MILLIMETER-WAVE SYSTEMS AND APPLICATIONS IN EUROPE

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ABSTRACT

Two major types of applications have to be distinguished in the millimeter-wave range: communication and radio-location. Millimeter-wave communication systems are used for railroad traffic control or telephone network enlargements, cellular radio is under investigation in the commercial area, while covert (LPI) communication has been developed for military purposes. The widest spread tasks are found in radar. The contact free measurement of velocity or distance for traffic control or industrial use are commercial applications, while intelligent seeker systems for terminal-guidance or 'smart'-weapons are military employments.

1.0 INTRODUCTION

In a review on millimeter-wave systems and applications in Europe it is almost impossible to mention all the activities, being persued momentarily. This contribution therefore will concentrate on representative work, on realistic applications, that will go or have gone already into realization or production. In general millimeter-wave technology is mature today and is exploited in various specialist applications, taking advantage of the atmosphere's unique propagation behaviour (1).

2.0 COMPONENT TECHNOLOGY

The spreading application of millimeter-waves is based on the component technology being available today, e.g. (2,3). Some recent advances will be reviewed:

2.1 Transmitter Performance

Millimeter-wave solid state source capability for local oscillator applications, employing GaAs as well as InP GUNN elements is well developed, a good overview is given in (4), while high power solid state source capabilities in- and outside Europe are somewhat limited. Silicon IMPATT diodes for operation with 1 W of continuous and 42 W of pulsed output power have been demonstrated, using MBE grown silicon double drift diodes (5). However, for some applications this is still not enough. Here the development of mini-magnetrons with a volume of some tens of ccm, delivering more than 400 W of pulsed output power (about 1 W mean) out of a low voltage power supply (24 V only) in the 80 and 94 GHz bands (6), is significant.

2.2 RECEIVER PERFORMANCE

Hybrid integrated receivers, employing beam-lead Schottky-Barrier GaAs diodes on finline (7) or microstrip circuits (3) are in production for frequencies up to 150 GHz. Noise figure values of about 8 dB are typical at 94 GHz. Fig. 1 shows a microstrip integrated receiver unit, consisting of 2 STC/mixer circuits and the LO power divider, built by Thomson-CSF of Malakoff, France (8).

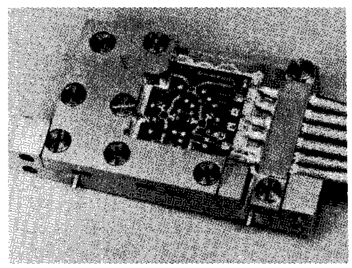

Fig. 1:
Dual W-band balanced mixer
(Courtesy of Thomson-CSF)

This unit showed very good reproducibility, a lot of about 40 mixer units exhibited an overall noise figure of 8.5 dB ±1.5 dB, using GaAs Schottky Barrier mixer diodes (9). However, this is only one way to realize integrated receivers; Fig. 2 presents a monolithic integrated 35 GHz receiver chip, consisting of a single balanced mixer and a single stage IF-amplifier, built by AEG of Ulm, West Germany.

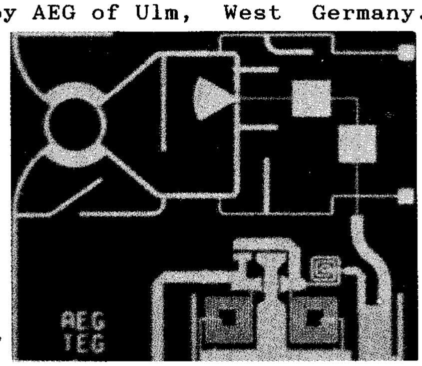

Fig. 2:
35 GHz receiver chip

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This balanced mixer shows a minimum noise figure of 6.5 dB at 35 GHz (10), while the amplifier gain was >10 dB over the 0.5 to 1.5 GHz IF band. More of this technology is presented at this conference in the previous paper of this session (11).

3.0 APPLICATIONS

Two major types of applications have to be distinguished in the millimeter-wave range, communications and radio-location (12), the latter being either active (radar) or passive (radiometry). Apart from the unique propagation behaviour, all millimeter-wave applications take advantage of the highly directive nature of the millimeter-wave beam, good angular resolution can be achieved with moderately small antennas, thus millimeter-wave systems are small in size and light in weight, compared to their microwave counterparts.

