Microwave/mm-wave Components & Technology for Short Haul Digital Radio Links

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Introduction:

The wireless revolution has created a number of new opportunities for microwave technology. Point to point radios are now being used to connect cellular and PCS cell sites with the central switching station as well as for private data links. With the saturation at frequencies below Ku band, 13,15,18,23 & 38 GHz radio bands have been internationally accepted for the emerging wireless applications. These radios however need to be cost competitive to leasing equivalent wireline capacity from the local telephone company for being successful in the urban areas. With the ever changing communication demands, customers are looking for flexible hardware that allows them to buy and re-configure as they grow. They want a reliable communication link and they want it fast. These radios must offer a faster deployment and better network control to the service providers. Another new application at mmw frequencies is the LMDS (Local Multipoint Distribution Service) at 28 and 42 GHz in North America and Europe respectively. This application is targeted towards interactive TV transmission, two way high speed data transmission as well as voice to homes and businesses.

In order to produce radios for these emerging needs, low cost, user friendly and high performance components at microwave /millimeter wave frequencies are a basic necessity. The most expensive components are the Transmitters & the Receivers at these frequencies. This paper will describe different approaches used in the transmitter & receiver design of these radios. A unique approach optimizing the use of silicon and GaAs technologies for a high performance and cost competitive solution for the Tx & Rx is presented. Components & technology developed for Transmitter and Receiver for 38 GHz radios is described.

Frequency Bands and Modulation Schemes:

Presently the frequency bands used internationally for applications to interconnect the cellular & PCS base stations are shown in the Table I below. The selection of frequencies for a particular application depends upon many variables including geographical location, regulatory issues, required range coverage & interaction with existing microwave radios for other applications. As an example while 23 & 38 GHz are commonly used frequencies in western Europe and United States, 13, 15 & 18 GHz are more popular in developing countries like of Eastern Europe, South America and India. Lower frequencies are generally preferred for areas prone to heavy rains in order to reduce the effect of rain attenuation on the link performance.

The radios needed for the LMDS applications in the US are are expected to be in the range of 27.5 to 28.35 GHz for the down stream (Hub Transmitter) and 31to 31.3 GHz for the upstream (Customer Premises Equipment CPE Tx). In Europe the frequency band for this application is 40.5 to 42.5 GHz. These are point-to-multipoint applications where a multi-sector base station can cover hundreds of subscribers for two way communication. Transmitter power required for these Hub stations is greater than 1W per sector. The volume of mmw devices and components required for this application is expected to be orders of magnitude larger than those for the point-to-point applications described above.

Table I Frequency Bands	
Frequency Band	**Power Out**
37.0 - 40.0 GHz	18 dBm
24.5 - 26.5 GHz	18 dBm
21.2 - 23.6 GHz	19 dBm
17.7 - 19.7 GHz	20 dBm
14.2 -15.3 GHz	20/23 dBm
12.7 -13.3 GHz	20/23 dBm

Table II Modulation Formats		
Modulation	**Efficiency**	**CNR for E-6**
4L FSK	~1.5 b/sec	~ 17 dB
QPSK	~1.6 b/sec	~ 14 dB
8 PSK	~ 2.5 b/sec	~ 19 dB
16 QAM	~3.2 b/sec	~ 21 dB
64 QAM	~5.0 b/sec	~ 27 dB

The data rates for the point-to-point radios vary from 2Mbits/s to45Mbits/s. A number of modulation schemes are presently used for the PCN/Cellular digital radios (see Table II). This includes 4L-FSK, QPSK, OQPSK & CPM. The difference between the technology requirements for different modulations is in the area of power amp linearity & phase noise for L.O./Tx. A 4L-FSK Tx can use saturated amplifiers compared to a 3 dB back off from P-1 dB required for a QPSK Tx and >10dB back off for higher levels of QAM modulation schemes. A 4L-FSK Tx can operate easily with -80dBc/Hz @ 100 KHz phase noise Tx, while a QPSK Tx will need about -95 dBc/Hz @100 KHz. Need for higher spectral efficiencies in the future will drive the need for higher level modulations.

