Low Cost Ka Band Transceiver for Digital Radios

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Abstract -The wireless revolution has created a number of new opportunities for microwave technology. Point to point radios have been used to connect cellular and PCN cell sites with the central switching station as well as for private data links. 15,18,23 and 38 GHz radio bands have emerged as internationally accepted bands for the emerging of wireless applications. Point to multi point radios are being used for the last mile access at 24, 28 and 38 GHz. The radios however need to be cost competitive to leasing equivalent wireline capacity from local telephone or cable TV companies. The most expensive component is the transceiver in these frequencies. In this paper we describes a low cost, high performance transceiver for the 38.6-40 GHz band. A high performance low cost transceiver is presented using thin film technology and standard semiconductor devices and MMICs. Design of various components is described and some of the system design considerations are discussed.

I. DESIGN APPROACH

The Ka band transceiver's configuration is shown in fig.1. A low phase noise and highly linear C- Band BJT VCO is followed by two GaAs frequency multipliers to achieve the final frequency of 37 to 40 GHz. This LO signal feeds the Ka Band up and down converters for both the transmitter and the receiver parts. IFin signal is upconverted to the final RFout frequency and RFin signal at the receive input is downconverted to IFout. An auxiliary output of the VCO feeds a silicon divider by four MMIC prescalar to generate L-Band signal to be used for phase locking.

The RF signal at the up converter output is amplified by HP MMIC amplifiers, and microstrip filters reject the spurious as well as the harmonics. The received RF signal is amplified by a MMIC LNA followed by an image reject filter and the down converter.

The ceramic substrates as well as the components are designed for epoxy attach using an automatic pick-and-place process. This assembly process is proven to be a fast and a repeatable process and can significantly reduce the product cost. The main features of this Ka Band transceiver are:

Transmitter: Output power of 18 dBm, . Phase noise better than –85 dBc/Hz @ 100 KHz. Maximum LO leakage < -10dBm at the output. Receiver Noise Figure < 5.5dB. Spurious signals at the IF to be lower than –85 dBm. The main subsystem circuits and the system design considerations are detailed in the following sections.

II. VCO & FREQUENCY DIVIDER

The C Band VCO is the main element of this unique source module. The challenge is to provide a low phase noise and high linearity VCO. An in house low 1/f noise silicon bipolar device is in conjunction with a high Q hyperubrupt varactor has been used. A resonator tank, which is composed of the varactor, a capacitor and an inductor in parallel, is used in the base of the transistor. The RF output is taken from the collector. A series feedback capacitor is used in the emitter to generate necessary negative resistance in the desired frequency range. High linearity is achieved by tuning the inductor value that resonates the total capacitance in the tank.

Power output of greater than 10 dBm has been obtained over 4 to 5 GHz. Phase noise at 100 KHz was measured to be better than –105dBc/Hz. The VCO was tuned to get 25 MHz/V of modulation sense. An HP silicon frequency divider by four is used on the second RF output port, lightly coupled to the VCO. This prescalar requires only –10 dBm and provides –5dBm power output at one fourth of the frequency. The phase noise of the VCO after multiplication by 9 is plotted in fig. 2.

III. FREQUENCY MULTIPLIERS & POWER MMICS

The VCO frequency is multiplied 9 times to the Ka band. The multiplier consists of two separated times 3 multipliers. The first is an active multiplier based on a HP GaAs FET with 0.25μm gate length and 250μm gate width, fabricated on MBE material. An open stub at the low frequency was connected to the drain for blocking the fundamental frequency mode while simultaneously presenting the necessary reactance for maximum multiplication gain. A highly selective band pass filter was used in the output to eliminate the undesired harmonics. A conversion gain of 0dB was obtained over 12 to 14 GHz.

The second frequency multiplier uses an HP GaAs PHEMT with a sub 0.2μm gate length and 448μm gate width, fabricated on MBE material. The device has a f_t of 70 GHz and f_{max} of 120 GHz and is capable of delivering 21 dBm of linear power with 9dB of gain at 20 GHz. The device has a high non-linear transconductance that is adequate for generation of high order harmonics once the bias and matching circuits are optimized [1]. A tunable short stub of electrical length of 180^0 at 13 GHz was connected to the drain for reflecting back the fundamental frequency in the correct phase in order to increase the power at 40 GHz range. A highly selective band pass filter was used in the output to eliminate the undesired harmonics. A conversion loss of 8 dB was achieved for multiplying of 12 to 14 GHz signal. HP MDS program was used for both frequency multipliers to optimize the input/output match as well as the bias.

HMMC2040 an HP 20-42 GHz MMIC 4-stage amplifier was used as a buffer at the output of the Ka band frequency multiplier and also for the Tx power stage. The device has a gain of greater than 20dB and saturated power of greater than 20dBm. This device dissipates about 300 mA at 4.5V.