3.1 Communications

Atmospheric propagation effects strongly influence considerations related to the application of millimeter-wave transmission links. Normally such systems will be operated in the atmospheric windows around 35 and 94 GHz, for some specific, mostly military applications, the maximum absorption range around 60 GHz will be taken (13).

3.1.1 Military Applications The employment of the 40-50 GHz band for EHF military satellite up-links is very important for the development of millimeter-wave technology (14). This frequency band offers increased bandwidth over the UHF and SHF bands being in current use today and permits the construction of small terminals; thus covert operation for various military platforms can be achieved. The SKYNET 4 series of satellites under development in the U.K. will carry EHF transponders (15), together with the MILSTAR program in the US this gives rise to a considerable future market for terminals.

The 60 GHz absorption band can be used for short range secure communications. The specific advantages and the versatility of this approach was pointed out earlier (16), today this is an area of rapid growth in all european countries (17). The block-diagram of a short-range communication system, with a portable power-supply and hand-carried in binocular form, is shown in Fig. 3, realized by Marconi of Stanmore, England (18):

Output Power (at IMPATT)	50 mW
Conversion Loss	7 dB
Antenna Gain	25 dB

Based on test results achieved with a set of hand-held 58 GHz transceivers (19), a military communication network and appropriate transceiver units are currently under development at AEG of Ulm, West Germany. Flight deck communications on air-

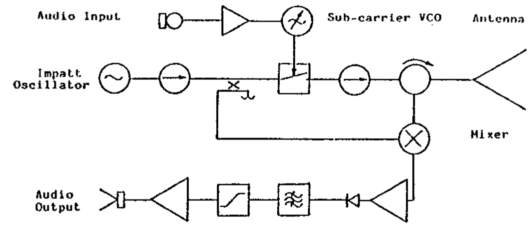


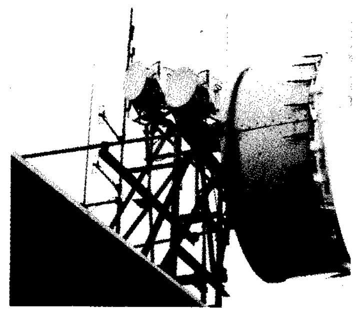
Fig. 3: 60 GHz covert communication link Schematic system diagram from: Brigginshaw et al. (18).

craft carriers or short-range inflight communication between aircrafts are also under consideration, respectively.

3.1.2 Commercial Applications As new services emerge for LAN (local area network) applications as well as in traffic control, the demand for a new generation of high data rate radio links has become obvious. VIDEO-CONFERENCE-SERVICES or SAT-and MEGASTREAM are examples for this upcoming new demand, as is the safety control of high speed trains.

POINT-TO-POINT transmission links, using portable equipment can be installed very rapidly on maximum hop lengths of up to 10 km. A good example for such a transmission link is the 29 GHz BTRL SYSTEM . Early work at British Telecom Research Laboratories (BTRL) was concentrated on developing a 70 Mbit/s system for transmission of data and fullband video traffic (21). The data of the resulting prototype system are given in Table 1 (20), while Figure 4 shows the installation of two 29 GHz transceiver units in conjuction with a microwave unit (6 GHz range). 70 transceiver units of this type have been built and the experience gained with these pilot production links now leads to a fully cost effective second generation product.

Fig. 4: 29 GHz BTRL System Installation of two transceiver sets (Courtesy of BTRL)



Manufact.	Type	Freq. GHz	Output Power mW	Modulation	Data Rate kbits/s	Hoplength km
BTRL		29	120	FSK/PSK	8k/70k	10
CNET		31	50	FM	528/704	10
AEG		40	100	FSK	1.2/64	3.5
Siemens	FSK 30k	36	100	FSK	4.3	.2-8
Alc.-Th.	TM 440	40	50	FM	BW:15MHz	15

TABLE 1: Performance data of millimeter-wave communication systems (20)

Besides the already described point-to-point connections a new type of application, called RADIOTUBE, has become important. The operation of modern railway systems with speeds as high as 300 km/h requires a high degree of safety and reliability. Due to the worldwide lack of frequencies for conventional mobile radio bands, millimeter-wave frequencies were chosen. as propagation measurements carried out earlier (22) have already shown the unique performance of this approach.

Two german firms, Siemens (23) and AEG (24), respectively, were involved in the development of a millimeter-wave railway communication system for the german federal railway, the 'Deutsche Bundesbahn'. The major system data of both systems are included in Table 1. According to the system requirements stationary and mobile transceiver units have been developed for the 40 GHz AEG SYSTEM. Fig. 5 shows a stationary unit during winter trials.

