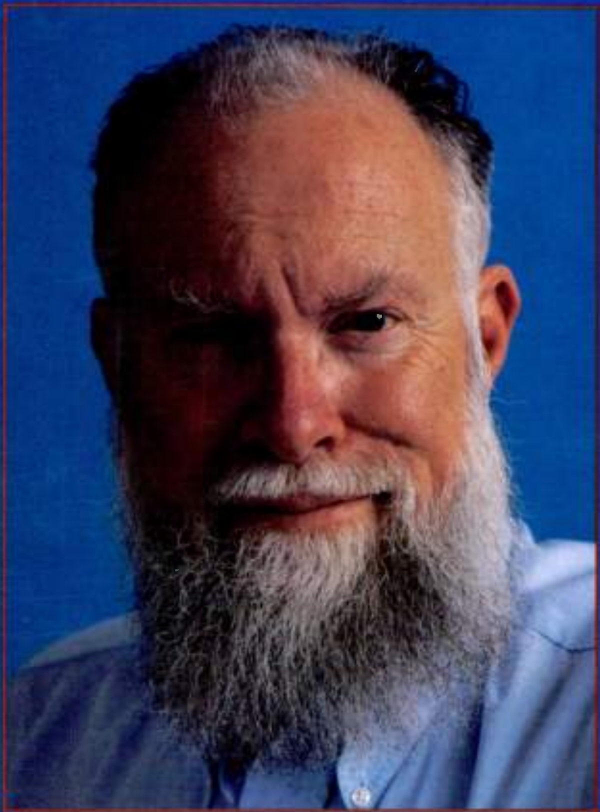
SUPPLEMENT TO ELECTRONIC DESIGN • AUGUST 4, 1997

ELECTRONIC DESIGN

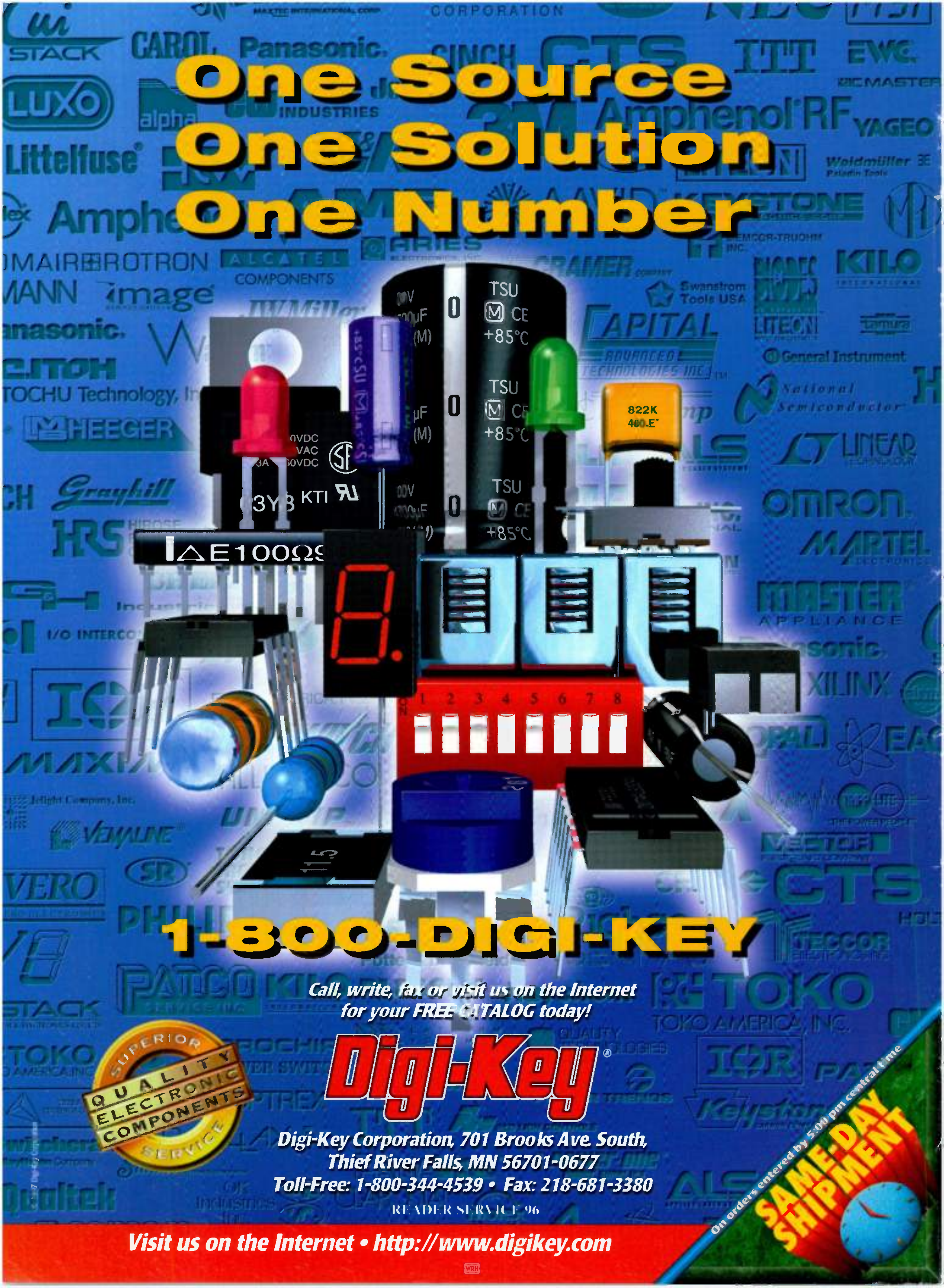
FOR ENGINEERS AND ENGINEERING MANAGERS - WORLDWIDE

BOB PEASE



WHAT'S ALL THIS STUFF, ANYHOW? VOLUME TWO

THE BEST OF PEASE PORRIDGE



One Source
One Solution
One Number
1-800-DIGI-KEY
Call, write, fax or visit us on the Internet
for your FREE CATALOG today!
Digi-Key®
SUPERIOR QUALITY ELECTRONIC COMPONENTS SERVICE
Digi-Key Corporation, 701 Brooks Ave. South,
Thief River Falls, MN 56701-0677
Toll-Free: 1-800-344-4539 • Fax: 218-681-3380
READER SERVICE 96
Visit us on the Internet • http://www.digikey.com
On orders entered by 5:00 pm central time
SAME-DAY SHIPMENT

Your long wait is now over. A line of standard DC to DC power converters has taken its proper place on the PC board.

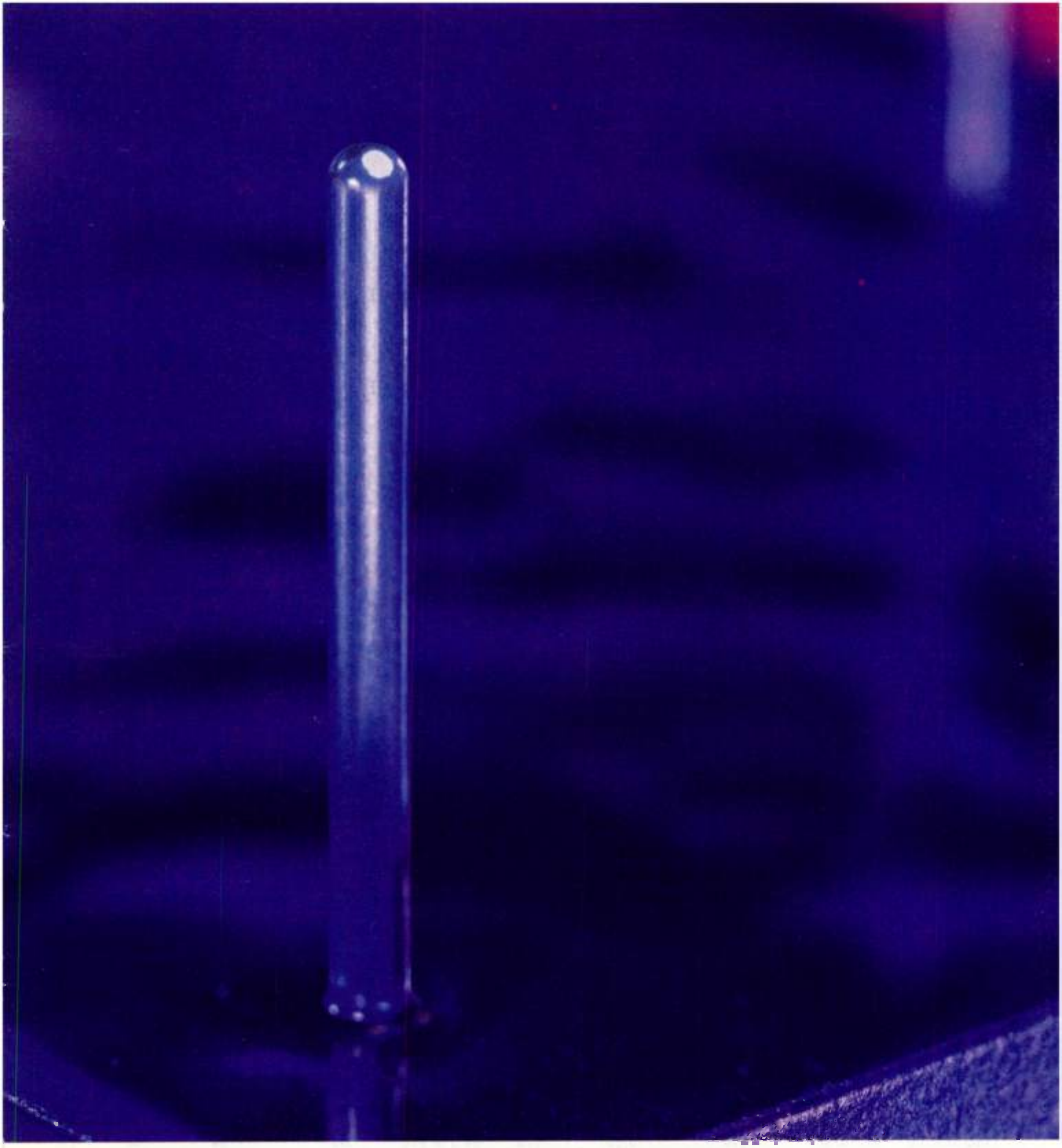
Right on the surface.

And it solves an elusive problem that's left most manufacturers scratching their heads — how do you dissipate heat without making the converter too heavy for a pick and place machine?

Enter the Lambda engineers. Through a unique layering of advanced materials, they've created a proprietary system that dissipates heat up and away from the board. Without the need for heavy thermal potting.

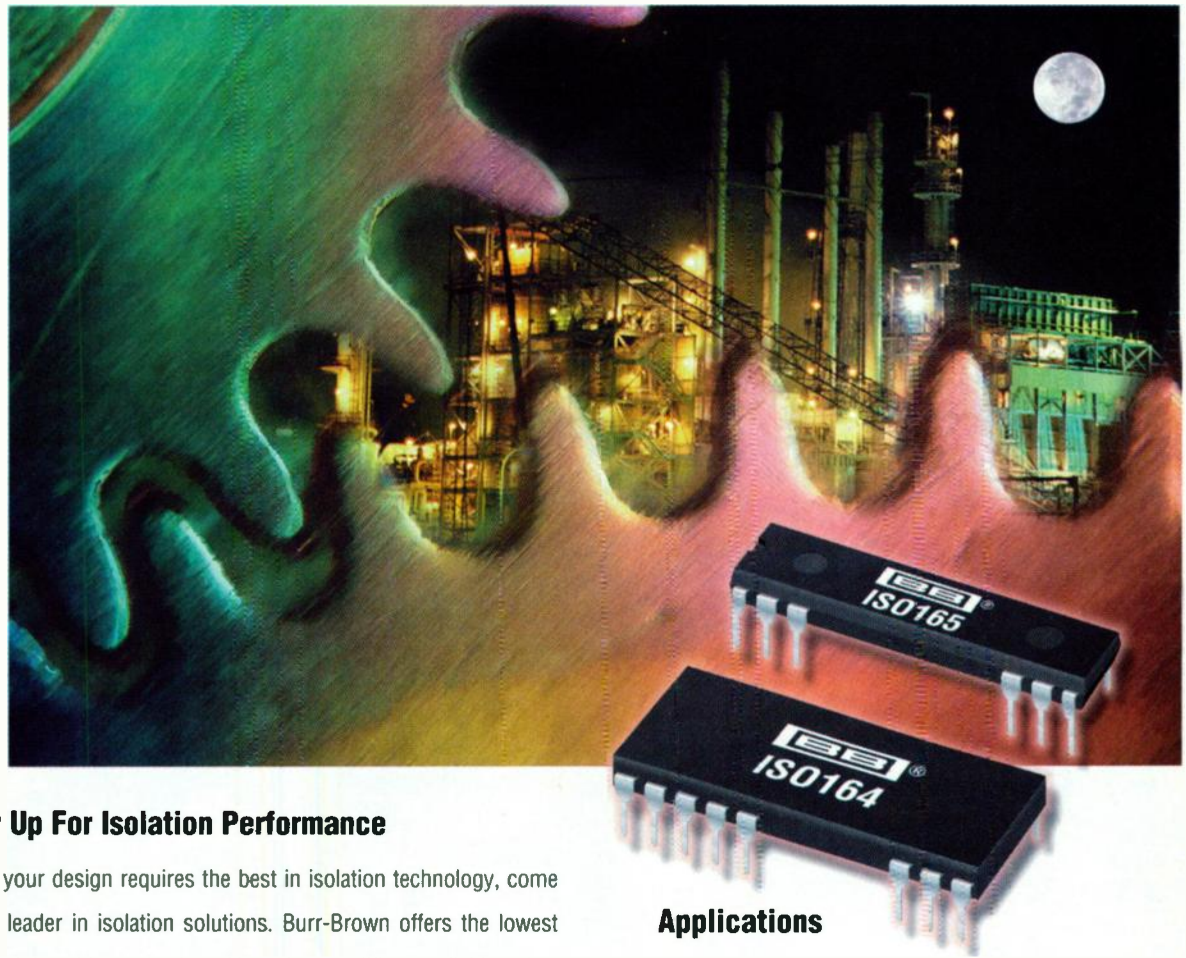
(We'd be happy to go into more detail, but then it wouldn't be proprietary anymore.)

