New MMIC's for Tuners in Multichannel Video Distribution Systems Using Optical Fiber Networks

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***Abstract*—New MMIC's have been developed for an ultra-broadband FM video tuner in a multi-channel video distribution system using optical fiber networks. The MMIC's provide both frequency synthesis and up-conversion. They are integrated on two GaAs MMIC chips and one Si LSI chip. The chips are mounted in a flat package to form a tunable block-up converter. By combining the MMIC's with currently available consumer product type components, a low cost FM video tuner with a 2 GHz tuning bandwidth was achieved in hardware. Successful tuning performance is obtained over the whole tuning frequency range.**

I. Introduction

Multichannel video distribution systems with more than several tens of video signals through optical fiber networks are emerging in commercial applications since optical fiber amplifiers, which can directly amplify optical signals without conversion to electronic signals, have been developed [1]–[3]. In video distribution systems, analog frequency division multiplexing (FDM) is still more economical than digital techniques. The FDM optical transmission networks have been introduced only as the super trunk lines and feeder lines for CATV systems, but our goal is to construct all-fiber video distribution systems, or fiber-to-the-home systems. The systems can transmit many video signals because of the high capacity of optical fibers. The FDM technique has two types, one is AM-FDM and the other is FM-FDM. FM-FDM optical transmission is less susceptible to nonlinear-distortion disturbance during transmission than AM-FDM. However, in all-fiber video distribution systems with more than several tens of channels using FM-FDM transmission, each subscriber must have an ultra broadband microwave tuner over about 2 GHz because the FM format require wider bandwidth than the AM format. Current FM-TV tuners do not have a large enough bandwidth, for example, in satellite broadcasting (BS) FM TV tuners have a 270-MHz bandwidth (8 channels) [4], [5]. In addition, commercial applications such as CATV systems require low cost tuners. One cost effective solution is to obtain an ultra broadband tuner by combining currently available consumer product type components and monolithic microwave integrated circuits (MMIC's) [6], [7].

Manuscript received May 28. 1994; revised January 28, 1995.

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IEEE Log Number 9412078.

This paper describes this ultrabroad and low cost FM-TV tuner configuration and newly developed MMIC's with successful performances.

II. Configuration of Multi-Channel FM Tuners

The frequency range of the FM-TV signals distributed to the subscribers in our multichannel video distribution system is 0.5–2.4 GHz [7]. To select one channel from among this broad frequency range, oscillators with a similarly broad tuning range are required in the tuners. The ratio of the tuning frequency range, Δf, over the center oscillation frequency, f_o, is mainly determined and limited by the characteristics of tuning components, such as varactors. Therefore, to obtain a broad tuning frequency range, a high f_o is needed, i.e., the distributed signal ought to be up-converted.

After the desired channel is selected, the signal in the channel must be demodulated. At that time, if commercial components can be used, the tuners become economical.

Accordingly, an FM tuner configuration is proposed as shown in Fig. 1. The FM-FDM signal after O/E conversion is up-converted to the *Ku*-band of 12.40–12.67 GHz, which is equal to the BS TV receiver input frequency, so that the commercially available BS TV receiver can be used. The tuning range of a BS tuner in the BS receiver, however, has only 8 FM-video channels while that of the multichannel video distribution system has 50 channels. Therefore, the BS tuner is linked to the frequency synthesizer of which output LO frequency range is 10.1–12 GHz. The frequency synthesizer selects one block, which contains 8 channels as shown in Fig. 2, and the BS TV tuner selects the desired channel within block and demodulated.

This tuner using a commercially available BS TV receiver extends its tuning frequency range. The key circuit of the tuner is the *Ku*-band synthesized up-converter. This consists of many analog and digital elements. Therefore, applying the MMIC technique to the synthesized up-converter reduces the number of component parts and adjustment cost.

