60GHz Ultra Compact Transmitter / Receiver with a Low Phase Noise PLL-Oscillator

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Abstract **— In this paper we present a transmitter and a receiver for millimeter-wave video transmission system. The size of each is 110mm x 55mm x 23mm, as a result of using an antenna-integrated millimeter-wave module and a filter-integrated SHP mixer MMIC. Each of the transmitter and the receiver has an local signal of 29.5GHz for up/down-conversion which is generated by multiplying a signal from 1.8GHz PLL-oscillator. A low phase noise of -103dBc/Hz at 100kHz offset was achieved.**

I. INTRODUCTION

Recently many millimeter-wave system applications such as millimeter-wave video transmission system, wireless LANs, and wireless IEEE1394 have been proposed [1-3].

In order to make these applications succeed especially in consumer markets, developing compact and low-cost RF modules is indispensable. However, there are several problems to be solved for that.

The first problem is how we connect millimeter-wave antennas "slimly" with RF circuits instead of using conventional bulky waveguides or expensive connectors.

The second problem is how we generate LO signals at millimeter-wave. In order to transmit and receive wireless signals with modulation such as QPSK or 8-PSK, low phase noise characteristics with less than -90dBc/Hz at 100kHz offset is required [4].

The third problem is how we suppress image or undesired signals in RF modules at low cost.

We have developed transmitters and receivers for millimeter-wave video transmission system. The features as solutions of the above-mentioned problems are as follows.

1. Integration of a planar antenna with a millimeter-wave module
2. Multiplying a low-frequency signal from a PLL oscillator with low phase noise
3. Integration of an image rejection filter with a sub-harmonically pumped mixer on a MMIC

In this paper we present our 60GHz transmitter and receiver, and their key technologies.

II. MILLIMETER-WAVE VIDEOTRANSMISSION SYSTEM CONCEPT AND SYSTEM BLOCK DIAGRAM

Fig. 1 illustrates the block diagram of millimeter-wave video transmission system. After the IF signals of satellite TV have been received by outside TV antennas, they are fed to a transmitter indoors. Then all these signals are up-converted to 60GHz band and transmitted to a receiver installed on a TV set. At the end in the receiver they are down-converted to original signals.

Each of the transmitter and the receiver has a local signal source that multiplies a frequency of 1.8GHz PLL-oscillator by 16 and that drives a sub-harmonically pumped mixer. The local signal frequency is doubled again and mixed with IF or RF signals within the mixer, so the original PLL-oscillator's frequency is multiplied by 32 substantially.

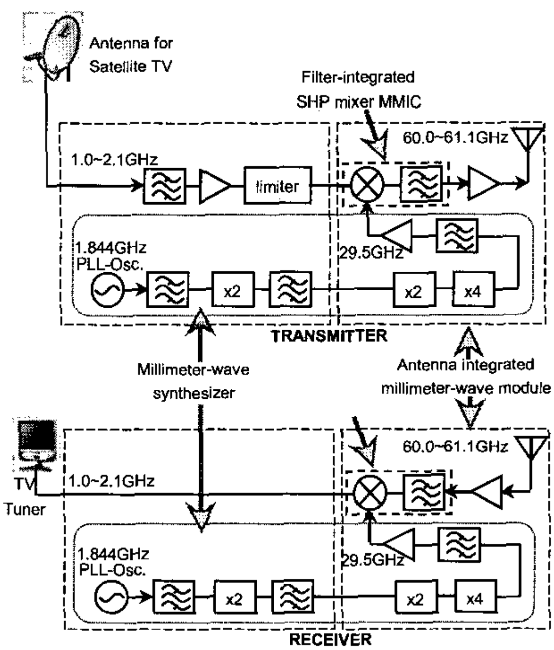

Fig. 1. Block diagram of millimeter-wave video transmission.

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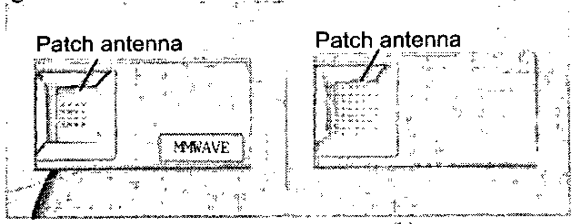
The appearance of the transmitter and the receiver is shown in Fig.2, and the inner of the transmitter is shown in Fig. 3. The size is 110mm x 55mm x 23mm.