So we've eliminated the need to manually place and solder through-hole converters.



Isolation PLUS™

Isolation Amplifiers



Gear Up For Isolation Performance

When your design requires the best in isolation technology, come to the leader in isolation solutions. Burr-Brown offers the lowest cost and the widest selection of isolation amplifiers available today. With our isolation products, you know you're getting the finest high performance products with quality and reliability built in.

Applications

- Power Monitoring
- Medical Instrumentation
- Data Acquisition
- Test Equipment
- Industrial Process Control
- Ground Loop Elimination

Products	Isolation Function	Input Voltage Range (V)	Full Scale Bandwidth (kHz)	IMR (dB)	Power Supply Range (V)	Self Powered	FAX*LINE*# (800) 548-6133	Reader Service #
ISO164/174	PGA	±10	6/60	115	±4.5 to ±18	No	11307	81
ISO165/175	INA	±10	6/60	115	±4.5 to ±18	No	11293	82
ISO166/176	OPA	±10	6/60	115	±4.5 to ±18	No	11294	83
ISO212/213	OPA/INA	±5/±12	0.2	115	±11.4 to ±16	Yes	10881/11281	84
ISO253/254	BUFFER/PGA	±10	50	120	±11 to ±18	Yes	11310/11308	85
ISO255/256	INA/OPA	±10	50	120	±11 to ±18	Yes	11312/11311	86

For Technical Information: http://www.burr-brown.com/Ads/ISO164-Ad.html

BURR - BROWN®

Burr-Brown Corporation

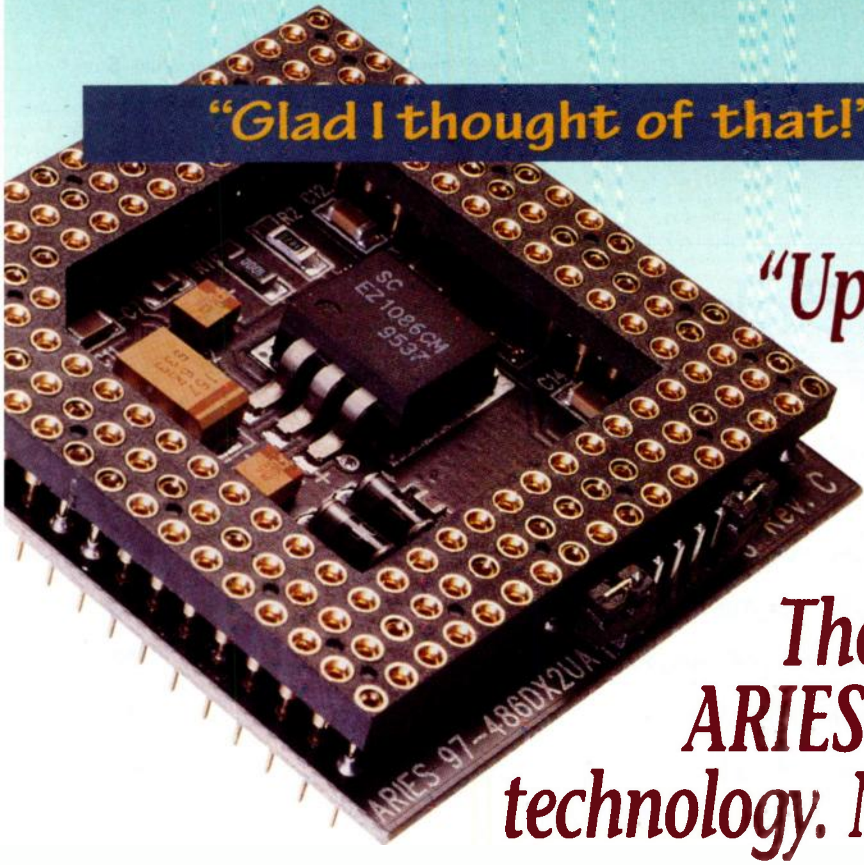
Burr-Brown Corporation • P.O. Box 11400 • Tucson, AZ • 85734-1400 • Call **(800) 548-6132** or use **FAX*LINE* (800) 548-6133** • **http://www.burr-brown.com/**

Distributors: Anthem: (800) 826-8436 • **Digi-Key Corp:** (800) 338-4105 • **Insight Electronics:** (800) 677-7716 • **J.I.T. Supply:** (800) 246-9000 • **Sager Electronics:** (800) 724-378[illegible] • **SEMAD (Canada):** (800) 567-3623

WRH

The Best Of Bob Pease Volume II

Bob Pease was awarded a Jesse H. Neal Certificate of Merit by the American Business Press for his "Pease Porridge" columns in 1992.

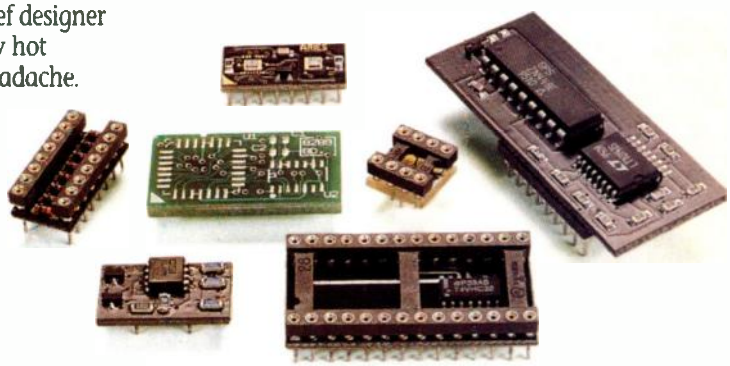


"Glad I thought of that!"

"Upgrading boards already in production used to be a nightmare. Then I discovered ARIES Correct-A-Chip™ technology. Now it's a dream."

THE PROBLEM

"Things change fast in this business…too fast, sometimes. Just when I'd get a new board into production, my phone would ring. The chief designer just had a vision! The boards must change!…we had some pretty hot discussions, let me tell you. *They* had a new toy – *I* had a new headache.



THE SOLUTION

"A friend at another company told me she used to have the same problem, and solved it with Aries Correct-A-Chip technology. She said Aries could let me change from through-hole to SMT, work with any kind of footprint, even crank up performance in the same board space. And she was right! Those design changes don't bother me anymore. In fact, now that I'm plugged into Correct-A-Chip, I sleep like a baby.

Thanks, Aries!"

ARIES®
ELECTRONICS, INC.

P.O. Box 130 Frenchtown, NJ 08825
(908) 996-6841 FAX (908) 996-3891
e-mail: info@arieselec.com

Visit us on the Web: www.arieselec.com

ISO 9002 CERTIFIED

THE PROOF

Look in the Correct-A-Chip Catalog, visit us on the Internet, or call our fax-on-demand at (908) 996-6841. You'll find plenty of sensible solutions to your problems…FAST.

Sensible Solutions. . . Fast!

READER SERVICE 103

Preface

What's All This Fun Stuff, Anyhow?

Well—first of all, we should have fun. We all should be *having* fun, most of the time. If we aren't having fun, maybe there is something wrong? As you guys have noticed, I seem to have a lot of fun writing these columns. And you guys seem to have fun *reading* these columns. I am encouraged when we agree on that. Heck, when I find myself reading one of my old columns, I often find myself smiling and shaking my fist (RIGHT ON!!), or wondering, "Hey, this is good writing! What NUT wrote this?"—and then I realize it was *me*. I do still have fun writing my columns—and *reading* them. If I didn't have any fun—how long would it take me to quit?

Hey, when I do my work, that is *fun*. When I do a SPICE run, and it agrees with my hand-computations, fine. That's fun. And if there's a discrepancy, and I figure out that I am right, and SPICE is wrong—that is FUN! BUT what if I find that SPICE is telling the truth, and my circuit has an error I did not expect? Happens to the best of us. I smile and thank the Lord that I did my homework, and I let SPICE give me an education. Hey, some kinds of self-education are more fun than others. And much less painful than letting your circuit go into production, and then finding out it does not yield well... for the same stupid reason that SPICE might have warned me about. When I make a customer happy, that is fun, too.

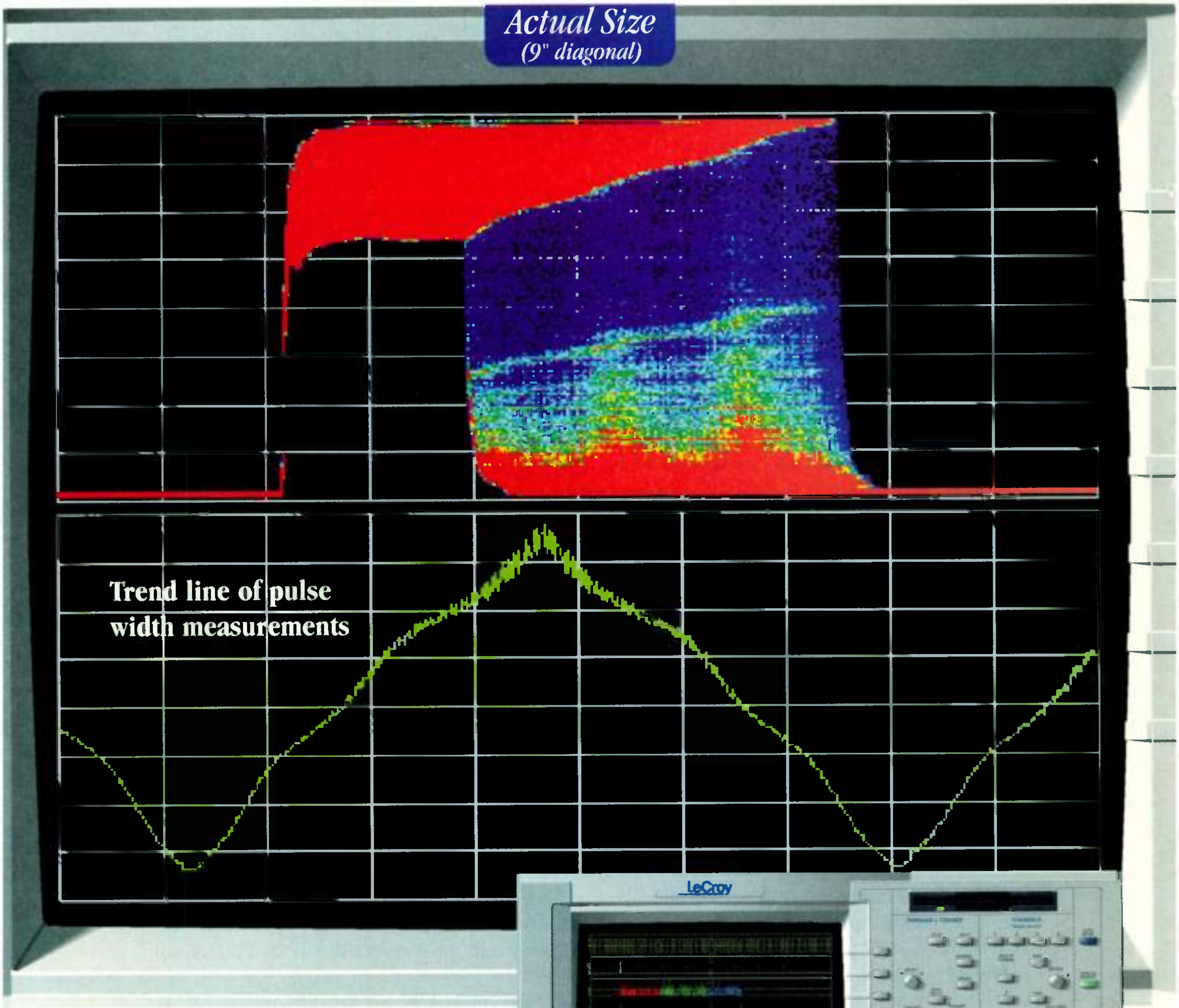
I was cooking a pot of Chili at 9:40 PM last night (21 May, 1997) and listening to a BBC program on KQED-FM. I heard a woman say that she had been having a great success as manager of a trendy Ad Agency in London. But she was getting very frustrated by all the pressures. She decided to take up Buddhism, and started doing a lot of meditation. She found this very satisfying—BUT she found that the pressures were increasing even faster because she had to work even *harder* to get all her work done and still fit in 1-1/2 hours a day of meditation. She said she finally gave up that line of work. (I am not kidding. I heard her say it.)