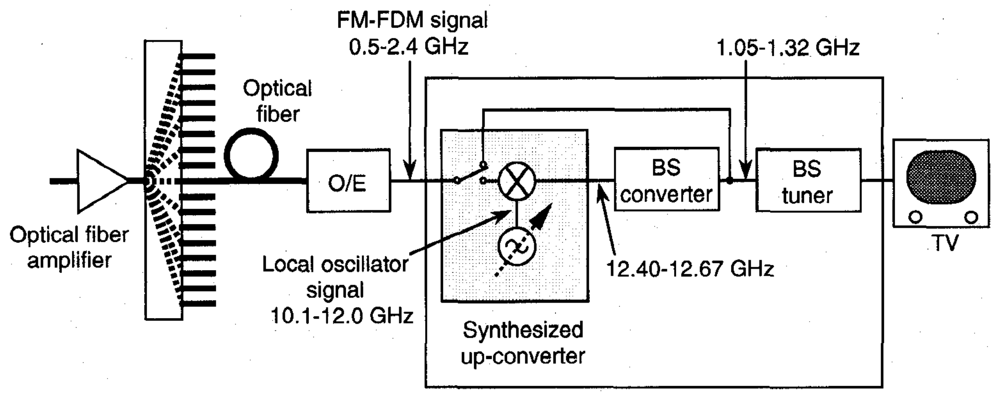

Fig. 1. Multichannel FM tuner.

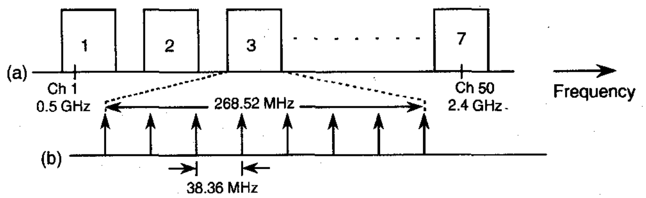

Fig. 2. Frequency arrangement of FM-FDM signal: (a) block arrangement; (b) channel arrangement.

III. Design and Performance of MMIC's

The newly developed MMIC synthesized up-converter configuration is shown in Fig. 3. In this configuration, six analog circuits are integrated onto two GaAs chips and three digital circuits are integrated onto one Si chip as follows:

Chip 1: Local MMIC
- Analog circuit 1: Voltage-controlled oscillator (VCO)
- Analog circuit 2: Buffer amplifier
- Analog circuit 3: Dual output amplifier

Chip 2: Converter MMIC
- Analog circuit 4: Mixer
- Analog circuit 5: IF amplifier
- Analog circuit 6: Switch

Chip 3: Si LSI
- Digital circuit 1: ÷4 frequency divider
- Digital circuit 2: Programmable divider
- Digital circuit 3: Exclusive-OR (EXOR)

In each GaAs MMIC, a uniplanar configuration [8] is used to reduce chip size. The fabrication process of GaAs MMIC's is 0.3 μm advanced self-aligned gate FET's with an asymmetric n^+ layer [9] and that of Si LSI's is super self-aligned process technology [10].

A. Local MMIC

The circuit configuration of the local MMIC chip is shown in Fig. 4. The VCO is an FET oscillator with a series feedback circuit which includes a varactor diode. The VCO consists of only monolithically integrated elements and does not need any external resonators. The VCO output frequency required in the multichannel video distribution system is broad, between 10.1 and 12 GHz. In addition, taking the fabrication process

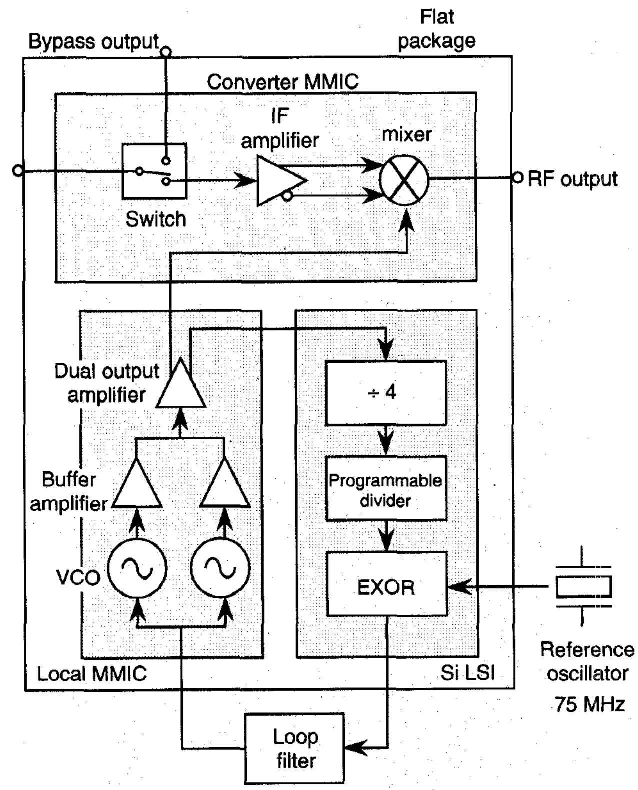

Fig. 3. An MMIC synthesized up-converter.

variation and temperature dependence into account, the tuning frequency range needs to be about 2.5 GHz. Then a dual VCO configuration is adopted, which has two VCOs with different frequency ranges and are selected by switching the supply voltage.

