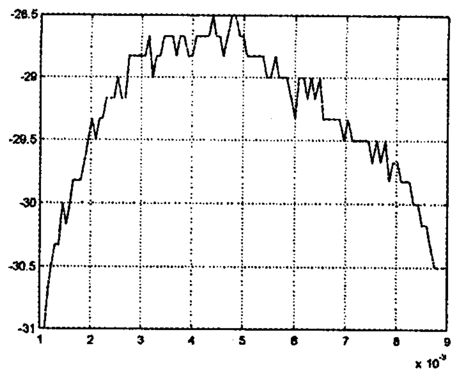


Figure 14 Tx radiated power measured with reference antenna at specified distance.

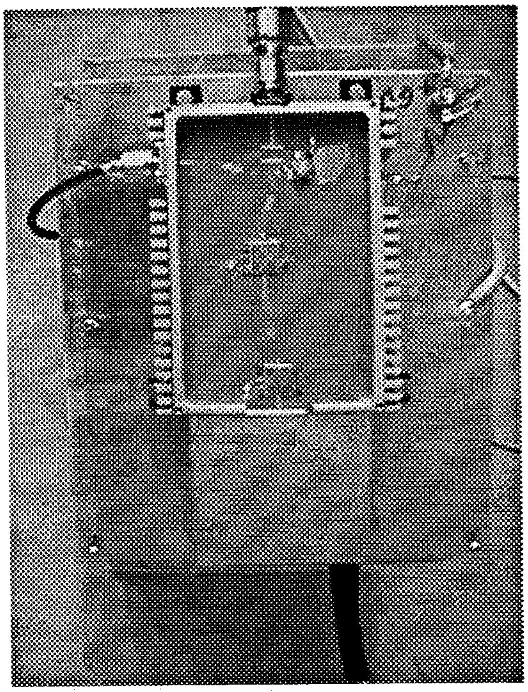


Figure 15 Photograph of the realized up converter.

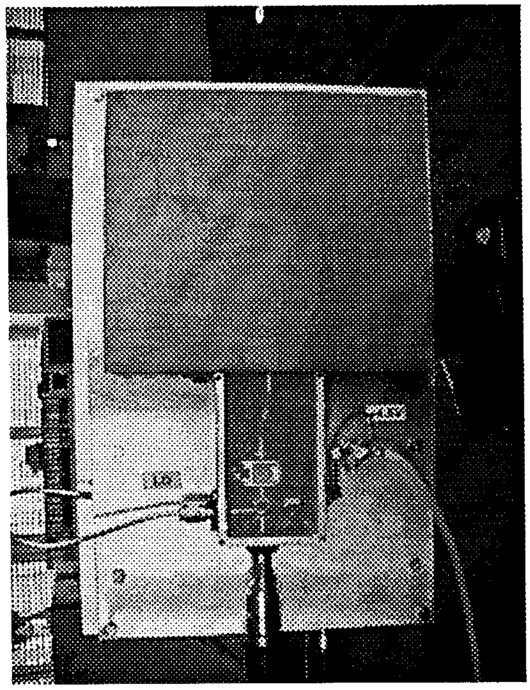


Figure 16 Photograph of the realized down converter.

of the radiated power versus level of the incoming signal at 5 GHz is given in Fig. 14.

Total conversion gain is 20 dB. Dynamic range of more than 50 dB with practical ideal linearity is obtained. Saturation begins with output signal levels of about 26 dBm.

Photo of the down converter is given in Fig. 16. Total isotropic conversion gain of the down converter is 20 dB.

CONCLUSION

Concept and possibilities of the new generation of mobile communication systems especially suitable for in-door communications is presented. System operates in microwave frequency range of 5 GHz and millimeter-wave range of 60 GHz with data rates up to 150Mb/s. Several solutions for expecteu problems during the investigation are proposed. The demonstration model operating at 5 GHz and 24 GHz is realized in order to performe experiments and to verify the basic concept.

All new ideas as well as new solutions will be applied also to new generation of microwave communication systems that are being under development in the IMTEL Institute.

REFERENCES:

[1] Branković, V., Nešić, A., Zimmermann, S.: *Antenna Solution for High Data Rate In-Door Communication* System in MM-wave Range, pp. 411-416, Mobile Comm. Summit, Rhodos, 1998.

[2] Branković, V., Dlle, T., Konschak, T., Krupežević, D., Nešić, A.: *Dual Frequency (24/5) GHz OFDM Based Front-end for In-door Communication Systems*, 4th Acts Mobile Communication Summit, June 1999, Sorrento, Italy.

[3] Nešić, A., Jovanović, S., Branković, V.: *Design of Printed Dipoles Near the Third Resonance*, IEEE AP-S, Atlanta, June 1998, Vol. 2. pp. 928- 931.

[4] Nešić, A., Radnović, I., Mikavića, M.: Printed Antenna and Array wuth Circular Polarization, Electronics Letters, Vol. 32, No. 9, pp. 785-786, April 1996.

[5] Nešić, A., Branković, V., Radnović, I.: *New Circularly Polarized Printed Antenna with Conical Beam*, Electronics Letters, Vol. 32, No. 12, pp. 1165-1166, June 1998.

[6] Nešić, A., Radnović, I., Branković, V.: *Ultra-wideband Printed Antenna Array for 60GHz Frequency Range*, IEEE AP-S International Symposium 1997, Montreal, Canada, July 1997, Conference Proceedings, Vol. 2, pp. 1272-1275.

[7] Nešić, A., Branković, V., Krupežević, D., Radnović, I.: *24 to 5 GHz Up/Down Converters with Integrated Antennas*, 29th European Microwave Conference, Munich 1999, Germany, Conference Proceedings, pp. 153-156.