How do we have fun? Hopefully I will not just get my "fun" by kicking my cat, nor my car. Nor my dog, nor my wife, nor my boss, nor my customer. But if our fate in life is eternal frustration and NO FUN AT ALL—how can we have any fun?

Ain't no simple answer. I really want us all to do our jobs well enough that WE can all have fun, and make our clients and customers happy. I want my company to make money, and I want my customers to make money, and I want you and your companies to make money. You can't have much fun if you are not making money. I wish that to all you guys. I hope the *stuff* I write is helpful, so you can preserve your sanity and have fun.

Comments invited! / RAP/
Robert A. Pease / Engineer
rap@webteam.nsc.com or
MS D2597A, National Semiconductor Corp.
P.O. Box 58090
Santa Clara, CA 95052-8090

See More... Do More



Get the Complete Picture

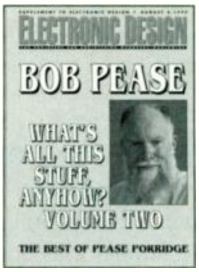
- **Capture** signals accurately with 500 MHz or 1 GHz front-ends and up to 4 GS/s sampling rate.
- **View** your signal on a large, bright 9" color CRT using Analog Persistence™ to emulate an analog scope.
- **Analyze** faults and solve problems fast. LeCroy DSOs provide a complete tool set. Perform math on 8 MByte waveforms, histogram any of 42 key parameters or draw a trend line like the lower trace above (making it easy to spot non-linearities in pulse width modulation).

LeCroy

1-800-4-LeCroy

http://www.lecroy.com

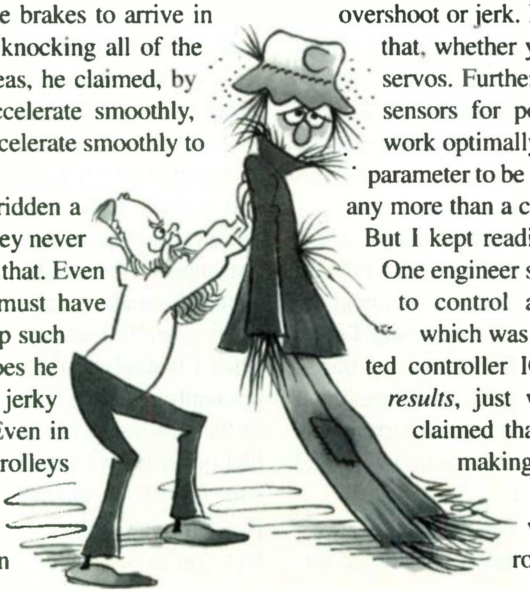
READER SERVICE 101



What's All This Fuzzy Logic Stuff, Anyhow?

As you may have noted, several people have asked me what I thought about "Fuzzy Logic" (abbreviated to F.L.). When I was finally able to stop laughing, I agreed that if its name wasn't so weird, it would be easier to take it seriously (*Bob's Mailbox*, July 9, 1992, p. 80F). Then several people wrote in (*Bob's Mailbox*, Oct. 1, 1992, p. 74) to explain that F.L. was just a set of simplified analog/digital conventions that weren't really so new after all.

All this time I kept inquiring, what does Fuzzy Logic do that you can't do in conventional or traditional ways. I kept hearing, "Oh, you can do wonderful things." And, "You can get better results than with conventional logic." But in the back of my head, I remembered the magazine article where I first learned about F.L. a few years ago. The writer explained that if you use ordinary logic to run a subway train, it will accelerate up to high speed, then jerk on the brakes, accelerate viciously again, brake, accelerate, brake, accelerate, and finally jam on the brakes to arrive in the station with a screech, after knocking all of the passengers off their seats. Whereas, he claimed, by using Fuzzy Logic, you can accelerate smoothly, hold a constant top speed, and decelerate smoothly to the station.



Well, anybody who has ever ridden a subway or streetcar knows that they never accelerate and jerk viciously like that. Even the guy who wrote the article must have known that. So why did he set up such an absurd straw man??? Why does he insist that F.L. is superior to a jerky system that has never existed? Even in the 1890s, electric trains and trolleys were operated smoothly with the "new" Westinghouse controllers. I know—I have ridden 90-year-old trolleys, and they operate almost as smoothly as modern ones (such as BART).

Now, I have never studied all the detailed languages of Fuzzy Logic, and I probably never will. But I have studied motion controllers of various types, both analog and digital. There are lots of modes of operation. If you want to provide good smoothness (to minimize the "jerk"$=da/dt=d^3x/dt^3$), there are many ways to do that. And if you just want to get there fast, there are ways to do that, too.

Of course, if you used the crudest possible bang-bang controller, you might get some of the disadvantages cited by the fans of F.L. But that's unfair. When you use some sensor (analog or digital) to detect where you are, you may use inexpensive data converters to get the information into either the analog or digital domain to tell the computer where you are, with adequate resolution. Then the controller can decide where you want to be, and how to converge smoothly on the correct answer without undesirable overshoot or jerk. It's not hard to make a controller do that, whether you rely on analog servos or digital servos. Further, even F.L. controllers may require sensors for position, velocity, etc. They cannot work optimally in a vacuum of information on the parameter to be controlled without any sensors—not any more than a conventional controller can.

But I kept reading strange claims in the literature. One engineer stated that he could use Fuzzy Logic to control a switch-mode voltage regulator, which was better than a conventional, committed controller IC could do. But I never saw any *results*, just wild claims. Then another person claimed that Fuzzy Logic would be ideal for making a better elevator controller, because without Fuzzy Logic, the elevator would surely lurch and come to a rough halt, knocking everybody off their feet.[1] Now, REALLY!

Another author stated that a controller for pressure in a steam boiler had greatly improved response when a Fuzzy Controller was added—including a rise-time that was at least twice as fast.[2] Don't look now, but you get 2× faster rise-time by applying twice as much power. If Fuzzy Logic seems to be achieving that advantage for you, that's only because the conventional system must have been terribly designed.

And various readers kept sending me copies of articles, ads, claims, even several examples of poetry—all KINDS of obscure observations on how WONDERFUL it must be to use Fuzzy Logic. I bounced some of these claims off my old friend Tom Harper in the Embedded Controller group at NSC. Tom observed that if you really know what you want to do, Fuzzy Logic does not always offer much of a performance advantage (if any) over a conventional or "deterministic" controller. In other words, maybe a F.L. power controller can do better than an old LM3524, but so can lots of other more modern controllers.

So it's not obvious where the actual advantage is if the "improvement" is just claimed to be the inherent advantage of the Fuzzy Logic. However, Tom pointed out, in some cases where nobody knows how to control the system, the F.L. controller may be able to control things better.[3] Then by watching the Fuzzy controller, you may learn how to control the system even better than the Fuzzy controller.

But the claims kept coming in. "Fuzzy controllers have inherent advantages." And, "The Japanese are putting Fuzzy controllers in refrigerators and washing machines and cameras." Well, if the Japanese are doing it, it must be superior, right??

Another example I heard on the radio: An "expert" stated that some new cars have an automatic transmission that uses Fuzzy Logic. They are much superior to transmissions without F.L., because transmissions without F.L. always shift at the same speed, whereas transmissions with F.L. can shift at different speeds.[4] Hey, get a life! Don't try to tell me about the right way to design automatic transmissions when you've apparently never even driven a car!

One day I was talking with Frank Goodenough, and I was griping that all I ever heard about F.L. was a whole lot of PLATITUDES and straw-man arguments, and about the OBVIOUS INHERENT SUPERIORITY of Fuzzy Logic. Then I just *cracked*—I got ticked off and pointed out to Frank that so far, everybody says that F.L. is so great, but we never see any *real* advantages, not any *real* examples. OKAY, here's a solution to this vexing situation. I will send out this CHALLENGE to any reader:

Show me a system—your system or somebody else's system—where Fuzzy Logic is claimed to provide performance advantages over conventional controllers or systems. You can show me any kind of system, whether it's electronic, electrical, electromechanical, a switch-mode-regulator, or whatever.

But, it cannot be just a conceptual system, or a block diagram, or just a computer simulation. For a fair comparison, it has to be something that really works—that really does *something*. Furthermore, you must show me the corresponding conventional controller, and the advantages of the Fuzzy system in terms of *actual performance*. You must also show the actual interface, including the sensor that provides the inputs to the controller, and the actuator that converts the controller's commands into the real world. Then I can build one if I want to.

HOWEVER, I reserve the right to point out that perhaps the CONVENTIONAL system was a real clunker, so it was no wonder the F.L. controller could do better than that. In fact, I may be able to show that any thoughtfully designed system could do better than the Fuzzy Controller. If you just set up a straw man and knock him down easily, you can be sure I will stand up that straw man and put some steel in his backbone, and we'll try again.

So, if there really is a place where Fuzzy Logic is better than ordinary controllers, you show me, and I'll check it out, and I'll concede that there are some interesting advantages. But if you make unrealistic comparisons, I may just show that you were sand-bagging.... Therefore, you'd better show me the improvements in a realistic system. And it must be in a format where I can really evaluate the results. Either build up a circuit and send me both versions, or show me how to build it.

As you can see, I am kinda tired of hearing all these platitudes and vacuous claims and unbelievable advantages and other BULLBLEEP. And theoretical stuff that ain't gonna hold no water. If Fuzzy Logic is better at *everything* (which some people claim, but which I doubt), we'll find out. If it really is better at a small class of special cases, that we will find out, too.

For example, if we both set up a controller to run a train, and it really runs very well in tests with the train empty, does it still stop safely when the train suddenly fills up with passengers? You might like to argue that your Fuzzy controller can make a train start and stop faster and more optimally when full, empty, or under any other load conditions. Then I'll surely reply that making a train stop at 0.7 Gs is not really practical if the improved performance knocks all of the passengers off their feet and makes them ill. So you had better have a rational improvement, with REAL numbers for REAL examples, because I won't be fooled by platitudes and baloney and bluster and bullbleep. And if in fact you're just trying to fool yourself and me, we'll just

publish it... and we'll have a good laugh.

Since Frank Goodenough and I will be the judges, I think we will see some interesting situations: "I can sing anything higher than you can." "No, you can't." "Yes I can...." We shall see. Meanwhile, readers' comments, on where F.L. really *does* and *does not* provide advantages, are invited. But no bullbleep, and no platitudes. And Frank and I reserve the right to use anything we want to, vacuum tubes or digital multipliers or analog multipliers, to show that conventional controllers are adequate, or just as good, or better, or whatever. And after Frank and I do our judging, and write up our results, YOU can study what we say, and YOU can make your own judgments.

Note, some thoughtful people are beginning to admit that F.L. controllers don't necessarily offer much better *performance* than a conventional digital controller. A Fuzzy controller may even be able to bring a boat to its dock just about as quickly and smoothly (and, just as jerkily) as other controllers. But the Fuzzy controllers are *adequate*, and they're claimed to have an advantage of being relatively easy to program.

Now I'll agree, that's a perfectly plausible set of advantages. But it's a little different from a writer who claims that conventional digital controllers are inherently terrible "...because a digital computer can only recognize a one or a zero."[5] Haven't these clowns noticed that computers don't operate on just one bit—they operate on *bytes*? Because a byte with 8 (or more) bits can represent a signal with a resolution of 1 part in 256 (or more), a well-designed digital controller can obviously operate as smoothly as you would like. I have yet to see proof that statement applies to Fuzzy Logic controllers.

Furthermore, some knowledgeable engineers do NOT agree that F.L. is any easier to program or optimize... they observe that Fuzzy Rules can be hard to write well. Emdad Khan in NSC's Intelligent Systems group cautioned that "for complex systems, developing Fuzzy Rules is very difficult, especially if the system needs more than 20 rules and has more than 3 inputs and/or outputs. At this point, the designer starts losing the capability to relate the rules together; in other words we lose the main capability of Fuzzy Logic."

NOW, it's true that some controllers do exhibit a sawtooth curve like the subway train example I mentioned earlier. The thermostat in my house gives that exact same response when I turn it on in the morning. But that's OK, perfectly adequate, so long as the peak-to-peak temperature band is only a few degrees. I'm certainly not going to go out and buy a proportional furnace and control system for the heat in my house!

Several friends have commented: "Bob—this column sounds like you are in favor of digital control systems? How *surreal*!!!..." Now, don't get me wrong. I'm not saying any one kind of controller is good or bad. I am just arguing that you should *think* about what your computer or controller is doing for you, and try to understand it. If somebody says his new Fuzzy controller can solve all your problems with greatly improved performance and no thinking is required... think again. Think it over. Ask to see examples of things that really work. Do they show real advantages, or just conceptual advantages compared to a straw man? Do a sanity check—a reality check.

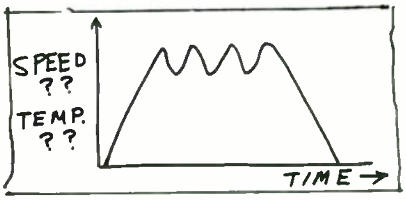
Comments invited! / RAP
Robert A. Pease / Engineer

1. *Electronic Design*, June 25, 1992, p. 37, "An elevator not based on Fuzzy Logic runs at constant speed until it reaches the destination, then comes to a rough halt". (NO, I am NOT making this up.)
2. *Fuzzy Logic*, Daniel McNeil and Paul Freiberger, p. 115, Simon & Schuster, 1993; about $22, not worth the price unless you really like *platitudes*.
3. NeuFuz 4 control system; announced by National Semiconductor, April 1993. It's not just Fuzzy Logic, but a whole lot more. For information, call 1-(800) 272-9959.
4. Daniel McNeill interviewed on "Marketplace Radio," KQED-FM, March 23, 1993 (6:49 P.M.).
5. *Fuzzy Logic*, McNeil & Freiberger, as quoted in the *San Francisco Chronicle* Book Review.