The buffer amplifiers are placed between the VCO output terminal and a combining node to prevent interference between two VCO's. The measured gain is 7.5 ± 0.5 dB for 10–12 GHz.

The dual output amplifier has two output ports. One is to feed the mixer with a local oscillator signal and the other provides the input to the phase-locked loop. The measured gain is 8.0 ± 1.0 dB for 10–12 GHz.

A photograph of the local MMIC is shown in Fig. 5. The chip size is 2.0 × 2.5 mm. The measured tuning performance

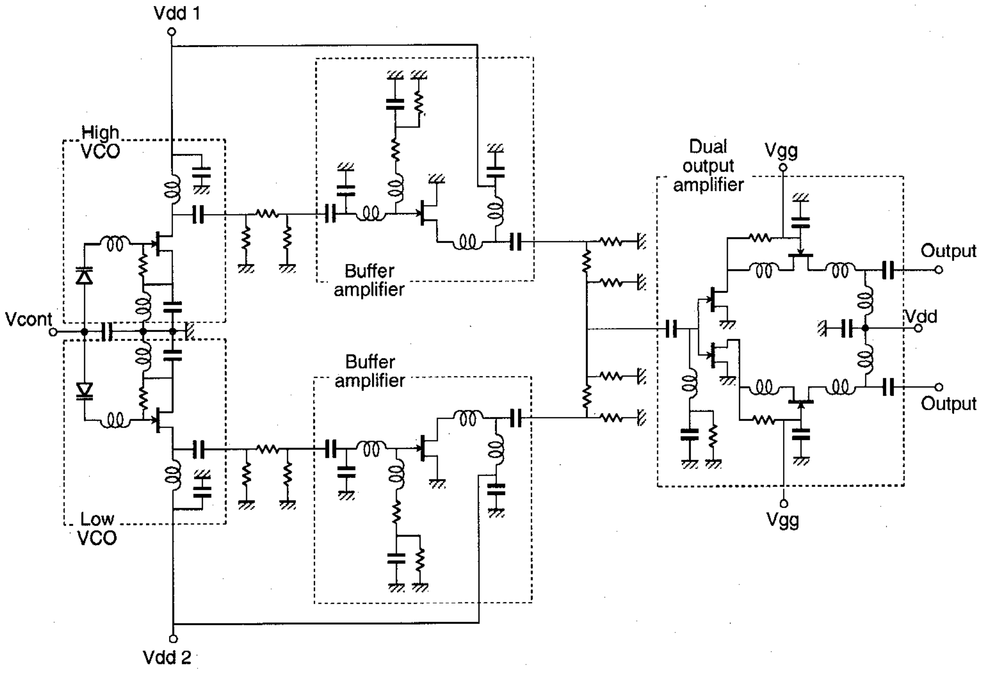

Fig. 4. Local MMIC circuit diagram.

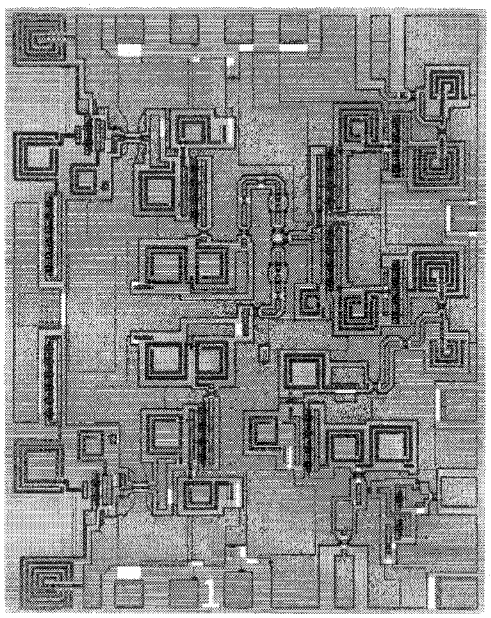

Fig. 5. Chip photograph of a local MMIC.