IV. UP AND DOWN CONVERTERS

Up and down converters are key parts of the transceiver. Even though the mixing function is similar for both applications, there is difference in the performance requirements. Up-converter mixer needs to be as balanced as possible in order to minimize the LO leakage while the down converter mixer needs to have low Noise Figure and high image rejection. In order to simplify the transmitter amplifying and filtering chain, an upconverter mixer with a high value of 1dB compression point and high LO to RF isolation was designed. The upconverter is a balanced microstrip rat race mixer fabricated on ceramic substrate. The beam lead shotkey diodes were matched using HP MDS program in order to minimize the reflected signals, and to improve the isolation between the LO and the RF ports. A few different pairs of shotkey diodes were tested. The best results were achieved with HP HSCH5511 diodes and 5 mils ceramic substrate. An LO to RF isolation of 28dB and a 1dB compression of 0dBm at the RF port were achieved in a bandwidth of 1 GHz.

The same mixer circuit was used for the down converter. Necessary image rejection to reject the LNA noise at the image frequency, can be obtained by using an image reject mixer or a band pass filter. In our case due to the narrow bandwidth requirement and selection of IF frequency, lower cost option of using a bandpass filter after the LNA was selected. The mixer Nose Figure was measured to be 8 dB. An HP MMIC HMMC-5038 was used as a Low Noise Amplifier. This four stage LNA device has gain of greater than 20 dB and noise figure of better than 5 dB from 35 to 42 GHz. This device dissipates 120 mA at 3V. Total receiver noise figure was 5.5 dB.

V. MICROSTRIP TRANSITION

A microstrip to waveguide transition, fabricated on ceramic substrate, was designed. The substrate was epoxied directly over the waveguide opening, located in the base of the case. The transition substrate circuit was used to transmit and to receive the RF signals and also to hermetically close the waveguide opening. An insertion loss of less than 0.5dB was achieved. The return loss was better than 12dB over a frequency bandwidth of 700MHz.

VI. WAVEGUIDE BEND

An integrated waveguide bend was designed, using HP HFSS, to link the Ka band waveguide transceiver output ports, located at the bottom of the case, with the antenna. This kind of solution, as shown in fig. 3, gives the flexibility to place the antenna or the duplexer in different locations. An insertion loss of less than 0.1dB was achieved. The return loss was better than -25dB in an extra wide frequency bandwidth.

VII. SYSTEM DESIGN CONSIDERATIONS

There are many system design considerations the designer should be aware of. We present here only two important issues, the frequency plan and the Transmitter to Receiver isolation.

a) *Frequency Plan*

Frequency plan- in the US the FCC has licensed 38.6 to 40 GHz (38.6-39.3 GHz and 39.3-40 GHz) band to cover a rectangular area. 700 MHz is the spacing between the received and transmitted RF frequencies and also between the IF_{in} and If_{out} frequencies. The three interdependent parameters involved in the frequency planning are the VCO, the IF_{in} and If_{out} frequencies. Choosing one of them automatically determines the other two. The criterion for designing a frequency plan is based on obtaining the simplest and cheapest signal filtration. Another criterion is to prevent the appearance of an undesired signal at the receiver IF port. Such a signal can be created by the combination of the VCO and the Tx IF frequencies, n*VCO+/-m* $IF_{in.}$ A low order intermodulation product is a severe problem that must be prevented by choosing a correct frequency plan.

b) *Transmitter-Receiver Isolation:*

A high isolation between the Transmitter and the Receiver ports can prevent a saturation of the LNA in the Receiver port by the Transmitter signal. Another good reason for this high isolation is to reject the filtered white noise that appears at the Transmitter output port. Such a noise, which is equal to KTGF W/Hz, might be injected into the receiver input and dramatically increase the system NF. It is important to design necessary Transmitter to Receiver isolation internally and externally to the unit.

VIII. EXPERIMENTAL RESULTS AND CONCLUSION

A low cost tranceiver for the band of 38.6 to 40 GHz has been described. A picture of the transceiver is shown in fig. 4. The softboard contains DC bias circuits as well as the IF amplifier stages at the transmitter input and Receiver output. The high frequency components including VCO, frequency multipliers, up & down converters and MMIC amplifiers were implemented on Alumina substrate using thin film chip and wire technology. Special consideration was paid to the circuit and mechanical layout in order to minimize any interference between transmitter and receiver. The system design considerations and the technology we used are the basis for making a low cost high performance transceiver. Total power dissipation of the transceiver was less than 8W. The dimensions of the transceiver unit are 3.5” x 2.5” x 0.4” (without the integrated waveguide bend) . The key results of the complete transceiver are as follows:

Transmitter

Frequency Range	38.6 – 40 GHz
Power Output	> 18 dBm
Signal Phase Noise	-85 dBc/Hz @100K
Spurious	< 40 dB

Receiver

Frequency Range	38.6 – 40 GHz
Rx Gain	30 dB
Noise Figure	5.5 dB
P-1 dB Rx In	-20 dBm

IX. ACKNOWLEDGEMENTS

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X. REFERENCES

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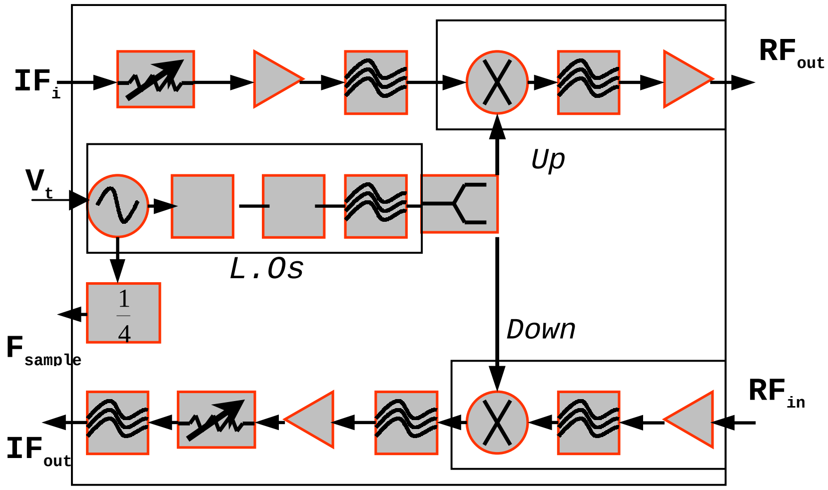

Fig. 1 The Ka Band Transceiver Block Diagram.

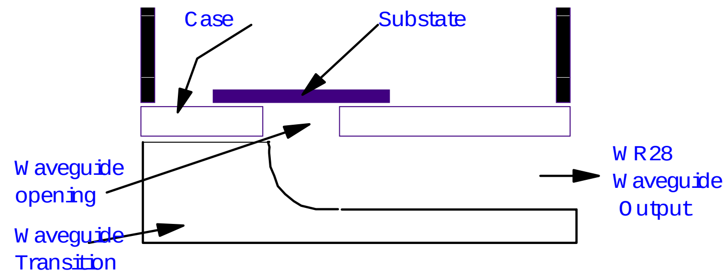

Fig. 3 Integrated Waveguide Bend

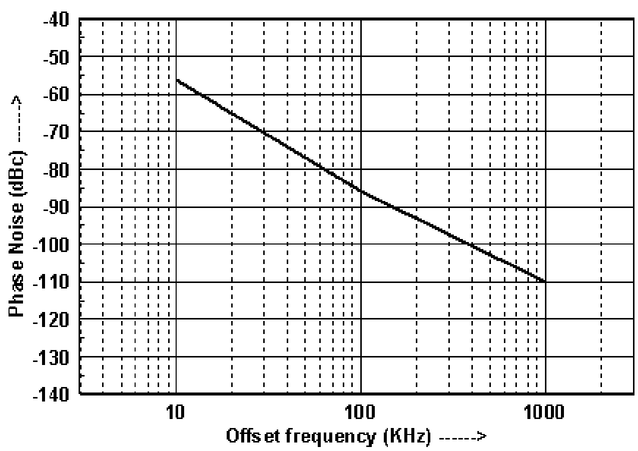

Fig. 3 Phase Noise Plot at 40 GHz

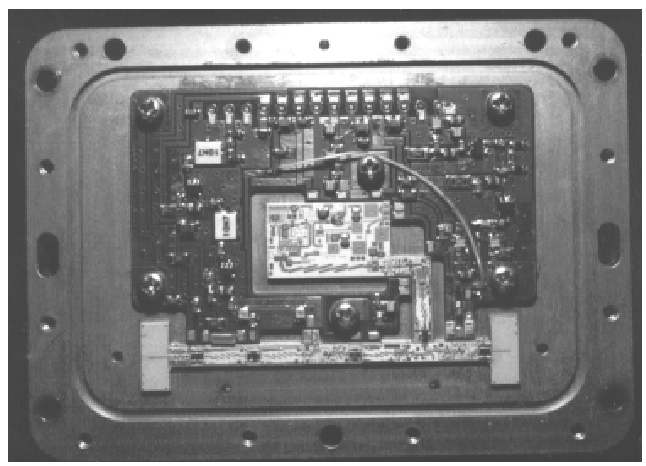

Fig. 4 Photograph of Ka Band Transceiver.