Originally published in
Electronic Design, May 13, 1993

RAP's 1997 comments: WELL, we sure did have a lot of fun in the last 5 years, talking about Fuzzy Logic. I've learned a lot. Most of the criticisms of F.L. Hype have stayed true, although the hype seems to be diminishing. And I have learned several places where F.L. is really pretty good. I have confirmed that many of the cases where F.L. was claimed to be *wonderful* were, as I suspected, just straw-man comparisons. Refer to the columns on Refrigerators and Acceleration in this reprint—and Ball-on-Beam Balancers. That was one of the *very few* examples where we were able to make a realistic comparison.

I searched in many places, and I never was able to find that old (1990?) story mentioned in the second paragraph, about how trains without Fuzzy would lurch ahead and back (see *curve*). I'm still looking!—*rap*

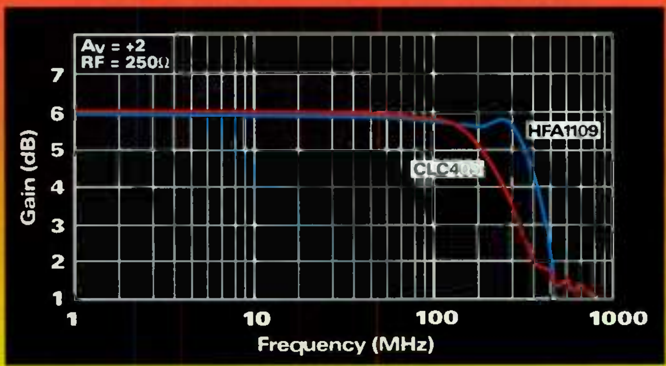


It's 1109. Guess where your op amps are.

Harris HFA1109/1149s are compatible, competitive and ready to ship.

- Available now and shipping from stock
- True drop-in replacement for CLC409 and CLC410. No feedback resistor change required.
- 50% lower input bias current (15µA)
- 30% lower supply current (10 mA)
- 22% higher bandwidth (500 MHz)
- Competitive pricing ($2.69 in 1000s)

HFA1109/49 Op Amps

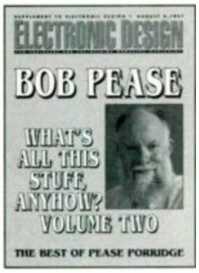


HARRIS
SEMICONDUCTOR

For more information: Call 1-800-4-HARRIS
and ask for ext. 7699. In Europe, fax 44-1234 328168.
Internet http://www.semi.harris.com – Technical assistance E-mail centapp@harris.com
AnswerFAX: 1-407-724-7800, doc. 4019

your next big idea is a trademark of Harris Corporation.

READER SERVICE 124



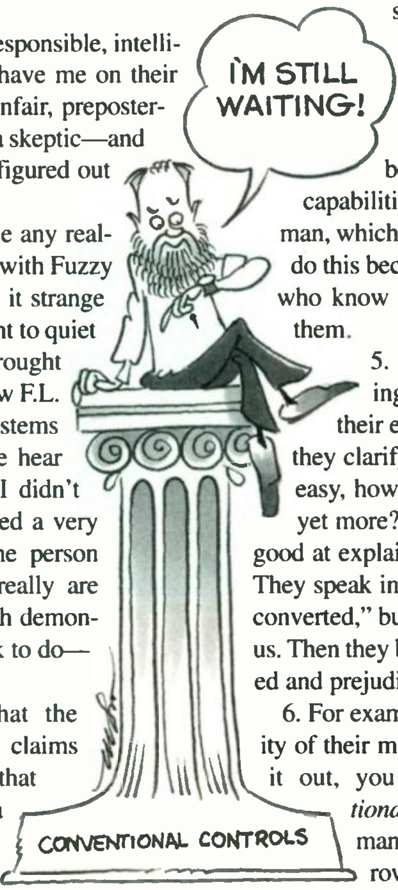
What's All This Fuzzy Logic Stuff, Anyhow (Part II)?

If you can think of an unlikely person to study Fuzzy Logic, it's RAP. While it's a dirty, nasty job, somebody must do it, and I've had lots of encouragement from all you readers since I put out my first column on the subject.[1] Note, some people have characterized me as being a detractor of Fuzzy Logic (F.L.), but I think I have done more good for the field of F.L. than lots of other guys all put together. I think it's to nobody's benefit to have people bragging about advantages that are unreal.

I believe people who are making responsible, intelligent claims for F.L. will be glad to have me on their side, to cut down on irresponsible, unfair, preposterous claims. I consider myself, rather, a skeptic—and here is a laundry list of ideas I have figured out or discovered so far:

1. Nobody has yet submitted to me any realistic task or control loop that they did with Fuzzy Logic which I could duplicate.[2] Isn't it strange that some Fuzzy Logic promoters want to quiet down Pease, but none of them has brought me a nice simple example to show how F.L. really is better than conventional systems (and, after we turn on the lights, we hear them scuttling under the cabinets). I didn't expect to get many, but zero is indeed a very interesting number. However, as one person pointed out, the F.L. experts who really are good are too busy to fool around with demonstrations, since they have lots of work to do—that's a fair explanation.

2. Almost everybody agrees that the examples I gave of outrageous F.L. claims were indeed pretty incredible, and that some F.L. promoters do exaggerate a lot. Several people sent in additional examples of Fuzzy Logic hype, such as pumps that allegedly come up to speed 2 times faster than with a "conventional" controller, and fuzzy motor controllers with miraculous "advantages"....



3. I have seen several readers give the same opinion that F.L. will be a lot more useful and valuable than its detractors predict, but a lot less useful and valuable than its promoters have said. Some of the claims, for example, that 50% of all microprocessors will be used for F.L. by 1996 seem a bit far-out.

4. Some promoters of F.L. are quite young, and when they promote F.L. as superior to other kinds of controllers, they show fantastic advantages—not out of malice, but just because they're not really familiar with the capabilities of other techniques. So they set up a straw man, which they then proceed to knock over easily. They do this because they don't know any better. Those of us who know better have an obligation to explain this to them.

5. Some F.L. guys aren't very good at explaining. Certain people think this may arise from their experiences in applying for research grants: If they clarify everything, and make it look too clear and easy, how can they apply for another grant to explain yet more? Even allowing for this, they still aren't very good at explaining things. They love to use lots of jargon. They speak in terms that are suitable for "preaching to the converted," but don't make clear explanations to the rest of us. Then they bleat that the rest of the world is closed-minded and prejudiced against them. I wonder why that is....

6. For example, some of them like to talk about the ability of their math to handle "probability." When you check it out, you find that they're talking about *proportionality*—the analog parameters. But because many of their old mathematical tools are borrowed from the probability experts, they persist

A Complete Solution for PLDs & CPLDs

Enhanced VHDL Synthesis for $99

It's surprising, but true. For only $99, Cypress's new *Warp2*™ Release 4.1 offers better behavioral synthesis than tools costing more than $20,000! New UltraGen™ technology uses module generation to provide the best VHDL synthesis for PLDs and CPLDs, as well as providing area and speed optimization for precise synthesis control.

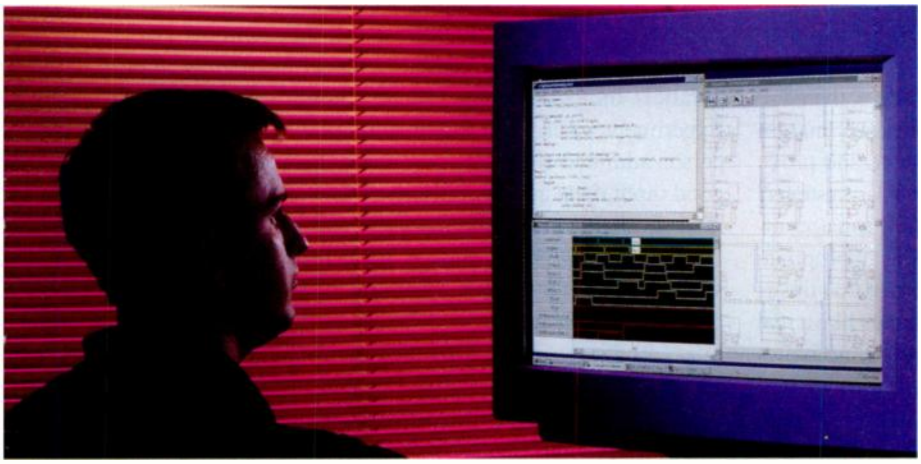
$20,000 VHDL SYNTHESIS FOR $99.00
Warp2 RELEASE 4.1

Everything You Need for Real VHDL Designs

Warp2 is a complete development system for all high-performance Cypress PLDs, and CPLDs

The *Warp2* kit includes:

- IEEE standard behavioral VHDL synthesis
- Automatic fitting
- VHDL & Verilog timing simulation output
- NOVA functional waveform simulator
- "VHDL for Programmable Logic" book



Order the New $99 *Warp2* Kit Now!

Platform:

- ❑ PC (Windows 3.1, Win'95, NT)
- ❑ Workstation (HP-UX, SunOS, Sun Solaris)

Please bill my:

❑ VISA ❑ MasterCard

Name ____________________

Title ____________________

Company ____________________

Address ____________________

City ____________ State ______ Zip ______

Phone ____________________

FAX ____________________

E-Mail ____________________

Credit Card # ____________________

Exp. Date ____________________

(Sales tax will be added as appropriate. $10 shipping & handling in the U.S., $15 in Canada)

FAX to: 1-408-943-6848

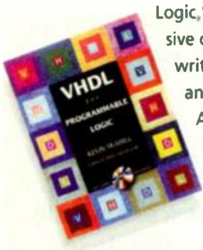
or call: **(800) WARP-VHDL, Kit #U023**

Warp2 Release 4.1 Supports:

FLASH370i™ CPLDs	7C371i (32 macrocells)
	7C372i (64 macrocells)
	7C373i (64 macrocells)
	7C374i (128 macrocells)
	7C375i (128 macrocells)
MAX340™ CPLDs	7C344 (32 macrocells)
	7C343 (64 macrocells)
	7C342 (128 macrocells)
	7C346 (128 macrocells)
	7C341 (192 macrocells)
SIMPLE PLDs	PALCE16V8
	PALCE20V8
	PALCE22V10

FLASH370i, MAX340, UltraGen, and *Warp2* are trademarks of Cypress Semiconductor.

Order *Warp2* today and receive a free copy of "VHDL for Programmable Logic," a comprehensive college textbook written by Cypress and published by Addison-Wesley.



CYPRESS

https://www.cypress.com/cypress/warp2/page2.htm in using that phrase. It bugs the hell out of me!!

7. Many F.L. guys love to make rash, outrageous philosophical claims: "With Fuzzy Logic controllers, you don't need any models." "With F.L., you never have to worry about the Nyquist sample rate." "You do not need to know the characteristics of a plant to design a controller for it." "The major advantage in the use of a fuzzy loop is that it reacts much faster to a process disturbance (or to overshoot and undershoot) than does a standard PID loop."[3] After much debate and criticism from conventional control experts, they may concede their claims aren't entirely true, but only after they have succeeded in getting everybody mad at them.

8. F.L. is claimed to make a good servo for some kinds of systems where conventional controllers don't work well. WELL, let's assume that in some cases it's true. Then how do you prove that such an F.L. system has good dynamic stability in all cases? For conventional controllers, there are methods to prove that a controller has a good safety margin of dynamic stability. How can you demonstrate and prove adequate safety margins/safety factors for F.L. systems? Remember—F.L. claims advantages because it can accommodate system nonlinearity by incorporating appropriate nonlinearity in the controller. How do you prove that this is safe? How much proof is necessary? That sounds like a real problem to me. If your new F.L. washing machine blows up, how can the manufacturer prove to the jury that he used the best available tests to ensure customer safety? As with any nonlinear controller system, extensive testing is needed to prove that no regions of instability will jeopardize proper system operation.

9. Some people pointed out that a Fuzzy Logic system is a kind of Expert System—a form of Artificial Intelligence. Now, the F.L. people may not like to talk about this because of the disappointments with Expert Systems in the past. But, are these not some of the same people who worked with Expert Systems and Artificial Intelligence in the past?? You tell me. Still, despite old disappointments, this seems to be a place where the Expert System, under the name of Fuzzy Logic, finally begins to fulfill its promise. MEANWHILE, some Artificial Intelligence experts are the most adamant detractors of F.L., because they have their math, and do not like to see F.L. people using "linguistic variables." Personally, if I hear "If the input is *small*, the output is *little*," one more time, I will *vomit*.

10. Let's assume that F.L. really can help make vacuum cleaners and washing machines work better. If that's the case, they do so because of the SENSORS. Which is more important, better sensors or the F.L.?? Maybe those smart, aggressive, and problem-solving F.L. guys will use the sensors very thoughtfully. Which is the chicken, which the egg? I can't say.