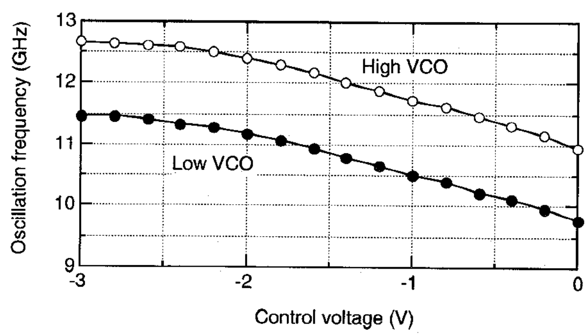

Fig. 6. Tuning performance of a local MMIC.

of the local MMIC is shown in Fig. 6. By varying the control voltage from 0 to −3 V, the oscillation frequency of the low frequency region VCO varies from 9.8–11.5 GHz and that of the high frequency region VCO varies from 11.0–12.7 GHz. Even if the tuning voltage range of the VCO's is extended to over 3 V, the oscillation frequency range does not become wider. This is because the varactors operate at the reverse voltage, or 0 or less, and at −3 V, the change of the oscillation frequency is saturated. The dual VCO's cover the frequency range that is required. The output power is +7.0 ± 2.0 dBm. The measured phase noise is −95 dBc/Hz at 1-MHz offset from the carrier.

B. Converter MMIC

The circuit configuration of the converter MMIC chip is shown in Fig. 7. The mixer is a balanced mixer using a lumped-element balun. The frequency range of the intermediate frequency (IF) signal input to the mixer is 0.5–2.4 GHz from the O/E converter. This broad frequency range degrades the mixer performance because the conversion loss is large in a high frequency region. The IF amplifier compensates for the frequency dependence of the mixer.

The IF amplifier consists of three FET stages. The first and second stage FET's are loaded with a capacitor and a low resistor in parallel with a high resistor at the source terminal to make the gain larger in the high frequency region than in the low frequency region; as a result, it compensates for the frequency dependence of the mixer conversion loss. The third stage FET provides two signals of equal amplitude and a 180° phase difference at drain and source terminals to drive the balanced mixer.

The switch is of a single-pole double-throw (SPDT) configuration and it bypasses the FM-FDM signal to the BS tuner