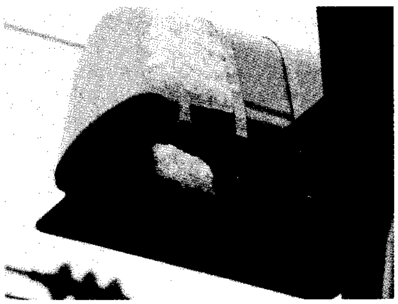


Fig. 5:
40 GHz AEG System
Stationary unit during winter trials

Several measurement campaigns have been carried out. Data rates between 1.2 kbits/s and 64 kbits/s were realized. The corresponding bit error rate was less than 10 * exp (-5) for a data rate of 1.2 kbits/s. Besides data transmission measurements, train control via 40 GHz transmission was demonstrated successfully.

Based on these results and the corresponding system design approach a 40 GHz communication system for the TVE, the german experimental Maglev Transportation System, is currently under construction at AEG-OLYMPIA of Berlin, West Germany. Besides train control, such systems will be taken for WAN (Wide Area Network) purposes also (25); corresponding developments are ongoing. High data rate millimeter-wave radios can be taken for various applications; 'Cellular Radio' in city environments (26) as well as 'Cordless Telephone' (27) are already published examples. Measured data show quite promissing results for future applications.

The described developments and investigations of millimeter-wave transmission links have rendered possible the commercial availability of such systems. Alcatel-Thomson's TM 440, NEC's Pasolink 50, Fujitsu's Facom 2160, and M/A-Com's 40 M are examples of COMMERCIALLY AVAILABLE mobile millimeter-wave communication links. The data of the first (28) is included in Table 1 for comparison.

3.2 Radar

The widest spread employments of millimeter-waves are found in radar. Seekers for terminal guided submunitions and battlefield radars, ground based or airborne, are military applications, while the contact-free measurement of distances or velocity in industry and road traffic are typical commercial uses.

3.2.1 Military Applications The most important application in this area are seekers for terminal guided submunitions (29). Besides stringent performance and low cost constraints a high production volume is required; thus the world-wide seeker development has stimulated todays millimeter-wave development efforts (30,31). Such seekers, engineered to production status, are available now from different manufacturers, as well in Europe as in the US, and make use of advanced integration techniques, like described in chapter 2.2 . Fig. 6 shows a dual polar FM-CW seeker module, built by Marconi of Stanmore, England (32).

Fig. 6:
W-band FM-CW seeker subsystem
Assembled transceiver unit
from: Nicholls et al. (32).

This subsystem has been realized, using microstrip on quartz technology. Some data are:

Output Power (single diode)	18	dBm
Noise Figure	10.5	dB
Antenna Beamwidth	2.25	deg.
Gain	35	dB

Efforts are ongoing in West Germany and France as well. A variety of instrumentation radars have been built, as data gathering of targets, terrain and clutter was the most important task for the development of signal processing algorithms, i.e. the tool to realize an 'intelligent' seeker.

Battlefield and terrain mapping radars at 94 GHz (33) have been developed and built in small quantities for measurement purposes, e.g. KORA (34). Besides these high resolution surveillance radars, there is a need for millimeter-wave tracking radars associated with radar controlled missile or gun systems. Such systems, e.g. (12), operate in the lower millimeter-wave regime (35 - 50 GHz) and provide ranging accuracies of better than 1 m for 10 or more km against targets of 0.1 m2 RCS. Fig. 7 shows a helicopterborne U-band solid state pulse compression radar (35) during first flight tests:

Output power	0.5	W peak
Compression ratio	30	
Antenna gain	37	dBi

Fig. 7:
U-band pulse compression radar during flight tests

Also an airborne millimeter-wave radar is the obstacle warning radar for helicopters (36). A non coherent pulse radar at a frequency of 66 GHz, this radar was designed to detect wire-like obstacles:

Output Power (min.)	1	W peak
Pulsewidth	50	nsec
Field of View		
azimuth	± 90	degrees
elevation	± 15	degrees

Depending on the wire diameter, 3 and 30 mm, detection ranges of 250 and 600 m minimum have been achieved under flight conditions, respectively. Instrumentation radars, that can be and have been taken for the same application - helicopter obstacle warning - have been built by Philips Research of Redhill, England (37) and Thomson-CSF of Malakoff, France (38), the millimeter-wave subsystem of the latter is shown in Fig. 8.