11. Fuzzy Logic doesn't really generate a control law. It maps an existing control law from one set of rules into a logic set.[4] If the rules permit this to be done efficiently, it may be able to accomplish the computing function just by remapping. That's a well-known way to get your computation done quickly. But the programmer or rule-maker has to provide the mapping functions—the rules. However, writing those rules isn't a trivial exercise. Even if you want to let Neural Networks write the rules for you, as with NeuFuz4,[5] that can be quite a piece of work.

12. F.L. guys universally ignore the role of their input sensors, their analog-to-digital converters, and the format of the (digital) interface to their Fuzzy Processors. I've heard people say that in some cases, F.L. works just fine with a single input bit stream. In other cases, the controller obviously requires an 8-bit, 10-bit, 12-bit, or higher-resolution parallel data bus. But (just about) every Fuzzy Experimenter makes ZERO mention of the input data. One person admitted about F.L. designers: "*Of course* they need good input data, and they just *assume* that the data will be made available to them in a suitable format."

...Well now, what format is that? It certainly isn't the same for every case, and, therefore, it should certainly be discussed. Every time I've looked at an "example" of a real Fuzzy Logic system or controller, the data inputs were left completely unmentioned. This frustrates the hell out of me because I know that in the real world, in a real system, this is quite important. Caution—don't be fooled into thinking, as one of my friends did, that a F.L. system only needs a 3-bit ADC at its input, because there are only 3 or 4 "rules." These few rules will take in and process the 8 or more bits of data (1 part in 256 resolution), which they then map into an output with full 8-bit (or more) resolution.

Also, don't think that the F.L. process is fuzzy or imprecise, or isn't "deterministic". I have been informed to point out that when the input moves a small amount, the output will move an appropriate amount, with no real uncertainty or doubt. A F.L. controller is, normally, just as "deterministic" as a conventional controller, whether analog or digital. It just uses different internal processes.

The "fuzziness" in F.L. just refers to the way that an object is in a set. In classical set theory, an object is either in a set or it is not. There's no "in-between," no grading. In the real world, of course, objects can be in a set "partially." F.L. extends classical set theory by assigning degrees of membership (typically, fractional amounts) to objects in such a way as to not conflict with classical set theory.[6]

Thus, F.L. can serve as a generalization and as an extension of existing set theory to help solve real-world problems in cases where traditional methods fail, or where nonlinear-

A Complete Solution for PLDs & CPLDs

Enhanced VHDL Synthesis for $99

It's surprising, but true. For only $99, Cypress's new *Warp2*™ Release 4.1 offers better behavioral synthesis than tools costing more than $20,000! New UltraGen™ technology uses module generation to provide the best VHDL synthesis for PLDs and CPLDs, as well as providing area and speed optimization for precise synthesis control.

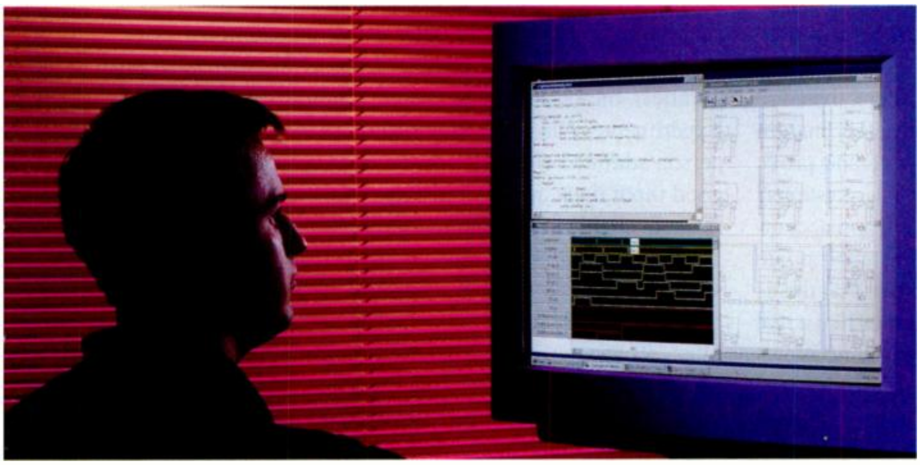
$20,000 VHDL SYNTHESIS FOR $99.00
Warp2 RELEASE 4.1

Everything You Need for Real VHDL Designs

Warp2 is a complete development system for all high-performance Cypress PLDs, and CPLDs

The *Warp2* kit includes:

- IEEE standard behavioral VHDL synthesis
- Automatic fitting
- VHDL & Verilog timing simulation output
- NOVA functional waveform simulator
- "VHDL for Programmable Logic" book

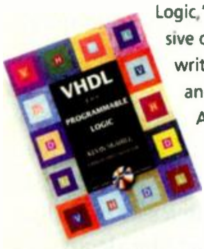


Warp2 Release 4.1 Supports:

Flash370i™ CPLDs	7C371i (32 macrocells) 7C372i (64 macrocells) 7C373i (64 macrocells) 7C374i (128 macrocells) 7C375i (128 macrocells)
MAX340™ CPLDs	7C344 (32 macrocells) 7C343 (64 macrocells) 7C342 (128 macrocells) 7C346 (128 macrocells) 7C341 (192 macrocells)
Simple PLDs	PALCE16V8 PALCE20V8 PALCE22V10

Flash370i, MAX340, UltraGen, and *Warp2* are trademarks of Cypress Semiconductor.

Order *Warp2* today and receive a free copy of "VHDL for Programmable Logic," a comprehensive college textbook written by Cypress and published by Addison-Wesley.



Order the New $99 *Warp2* Kit Now!

Platform:

❑ PC (Windows 3.1, Win'95, NT)

❑ Workstation (HP-UX, SunOS, Sun Solaris)

Please bill my:

❑ VISA ❑ MasterCard

Name ______

Title ______

Company ______

Address ______

City ______ State ____ Zip ______

Phone ______

FAX ______

E-Mail ______

Credit Card # ______

Exp. Date ______

(Sales tax will be added as appropriate. $10 shipping & handling in the U.S., $15 in Canada)

FAX to: 1-408-943-6848

or call: **(800) WARP-VHDL, Kit #U023**

CYPRESS

https://www.cypress.com/cypress/warp2/page2.htm in using that phrase. It bugs the hell out of me!!

7. Many F.L. guys love to make rash, outrageous philosophical claims: "With Fuzzy Logic controllers, you don't need any models." "With F.L., you never have to worry about the Nyquist sample rate." "You do not need to know the characteristics of a plant to design a controller for it." "The major advantage in the use of a fuzzy loop is that it reacts much faster to a process disturbance (or to overshoot and undershoot) than does a standard PID loop."[3] After much debate and criticism from conventional control experts, they may concede their claims aren't entirely true, but only after they have succeeded in getting everybody mad at them.

8. F.L. is claimed to make a good servo for some kinds of systems where conventional controllers don't work well. WELL, let's assume that in some cases it's true. Then how do you prove that such an F.L. system has good dynamic stability in all cases? For conventional controllers, there are methods to prove that a controller has a good safety margin of dynamic stability. How can you demonstrate and prove adequate safety margins/safety factors for F.L. systems? Remember—F.L. claims advantages because it can accommodate system nonlinearity by incorporating appropriate nonlinearity in the controller. How do you prove that this is safe? How much proof is necessary? That sounds like a real problem to me. If your new F.L. washing machine blows up, how can the manufacturer prove to the jury that he used the best available tests to ensure customer safety? As with any nonlinear controller system, extensive testing is needed to prove that no regions of instability will jeopardize proper system operation.

9. Some people pointed out that a Fuzzy Logic system is a kind of Expert System—a form of Artificial Intelligence. Now, the F.L. people may not like to talk about this because of the disappointments with Expert Systems in the past. But, are these not some of the same people who worked with Expert Systems and Artificial Intelligence in the past?? You tell me. Still, despite old disappointments, this seems to be a place where the Expert System, under the name of Fuzzy Logic, finally begins to fulfill its promise. MEANWHILE, some Artificial Intelligence experts are the most adamant detractors of F.L., because they have their math, and do not like to see F.L. people using "linguistic variables." Personally, if I hear "If the input is *small*, the output is *little*," one more time, I will *vomit.*

10. Let's assume that F.L. really can help make vacuum cleaners and washing machines work better. If that's the case, they do so because of the SENSORS. Which is more important, better sensors or the F.L.?? Maybe those smart, aggressive, and problem-solving F.L. guys will use the sensors very thoughtfully. Which is the chicken, which the egg? I can't say.

11. Fuzzy Logic doesn't really generate a control law. It maps an existing control law from one set of rules into a logic set.[4] If the rules permit this to be done efficiently, it may be able to accomplish the computing function just by remapping. That's a well-known way to get your computation done quickly. But the programmer or rule-maker has to provide the mapping functions—the rules. However, writing those rules isn't a trivial exercise. Even if you want to let Neural Networks write the rules for you, as with NeuFuz4,[5] that can be quite a piece of work.

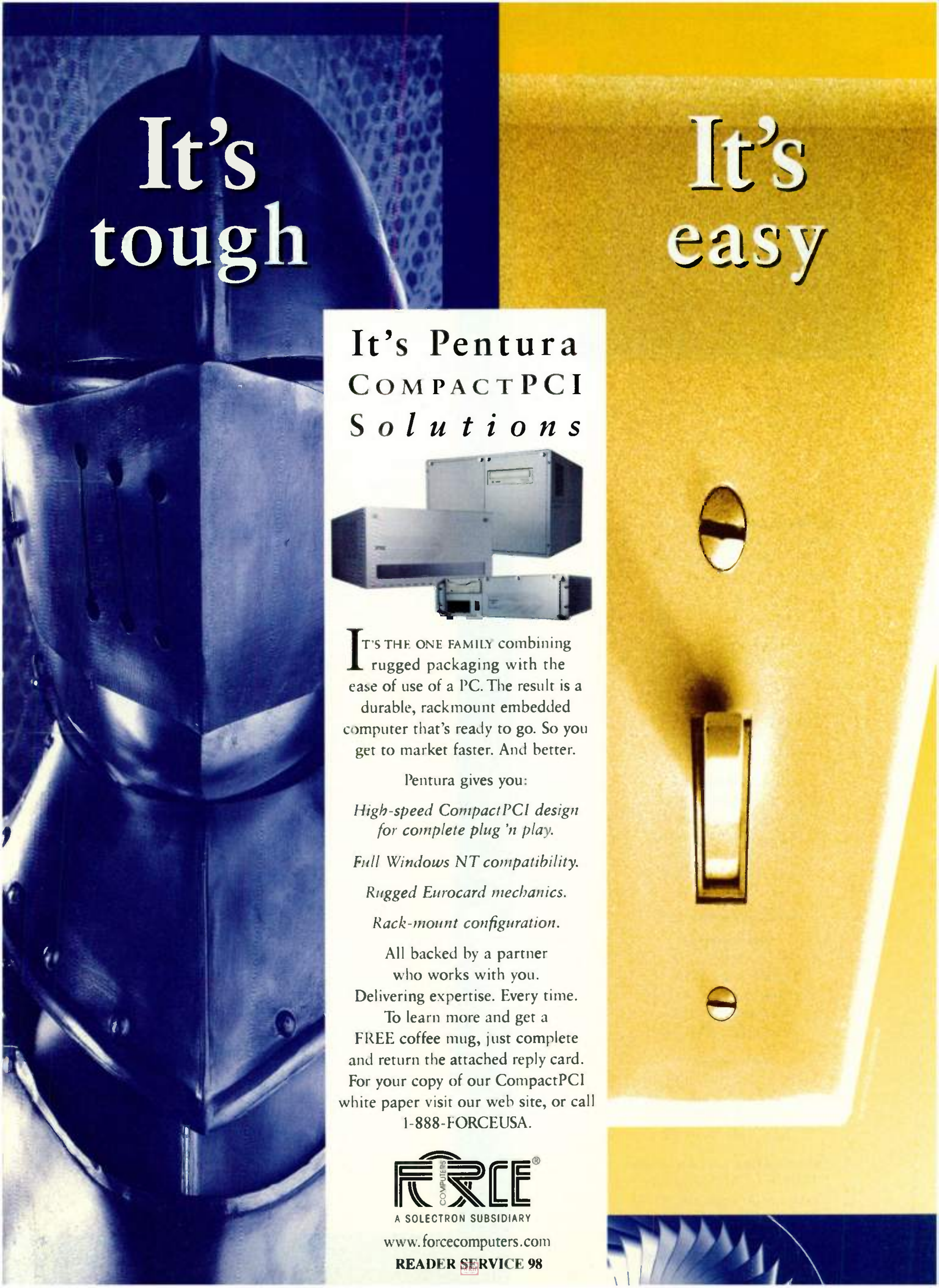
12. F.L. guys universally ignore the role of their input sensors, their analog-to-digital converters, and the format of the (digital) interface to their Fuzzy Processors. I've heard people say that in some cases, F.L. works just fine with a single input bit stream. In other cases, the controller obviously requires an 8-bit, 10-bit, 12-bit, or higher-resolution parallel data bus. But (just about) every Fuzzy Experimenter makes ZERO mention of the input data. One person admitted about F.L. designers: "*Of course* they need good input data, and they just *assume* that the data will be made available to them in a suitable format."

