A New Design Technique of 40 GHz Up-Converter Modules for Digital Microwave Radios

Kang Wook Kim† and Dong-Sik Woo*

Abstract - A new design technique of fabricating 40 GHz up-converter modules for digital microwave radios has been developed. The design of the up-converter module is based on unit circuit blocks, which are to be characterized using a special test fixture. The complete module design may be as simple as a cascade layout of these unit circuit blocks. Also, the 40 GHz up-converter module employs a new microstrip-to-waveguide transition and a tapped edge-coupled filter, which are less sensitive to fabrication tolerances.

Keywords: converter, LMDS, microwave, module, radio

1. Introduction

Recently, thanks to ever increasing requests for broadband data communications over the internet, there are increased interests in microwave/millimeter-wave digital microwave radios, such as 28 GHz and 40 GHz LMDS (Local Multipoint Distribution System) and point-to-point radios, which can provide broadband wireless connections [1]. The front-end components of these digital microwave radios are microwave/millimeter-wave transceivers. One of the major factors for the success of digital microwave radios is low-cost mass production of CPE (consumer premise equipment) transceivers [2]. However, for these microwave/ millimeter-wave transceivers, the surface-mount technique that is usually utilized for RF circuit fabrication cannot be directly applied due to electromagnetic interactions of circuit components at these high frequencies. Generally, millimeter-wave transceiver modules are expensive due to costly circuit components (MMICs, diodes, discrete FETs, etc.), complexity of module fabrication technique, and difficulty in performance measurements. Therefore, development of low-cost and reliable fabrication techniques of millimeter-wave transceiver modules is considered to be essential for achieving successful wireless broadband communications.

In this paper, a new design technique based on unit circuit blocks is presented for the design and prototype of a low-cost, reliable 40 GHz up-converter module. Unit circuit blocks are defined and used in the design of the up-converter. Once the performance of each unit circuit block is identified, the complete module can be designed as a simple cascade of these unit circuit blocks. The design technique based on unit circuit blocks has been widely used in microwave companies for circuit designs using thin-film based circuits. However, this design technique has been first adopted in this paper for the circuit design using soft-boards such as Duroid 5880®. This design technique applied to soft-boards provides an additional advantage over the thin-film design approach. First, it allows module construction based on tested unit circuit blocks. Second, it provides an option to build cascaded unit circuit blocks into one RF board. In addition, designing modules using soft-boards can result in low-cost solutions. Also, unlike the conventional soft-board design technique, this design technique helps to reuse expensive circuit components after prototyping for one application. Once the unit circuit blocks are built and tested, they may be saved to build a circuit library for fast prototyping of the variety of transceiver modules that the market requires.

The up-converter module in this paper employs new circuit components such as the dielectric-covered microstrip-to-waveguide transition [3], and tapped edge-coupled filters [4], which are less sensitive to fabrication tolerances.

2. Design of the 40 GHz Up-converter Module

Since the specifications of 40 GHz up-converters may differ depending on types of digital microwave radios, typical specifications for general high-performance up-converters are chosen as shown in Table 1. The design technique based on the unit circuit blocks is then applied to design the up-converter module to satisfy the chosen specifications. System analysis and design software, SysCalc®, is used for the design of the 40 GHz up-