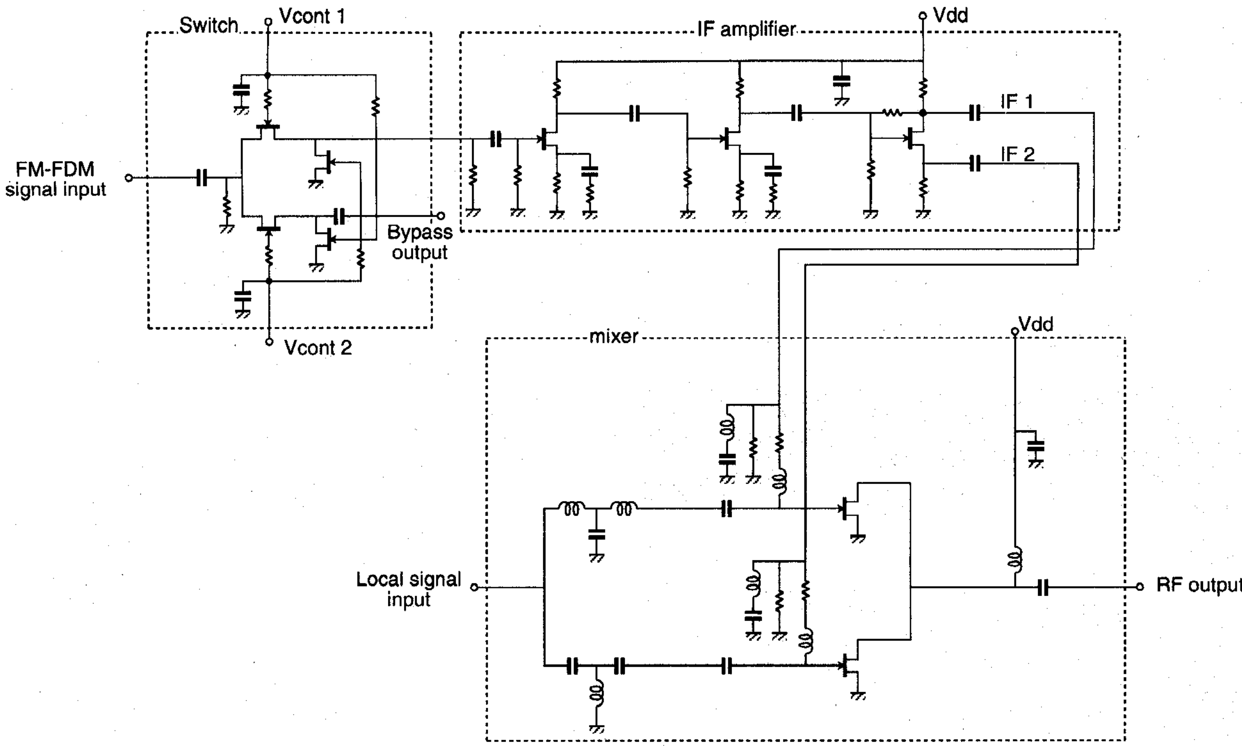

Fig. 7. Converter MMIC circuit diagram.

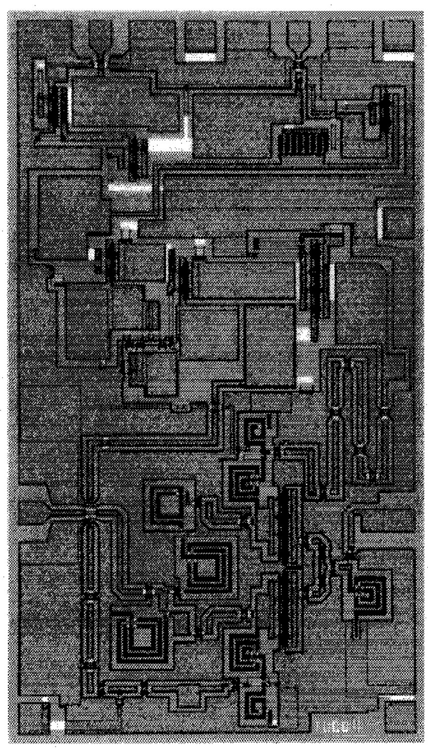

Fig. 8. Chip photograph of a converter MMIC.

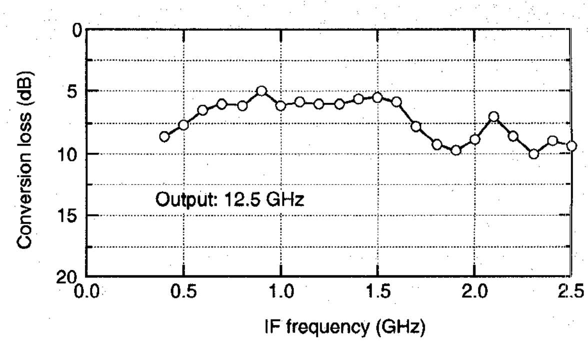

Fig. 9. Conversion loss versus IF input frequency of the converter MMIC.

when the frequency of the FM-FDM signal corresponds with the BS tuners input (1.05–1.32 GHz). The measured insertion loss is 3.0 dB and the isolation is 27 dB at 1.5 GHz.

A photograph of the converter MMIC is shown in Fig. 8. The chip size is 1.5 × 2.5 mm. The measured conversion loss of the converter MMIC is shown in Fig. 9. The conversion loss is below 10 dB for 0.5–2.4 GHz. The two-tone third order intermodulation product (IM) is −40 dBc at an input level of −10 dBm/tone.

C. Si LSI

The one-fourth divider is a regenerative divider which is suitable for a high frequency circuit [10], [11]. The programmable divider consists of a ÷4/÷5 dual-modulus prescaler, a 4-bit programmable counter, and a 2-bit swallow counter. The EXOR is used as the phase detector because the EXOR has a large detector gain constant and the phase noise within the phase-locking loop bandwidth is low [12].

The chip size of the Si LSI is 3.0 × 3.0 mm. The measured frequency response of the Si LSI is shown in Fig. 10. This performance is determined by the one-fourth divider.

