DEVELOPMENT OF A COMMERCIAL, 38 GHZ, COMMUNICATION LINK

W.Gulloch, M.Politi, R.Nobili (*)
and M.Amati, G.Colombo (**)

Alcatel Telettra, Vimercate, Italy
(*) Microwave Laboratory, (**) Systems Division

Abstract

This paper presents the work which has been carried out in the development of commercial radio links at Millimeter (MM) wave frequencies. The first part deals with the system aspects while in the second, results are presented for the MM wave components which have been developed. A common system approach has been used which is modular thus enabling the economic reuse of most of the lower frequency system functions. The modulation options which have been considered and their effect on the millimeter wave components are discussed. From this analysis a low cost system approach is presented based on the use of MMICs and broadband RF components. Offset 4QAM modulation (4OQAM) was used in order to provide a good compromise between amplifier linearity and spectral efficiency. This system design has been implemented at 38 GHz and various system results are presented.

System approach

New applications such as cellular systems have created the need for short range microwave links and due to overcrowding at lower frequencies it is foreseen that MM Wave frequencies will be used. The development of commercial MM wave equipment has been facilitated by the definition of common standards (Ref.1) and various bands have been cleared for use ranging from 28 to 58 GHz. Here the development of a low capacity (2-8 Mb/s) radio link is reported. These links will be used to provide Base Tranceiver Station (BTS) and Base Station Controller (BSC) connections in urban cellular networks. The work concentrates on links operating at 28 GHz and 38 GHz. The frequency choice depends on the climatic zone (eg 38 GHz in England and 28 GHz in Southern Europe). The system block diagram is shown in Fig. 1. The key points in this low cost system solution are as follows:

- Simplified system structure with a small number of MM wave components
- MMIC circuits to improve performance while reducing production costs
- Modular approach between the two frequency bands enabling circuit reuse
- Integration of the Modem unit with the outdoor tranceiver unit
- Integration of the tranceiver unit with the antenna

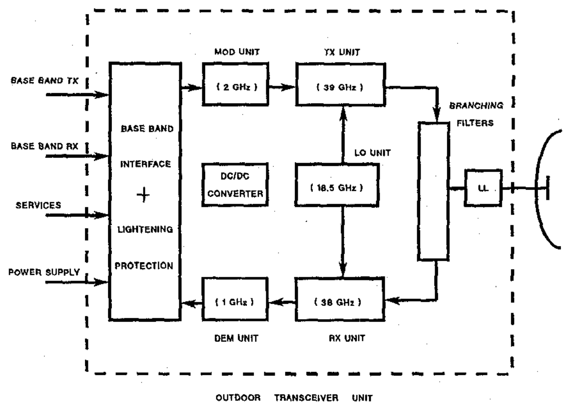


Fig.1 Simplified system block diagram

As shown in the system block diagram an Intermediate Frequency (IF) of approximately 2 GHz was used in the Transmitter (Tx) arm. This IF was upconverted to 39 GHz using a Single Side Band (SSB) mixer where it was amplified using a cascade of two MMIC amplifiers. A waveguide Diplexer with five resonator filters was used to complete the link to the antenna. On the Receiver (Rx) side a Double Side Band (DSB) mixer was used to convert the incoming signal to a fixed receiver IF of 1 GHz. Various amplification and filtering functions were then carried out before demodulation. For the 28 GHz system the use of an RF Low Noise Amplifier (LNA) was foreseen. Both the Tx and Rx mixers are operated in the subharmonic mode and a single (18.5 GHz) Local Oscillator (LO) was used.

CH3277-1/93/0000-0681$01.00 © 1993 IEEE

Modulation choices

For the modulation choice one of the initial solutions envisaged was the use of 2-level (or 4-level) FSK modulation, which could be implemented using traditional Gunn diode based oscillators operating directly at MM frequencies. For the 38 GHz band 2-level modulation is currently sufficient, however for the 28 GHz band a 4-level modulation is required. In order to have a common system approach it was decided to use a 4-level modulation. As the system threshold performance for 4FSK is considerably inferior to other more efficient 4-level modulations various alternative modulation schemes were considered, including 4PSK, 4QAM, 4OQAM and 4MSK. From these possibilities 4OQAM (roll off factor=0.5) was chosen as it offered a good compromise between the following parameters:

- Spectral efficiency (8 MB/s channel raster with 7 MHz step (Ref. 1)
- Transmitted power saving due to reduced backoff
- PA gain saving as higher upconverter power outputs can be achieved for the same intermodulation levels
- Improved threshold versus carrier-to-noise (C/N) ratio

Fig.2 shows a comparison between the RF output spectrum for 4OQAM and 4QAM.