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converter module as presented in Fig. 1. The circuit components (amplifiers, frequency multiplier, etc.) in the RF chain of the module are chosen among the commercially-available MMIC chips. In Fig. 1, a modulated IF signal passes through a pi-pad attenuator, which improves the return loss. The IF signal is then amplified by an IF amplifier, which should be chosen to reduce the output noise power from the up-converter module. Then, two Thermopad® attenuators are used to compensate power gain variation over the temperature range of -30 to +80° C. As the temperature increases, the power gain of the MMIC amplifier deceases by about -0.012 dB/° C per amplifier stage. The modulated IF signal is then mixed and up-converted by a ring mixer, which consists of a rat-race hybrid coupler and two flip-chip diodes. An attenuator is inserted after the mixer to improve isolation between this mixer and the following filter. The bandpass filter is attached next to the mixer since the measured LO-RF isolation of the ring mixer is about 20 dB, and it was necessary to suppress the LO component before amplifying the RF signal. Otherwise, the subsequent amplifier became saturated due to the LO leakage signal. Therefore, the bandpass filter was designed to suppress the LO frequency (38 GHz) by at least 20 dB. The up-converted and filtered 40 GHz signal is then amplified using a low-noise high-gain amplifier, Raytheon RMWL38001. Then, the RF signal is further amplified using a driver amplifier, UMS CHA3093C. The RF signal is finally amplified by a power amplifier (PA), Triquint TGA1171 to achieve the power level according to the specification. The power gain, power compression (P1dB) and third-order intercept point (IP3) of the interstage amplifiers and passive components should be properly chosen to satisfy the overall specifications of the module. Due to the temperature compensating property of Thermopad®, the up-converter module is designed to perform with power gain variation less than 1.5 dB, and P1dB and IP3 less than 2 dB over the temperature range of -30 to +80° C. For the LO chain, a stable 12.67 GHz signal is supplied externally. The frequency of the LO signal is then tripled using a MMIC multiplier, UMS CHX1094. The multiplied signal is filtered to remove spurious components, and then amplified to provide sufficient power, i.e., +10 dBm, to drive the ring mixer.

Table 1 Typical specifications for a 40 GHz up-converter

Parameters	Unit	Spec.
RF Frequency Range	GHz	38.5 - 40
IF Frequency	GHz	2
LO Multiplier		3
Operating Temperature	°C	-30 to 80
RF Power Output	dBm	27 min.
Conversion Gain	dB	30
Conversion Gain Variation	dB	±2 max.
Input Return Loss	dB	10 min.
Output Return Loss	dB	10 min.
1dB Compression Point (P1dB)	dBm	26 min.(Output)
3rd-order Intermodulation Point (PIP3)	dBm	32 min.(Output)
Stability	Unconditionally stable	
DC Bias (positive)	max.	+8V, 1400 mA
DC Bias (negative)	max.	-5V, 100 mA

3. Implementation of the 40 GHz Up-Converter Module

For the substrate of the RF board, Roger Duroid® 5880, which is a PTFE composite material, is used. The relative dielectric constant of Duroid® 5880 is 2.2, and its loss tangent is 0.0009. All circuit boards of the 40 GHz up-converter module were fabricated in-house using the RF circuit prototyping machine, LPKF C-60.

3.1 Design of the Up-Converter Module using Unit Circuit Blocks

With the module design using the cascade analysis tool as shown in Fig. 1, the circuit components were chosen. In order to test the DC and RF properties of each circuit component, a unit circuit block is defined. The unit circuit block contains one major circuit component (such as MMIC LNA, MMIC PA, mixer, filter, etc.), transmission lines, and bias circuitry. In order to install MMIC components and to attach the Duroid® substrate, a carrier, which is composed of Molybdenum the size of 298-mil x 600-mil (7.56mm x 15.25mm) and thickness of 15-mil, is used. Molybdenum is chosen among other materials for the

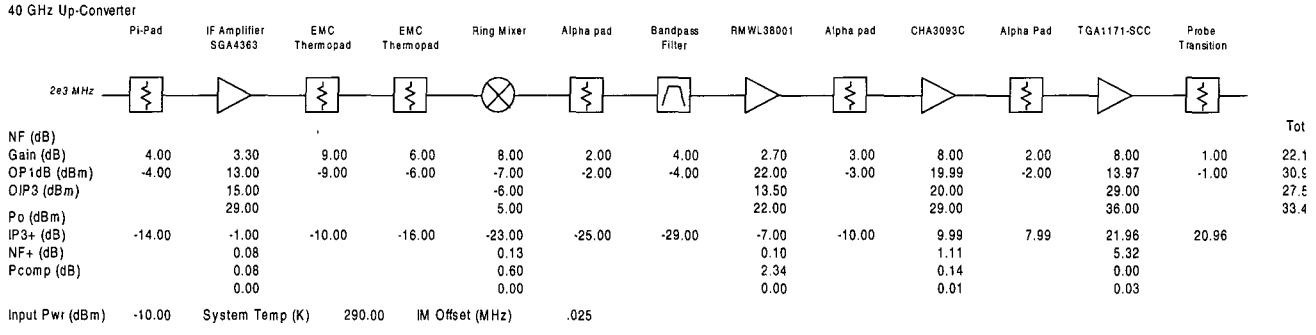


Fig. 1 Linear cascade analysis and design of a 40 GHz up-converter module

circuit carrier by considering good thermal expansion and heat conduction properties. Using this carrier for constructing a unit circuit block, the major circuit blocks are designed and shown in Fig. 2.