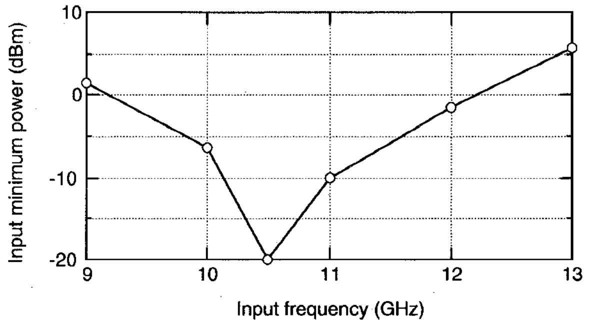

Fig. 10. Si LSI frequency response.

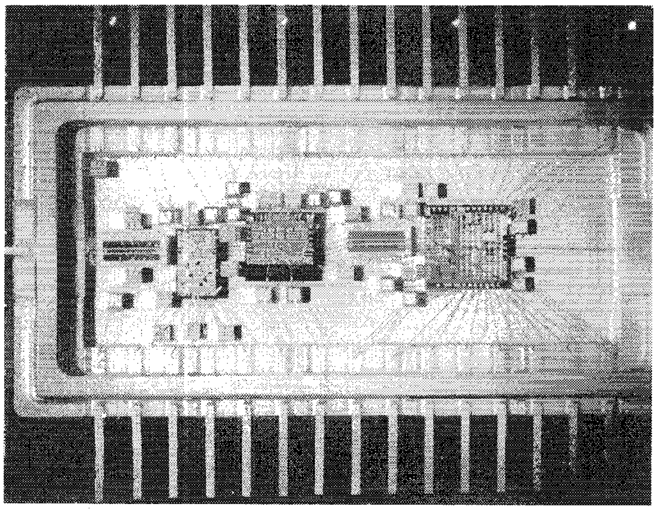

Fig. 11. MMIC synthesized up-converter integrated in a flat package.

IV. Performance of Synthesized Up-Converter

All chips are mounted in a flat package as shown in Fig. 11. From the left side, they are the converter MMIC, the local MMIC, and the Si LSI. The package size is 23 × 11 mm.

The phase-locking loop is formed using the local MMIC, the Si LSI, and an external loop filter. The measured phase noise performance is shown in Fig. 12. The phase noise is less than −85 dBc/Hz for 1 kHz–10 MHz offset from the carrier. Up-converting performance is the same as the case where only the converter MMIC is measured.

V. Performance of Multichannel FM Tuner

The new configuration in hardware of a multichannel FM tuner shown in Fig. 1 was achieved by combining the MMIC synthesized up-converter with the BS receiver. Successful tuning performance has been obtained over about 2 GHz as shown in Fig. 13. A good weighted SNR of more than 50 dB is obtained over the whole tuning bandwidth.

VI. Conclusion

A new MMIC synthesized up-converter has been developed for use in ultra-broadband FM video tuners for a multichannel video distribution systems. The components of the converter are integrated onto two GaAs MMIC chips and a Si LSI chip. These chips are mounted in a 23 × 11 mm flat package. The phase noise of the frequency synthesizer is less than −85 dBc/Hz for 1 kHz–10 MHz offset from the carrier. The conversion loss of the up-converter is below 10 dB for

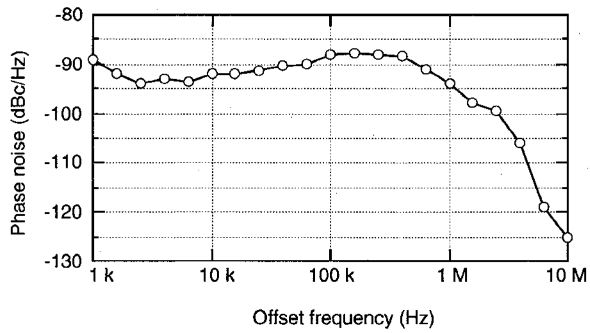

Fig. 12. Phase noise performance of the MMIC synthesizer.

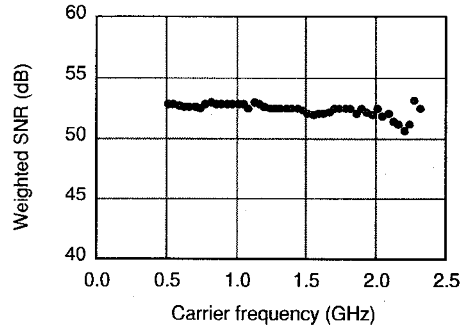

Fig. 13. Tuning performance for video signals.