...Well now, what format is that? It certainly isn't the same for every case, and, therefore, it should certainly be discussed. Every time I've looked at an "example" of a real Fuzzy Logic system or controller, the data inputs were left completely unmentioned. This frustrates the hell out of me because I know that in the real world, in a real system, this is quite important. Caution—don't be fooled into thinking, as one of my friends did, that a F.L. system only needs a 3-bit ADC at its input, because there are only 3 or 4 "rules." These few rules will take in and process the 8 or more bits of data (1 part in 256 resolution), which they then map into an output with full 8-bit (or more) resolution.

Also, don't think that the F.L. process is fuzzy or imprecise, or isn't "deterministic". I have been informed to point out that when the input moves a small amount, the output will move an appropriate amount, with no real uncertainty or doubt. A F.L. controller is, normally, just as "deterministic" as a conventional controller, whether analog or digital. It just uses different internal processes.

The "fuzziness" in F.L. just refers to the way that an object is in a set. In classical set theory, an object is either in a set or it is not. There's no "in-between," no grading. In the real world, of course, objects can be in a set "partially." F.L. extends classical set theory by assigning degrees of membership (typically, fractional amounts) to objects in such a way as to not conflict with classical set theory.[6]

Thus, F.L. can serve as a generalization and as an extension of existing set theory to help solve real-world problems in cases where traditional methods fail, or where nonlinear-



It's tough
It's easy
It's Pentura
CompactPCI
Solutions
It's the one family combining rugged packaging with the ease of use of a PC. The result is a durable, rackmount embedded computer that's ready to go. So you get to market faster. And better.
Pentura gives you:
High-speed CompactPCI design for complete plug 'n play.
Full Windows NT compatibility.
Rugged Eurocard mechanics.
Rack-mount configuration.
All backed by a partner who works with you. Delivering expertise. Every time.
To learn more and get a FREE coffee mug, just complete and return the attached reply card. For your copy of our CompactPCI white paper visit our web site, or call 1-888-FORCEUSA.
FORCE COMPUTERS®
A SOLECTRON SUBSIDIARY
www.forcecomputers.com
READER SERVICE 98

For Easy Answers to Tough Questions Contact Your Nearest Force Office

Corporate Headquarters
FORCE COMPUTERS Inc.
2001 Logic Drive
San Jose, CA 95124-3468
Tel.: (408) 369-6000
Fax: (408) 371-3382

European Headquarters
FORCE COMPUTERS GmbH
Prof.-Messerschmitt-Str. 1
D-85579 Neubiberg/Munchen
Tel.: 011 49 89 608 140
Fax: (0 89) 609 77 93

Japanese Headquarters
FORCE COMPUTERS Japan KK
Shiba Daimon MF Building
2-1-16 Shiba Daimon
Minato-ku, Tokyo 105 Japan
Tel.: (03) 3437 3948
Fax: (03) 3437 3968

Latin America
FORCE COMPUTERS Inc.
14643 Dallas Pkwy, Suite 500 LB70
Dallas, TX 75240-8806
Tel.: (972) 774-1888
Fax: (972) 774-1889

US Sales Offices

Northwest
FORCE COMPUTERS Inc.
2001 Logic Drive
San Jose, CA 95124-3468
Tel.: (408) 369-6000
Fax: (408) 371-3382

Southwest
FORCE COMPUTERS Inc.
2600 Michelson Drive, Suite 980
Irvine, CA 92612-1550
Tel.: (714) 757-0502

Southwest/Los Angeles
FORCE COMPUTERS Inc.
1446 Los Angeles Ave. #301J
Simi Valley, CA 93065
Tel.: (805) 582-6550

Southwest/Colorado
FORCE COMPUTERS Inc.
1333 West 120th Avenue 110C
Westminister, CO 80234
Tel.: (303) 452-7409

Midwest
FORCE COMPUTERS Inc.
601 Carlson Pkwy, Suite 710
Minnetonka, MN 55305-5207
Tel.: (612) 449-4224

Midwest/Chicago
FORCE COMPUTERS Inc.
1755 Park Street, Suite 200
Naperville, IL 60563-8496
Tel.: (708) 778-2316

Southeast
FORCE COMPUTERS Inc.
14643 Dallas Pkwy, Suite 500 LB70
Dallas, TX 75240-8806
Tel.: (972) 774-1888

Southeast/Austin
FORCE COMPUTERS Inc.
1150 Lakeway Drive, Suite 200
Austin, TX 78734-4440
Tel.: (512) 261-2020

Southeast/Melbourne
FORCE COMPUTERS Inc.
100 Rialto Place, Suite 718
Melbourne, FL 32901
Tel.: (407) 953-9770

Northeast
FORCE COMPUTERS Inc.
1130 Annapolis Road, Suite 203
Odenton, MD 21113
Tel.: (410) 674-0003

Northeast/Boston
FORCE COMPUTERS Inc.
164 Westford Road, Suite 16
Tyngsborough, MA 01879-2509
Tel.: (508) 649-9222

Northeast/Pennsylvania
FORCE COMPUTERS Inc.
100 Dickenson Drive, Suite 111
Chadds Ford, PA 19317
Tel.: (610) 358-3694

Northeast/Virginia
FORCE COMPUTERS Inc.
11350 Random Hills Rd., Suite 800
Fairfax, VA 22030
Tel.: (703) 934-6037

FORCE COMPUTERS®
A SOLECTRON SUBSIDIARY

ities cause poor results in price or performance. Of course, many of us engineers use analog signals to represent that proportionality.

13. Note that in most real systems, whether F.L. or conventional, it's important for the system to be given good information, with good resolution and good accuracy. If adequate information isn't made available, it's unclear how either one will do a good job. Specifically, when F.L. guys say that "You never have to worry about the Nyquist sample rate," that is true only if you have a big safety margin. If your F.L. system's sample rate is too low, and your system works badly, then *of course* you have to worry about it, just as everybody else does.[7]

14. In a conventional digital or analog controller, it is customary to provide a parameter, such as distance or rotation, to the controller. The controller then computes a derivative or difference signal, dx/dt, or, $\Delta x/\Delta t$. But in a F.L. system, you have to *provide* the x data and then a derivative, dx/dt. Apparently F.L. does not do timing or counting, so the F.L. controller can't compute the derivative function—*you* have to provide it that. Therefore it's *not* quite true that an F.L. system needs the same information as a conventional controller—sometimes it needs *more* information.

15. LIKEWISE, Fuzzy guys uniformly ignore the output format of their systems. Is it serial or parallel? They're always too shy to mention this. I did hear that for the Inverted Pendulum experiment, the F.L. approach is so greatly superior to conventional controllers that it puts out just a serial pulse train (the signal is the duty cycle) which controls the loop without any trouble. Yet in other cases, it's obvious that the output must comprise parallel bits to a conventional DAC. But they never make any reference to this, either. How many bits, 8, 12, or 16? Nobody talks about this; it's "academic" and is left as an exercise to the reader.

16. Not only do the F.L. guys never talk about their input interface or their outputs, they also avoid talking about the actual computer or microprocessor they use. They rarely mention the number of bits, or the clock rate, or the software. They always try to keep things "academic"—and they don't tell you what they really did.

NOW, let's talk about cases where F.L. may have advantages:

17. Fuzzy Logic is generally admitted—even by RAP—to have real advantages where the system is nonlinear. One simple example, again, is the Inverted Pendulum, where the base of a stick on a pivot is moved along a track by a little motor. The angular acceleration of the pendulum is NOT a linear function of its angle away from vertical, but a sort of third-power law. If you try to approximate this with a linear function, it's hard to get the gain right. It's either too low at the ends or too high in the middle. Or else you have to compute the function precisely, which takes a LOT of computation. But with F.L., you can get the gain approximately right with just a few segments of F.L. coding—perhaps just 5 rules. These rules now are so simple, that the F.L. computing processors can compute this with good speed, and a cheap computer, faster and cheaper than a conventional computer can do when it computes EXACTLY the equations of motion for that Inverted Pendulum. Consequently, if the computer can go faster, it may be able to do a superior job of controlling, because although its math is crude, it's plenty accurate enough, and it's *fast*. NOW, when you compound the problem by stacking *two* inverted pendulums on top of each other, F.L. can still do it easily. For the *triple* inverted pendulum, F.L. can still do it, whereas conventional controllers apparently can't do all of the complicated math fast enough. *Maybe* if you made some simplifying assumptions, some approximations, the conventional controller could then go fast enough, but this is generally ignored. F.L. can make certain assumptions, approximations, and simplifications, but other controllers aren't supposed to be able to do this.

18. F.L. is supposed to have real advantages where an approximate system solution is adequate. For example, I read a statement by a F.L. promoter[8] that said if you want a computer to park your car for you, you should exploit imprecision. If you don't need the car at exactly 6.00 ±0.02 inches from the curb, but something like 6 ±2 inches, then F.L. may be able to do a superior job, especially since you can use a cheap computer. When I read this, I was struck by its wisdom. But who would dare to admit that F.L. is not only not always better, but sometimes, *inferior* in accuracy, yet it's still plenty good enough? I looked, and it was Lotfi Zadeh himself, the creator of Fuzzy Logic. He was wise enough to say that, and I'm delighted to say I agree that when a solution is good enough, don't worry about perfection. I'm absolutely in favor of pragmatism, and of good-enough engineering. Perfectionism is the bane of cost-effective engineering. Anybody who knows when to do a good-enough job and *stop* is a friend of mine.

19. Let me insert an esaeP's fable here: One time I was bicycling down Massachusetts Avenue in Cambridge, Mass. on a quiet Sunday morning, and a dog started chasing me. Because I was on a downgrade I accelerated well, and the dog fell a few yards behind me. He could not gain on me, and I was going fast enough, so I did not bother to pull further away from him. At a split in the road, I continued on down Mass Ave. The dog veered off onto Mt. Auburn Street, barking all the way, as if to say that he was not really chasing me at all, so he did not care if he had not caught me.

WELL, when I make a few convincing arguments to rebut the F.L. claim that "F.L. is always better", the F.L. experts often veer away, saying, "Even if it is not always more precise, it is less expensive...." NOW, F.L. is *alleged* to be a less expensive way to run a controller. In some cases, it may be able to use a cheap computer. It may use fewer lines of code or a smaller ROM. The F.L. guys love to claim this. But I don't automatically trust them when they say "it's cheaper." After all, what would you expect them to say?? I am still skeptical about these guys. Other experienced engineers find that for some cases *conventional* controllers can be more compact, cheaper, and easier to program than F.L. So, if in a given system the F.L. experts claim that F.L. is cheaper, you had better check their data. Make your own cost comparisons. Don't let them just set up straw comparisons.

Stay tuned for more Fuzzy Logic stuff in the next issue...

Comments invited! / RAP
Robert A. Pease / Engineer

References:

1. "What's All This Fuzzy Logic Stuff, Anyhow?," R. A. Pease, *Electronic Design*, May 13, 1993, pp. 77-79.

2. One reader sent a report on a design involving a focusing system for a laser's lenses, but I couldn't very well duplicate that. Another person promised to send me more info about a motor speed controller, but never sent anything. One writer said that "all of the arguments of the above writer are not right," but gave no specific example of anything in my writing he thought was wrong....

3. "Fuzzy Logic: A Clear Choice For Temperature Control", Haubold vom Berg, *Instruments and Control Systems*, June 1993, pp. 39-41.

4. Private correspondence with Daniel Abramovitch, Hewlett-Packard Labs, Palo Alto, Calif. June 30, 1993.

5. NeuFuz4 from NSC, combining Neural Networks and Fuzzy Logic. The Neural Network part can learn from recorded data, then generate fuzzy rules and membership functions. Thus, it can learn the best way to control the system. Call (800) 272-9959 for details.

6. "Fuzzy Models—What Are They, And Why?" J. Bezdek, IEEE Transactions on Fuzzy Systems. Feb. 1993, pp. 1-6. A good introduction to Fuzzy Sets and concepts.

7. Private correspondence with Daniel Abramovitch, Hewlett-Packard Labs, Palo Alto, CA. June 30, 1993.

8. "On The Fuzzy Edge Of Technology", Tom Williams (quote of Lotfi Zadeh), *Computer Design*, April 1993, p. 14.

Originally published in
Electronic Design, November 1, 1993

RAP's 1997 comments: On Section 1, it took a long time before I was able to find examples, but the Sendai Train, the Refrigerator for the Space Shuttle, and the Ball-On-Beam-Balancer did come in, eventually. These are all covered in Columns in this reprint. What did we find? Read on!

Per Section 10, I did find several examples of F.L. appliances—washing machines and dishwashers. When Consumer Reports evaluated them, they found they were NOT more efficient in terms of energy or water used. Most of them were *worse* than average... you can look it up.

In Section 17, I mentioned a "Triple-inverted pendulum." This is claimed as an example of F.L.'s superiority. Actually, the TRIPLE pendulum was not actually *built*, it was just *simulated*. It's true that if you let an Inverted Pendulum lean 'WAY over, it's pretty nonlinear. But in most cases, the angle of tilt is so small that it's effectively linear. The advantages of F.L. in this case are—fuzzy? unclear?

The rest of the comments I made in this Column have held up pretty well.—*rap*

www.linear-tech.com

Linear Technology QuickSearch and FirstView– No more waiting for documents to download!

No other web site provides faster access to data sheets!

- Search by part number or keyword
- Immediately view documents
- Compare data sheets online
- Download data sheet files
- Fax back data sheets
- Review new products

No other web site provides more application support!