(a) (b)

Fig. 2. Photographs of (a) transmitter and (b) receiver. The size is 110 x 55 x 23 (mm^3).

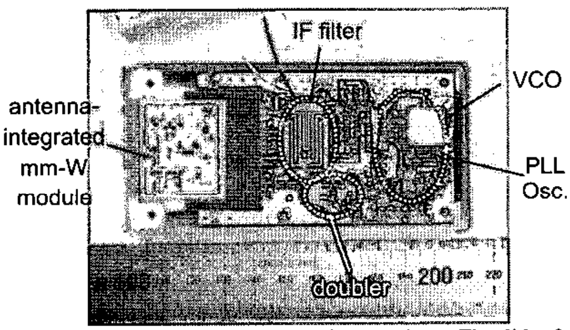


Fig. 3. Photographs of inside of transmitter. The lid of the millimeter-wave module is removed.

III. ANTENNA INTEGRATED MILLIMETER-WAVE MODULES

Fig. 4 illustrates the schematic cross-sectional view of transmitter / receiver. The transmitter or receiver mainly consists of two parts. One is an antenna integrated millimeter-wave module, and the other is a glass epoxy (FR4) printed circuit board for low-frequency blocks such as IF, PLL and DC power supply circuits.

The millimeter-wave module and the FR4 board are connected with each other through a "card edge" type connector that has ability to transmit signals up to 6GHz.

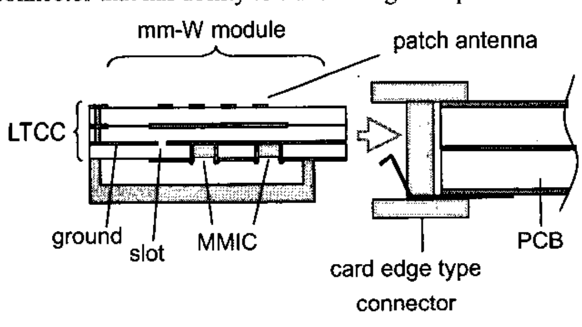
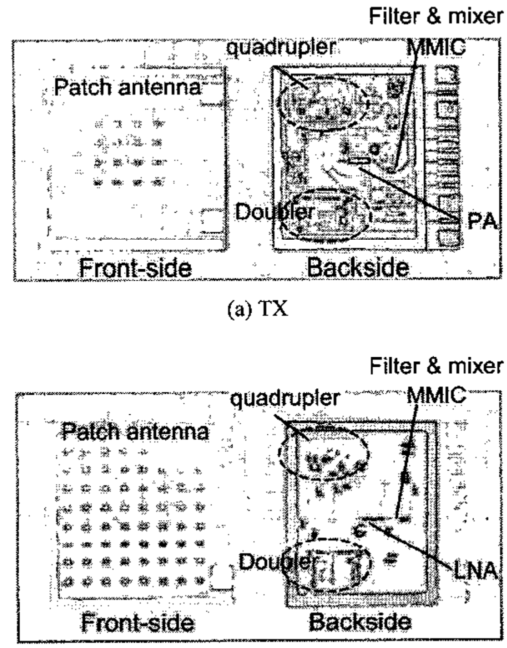


Fig. 4. Cross-sectional view of the transmitter / receiver.

In the millimeter-wave module, LNA/PA, a mixer, an LO amplifier, and multipliers are mounted on one side of an LTCC substrate. They are directly die-bonded on an internal ground plane to reduce ground inductance. While a micro-strip patch antenna array is printed on the other side of the LTCC substrate. The LTCC substrate has three dielectric layers and each layer thickness is 150µm. The RF circuits and an antenna feed line are connected by electromagnetic coupling through a slot on the internal ground plane. The insertion loss at the slot is less than 1dB.

Fig. 5 shows photographs of the antenna-integrated module. The size is 32mm x 32mm.