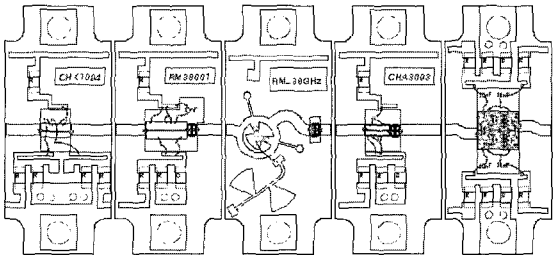
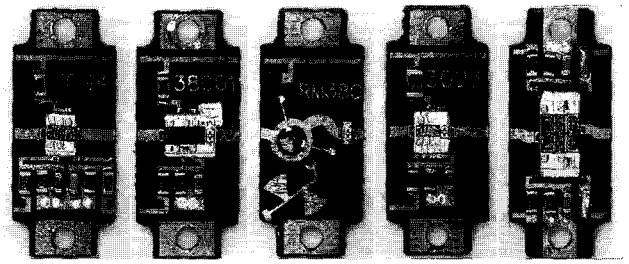


Fig. 2 Design of unit circuit blocks for the 40 GHz up-converter

3.2 Testing of the Circuit Blocks

After identifying the DC and RF properties of each circuit block, the up-converter module can be constructed as a cascade connection of these unit circuit blocks. Since the operation frequency is very high, i.e., 40 GHz, the separation distance between these circuit blocks should be minimized, preferably less than 4-mil (100-μm), in order to minimize performance degradation due to interconnection between the circuit blocks. Some of the fabricated unit circuit blocks are shown in Fig. 3. Figure 4 is the magnified picture of a MMIC amplifier with wire-bonding. A 10-mil gold ribbon is attached on the surface of the copper microstrip line, since wire-bonding operation cannot be directly performed on the surface of the copper.