0.5–2.4 GHz. The third order IM is −40 dBc at an input level of −10 dBm. By combining the MMIC synthesized up-converter with a commercially available BS receiver, a low cost FM video tuner with 2-GHz tuning bandwidth was achieved in hardware. Successful tuning performance with a weighted SNR of more than 50 dB is obtained over the whole tuning frequency range.

Acknowledgment

The authors would like to thank Dr. K. Morita for his encouragement. They also wish to thank M. Nakamae for his helpful discussion.

References

[1] W. I. Way, M. M. Choy, A. Yi-Yan, M. Andrejco, M. Saifi, and C. Lin, "Multi-channel AM-VSB television signal transmission using an erbium-doped optical fiber power amplifier," in *IOOC 89 Dig.*, vol. 5, 1989, paper 20PDA-10.

[2] E. Yoneda, K. Kikushima, T. Tsuchiya, and K. Suto, "Erbium-doped fiber amplifier for video distribution network," *IEEE J. Selected Areas Commun.*, vol. 8, pp. 1249–1256, Sept. 1990.

[3] A. M. Hill, R. Wyatt, J. F. Massicott, K. J. Bryth, D. S. Forrester, R. A. Lobbett, P. J. Smith, and D. B. Payne, "39.5 million-way WDM broadcast network employing two stages of erbium-doped fiber amplifiers," *Electron. Lett.*, vol. 26, pp. 1882–1884, Oct. 1990.

[4] T. Hasegawa, "An overview of the Japanese satellite broadcasting program," in *Proc. AIAA 12th Int. Commun. Satellite Syst. Conf.*, 1988, pp. 278–284.

[5] Y. Takahashi, "The development of satellite broadcasting in Japan," *Space Commun.*, vol. 8, pp. 375–387, 1991.

[6] T. Ohira, T. Hirota, T. Hiraoka, T. Nakagawa, M. Aikawa, K. Suto, T. Kokubun, and E. Yoneda, "GaAs/Si MMIC synthesized upconverter for broadband tuners in optical-fiber CATV systems," in *Proc. 21st Euro. Microwave Conf.*, 1991, pp. 473–478.

[7] K. Suto, K. Kikushima, T. Kokubun, H. Yoshinaga, S. Matsui, T. Hirota, and E. Yoneda, "An SCM multi-channel video distribution system for passive double star local networks," in *3rd IEEE Workshop Local Opt. Networks Dig.*, 1991, paper 6.4.

[8] M. Muraguchi, T. Hirota, A. Minakawa, K. Ohwada, and T. Sugeta, "Uniplanar MMIC's and their applications," *IEEE Trans. Microwave Theory Tech.*, vol. 36, pp. 1896–1901, Dec. 1988.

[9] T. Enoki, K. Yamasaki, K. Osafune, and K. Ohwada, "0.3 mm advanced SAINT FET's having asymmetric n^+-layers for ultra-high-frequency GaAs MMIC's," *IEEE Trans. Electron Dev.,* vol. 35, pp. 18–24, Jan. 1988.
[10] H. Ichino, N. Ishihara, M. Suzuki, and S. Konaka, "18 GHz 1/8 dynamic frequency divider using Si bipolar technologies," *IEEE J. Solid State Circuits,* vol. 24, pp. 1723–1728, Dec. 1989.
[11] R. D. Miller, "Fractional-frequency generators utilizing regenerative modulation," in *Proc. IRE,* 1939, pp. 446–457.
[12] T. Nakagawa, H. Suwaki, and T. Ohira, "Low-noise MMIC phase-locked oscillators using an EXOR and a PFC," *IEICE Trans. Electron.,* vol. E76-C, June 1993.

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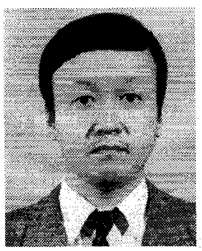

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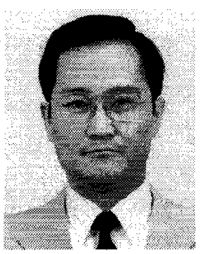

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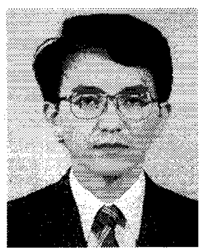

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