(a) TX

(b) RX

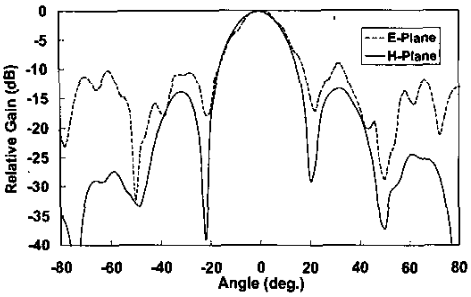
Fig. 5. Photographs of an antenna-integrated millimeter module of (a) transmitter, and (b) receiver. The size is 32mm x 32mm. The lid of the millimeter-wave module is removed.

IV. ANTENNA PERFORANCE

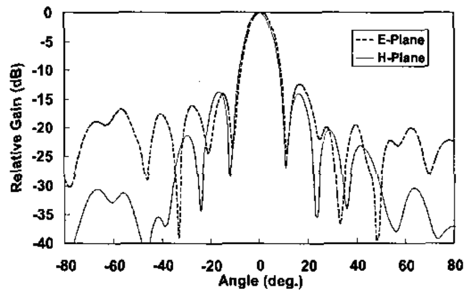
The receiver has a 64-element array antenna [5] for high sensitivity, while the transmitter has a 16-element array antenna for wider coverage.

Fig. 6 demonstrates the measured radiation patterns of the antennas for the transmitter and the receiver. The beam width is ±10° for the transmitter and ±5° for the receiver.

Fig. 7 demonstrates measured antenna gains as a function of frequency. The transmitter has an antenna gain of 17dBi, while the receiver has 21 dBi at 60GHz. Each of the antennas has very broad band characteristics.



(a)



(b)

Fig. 6. Radiation pattern of (a) transmitter antenna (16-element array), and (b) receiver antenna (64-element array) at 60GHz.

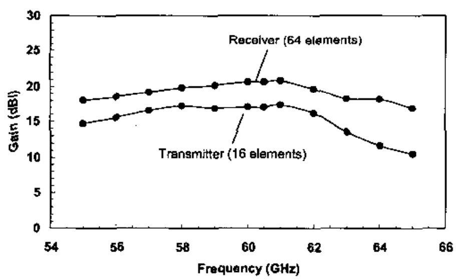


Fig. 7. Frequency dependence of antenna gain

V. LOCAL SIGNAL GENERATION

We have developed a 29.5GHz signal source in which a 1.8GHz VCO signal is multiplied by 16 by two doublers and a quadrupler, because several high-Q VCOs at around 1.8GHz are commercially available at low cost and it is comparatively easy to suppress spurs by filters after multiplying the frequency.

As an original signal source we adopted a 1.8GHz band VCO of which phase noise is -126~-130dBc/Hz at 100kHz offset.

As a reference signal for a PLL-IC, we used a 25.612MHz TCXO, of which phase noise is -150dBc/Hz at 10kHz off. This is also commercially available at low cost.

The first stage doubler consists of a packaged p-HEMT and is located on the FR4 board, while the second stage doubler and the third stage quadrupler are built by HMICs on aluminum substrates by using bare chip p-HEMTs and are located in the millimeter-wave modules.

Fig.8 demonstrates the frequency spectrum of the local signal that is to be input into sub-harmonic mixers. All spurious levels are less than -47dBc.

The total power consumption of the local signal source is 5V x 250mA.

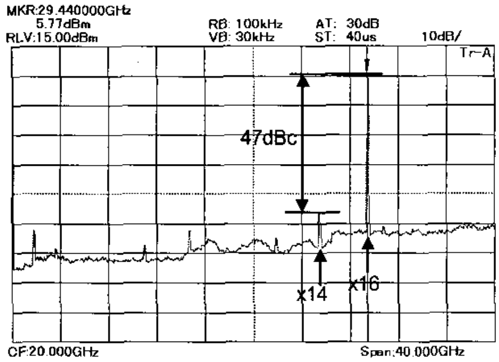


Fig. 8. Frequency spectrum of the local signal. RBW=100kHz.

Fig. 9 shows the phase noise performance of the local signal after multiplying original VCO's frequency by 2 (3.688GHz) and by 16 (29.5GHz). The difference of the two is about 18dB, and that is noise degradation by multiplying as theory. The phase noise is -103dBc/Hz @100kHz offset at 29.5GHz and we can estimate the phase noise at 59GHz to be -97dBc/Hz from this result.