Tripler LNA Ring Mixer Driver Amp Power Amp

Fig. 3 Unit circuit blocks used for the 40 GHz up-converter

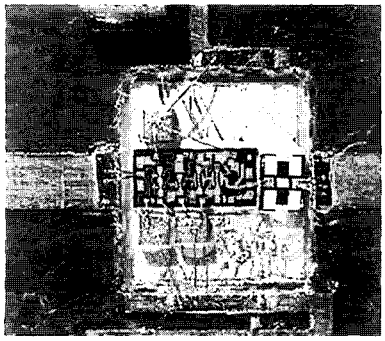


Fig. 4 Magnified portion of a unit circuit block

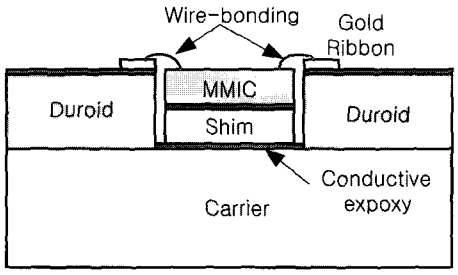


Fig. 5 A schematic of MMIC chip assembly

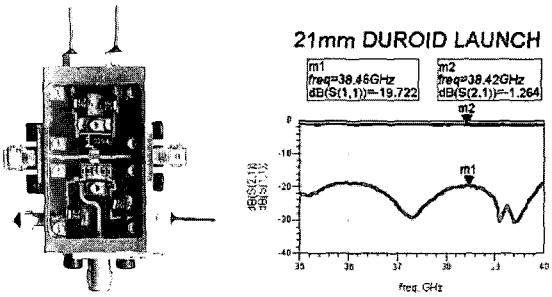


Fig. 6 Test fixture for 40 GHz circuits

Also, as illustrated in Fig. 5, a 5-mil-thick shim is used under the MMIC chip in order to minimize the length of wire-bonding by adjusting the height of MMICs since the thickness of the Duroid substrate is 10-mil while the thickness of the MMIC chip is 4~5 mil. A test fixture is needed to test the DC (bias voltages of drain, gate and control lines) and RF (power gain, input and output return losses, power compression, intermodulation products, etc.) characteristics of unit circuit blocks. A new test fixture that performs up to 40 GHz is implemented as can be seen in Fig. 6. The connector used for this test fixture is SuperSMA, which is developed at GigaLane Co., LTD. and has good performance comparable to the K-connector (2.9-mm connector) up to 40 GHz. This test fixture has 3 RF ports, and 4 DC bias lines, and can be used to test various amplifiers, mixers, and filters. Up to 40 GHz, measured insertion loss and return loss was –1.26 dB and –18.7 dB, respectively.

3.3 Design of Waveguide-to-Microstrip Transition and Band-pass filter

The RF signal from the power amplifier is connected to the newly-developed microstrip-to-waveguide transition [3] as shown in Fig. 7. This probe transition provides moisture barrier, robustness, and insensitivity to fabrication tolerances as compared with the conventional probe transition. The average insertion loss of the back-to-back measurements is measured about 0.8 dB. Since the theoretical insertion loss of the microstrip line is ~0.3 dB, insertion loss per transition is estimated as ~0.25 dB.

Also, a filter at 40 GHz was designed and fabricated. The filter type is the tapped coupled-line filter; the tapped-line is designed by replacing the input/output coupled lines, which tends to have very narrow gaps, from the edge-coupled filter. The simple design procedure for this tapped-filter has been developed and tested [4]. Once the input/output coupled lines are replaced by tapped-lines, gaps of the coupled-lines of the filter are usually wide enough to be easily fabricated.

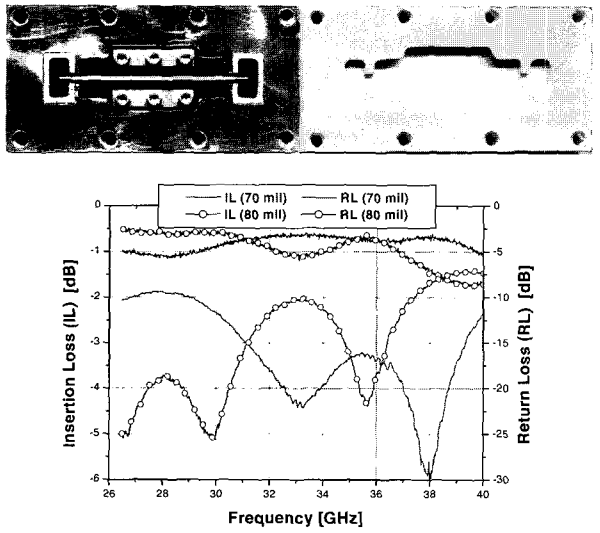


Fig. 7 Fabricated back-to-back waveguide-to-microstrip transition

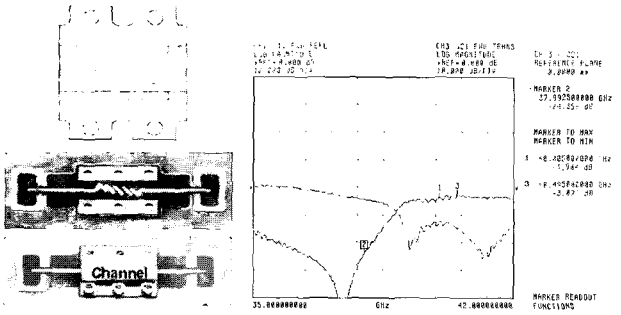


Fig. 8 Fabricated 40 GHz filter and measurement result

The fabricated filter and measurement result are indicated in Fig. 8. The measured result agrees well with the filter simulation result. With this filter a metal channel is made to cover the filter section to remove higher-order modes when the filter interacts with the housing. The measured insertion loss was 3.8 dB (with ~1 dB transition loss) and the return loss was more than 10 dB at 40 GHz.