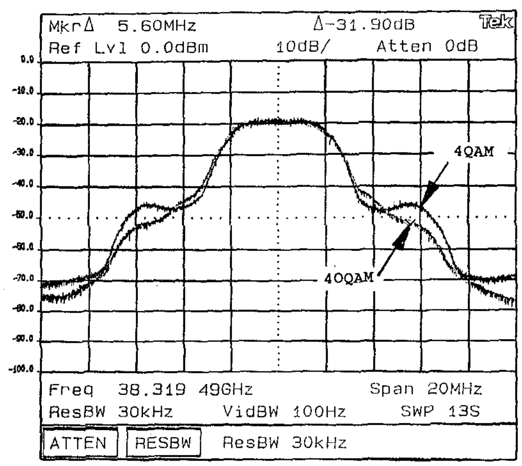


Fig.2. Comparison between 4OQAM and 4QAM spectra at 38 GHz

With 4OQAM modulation it was possible to obtain up to 2 dB more output power than with 4QAM for the same intermodulation level due to the reduced amplitude variation in the RF envelope with 4OQAM (only 3 dB), thus making this modulation less sensitive to mixer and amplifier nonlinearities. An example of a modulation type which has a rigorously constant RF amplitude envelope is MSK however it has increased spectral occupancy (near the carrier) when compared with QAM types, see Fig.3 (Ref.2) and poorer thermal noise threshold.

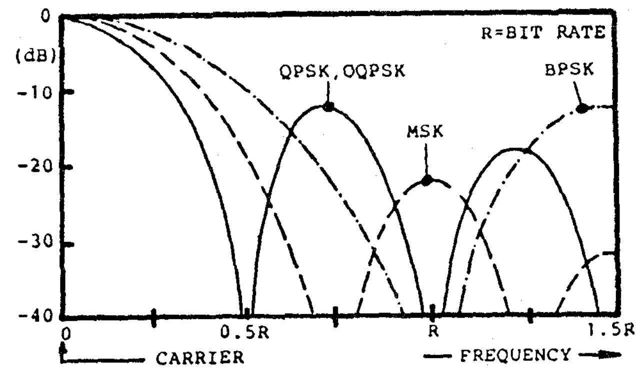


Fig.3 Power Spectra plot of MSK and QAM type modulations

Intermediate Frequency choice

The system was realised using a Tx IF of approximately 2 GHz with direct demodulation at a fixed frequency of 1 GHz. This choice has the following advantages:

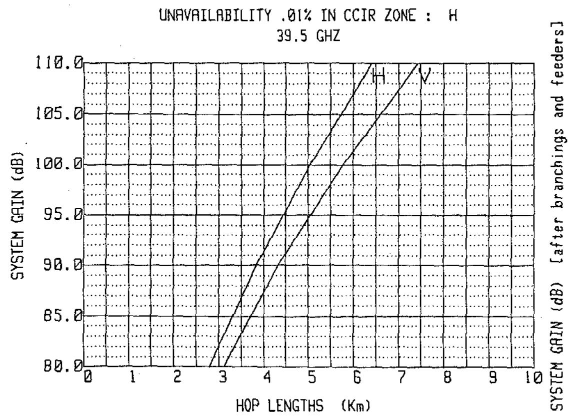
- Only one Local Oscillator for the Transmitter and Receiver
- Large bandwidth branching filters (lower loss). The channel used can be changed in the operator band without filter substitution
- Optimisation of the Mod/Demod processes at fixed frequencies

BER Threshold performance

The system has a BER 10E-3 threshold of -88 dBm at 2.3 MBt/s (including service channels) due to the following:

- Carrier-to-noise ratio of 11 dB (FEC contribution)
- Noise Figure equal to or less than 14 dB (no LNA used at 38 GHz)

The 28 GHz system will use a RF LNA thus lowering the NF to 9 dB with a corresponding improvement of 5 dB in the BER threshold. For the 38 GHz link a 38 dBi gain antenna was used, which together with a transmitted power of 17 dBm gives a link length (0.01 % unavailability, H zone (UK) see figure below) of greater than 5 Km at 39.5 GHz.