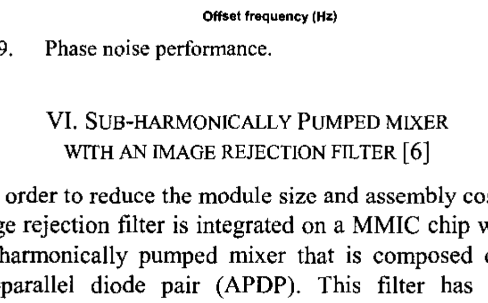


Fig. 9. Phase noise performance.

VI. SUB-HARMONICALLY PUMPED MIXER WITH AN IMAGE REJECTION FILTER [6]

In order to reduce the module size and assembly cost, an image rejection filter is integrated on a MMIC chip with a sub-harmonically pumped mixer that is composed of an anti-parallel diode pair (APDP). This filter has good reproduciblity because it is patterned by semiconductor processes, and it doesn't require another assembling process except for MMIC bonding. Moreover the 2nd harmonic level of LO is canceled within the APDP.

Fig. 10 shows the down-conversion frequency response of the mixer with the filter. LO frequency is fixed to 29.5GHz, and its drive level is 6dBm. The conversion loss is 11~13dB, including the filter loss, and an image rejection ratio is more than 30dB in the pass band.

Fig. 11 shows the frequency response of the fabricated mixer for up-conversion. The frequency response for up-conversion shows the almost same tendency as that for down-conversion. The conversion loss of upper side band is 11~13dB in the IF band, and the rejection ratio of lower side band is greater than 30dB.

The output level of the 2nd harmonics of LO was about -54dBm.

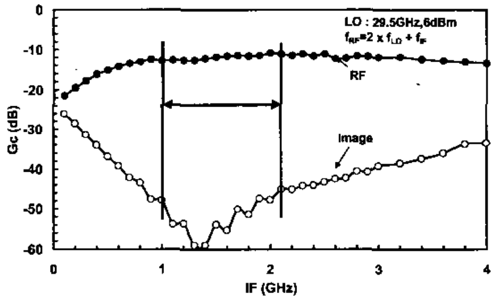


Fig. 10. Down-conversion frequency response of the filter-integrated mixer MMIC.

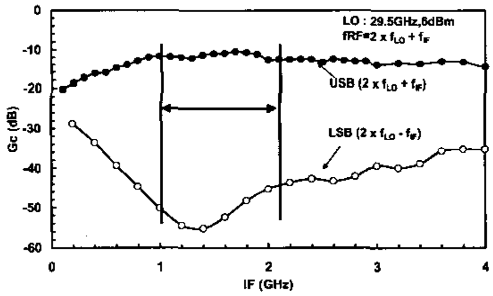


Fig. 11. Up-conversion frequency response of the filter-integrated mixer MMIC.

VII. Performance of Transimitter and Receiver

The performance of the transmitter and the receiver is summarized in table I and table II.

By using this pair, clear pictures of all channels of Digital Broadcast Satellite (TC-8PSK; 52Mbps/block) and Communication Satellite (QPSK; 42.192Mbps/block) in Japan were successfully transferred over a 20m distance without any block noise.

Table I
Transmitter performance

Size	110x55x23 (mm^3)
Input IF band	1.0~2.1GHz
Output RF band	60.0~61.1GHz
Phase noise (100kHz off)	-103dBc/Hz
Output Power	10mW
Spurious level	<100μW
2 LO leak	<10μW
Antenna Gain	17dBi
Power Consumption	1.85W

Table II
Receiver performance

Size	110x55x23 (mm^3)
Input RF band	60.0~61.1GHz
Output IF band	1.0~2.1GHz
Phase noise (100kHz off)	-103dBc/Hz
Image Rejection	>30dBc
Antenna Gain	21dBi
Power Consumption	1.75W

VIII. Conclusion

We presented a ultra compact 60GHz transmitter and receiver, of which size is 110mm x 55mm x 23mm. A local signal is generated by multiplying a frequency of a low-phase noise PLL oscillator by 16. A planar antenna was integrated with a millimeter-wave module. And an image rejection filter was integrated with a sub-harmonically pumped mixer on a MMIC chip.

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