Components & Technology for Transmitters:

The architecture for the point-to-point and point-to-multi point radios depends upon several factors including modulation scheme and available technology and can be represented by two general topologies as follows:

a) *Block Upconverted Transmitter:*

This approach is shown in figure 1 below. In this case a modulated lower IF frequency, generally between 2 to 4 GHz, is upconverted to the desired Transmitter frequency, filtered and amplified. This approach can be used for 4L-FSK as well as for QPSK/QAM schemes. Higher IF will make the filtering and hence meeting the spurious specifications easier. A typical communication band is covered in two bands. L.O. phase noise and power amplifier linearity is defined by the modulation scheme. In case of modulation requiring linear amplifier, the output power control can be implemented at the IF section.

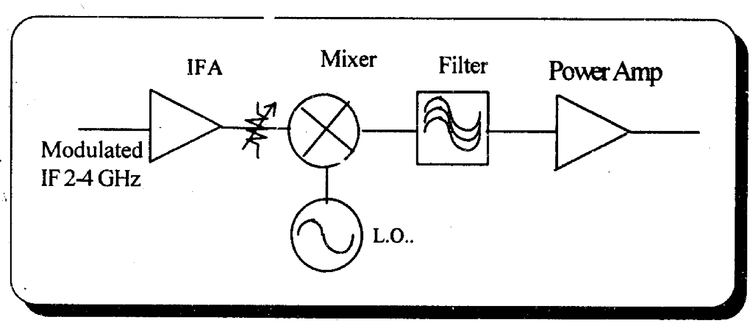

Fig. 1 Upconverter Transmitter Block Diagram

b) *Direct VCO Modulation Transmitter:*

This approach shown in fig. 2 is a VCO based Tx in which a fundamental VCO at the sub-harmonic of the desired radio frequency is directly modulated through the tuning port. This approach is typically used for the 4L FSK modulation radios. A single module can be used to cover full communication band using this approach. Transmitter modules for 15, 18, 23, 26 & 38 GHz have been developed In this paper we will discuss the technology & performance results of this approach at 38 GHz.

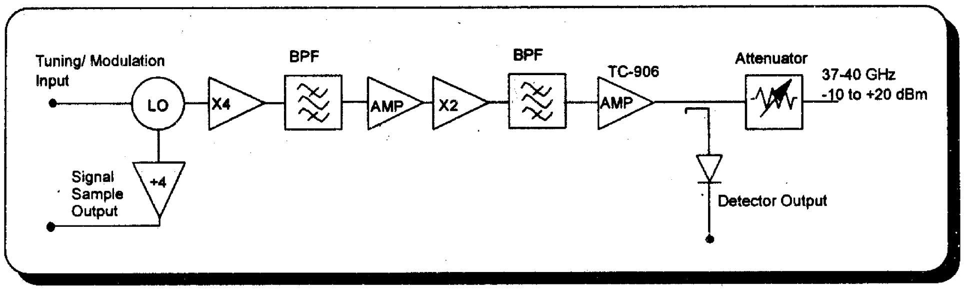

Fig. 2 Direct VCO modulation based Transmitter Module at 38 GHz

In this approach optimum use of silicon and GaAs technologies has been made to achieve a high performance, state of the art and cost competitive solution for the Tx source at 38 GHz (figure 2). This source simultaneously provides an L-Band signal in addition to the final frequency. A low phase noise C-Band VCO with two outputs represents the basic source. One output feeds a GaAs FET frequency quadrupler with 10 dB loss to generate a Ku-Band signal. The second output feeds a silicon 'divide by four' MMIC in order to generate an L-Band signal intended for phase locking the VCO with an external circuit. A GaAs PHEMT frequency doubler with 6 dB loss is then used to convert Ku-Band signal into 38 GHz band. A high gain 20 dBm power MMIC represents the output amplifier stage. Bias of this device is switched off to provide mute control. A PIN diode attenuator at the output allows to control the output power by more than 30 dB. A diode detector in the output provides a power monitor feature.

The performance of this transmitter can be summarized as follows:

Frequency Range: 37 to 40 GHz
Power Output : 20 dBm typ. 18 dBm min
Phase Noise @ 40 GHz: -85 dBc/Hz @ 100 KHz
Tuning Voltage: 1 to 12 Volts

Components & Technology for Receivers:

Typical receiver block diagram is shown in figure 3 which represents a modern microwave/mmw receiver incorporating a low noise LNA. Receiver Down-Converters have been developed for 15, 18,23,26 & 38 GHz bands. Figure 3 describes the down-converter at 38 GHz.

