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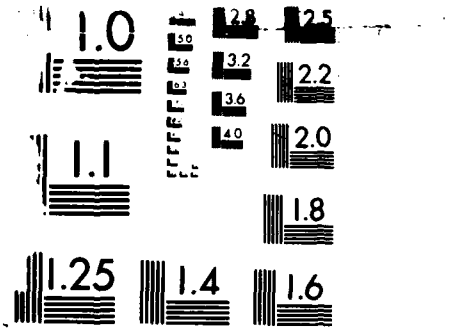

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for
Linearization of Nonlinear Systems
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1 Equipment

Over the first year of the contract, we have acquired all equipment proposed in the equipment grant. Unexpected costs (e.g. ethernet cable and connectors) were more than offset by dropping equipment prices. The installation of a small cluster of 68020-based SUN-3 workstations has meant a huge increase in computing power available to students, and we are already seeing the results of this.

2 Progress

We have made progress in a number of areas. First, we have made a detailed study of the problem of low crest-factor signals, based on the techniques used in earlier work on harmonic probing of nonlinear systems [BTC83,BCD84]. Particularly interesting here is the numerical evidence suggesting that the phases used in the original work exceed the performance achievable with the Shapiro-Rudin phases, which can be proved to yield bounded crest factor for multitone signals containing an arbitrarily large number of tones. This work has practical application for frequency response measurements of *linear systems*, and of course is critical for measurements of small distortions in nonlinear systems. An offprint is attached [Boy86a].

The crest factor problem relates two norms, L^2 and L^∞, of a signal; comparing the *gains* of an operator with respect to two norms is much harder. Here a new bound was recently derived in [BD86]. A preprint of this work is attached.

Perhaps the most exciting area of progress is in the design of an *adaptive linearizing compensator* for a slightly nonlinear system. In collaboration with B. Widrow, a preliminary design has been proposed, and just last week the first full simulation results showed typical distortion nulling by a factor of 10 (-20dB) for some simple nonlinearities. Of course these are preliminary results, and much more needs to be done, but basic feasibility has been demonstrated.

One related area where great progress has been made is in CAD for controllers and filters. In this work, a practical method is proposed for tak-

ing advantage of recent results which parameterize all the controllers which stabilize a given plant, or more importantly, all the I/O maps achievable with controllers which stabilize the plant. A *compiler* accepts as input a description of the plant, nominal controller, and design specifications (expressed in a *Control Specification Language*) and as output produces a large convex program which may be solved numerically to yield the desired controller or filter. We have a rough implementation of such a compiler. All details can be found in the attached preprint [BBB*86].

3 Awards and Honors

- NSF Presidential Young Investigator Award.
- D. J. Sakrison Memorial Prize for dissertation research.
- Fannie and John Hertz Foundation Doctoral Thesis Prize.
- Invitation to give talk *Linearization of Nonlinear System by I/O Methods,* ISCAS 1987.
- Invitation to give talk *Overview of ℓ_1-optimal Controller Design,* MTNS 1987.

References

[BBB*86] S. P. Boyd, V. Balakrishnan, C. H. Barratt, N. M. Khraishi, X. Li, D. G. Meyer, and S. A. Norman. A CAD method and associated architectures for linear controllers. In *Proc. 1986 Allerton Conf.*, 1986.

[BC85a] S. Boyd and L. O. Chua. Fading memory and the problem of approximating nonlinear operators with Volterra series. *IEEE Trans. Circuits Syst.*, CAS-32(11):1150–1171, November 1985.

[BC85b] S. Boyd and L. O. Chua. Uniqueness of circuits and systems containing one nonlinearity. *IEEE Trans. Autom. Control*, AC-30(7):674–681, July 1985. Also in *Math. Theory of Networks and Systems Conf. Proc.* Lecture Notes in Control and Information Sciences vol. 58, p101–119, June 1983.

[BC85c] S. Boyd and L. O. Chua. Volterra series for nonlinear circuits. In *Proc. IEEE ISCAS*, Tokyo, June 1985.

[BCD84] S. Boyd, L. O. Chua, and C. A. Desoer. Analytical foundations of Volterra series. *IMA Journal of Mathematical Control and Information*, 1:243–282, 1984.

[BD85] S. Boyd and C. A. Desoer. Subharmonic functions and performance bounds on linear time-invariant feedback systems. *IMA Journal of Mathematical Control and Information*, 2:153–170, 1985. Also in *Proc. 1984 Conf. on Decision and Control.*

[BD86] S. Boyd and J. Doyle. Comparison of peak and RMS gains for discrete-time systems. *Syst. Control Lett.*, 1986. Submitted for Publication.

[Boy86a] S. Boyd. Multitone signals with low crest factor. *IEEE Trans. Circuits Syst.*, CAS-33:1018–1022, October 1986.

[Boy86b] S. Boyd. A note on parametric and nonparametric uncertainties in control systems. In *Proc. American Control Conf.*, pages 1847–1849, Seattle, Washington, June 1986.

[BS84] S. Boyd and S. S. Sastry. Necessary and sufficient conditions for parameter convergence in adaptive control. In *Proc. American Control Conf.*, 1984. Full length version in *Proc. 1983 Berkeley-Ames Conf. on Problems of Nonlinear Control and Fluid Mechanics.* Also, to appear in *Automatica.*

[BTC83] S. Boyd, Y. S. Tang, and L. O. Chua. Measuring Volterra kernels. *IEEE Trans. Circuits Syst.*, CAS-30(8):571–577, August 1983.

[GBL85] R. M. Gray, S. Boyd, and T. Lookabaugh. Low rate distributed quantization of noisy observations. In *Proc. Allerton Conf. Signal Processing*, October 1985.

[MB86] D. G. Meyer and S. P. Boyd. A note on the order of ℓ^1 optimal compensators. In *Proc. IEEE Conf. on Decision and Control*, December 1986.

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