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This report summarizes our research results in Integrated, High-Frequency Communication Circuits. A monolithic integrated circuit process giving 1.7 GHz transistors has been realized. This allowed realization of an optimum, wideband, low-distortion, monolithic amplifier with 20 dB gain and 370 MHz bandwidth. The circuit incorporates low-noise Zener diodes and has a worst case noise figure of 9 dB.

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Research on monolithic VCOs yielded an optimum topology for a temperature-stable high-frequency VCO. A monolithic triangle sine wave converter yielding 0.3% total harmonic distortion over a 70°C temperature range has been realized for use with such VCOs. A computer-aided design program SINC-S has been written for the analysis of oscillator circuits. This typically gives a factor of three improvement in computation time compared with conventional techniques.

A publication list is included together with a list of Ph.D. and M.S. reports resulting from this work.

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The research supported under Grant DAHC04-74-G-0151 led to significant results in a number of related areas. The various aspects of the work included high-frequency integrated circuit (IC) processing, investigation of new circuit techniques and computer-aided design (CAD). These areas complemented one another and allowed some major advances to be made.

In the area of IC processing, a new process was designed and realized which yielded 1.7 GHz bipolar transistors. The process incorporates shallow diffusions (about 1 μm) on thin epitaxial material (3 μm) and uses eight mask steps. Through careful process design, the transistors produced by the process had simultaneously good noise performance and excellent linearity at high frequencies. In addition, the process produced low-noise Zener diodes giving broadband noise as low as $10nV/\sqrt{Hz}$ at 5 mA current levels.

The process described above was an essential element in the realization of a unique monolithic low-distortion wideband amplifier. Also important were previous investigations of amplifier and device nonlinearity and our ongoing research in the area of CAD. The monolithic amplifier resulting from this work achieved 20 dB gain and 250 MHz bandwidth using an early 800 MHz IC process. Using the more advanced 1.7 GHz process the circuit yielded 370 MHz bandwidth. These results agreed well with computer-predicted values. Computer optimization yielded second-order intermodulation distortion below -42 dB across the band. At present, this performance is bettered only by expensive thin-film hybrid circuits. Other aspects of the circuit performance are input and output impedances matched to 75Ω with VSWR less than 1.7 and a worst-case noise figure of 9 dB at 250 MHz.

A second area of circuit research has centered on high-stable monolithic voltage-controlled oscillators (VCO). The fundamental limitations on the temperature stability of high-frequency monolithic VCO's were determined. A general investigation of methods of VCO implementation showed that charge storage in the transistor base was not a significant factor, but that parasitic capacitance was the basic limitation. Extensive computer analysis of a number of oscillator configurations has shown the superiority of configurations using a grounded timing capacitor. This is in contrast to the more commonly-found balanced multivibrator configurations using floating timing capacitors. An optimum topology for a temperature-stable high-frequency VCO has been defined and computer analysis has confirmed its desirable characteristics. Extremely fast ECL-type comparators and current switches are combined with better high-frequency characteristics than was previously attainable. Features include keep-alive Schottky diodes in the current switch in order to reduce delays due to parasitic capacitance. The threshold voltage of the comparator is compensated against temperature drift by a temperature-dependent bias current source.

Monolithic voltage-controlled oscillators of the type described above produce triangle or square wave outputs. A sinusoidal output is often desired and this can be realized by passing the triangle wave through a triangle-sine wave converter. The emitter-degenerated differential pair was investigated for use in such applications. The basic circuit was shown to give total harmonic distortion less than 1% in the output sinusoid over a 50°C temperature range with appropriate choice of parameter values. In addition first order temperature compensation has yielded distortion less than 0.3% over this range. Finally, the frequency response of the circuit has been investigated and the major limitation shown to be waveform distortion produced as the peaks of the sine wave. This is due to the reduced value of f_T of the active devices at this point in the cycle. The results achieved by this triangle-sine wave converter are significantly better than most discrete versions employing many more components. In addition, the small die area of the circuit allows its use in more complex monolithic subsystems.

The success of the circuit research described above depended greatly on our CAD capability. The analysis of oscillators in particular was aided by the creation of the program SINC-S. This incorporated the Aprille-Colon-Trick (ACT) algorithm for nonlinear dc and time-domain transient and steady-state analysis in the program SINC. The basic SINC program is a compact program using modified nodal analysis for dc and time-domain simulation of transistor circuits. In the simulation of relaxation oscillators, Gear's 2nd-order integration method with the solution-iteration-count time-step control was found to be most effective. Direct time-domain simulation becomes impractical for steady-stage analysis to eliminate the start-up transients if initial conditions are improperly chosen. Also, small time-steps are required to simulate high-Q circuits accurately. The ACT algorithm finds initial conditions satisfying the periodicity requirement using Newton's method, with the Jacobian matrix obtained from the sensitivity circuits. In many applications, steady-state analysis using the ACT algorithm reduces the computation time by more than a factor of 3 over conventional time-domain transient analysis.

The research described above resulted in 6 publications, 2 Ph.D reports and 5 M.S. reports as listed below.

Publications

1. R. G. Meyer and M. L. Stephens, "Distortion in Variable-Capacitance Diodes," Proceedings, Eighth Asilomar Conference on Circuits, Systems and Computers, December 1974, pp. 165-167. Published in full in IEEE J. Solid-State Circuits, Vol. SC-10, No. 1, February 1975, pp. 529-538.

2. R. G. Meyer, R. Eschenbach and W. M. Edgerley, Jr., "A Wideband Feedforward Amplifier," IEEE J. Solid-State Circuits, Vol. SC-9, No. 6, Dec. 1974, pp. 422-428.

3. R. G. Meyer, W. M. C. Sansen, S. Lui and S. Peeters, "The Differential Pair as a Triangle-Sine Wave Converter," IEEE J. of Solid-State Circuits, Vol. SC-11, June 1976, pp. 418-420.

4. E. Cohen, L. Nagel and D. Pederson, "Computer Simulation of Microcircuits," International Electronic Conference, IREE (Australia), Sydney, Australia, August 1975.

5. H. A. Abraham and R. G. Meyer, "Transistor Design for Low Distortion at High Frequencies," IEEE Trans. Electron Devices, Vol. ED-23, No. 12, Dec. 1976, pp. 1290-1297.

6. K. H. Chan and R. G. Meyer, "A Low-Distortion Monolithic Wideband Amplifier," IEEE ISSCC Digest, Vol. 20, 1977, pp. 208-209.

Ph.D. Dissertations

1. S. P. Fan, "SINC-S: A Computer Program for the Steady-State Analysis of Transistor Oscillators," 1975.

2. K. H. Chan, "Optimum Design of Low-Distortion Monolithic Wideband Amplifiers," 1977.

M.S. Reports

1. K. Chan, "Distortion Analysis of Transistor Output Stages at High Frequencies," 1[illegible]

2. S. Lui, "Investigation of a Sine-Shaping Circuit," 1975.

3. M. Stephens, "Distortion in Variable-Capacitance Diodes," 1975.

4. G. Hunsinger, "A High-Frequency Integrated-Circuit Process," 1975.

5. I. Kukielka, "Analysis of the Emitter-Coupled Multivibrator," 1976.