Technologies

Most of the RF part of the system was realised in microstrip due to its ease of manufacture and relatively low cost. The availibility of good commercial software modeling was also an important factor. For the initial prototype a mixture of hybrid and MMIC circuits were used. The MM wave hybrid circuits were directly soldered into the RF housing thus avoiding any possible grounding problems and no RF tuning of the microstrip circuits was used. The branching filters were manufactured in waveguide while most of the lower frequency circuits were realised using automated assembly techniques. For the microstrip circuits 0.254 mm (10 mil) alumina (Er 9.9) was used which is suitable for use up to at least 50 GHz. The insertion loss of a 50 ohm line on this substrate was found to be approximatly 0.3 dB/cm. Good agreement was found between experimental results for both linear and nonlinear simulation.

Initial tests on substrates were carried out using a commercial microstrip test jig. This jig enabled S-parameter tests to be carried out without the need for mounting the alumina substrates on metal carriers. The choice of microstrip as the main transmission medium was also made with the intention of transporting the hybrid designs (eg mixers) onto GaAs using MMIC techology at a future date. The use of MMIC circuits not only lowers the costs (for production quantities of greater than 1000 systems per annum) but also improves production yields.

Mixer and LO circuits

Simplification of the Local Oscillator circuit was achieved by the use of subharmonic mixers (LO at 18.5 GHz). In the system design the use of a single (high RF) LO was an important factor in cost reduction. The use of subharmonic mixers also has the advantage of high LO to RF isolation (Ref. 3). The conversion loss of the DSB subharmonic mixer (down conversion) was approximatly 7 dB which compares favorably with that of direct mixers. For the Tx SSB mixer the two most important factors are the side band rejection and the LO to RF isolation. Typical SSB mixer results are shown in Fig.4.

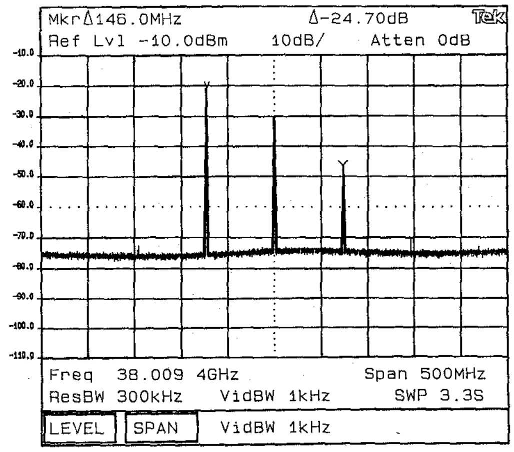


Fig.4 Hybrid mixer results

The side band rejection shown above is 25 dB while across the band (37 to 39.5 GHz) the minimum measured was 18 dB. For the same band a minimum LO rejection of 40 dB was measured. These results were obtained without any RF tuning of the mixer circuit .

MMIC Power Amplifier

Commercially available MMIC power amplifiers were used in the transmitter arm due to their good performance and low cost. These devices are based on 0.25 micron FET technology (Ref.4). Each MMIC chip consists of five FETs, a single FET was used on the input and the signal was then split using a Lange coupler into two arms each with two FETs in series. A second Lange coupler was then used to recombine the signal. The use of a Lange coupler on the output port ensures a good output match. Each MMIC chip had a minimum gain of 14 dB with a DC power consumption of less than 3 Watts. The use of MMICs was found to be a key point as the cost of current hybrid amplifier structures was prohibitive. The initial amplifier MMICs were mounted in a coaxial housing however for production a hermetic package will be used. A hermetic microstrip compatible package has been tested and the insertion loss due to each transition was found to be 0.2 dB. The hermetic transitions were realised using a short section of stripline (with stray capacitance compensation).