In order to reduce the LNA contribution to the noise an image reject mixer needs to be employed. The requirements on the linearity of LNA, mixer & L.O. phase noise are dictated by the modulation scheme used. Once an LNA precedes the first down-converter, the requirements on the mixer are not as stringent as they are in an unbuffered system. It is important to keep the noise-figure of the receiver as low as possible, as this front-end value ultimately determines the threshold level of the receive channel and the overall sensitivity of the radio system. The desired frequency bandwidth can be covered in one or two bands depending upon the system requirements of flexibility for T/R spacing and IF.

A low noise at the front end not only improves the overall system noise figure but also provides a highly desirable consistency for high volume manufacturing. A good LNA can provide enough isolation between the mixer and diplexer/antenna without the need of an expensive isolator. An

HP PHEMT MMICs is used at the 38 GHz band. This device offers typically about 5 dB NF and 20 dB gain over 38 GHz band.

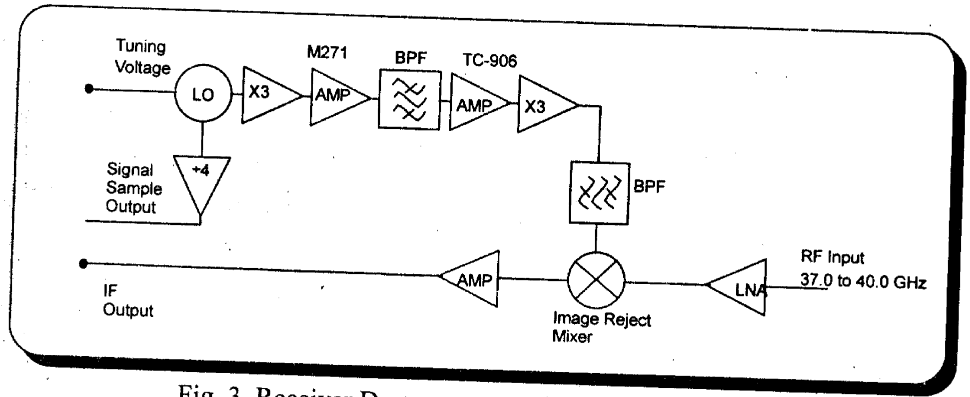

Fig. 3 Receiver Down-converter Module at 38 GHz

Image Rejection is necessary when an LNA is used in the down-converter. Image rejection can be achieved by using either a bandpass filter or by using an image reject mixer (IRM). IRM Mixer is an attractive option as it is universal in nature and does not depend upon the filtering requirements of any particular system configuration. In the down-converter under consideration, hybrid IRMs have been used in order to achieve the desired rejection of 14 dB at 23 GHz and 12 dB at 38 GHz. The balanced mixer is a microstrip rat race mixer the layout of which is optimized over the communication band.

The L.O. configuration is similar to that of the Transmitter. Phase noise of better than -85 dBc/Hz at 100 KHz offset has been achieved at 40 GHz to help meet the system requirements of the 4L FSK digital radio links. A low noise HP silicon IF amplifier MSA1100 is used as IF amplifier. It has a gain of >10 dB at the IF frequencies up to 1350 MHz and has a noise figure of 5 dB. P-1 dB of this amplifier is better than 13 dBm. A noise figure of better than 7.5 dB was achieved for the down converter shown in figure 3 above.

Technology Direction:

The growth in the wireless (cellular, PCS & private links) market is a driver for the high volumes and lower prices for the components described in this paper. In the future the component manufacturers are going to see an intense pressure for delivering just enough performance at the lowest possible cost. Improved phase noise sources and linear higher power output devices will be required to meet the emerging higher spectral efficiency needs of the Information super highway. Increased MMIC insertion will be the key to reduced cost in volume production. An optimum combination of GaAs MESFET, PHEMT, HBTs and Si devices will be used to achieve the necessary integration to achieve performance and cost objectives. A significant effort on innovative packaging, substrate and interface techniques will be necessary, in order to develop competitive products. The cost targets, particularly on the CPE (Customer Premises Equipment) for the LMDS market represent a challenging opportunity for the mmw engineers. In addition to getting used to continuous cost reduction, the mmw component manufacturers will need to learn the high volume manufacturing techniques to meet the growing needs of the markets described above.

Conclusion:

Emerging radio applications of the microwave and millimeter wave technology have been presented. RF subsystem architecture for digital radios is described. Transmitter and Receiver module configurations and performance for a typical 38 GHz point-to-point radio application has been reported.