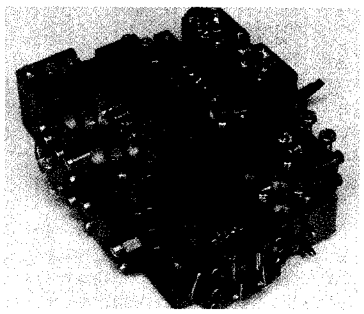


Fig. 8:
90 GHz range instrumentation radar RF module
(Courtesy of Thomson-CSF)

It should be noticed, that helicopter obstacle warning is not only a military necessity, this is also an important commercial application, provided that safty and cost requirements can be matched.

3.2.2 Commercial Applications 61.5 GHz vehicle sensors can be applied successfully for traffic jam avoidance or warning. These compact Doppler sensors were developed, making use of digital signal processing for the analysis of traffic situations (39). The sensor is relatively small, Fig. 9, and can be mounted easily on already existing signposts (-bridges) etc.. Since it is not necessary to open up the pavement, like it is with inductive loops, such a sensor is

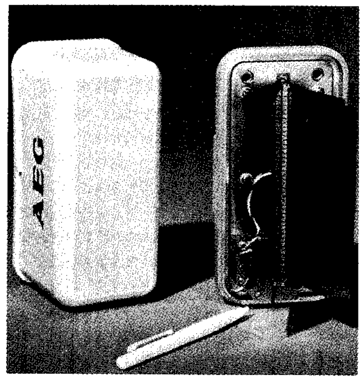


Fig. 9:
61.5 GHz vehicle sensor
Realized unit

especially suited for mobile installations, e.g. on construction sites.

In industry millimeter-wave radar can be employed in any situation, where movements, length or height have to be measured in a contactfree manner. Doppler sensing will be taken to gain information for automatic process control. An example of the later is the Top-Dead-Center (TDC) measurement of combustion engines. The exact turn-around-point of the piston in an engine is of great importance for fuel efficient car ignition. This can be accomplished, using Doppler sensing (40). The advantage of the millimeter-wave approach - again the 60 GHz range ISM-band - is the possible wave propagation through the spark plug. No seperate holes are necessary. The sensor was developed by AEG of Ulm, West Germany together with Volkswagen AG of Wolfsburg, West Germany. The TDC can be measured in fired engines with an accuracy of a few angle minutes.

It should be mentioned, that the just described Doppler sensor was built quite similar to the previously described vehicle sensor, showing that sensor standardization will be possible in spite of very different applications.

3.3 Remote Sensing
Radio Astronomy is the most important employment area for millimeter-wave remote sensing. As an excellent overview of this topic has been given by Dr. E. Kollberg in an invited paper at the last MTT-S venue in Las Vegas (41) this subject will not be covered here.

3.4 Reconnaisance
Millimeter-wave technology is advancing and first systems are already deployed in the military arena; thus millimeter-wave reconnaisance is becoming an urgent necessity today. A Ka-band DIFM receiver was developed by Philips Research of Redhill, England (42), having the following data:

Operating band	27 - 39 GHz
Sensitivity	- 62 dBm
Resolution (9 bit)	25 MHz

A millimeter-wave downconverter based on the 'superhet' principle was built by AEG

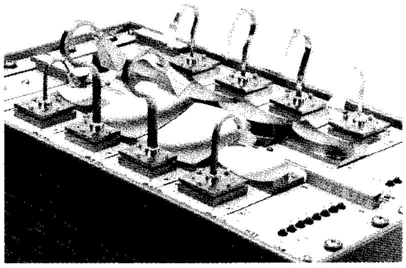


Fig. 10:
Millimeter-wave
downconverter

of Ulm, West Germany (43). Fig. 10 shows the downconverter with seperated directional antennas for each band.

4. CONCLUSION

It has been shown that millimeter-wave systems are applied successfully for various applications. However, wide spread applications will be hampered as long as millimeter-wave instrumentation is as expensive as it was. Emphazise is therefore now on low cost millimeter-wave technologies, being suited for large scale production as well; thus providing the background for terminal guided submunitions, precision tracking radar, or short range secure communications. Europe is in the forefront of this area; this is not only based on industrial efforts, but also a result of the excellent research work going on at european Universities. However, considerable effort is still necessary to get reliable, reproducible, and low-cost millimeter-wave sources. As demonstrated, millimter-wave technology was pushed by military needs, but today we have also a spreading commercial market.

5. ACKNOWLEDGEMENT

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