3.4 Construction of the 40 GHz Up-Converter Module

A 40 GHz up-converter module was designed by combining the unit circuit blocks after they were characterized by the test fixture. Fig. 9 shows the implemented 40 GHz up-converter module. The 12.67 GHz LO signal is launched to the microstrip line through the SMA connector, and then tripled to 38 GHz by a MMIC tripler. The LO signal is then mixed with a 2 GHz IF signal through a ring mixer to produce a 40 GHz RF signal. The RF signal is then filtered to reduce the LO components. The filtered signal is amplified by a high gain low-noise amplifier and a driver amplifier. Then, the RF signal is amplified by a power amplifier, and connected to the microstrip-to-waveguide transition.

Fig. 9 also presents the IF circuit board, which consists of one pi-pad attenuator, an IF amplifier, and two Themopad® attenuators. The bias board contains a regulator circuit that implements the FET bias sequence: a negative bias is always applied first before the positive bias is applied to the FET. If a positive bias input is applied before the negative bias is available, this bias board disables the regulator output until the negative bias is available. The regulated output from the bias board is +7V and -2V.

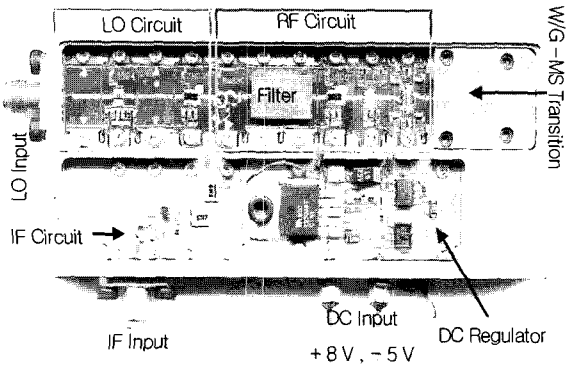


Fig. 9 Implemented 40 GHz up-converter module

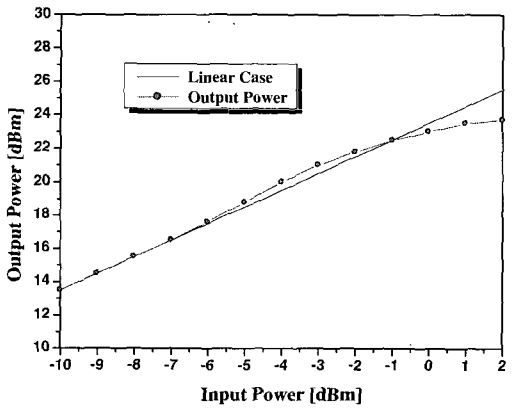


Fig. 10 Output power variation as the input power is increased

Fig. 10 illustrates the output power variation as the input power is increased. From the graph we can obtain the gain of 23.5 dB and P1dB of +23.5 dBm. While this result is

reasonably good, the gain is degraded by ~8 dB as compared to the cascade analysis value since the insertion loss exists in connected unit circuit blocks (~1.5 dB per one connection) due to ground discontinuity between carriers. The 1 dB gain compression point is also degraded by 3.5 dB due to connection loss. The performance of the module will approach the design value by implementing one RF board as connecting the unit circuit blocks. In this case, special care should be taken to remove possible oscillation due to very high gain ~55 dB by cascading three high gain amplifiers.

4. Conclusion

In this paper, a new design technique utilizing unit circuit blocks for fabricating low-cost 40 up-converters for digital microwave radios is presented. The size of the up-converter module is scaled by the number of unit circuit blocks. The performance of unit circuit blocks was measured via a newly developed test fixture. The up-converter module design can be as simple as cascade layout of these circuit blocks. However, at this high frequency, the interaction between the unit circuit blocks and insertion loss for each connection are not negligible. Future study is needed in order to reduce these interactions between the unit circuit blocks. Moreover, a newly developed moisture-sealed microstrip-to-waveguide transition is utilized in the module design.

The implemented up-converter module can be used as a low-cost, high performance converter module for Ka-band LMDS systems. Also, this new design technique can be utilized for designing microwave/millimeter-wave modules for a variety of applications.

Acknowledgements

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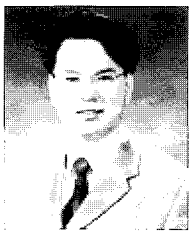

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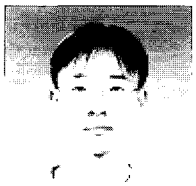

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