HIGH-FREQUENCY SIGNAL-PROCESSING INTEGRATED CIRCUITS

Final Report

by

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13. ABSTRACT *(Maximum 200 words)*

A new topology for maximum-bandwidth matched-impedance monolithic amplifiers has been synthesized, fabricated, and tested. Stage gain of 9.3 dB and bandwidth of 3.2 GHz were realized in a 9 GHz Si bipolar monolithic technology. A new variable-gain amplifier with maximum dynamic range has been devised, fabricated, and tested. This achieved 850 MHz bandwidth, 30 dB gain control range and 25 dB maximum gain. Equivalent input noise resistance was 400 Ω. The successful fabrication of on-chip inductors in Si monolithic circuits was demonstrated, with application to passive filters and bandpass amplifiers in the GHz frequency range. New high-performance monolithic voltage-controlled-oscillators and phase-locked loops were synthesized, built, and tested to verify new design procedures.

14. SUBJECT TERMS
wideband monolithic amplifiers, voltage-controlled oscillators, phase-locked loops, variable-gain amplifiers, monolithic inductors

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A. STATEMENT OF THE PROBLEM STUDIED

This research focussed on the synthesis and fabrication in monolithic form of the circuit functions required for a microwave communications receiver. This involves low-noise monolithic amplifiers with wide dynamic range, variable-gain amplifiers, voltage-controlled oscillators (VCOs) and phase-locked loops. The goal was to develop theoretical analysis and synthesis procedures to derive optimum topologies for these functions and then to build and evaluate test circuits in high-speed monolithic processes.

B. RESEARCH RESULTS

Our research into wideband monolithic amplifiers led to the synthesis of a new topology [1] for maximum bandwidth matched-impedance monolithic amplifiers which allows realization of optimum stage gain and bandwidth for a given process. Test circuits based on these principles were fabricated and characterized and performed close to the predicted performance. Stage gain and bandwidth of 9.3 dB and 3.2 GHz respectively were realized in a packaged circuit using a 9 GHz Si bipolar monolithic technology.

Variable-gain amplifiers are also widely used in communication systems. Important characteristics in this case are linearity and noise performance as the gain is varied. We devised and built a new monolithic variable-gain amplifier with optimum dynamic range [9]. The test circuit measurements agreed well with the theoretical predictions and showed 25 dB maximum gain with 30 dB of gain-control range operating in the dc-1 GHz frequency range. The circuit showed only 400 Ω of equivalent input noise resistance and an output third-order intercept of +13.5 dBm. New design techniques allowed realization of an extremely linear gain-control characteristic with 20 MHz control bandwidth and extremely low temperature and supply voltage dependence.

Another circuit function of interest for high-frequency communication systems is power amplification. Our recent research has led to the synthesis of a new high-frequency Class AB monolithic power amplifier topology [2] with high efficiency in the frequency range dc-1 GHz. The topology has matched input and output impedances, and a monolithic test circuit based on these results delivered +20 dBm at P_{-1dB} to a 50 Ω load while consuming 540 mW quiescent power from a 12V supply.

The frequency response of high-frequency amplifiers can be improved significantly by the use of inductive peaking elements. This is a well-established method in microwave hybrids and GaAs monolithic circuits, but has not been reported successfully in Si monolithic circuits. Based on theoretical investigations which predicted the possibility of realizing useful inductors in standard Si technology, we designed and fabricated a number of test inductors and LC passive filters in the Si bipolar monolithic technology described previously [8]. Evaluation of these elements gave measured Q values up to 8 in the GHz range, and measured self-resonant frequencies up to 10 GHz. A test filter based on a 5-pole LC Butterworth configuration gave measured mid-band insertion loss and –3 dB frequency close to the design values of –2.25 dB and 880 MHz, respectively. The measured third-order intercept was in excess of the measurement limit of +42 dBm. Theoretical and experimental evaluation of these elements show no apparent problems of reproducibility or manufacturability. The availability of such components in standard Si monolithic technology has wide implications for the realization of complex, low-cost microwave communications and signal-processing functions.

The monolithic inductors described above were applied to the realization of low-noise microwave monolithic bandpass amplifiers. A new bandpass amplifier configuration was devised and built in monolithic form [10]. The amplifier incorporated a 4 nH silicon integrated inductor and realized a peak gain of S_{21} = 8 dB, noise figure of 6.4 dB, and a matched input impedance of 50 Ω in the frequency range 1–2 GHz. Important practical issues such as substrate coupling mechanisms were also addressed.