- Search application notes by keyword
- Search design notes and LT Magazine
- Browse by product function
- Request the LinearView™ CD-ROM

The Linear Technology web site provides timely and easy access to our broad selection of product information and application support tools. The search capabilities are extensive. You can search all LTC data sheets, application notes, design notes, LT magazine articles, LT Chronicle articles and LT press releases.

Retrieve a document and view page one of the material prior to downloading the full file.

Documents are downloaded as Portable Document Format files (PDF) and can be viewed with Adobe Acrobat™

Log on today at **www.linear-tech.com** or contact Linear Technology Corporation, 1630 McCarthy Blvd., Milpitas, CA 95035-7417, (408)432-1900, Fax: (408)434-0507. For literature only, call 1-800-4-LINEAR.

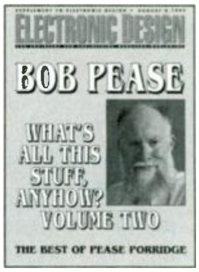
LT, LTC and LT are registered trademarks of Linear Technology Corporation. LinearView is a trademark of Linear Technology Corporation. FirstView is a trademark of NanoSpace, Inc. Adobe and Acrobat are trademarks of Adobe Systems, Inc.

LINEAR TECHNOLOGY

FROM YOUR MIND TO YOUR MARKET
AND EVERYTHING IN BETWEEN

READER SERVICE 102

READER SERVICE 121



What's All This Fuzzy Logic Stuff, Anyhow (Part III)?

Let's jump right in and continue on with the Fuzzy Logic laundry list I started in the last issue.

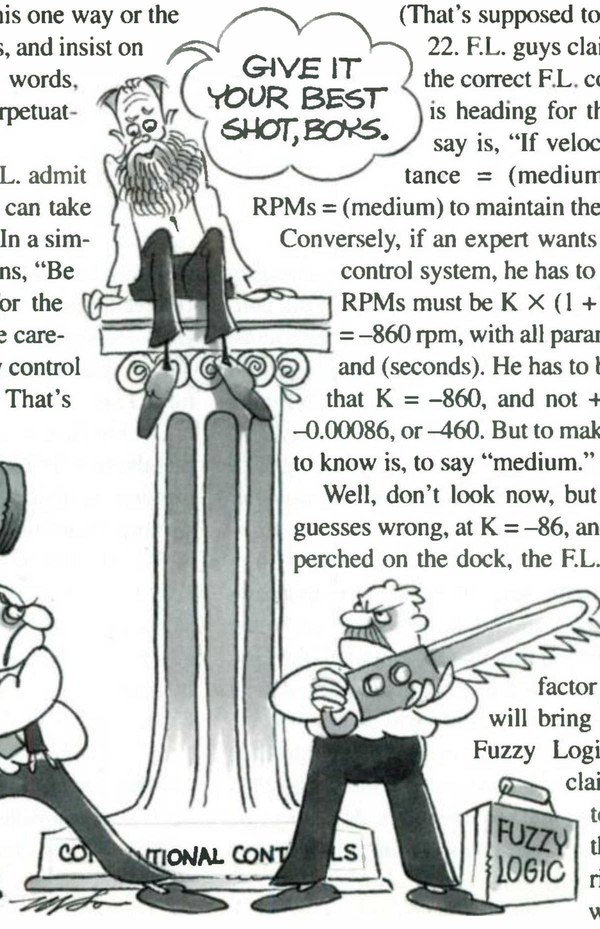
20. F.L. is alleged to be "faster and easier to develop." That's what the F.L. guys like to claim. Again, I still don't really trust them. What would you expect them to say? Other engineers argue that the claimed ease and speed are not always there.

I am not in any position to prove this one way or the other, but you had best be on your toes, and insist on satisfactory comparisons. In other words, don't permit any straw men to be perpetuated. Or perpetrated.

Besides, even the proponents of F.L. admit that sometimes, tuning a F.L. system can take "hours or days of computer time...."[9] In a similar vein, Haubold vom Berg[10] cautions, "Be careful here, though: Applications for the possible use of fuzzy loops have to be carefully selected, and the degree of fuzzy control must be determined in advance. That's because a significant number of loops will not be optimized with a low-end fuzzy loop, and the instrumentation can be damaged."

Is it just possible that the optimization of F.L. controllers should not be left to the judgment of a technician with 15 minutes of training? Refer to the next paragraph....

21. F.L. guys claim that you do not have to be an expert to apply F.L. In fact, some of them say that any good technician can be taught in a few minutes to be an expert on Fuzzy-Logic controllers, replacing engineers with many months and years of schooling and experience.[11] Sure, they can say that any time, but I don't have to believe it. I am certainly not going to take this technician and set him in charge of my Nuclear Reactors. (Did they use Fuzzy Logic at Chernobyl?) (That's supposed to be a joke....)



22. F.L. guys claim that it is *easy* to put in the correct F.L. coefficients. If a ferry boat is heading for the dock, all you have to say is, "If velocity = (medium) and distance = (medium), then keep negative RPMs = (medium) to maintain the necessary deceleration." Conversely, if an expert wants to set up a conventional control system, he has to know that the number of RPMs must be $K \times (1 + V - (2\,a\,x)^{1/2})$, where $K = -860$ rpm, with all parameters expressed in (feet) and (seconds). He has to be smart enough to know that K = –860, and not +860, or –86, –0.086, or –0.00086, or –460. But to make F.L. work, all you have to know is, to say "medium."

Well, don't look now, but if the conventional guy guesses wrong, at K = –86, and the ferry boat winds up perched on the dock, the F.L. guy can certainly make the same error, and HIS ferry boat will wind up on the dock, too. Hey, a factor of 10 error in either case will bring you to that same result. Fuzzy Logic computers are NOT clairvoyant. If you tell them to do the wrong thing, they will not just "do the right thing," they will do what you tell them. Magic is not an appropriate element to invoke, nor to depend on....

23. It is sometimes claimed that F.L. can "learn" how to get the right answer—this is supposed to be a big advantage. However, Fuzzy Logic by itself cannot "learn" anything. If you want to get the F.L. to "learn," you have to use adaptive F.L. (non-trivial) or use Neural Networks. The knowledgeable guys with NeuFuz4 showed me that if you use Neural Networks to find a solution, and set the Membership Function, and generate the rules, these rules may be non-heuristic, not at all the same old rules, but improved rules with new advantages. Sounds impressive. Call them for details.[12]

Still, if you want to run the F.L. in a learning mode, be aware that a F.L. controller may make a lot of mistakes as it learns. Again, this is not the place to let loose the F.L. controller on your brand-new Nuclear Reactor, or your new catalytic cracking plant, or your epoxy resin kilns. F.L. controllers can be coached to learn a task when you have saved up a lot of data on how the system runs. It can look at the input data and the output data, and figure out how to control the plant. *BUT* only if you have that data, for all relevant regimes of control.

If you have a nuclear reactor, and if you had a Fuzzy controller for all normal operating modes, you would NOT use F.L. to control the system in the case of a breakdown, emergency, blow-up, melt-down, loss of pressure, thermal run-away, or any other non-standard mode, because F.L. only works well when you have run your system in that mode, and have a lot of data on that mode. You don't want to engineer your control of emergencies that way.

24. Further, it is claimed that F.L. can adapt to changing systems—as if conventional controllers could not. But conventional controllers can operate with adaptive coefficients. You can take a conventional PID (Proportional-Integral-Derivative) controller, and add on adaptive or self-tuning procedures. If you *know* the Control System Industry, you would know that. If you *didn't know* that, you might be willing to give F.L. some credit for miraculous advantages, which are not new advantages at all.

25. Remember the old saying, "To a man with a hammer, everything looks like a nail." Well, if a person knows how to apply Fuzzy Logic, and he doesn't know any other way to do it, I should not tell him that he cannot do the task. However, he has no right to tell me that is the only way, or the best way, just because it is the only way he knows....

26. F.L. has been stated[13] to be quite good at controlling the same kind of systems that people can, but with faster sampling, fewer mistakes, and more features. Anything you can do, slow as you are, a computer can do a little faster, better, and more consistently. Okay, that's not a silly statement: Anything I can do, that gets boring and repetitive, such as, starting and stopping a subway train smoothly and precisely, time after time, may be a good candidate for F.L. As far as I am concerned, that is arguably the best thing we can say about Fuzzy Logic.

27. Now, where are the cases where F.L. really is not suitable to do a good job? I suspect there are cases where the F.L. computing speed is not adequate, and maybe even a fast analog controller is necessary. Also, cases where timing, counting, integrating, and differentiating are required are not feasible unless you combine some F.L. and some conventional logic.

While we hate to be negative, it is important to be honest, because if there really are tasks that F.L. cannot do, we don't want to waste people's time on them. I think that F.L. people ought to make known, and *publicize*, cases where F.L. is really unsuitable, and, if possible, the reasons why. This is for the good of their industry.

28. Also, several people sent in reminders, that if you have a conventional controller, and it is working OK, there is usually not any advantage to throwing it out and replacing it with a F.L. controller, despite all the HYPE to the contrary. Any case where F.L. is shown to provide a WONDERFUL advantage over a conventional control system, is either a case where the conventional controller was not at all optimized, or, the system was nonlinear so the conventional controller could not do well.

Lastly, let's look at a couple of specific examples about Fuzzy Logic.

29. By the way, nobody yet has recollected where the original magazine article was, that said that a Fuzzy Logic Controller could control a subway train smoothly, but a "conventional" digital controller would jerk, jerk, jerk, jerk... Does anybody recall seeing that—can you tell me where that was published? I did a search, but nothing turned up....

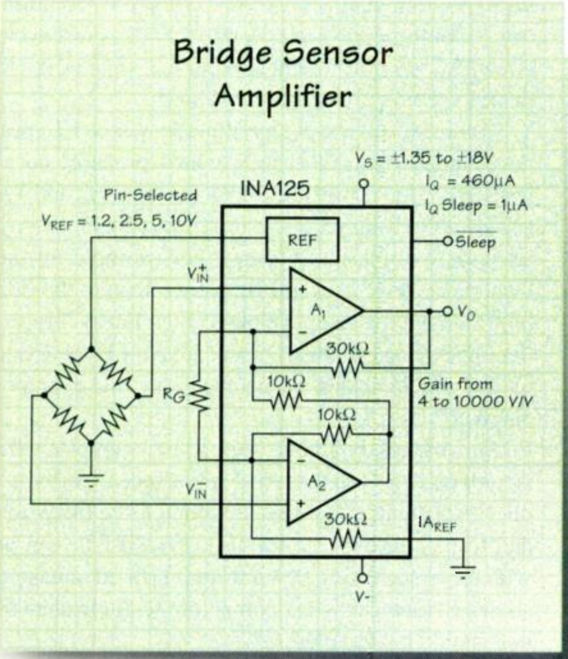
30. On American Public Radio,[14] Daniel McNeill stated that the new 1993 Saturn has an improved automatic transmission, so that on steep upgrades, it uses F.L. to cut out surging, "hunting," and excessive shifting up and down.

WELL, the Saturn's transmission *has* been improved, and it *does* use Fuzzy Logic to provide automatic downshifts on downhills. But the transmission does NOT use F.L. to avoid "hunting" on upgrades.[15] It uses conventional hysteresis. Fuzzy Logic is NOT needed to do that, and is NOT used for that.

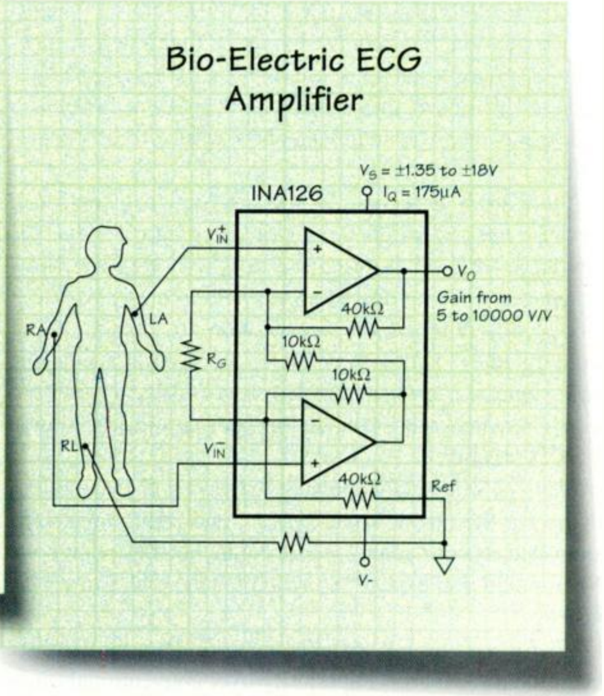
31. Also, I have always been skeptical that F.L. can make a subway train run much more smoothly than a good conventional controller. In a recent magazine,[16] Bart Kosko admits that the conventional train control system that was compared to Hitachi's F.L. controller, in Sendai, Japan, was pretty crude and jerky. "Conventional controllers start or

*micro*POWER, *micro*PRICE Instrumentation Amps!

with V_{REF}...



and without

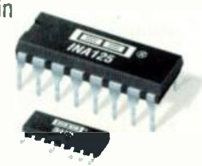


INA125—With V_{REF}

INA125 combines a precision instrumentation amp with an on-board voltage reference—what a concept! Perfect for amplifying low-level signals from bridges or other sensors that require dc excitation. Plus, you can use the reference output for your A/D converter to produce ratiometric error reduction—a great combination.

