$L_dC(I+G))^T P_2^{-1}(G - L_dC(I+G)) - P_2^{-1} < 0$. Using the Schur complement, matrix inequality (31) is equivalent to

$$\nu_1\Psi_{22}^1 + \nu_2\Psi_{22}^2 - \nu_1\Psi_{12}^T\Psi_{11}^{-1}\Psi_{12} < 0 \quad (32)$$

$$\nu_1\Psi_{11} < 0. \quad (33)$$

It is readily seen that (33) is satisfied for all $\nu_1 > 0$. Inequality (32) holds, if

$$\frac{\nu_1}{\nu_2} < -\frac{\lambda_{\max}\left(\Psi_{22}^2\right)}{\lambda_{\max}\left(\Psi_{22}^1 - \Psi_{12}^T\Psi_{11}^{-1}\Psi_{12}\right)}. \quad (34)$$

Consider the set of all pairs (ν_1, ν_2) that meet (34). Within this set, (33) always holds owing to (28), which means that without violating (33), one can choose sufficiently large $\nu_2 > 0$ and small $\nu_1 > 0$ so that the LHS of (34) is arbitrary close to zero. Hence, the positive definite matrix P always exists for the Lyapunov functional (26) and we conclude that (10) is asymptotically stable in the sense of Lyapunov, if LMIs (16) and (18) hold.

REFERENCES

[1] Y. H. Joo, G. Chen, and L. S. Shieh, "Hybrid state-space fuzzy model-based controller with dual-rate sampling for digital control of chaotic systems," *IEEE Trans. Fuzzy Systems*, vol. 7, pp. 394–408, Aug. 1999.

[2] W. Chang, J. B. Park, Y. H. Joo, and G. Chen, "Design of sampled-data fuzzy-model-based control systems by using intelligent digital redesign," *IEEE Trans. Circuits Syst. I*, vol. 49, pp. 509–517, Apr. 2002.

[3] L. S. Shieh, W. M. Wang, and M. K. Appu Panicker, "Design of PAM and PWM digital controllers for cascaded analog systems," *ISA Trans.*, vol. 37, pp. 201–213, 1998.

[4] S. M. Guo, L. S. Shieh, G. Chen, and C. F. Lin, "Effective chaotic orbit tracker: a prediction-based digital redesign approach," *IEEE Trans. Circuits Syst. I*, vol. 47, pp. 1557–1570, Nov. 2000.

[5] S. M. Guo, W. Wang, and L. S. Shieh, "Discretization of two degree-of-freedom controller and system with state, input and output delays," *Proc. IEE Control Theory Appl.*, vol. 147, no. 1, pp. 87–96, Jan. 2000.

[6] J. Xu, G. Chen, and L. S. Shieh, "Digital redesign for controlling chaotic Chua's circuit," *IEEE Trans. Aerosp. Electron. Syst.*, vol. 32, pp. 1488–1499, Oct. 1996.

[7] L. S. Shieh, W. M. Wang, J. Bain, and J. W. Sunkel, "Design of lifted dual-rate digital controllers for X-38 vehicle," *J. Guid. Control Dyn.*, vol. 23, pp. 629–639, 2000.

[8] T. Yokoyama, K. Kosuge, and K. Furuta, "Digital redesign of robot control," in *Proc. IECON '89*, vol. 2, 1989, pp. 409–414.

[9] B. C. Kuo, *Digital Control Systems*. New York: Holt, Rinehart, and Winston, 1980.

[10] W. E. Schmitendrof, "A design methodology for robust stabilizing controllers," *AIAA J. Guid. Control Dyn.*, vol. 10, pp. 250–254, 1987.

[11] J. W. Sunkel, L. S. Shieh, and J. L. Zhang, "Digital redesign of an optimal momentum management controller for the space station," *J. Guid. Control Dyn.*, vol. 14, no. 4, pp. 712–723, 1991.