Voltage-controlled oscillators (VCOs) are essential elements in communication systems and have been another important element of our research program. This work yielded a new temperature-stable monolithic VCO with a 5:1 highly-linear frequency deviation and capable of operating from dc –250 MHz [4]. Design methods were devised to allow precision temperature compensation of high-frequency signal paths in monolithic circuits. These were applied to the realization of the VCO function and can be used in other applications.

We also investigated monolithic varactor-tuned LC oscillators and demonstrated a test oscillator as part of a monolithic phase-locked loop (PLL) operating at 350 MHz [5,6]. Optimum methods of temperature compensation in varactor-tuned LC oscillators were investigated and tested as part of this research. Our research into monolithic PLLs also extended to investigations of methods of realizing the phase-detector function at high frequencies [7]. The frequency limitations of some common structures were defined theoretically and optimum realizations identified.

The realization of a high-performance monolithic receiver requires the use of a synthesized local oscillator. Having investigated methods of VCO realization, we next turned to the problem of low-power high-frequency monolithic dividers. We derived general theoretical results linking divider speed and power to technology parameters and circuit topology. We then fabricated and tested a monolithic divide-by-2, 4, 8, 16 counter in a 9 GHz silicon bipolar monolithic technology. This circuit operated as predicted from dc-3.4 GHz and allowed verification of our theoretical results.

C. PUBLICATIONS AND DISSERTATIONS

Ph.D. Dissertations

1. M. Soyuer, "High-Frequency Monolithic Phase-Locked Loops," 1988. Published as U.C. Berkeley, Memo No. UCB/ERL M88/10, February 1988.

2. T. P. Liu, "High-Frequency Temperature-Compensated Voltage-Controlled Oscillator Design Techniques," 1988. Published as U.C. Berkeley, Memo No. UCB/ERL M88/33, May 1988.

3. N. Nguyen, "Monolithic Microwave Oscillators and Amplifiers," 1991. Published as U.C. Berkeley, Memo No. UCB/ERL M91/36, April 1991.

M.S. Reports

1. C. Armijo, "A Wideband Matched-Impedance Darlington Amplifier, 1989.

2. C. Hull, "Low-Frequency Dynamic Range of the Bipolar Transistor Quad Mixer," 1989.

3. N. Nguyen, "A Low-Noise, Low-Distortion Monolithic Preamplifier," 1988.

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1. C. T. Armijo and R. G. Meyer, "A New Wideband Darlington Amplifier," *IEEE J. Solid-State Circuits*, Vol. 24, No. 4, August 1989, pp. 1105–1109.

2. R. G. Meyer and W. D. Mack, "A Wideband Class AB Monolithic Power Amplifier," *IEEE J. Solid-State Circuits*, Vol. 24, No. 1, February 1989, pp. 7–12.

3. T. P. Liu and R. G. Meyer, "A 250 MHz Monolithic Voltage-Controlled Oscillator with Low Temperature Coefficient," *IEEE J. Solid-State Circuits*, Vol. 25, No. 2, April 1990, pp. 555–561.

4. T. P. Liu and R. G. Meyer, "A 250 MHz Monolithic Voltage-Controlled Oscillator," *IEEE ISSCC Digest*, Vol. 31, February 1988, pp. 22–23.

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6. M. Soyuer and R. G. Meyer, "A 350 MHz Bipolar Monolithic PLL," *IEEE CICC Digest*, May 1988, pp. 961–964.

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8. N. Nguyen and R. G. Meyer, "Si IC-Compatible Inductors and LC Passive Filters," *IEEE J. Solid-State Circuits*, Vol. 25, No. 4, August 1990, pp. 1028–1031.

9. R. G. Meyer and W. D. Mack, "A DC-1GHz Differential Monolithic Variable-Gain Amplifier," *IEEE J. Solid-State Circuits*, accepted for publication.

10. Nhat M. Nguyen and R. G. Meyer, "A Si Bipolar Monolithic RF Bandpass Amplifier," *IEEE J. Solid-State Circuits*, accepted for publication.

D. PARTICIPATING PERSONNEL

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