Testa, Pérez, and Jeffries Respond: Hunt's Comment[1] raises interesting questions: What properties of a p-n junction diode give rise to bifurcation in a driven circuit; and what conditions lead to the specific period-doubling (PD) bifurcation sequence previously reported.[2] Although Hunt implies that we ascribe the nonlinearity of the diode solely to its junction capacitance, this is stated nowhere in our paper. In fact, the exact nonlinearity of the varactor was not our concern. Diodes are characterized by nonlinear conduction (the well-known I-V characteristic curve), by a reverse recovery time τ, and by two types of capacitance[3]: (1) the junction capacitance C_j, dominant under reverse bias, and (2) the charge storage capacitance C_s, dominant under forward bias. Ordinary rectifier diodes usually have $C_s > C_j$ and $\tau \sim 1$ μs. Varactor diodes usually have $C_j > C_s$ and $\tau \sim 0.1$ to 1 μs. Fast signal diodes have $\tau \sim 1$ ns. Experiments done here on many diodes in a series circuit driven near resonance at period $T \approx 10^{-5}$ s gave the following results: (1) Fast signal diodes do not bifurcate. (2) Two diodes in series back to back do not bifurcate. (3) Diodes always reversed biased do not bifurcate. (4) Diodes with $\tau \sim (0.1$ to $0.6)T$ readily bifurcate, but not always in a PD sequence. (5) If the total circuit resistance is made sufficiently large, a PD route is usually observed, as in the case of Ref. 2. From these experiments we conclude that a diode must switch to show bifurcation and that the reverse recovery time must be a reasonable fraction of the driving period. To this extent we do agree with Hunt's Comment.[1] However, since the requisite reverse-recovery-switching characteristic is related to both the nonlinear conduction and the nonlinear charge-storage capacitance which are not separable in a real diode (in contrast to analog simulations), we do not conclude with Hunt that the nonlinear conduction is more "important" than the nonlinear capacitance. From measurements of the resonant frequency dependence on the driving voltage, we find that C_j is the dominant frequency-determining nonlinearity for driven RLC circuits using varactor diodes, and that C_s is dominant for rectifier diodes. However, the nonlinearity giving rise to bifurcation may be different.

We note that this Comment and Response do not in any way invalidate our observations and conclusions[2,4] that the nonlinear oscillator used (diode 1N953) displays a universal period-doubling bifurcation sequence to chaos.[5] That this is so is quite interesting in view of the complexity of the nonlinearity and the higher-order differential equations of the system. Apparently because of the dissipation, it behaves as if it were approximated by a one-dimensional quadratic map.

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[1]E. R. Hunt, preceding Comment [Phys. Rev. Lett. 49, 1054 (1982)].
[2]J. Testa, J. Pérez, and C. Jeffries, Phys. Rev. Lett. 48, 714 (1982).
[3]B. G. Streetman, *Solid State Electronic Devices* (Prentice Hall, Englewood Cliffs, 1972).
[4]J. Pérez and C. Jeffries, Phys. Rev. B 26, 3460 (1982).
[5]M. J. Feigenbaum, J. Stat. Phys. 19, 25 (1978).