[12] S. M. Guo, L. S. Shieh, C. F. Lin, and J. Chandra, "State-space self-tuning control for nonlinear stochastic and chaotic hybrid systems," *Int. J. Birfurcation Chaos*, vol. 11, no. 4, pp. 1079–1113, 2001.

[13] L. S. Shieh, W. M. Wang, and J. B. Zheng, "Robust control of sampled-data uncertain systems using digitally redesigned observer-based controllers," *Int. J. Control*, vol. 66, no. 1, pp. 43–64, 1997.

[14] C. A. R.César A. R. Crusius and A.Alexandre Trofino, "Sufficient LMI conditions for output feedback control problems," *IEEE Trans. Automat. Contr.*, vol. 44, pp. 1053–1056, May 1999.

[15] T. Chen and B. Francis, *Optimal Sampled-Data Control Systems*. Berlin, Germany: Springer-Verlag, 1995.

Comments on "A CMOS Fully Balanced Four-Terminal Floating Nullor"

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***Index Terms*—Current conveyor, nullor, operational amplifier, universal active element.**

The authors of [1] write in the introduction to their paper that the four-terminal floating nullor (FTFN) is more versatile than the opamp or the second-generation current conveyor (CCII), because any circuit function can be realized with FTFNs as the only active elements [2]. In this sense, the FTFN is universally versatile.

This is often written in introductions to FTFN papers, but it is not correct. The FTFN is not *more* versatile than the CCII, because any circuit can also be realized with CCIIs as the only active elements. This was shown already in [2], where the CCII− was called "three-terminal nullor." It is also implied in [1], when the authors show in Fig. 2(b) how one FTFN can be replaced by two CCIIs, and therefore how any FTFN circuit can be replaced by a CCII circuit.

It was shown in [3] that the FTFN and the CCII are not the only universally versatile elements. Other such elements are *all* first-, second-, and third-generation current conveyors as well as all nine classes of operational amplifiers: the OTA[1, Fig. 2(b)], the opamp, the floating opamp [1,Fig. 2(a)], the current-mode opamp, the operational transresistance amplifier (OTRA), the floating OTRA, the current-feedback OTA, the current-feedback opamp, and the operational floating conveyor. Since all of these elements are universally versatile, it is not correct to say that one of them is more versatile than the others.

If an FTFN is defined as a nullor approximation with four available terminals, then the OTA and the floating opamp shown in [1] are not the only FTFN realizations. Other possibilities are the operational floating conveyor [4] and the current-feedback OTA [5].

Finally, the authors of [1] state that the FTFN is not yet commercially available. One counterexample is the MAX 435 by Maxim [6], which is an implementation of [1, Fig. 2(b)]. There are others as well. To our knowledge, none of the commercially available FTFNs have actually been given the name "nullor," which may be the reason why few people seem to know of the commercial availability of FTFNs.

REFERENCES

[1] H. Alzaher and M. Ismail, "A CMOS fully balanced four-terminal floating nullor," *IEEE Trans. Circuits Syst. I*, vol. 49, pp. 413–424, Apr. 2002.

[2] H. J. Carlin, "Singular network elements," *IEEE Trans. Circuit Theory*, vol. 11, pp. 67–72, Mar. 1964.

[3] H. Schmid, "Approximating the universal active element," *IEEE Trans. Circuits Syst. II*, vol. 47, pp. 1160–1169, Nov. 2000.

[4] A. Payne and C. Toumazou, "Operational floating conveyor," in *Proc. IEEE Int. Symp. Circuits and Systems*, vol. 3, Singapore, 1991, pp. 1813–1816.

[5] H. Schmid, "The current-feedback OTA," in *Proc. IEEE Int. Symp. Circuits and Systems*, vol. 1, Sydney, Australia, May 2001, pp. 655–658.

[6] Maxim integrated products, MAX435 Wideband Transconductance Amplifier Datasheet, Apr. 1993.

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