Measurements carried out indicated a useful frequency range of 30 to 45 GHz. For the Transmitter amplifier a gain plot is shown in Fig.5 (upper band, 38.25 to 39.5 GHz)

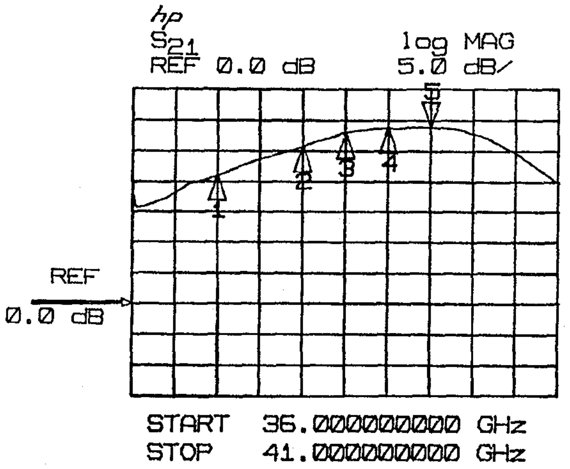


Fig.5. MMIC Amplifier gain plot

This amplifier result were obtained for a cascade of two MMIC PA chips.

Branching Filters

In order to fabricate the required branching filters at 38 GHz, waveguide was chosen due to its intrinsic low loss. E-Plane metal insert filters (inductive post filters) were identified as the most suitable due to simplicity, ease of assembly and suitability for high volumn production. In order to analyse and design E-Plane filters accurate software was developed (Ref. 5). Following on from this work a waveguide diplexer was developed (Ref. 6). See Fig. 6 for results plot.

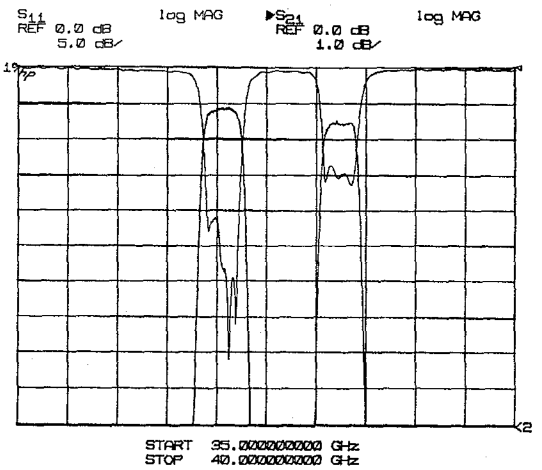


Fig.6. Diplexer experimental results showing the Rx and Tx path loss and match.

The use of a diplexer eliminates the need for a circulator and results in a compact structure. The filters were realised by etching a metal insert to the correct dimensions using a double sided etching process. The insert was then clamped between two split waveguide blocks to complete the construction. Given the accuracy of the software and construction techniques no RF tuning was found to be necessary during testing of the initial filters. For production a temperature compensation structure was also added.

Conclusions

The requirement for low cost MM wave systems has been analysed and a common system for low capacity data rates has been developed and presented. It was found that a system based on 40QAM modulation offered a very good compromise between spectral efficency, power output and receiver threshold. The use of MMIC circuits was found to be necessary in order to reduce system costs.

Acknowledgements

The assistance of Alpha Industries Inc. is acknowledged for the provision of MM wave MMIC power amplifers.

References

1. ETSI Standards
   TM4(92) 101 and DE/TM-4001

2. F. Ananasso
   "A Novel Technique to Realise SMSK Conversion and Matched Filters"
   IEEE MTT-S, Symposium Digest, June 1985

3. S. Maas.
   "Microwave Mixers"
   Artech House Inc. Washington, 1986.

4. L.Raffaelli and E.Stewart
   "A Standard Monolithic Transmitter for 38 GHz PCN Applications"
   Microwave Journal, Oct 92.

5. T.Rozzi, A.Morini, F.Moglie, M.Politi and W.Gulloch.
   "Wide Band Equivalent Circuits of Inductive Posts in Waveguide".
   IEEE MTI Volume 40, May 1992.

6. A.Morini T.Rozzi, D.De Angelis and W.Gulloch
   "A Novel Matched Diplexer Configuration in E-Plane Technology"
   Accepted for publication in the IEEE MTT-S, Atlanta, June 1993