INA125's internal instrumentation amp uses the familiar two-op-amp topology, similar to the INA126. Laser trimmed on-chip resistors provide excellent gain accuracy and reject common-mode input signals such as that produced by a bridge sensor.

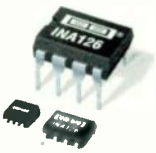
Available in SO-14 surface-mount or 14-pin DIP, INA125 is a low cost, compact solution to your difficult application problem.



INA125..............$2.50 in 1000s

INA126—Without V_{REF}

INA126 is a low cost, precision instrumentation amplifier for low-level differential signal acquisition. Its two-op-amp design provides excellent performance with only 175µA quiescent current. And a wide power supply voltage range of ±1.35 to ±18V makes it ideal for portable or battery operated instrumentation. INA126's tiny MSOP-8 package option is a space saver, too. Also available in SO-8 and 8-pin DIP.



INA126...............$1.60 in 1000s

With or without a voltage reference, Burr-Brown provides you the best value in instrumentation amplifiers.

For Technical Info: http://www.burr-brown.com/Ads/INA125-Ad.html

BURR - BROWN®

Burr-Brown Corporation

Burr-Brown Corporation • P.O. Box 11400 • Tucson, AZ • 85734-1400 • Call **(800) 548-6132** or use **FAX*LINE* (800) 548-6133** • **http://www.burr-brown.com/**
Distributors: Anthem: (800) 826-8436 • **Digi-Key Corp:** (800) 338-4105 • **Insight Electronics:** (800) 677-7716 • **J.I.T. Supply:** (800) 246-9000 • **Sager Electronics:** (800) 724-3780 • **SEMAD (Canada):** (800) 567-3623

stop a train by reacting to position markers that show how far the vehicle is from a station...the automated controller will apply the same brake pressure when a train is, say, 100 meters from a station, even if the train is going uphill or downhill."

Well, if the best competing "conventional" control system was so shoddily engineered, and was not intelligent enough, not adaptive enough, to apply the brakes differently, if the train was going fast or slow, uphill or down, empty or fully loaded, then of course the Fuzzy Logic system deserved to win, but only by default, not by inherent superiority. If nobody had the sense to *move* the "apply brakes" markers 130 meters out, on a downhill, or 80 meters out, on an upgrade, then we are talking about relative levels of stupidity.

And Kosko observes, on the conventional controller, "because the controllers are rigidly programmed, the ride may be jerky..." Well, of course, a F.L. system can show advantages when compared to a system as crude as that, if nobody programmed the acceleration to feather off, to avoid $d^2v/dt^2 = da/dt$ = "jerk." Also, I heard statements that during quiet times when human operators drive the trains to keep in practice, riders can tell this because the acceleration is not as smooth.

Well, of course the planners reserved the smoothest modes for the Fuzzy Logic system, and left the operator-controlled system lurchy, so it could not be as smooth. What would you expect? So much for the Old Straw Man business.

32. Also, some F.L. experts are *still* claiming that F.L. has some real inherent superiority over conventional (digital) controllers, because F.L. can represent a range of signals, whereas a conventional digital control system can only correspond to one ONE, or one ZERO.[17]

They still seem to be good at pretending that computers have only one bit—that computers do not have 8 (or more) bits in each digital word. Perhaps they try to perpetrate this story by pretending that Fuzzy Controllers work with miraculous awareness of the surrounding world, and do not depend on the *same* sensors and the *same* analog-to-digital converters that conventional digital controllers use.

If more people were aware that Fuzzy Controllers and Digital Controllers used the exact same input signals, the Fuzzy systems might seem less fantastic and revolutionary and amazing.

33. Even recently I heard of a system where F.L. engineers made a demonstration system to control the height of a ping-pong ball above a stream of air. The F.L. system was claimed to have taken only 15 days to develop, vs. 30 days for the "conventional" PID controller, which gave inferior results.

So, it sounds as if F.L. excelled in a fair test... But, when you think about it, this is obviously a very nonlinear system. Of course it is not surprising that a linear conventional controller does poorly, trying to handle a nonlinear problem. Of course, a well-designed F.L. controller can do a better job accommodating this kind of nonlinear problem.

The Fuzzy-Logic controller was obviously showcased—set up to look good. But showing that a conventional controller could not do well despite "30 days of development effort," shows how much work these people were willing to put into setting up their Straw Man!!

34. So we still see plenty of places where F.L. promoters have engaged in HYPE, and we have probably not seen the last of it. But if we protest to the editors, and refuse to accept stonewalling, we can force editors to pay some attention to truth and honesty. For example, in the IEEE Control Society,[18] several people wrote in to the Editors, to protest about misleading claims about Fuzzy Logic. Maybe the Fuzzy Logic Industry needs an Anti-Hype Committee, to rap the knuckles of people who make preposterous claims?

35. Conversely, I have seen a few examples where F.L. is proposed to offer modest advantages, perhaps 1 or 2 dB.[19] Advantages like that are much more likely to be true and to be believed. I think it is great if F.L. can compete with the best existing systems and show advantages. If F.L. shows advantages when competing with obsolete systems, that should be admitted.

36. Several people pointed out that there are a lot of engineers and scientists working with Fuzzy Logic, and just a small fraction of them generate most of the hype. So I want to apologize to anybody who has been offended by my broad accusations: if *you* ain't guilty, then I wasn't talking about *you*.

37. At a recent Fuzzy Logic Convention, several people said, "I hope we don't see any more demonstrations with the Inverted Pendulum, because it's boring and not very relevant." Well, F.L. people are still bragging about their advantages in stabilizing the Inverted Pendulums—Single, Double, and Triple. Maybe if they don't want to hear any more about it, maybe that is exactly why I should do it, without Fuzzy Logic, as a counter-example?...

38. At that Fuzzy Logic Convention, it was suggested (by several people, not just RAP), that maybe a new name should be developed for F.L., to take away the stigma and the negative connotations.

Maybe there should be a contest for the best name for F.L. I'll chip in $10.00 for prizes, for the best new name. But in Japan, F.L. is not called by the name ai-mai, which means "fuzzy;" it is called, "Fa-Zhi." Maybe American promoters can figure out how to promote "ai-mai logic?"

The Speed ATM Needs At Costs You Want

Maximize Throughput Address processing bottlenecks make any gigabit network crawl. Every time a cell goes through an ATM switch, routing information must be translated - almost 10% of the datastream. MUSIC ATMCAMs (Content Addressable Memory) compare and output the full 28 bit VPI/VCI *in a single clock cycle, as short as 70ns. Datastreams are kept moving.*

Optimize Bandwidth Network activity is unpredictable in high speed ATM. Unless bandwidth is dynamically allocated, it is wasted or lost. MUSIC ATMCAMs adapt quickly to traffic without cell loss; add or delete connections as fast as 70ns. The full bandwidth is always available. Interoperability and Quality of Service are never compromised: *key factors to selling your ATM System.*

Minimize Design A 100 pin PQFP package, 3.3V, 4K by 32 CAM array, 32 Bit I/O, multiple data/processor ports, Verilog and VHDL models all add up to less development overhead. For less than $20* each (half a cent per connection!) only MUSIC delivers real CAM benefits to ATM systems at the right price. ATMCAMs *are simply a sound design investment.*

Follow the Leaders 3Com Corporation, Bay Networks, Inc. and Cisco Systems, Inc. already design MUSIC CAM technology into their networking products. *They know MUSIC CAMs make sense!*

**MU9C4320L-12, per 1,000*

Email info@music.com
Internet http://www.music.com

Distributors in USA:

Sager Electronics	800-SAGER800
All American	800-573-ASAP
USA	Voice 888-CAM-MUSIC Fax 908-979-1035
In Europe: Holland	Voice +31 45546 2177 Fax +31 45546 3738
In Asia: Manila	Voice +6392 549 1480 Fax +6392 549 1024

MUSIC SEMICONDUCTORS
CAMs World Leader™

READER SERVICE 108

39. In this vein, I talked to a smart engineer who has been earning his living, designing systems using F.L. His designs have been successful, and his clients have been delighted. So why can't he show me a good F.L. example? Because most of his recent clients have *forbidden* him to talk about his designs. Half of them were concerned that their competitors would find out how well the Fuzzy Logic worked—and the other half were scared that their customers would find out they were using Fuzzy Logic. Besides, he's too busy to show demos....

40. I do not think this is *the last word* on Fuzzy Logic, but I think we have at least raised the right questions. The answers will not come easily, because some of these people do not have much incentive to answer questions clearly.

But here's the situation as I see it. If we stick to our guns, then maybe we can instill enough honesty that people will be able to see where Fuzzy Logic really is appropriate.

Then, hopefully, they'll start to use it mainly for just those applications. And we really could use some concrete examples of where Fuzzy Logic is really good, and where it is *not* good. I'm still waiting, and so are the readers of this column. We'll be interested to hear your stories and letters.

Comments invited! / RAP
Robert A. Pease / Engineer

References:

9. "Fuzzy Logic," Bart Kosko and Satoru Isaka. *Scientific American*, July 1993, pp. 76-77.

10. "Fuzzy logic: A Clear Choice for temperature control," Haubold vom Berg, *Instruments and Control Systems*, June 1993, p. 41.

11. "Any technician can understand in few minutes the basic principles of fuzzy logic, and can apply this method with success even in the case of multivariable systems." Prof. C. Vibet, Evry, France; letter to *Fuzzy Sets and Systems*, Amsterdam, Netherlands.

12. NeuFuz4 from NSC; see note 5 in the last issue.

13. Private correspondence with Daniel Abramovitch, Hewlett-Packard Labs, Palo Alto, CA. June 30, 1993.

14. Daniel McNeill interviewed on "Marketplace Radio," KQED-FM, March 23, 1993 (6:49 P.M.)

15. "Saturn engineers have developed a '93 transmission control system—using fuzzy logic on the downhill side... Saturn doesn't use fuzzy for uphill driving because all the information is right there in front of the computer." *Automotive Industries*, Feb. 1993, pp. 149-150.

16. "Fuzzy logic," Bart Kosko and Satoru Isaka, *Scientific American*, July 1993, p. 78.

17. Ibid., pp. 76-77.

18. "On Fuzzy Control and Fuzzy Reviewing...," *IEEE Control Systems* magazine, June 1993, pp. 5-7, 86.

19. "Fuzzy-logic steers Electron Discharge Machining with finesse," Frederick Mason, *American Machinist* magazine, June 1993, pp. 31-34.

Originally published in
Electronic Design, November 11, 1993

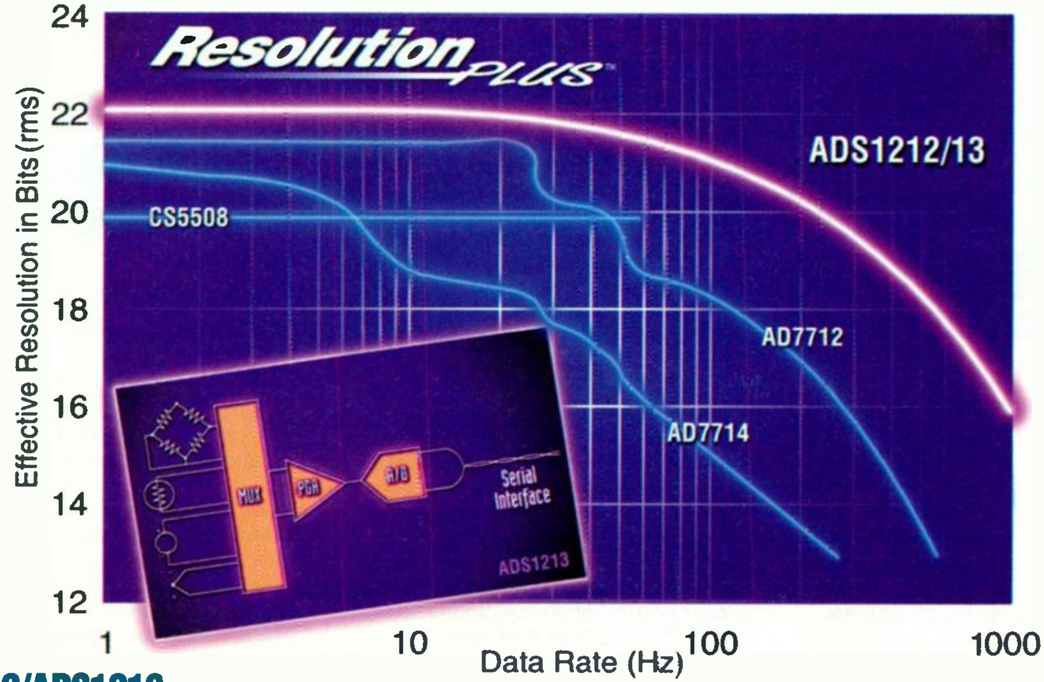
RAP's 1997 comments: Again, most of these comments have held up pretty well; I don't have to retract very much. At Section 22, I was told by some smart F.L. guys that in most cases, I am absolutely right: You have to make a good guess or estimate at the coefficients, or F.L. won't work any better than any other controller.

At Section 28, maybe there are some examples where F.L. does not work well, but, except for the comments of Mr. vom Berg in Section 20, nobody wants to talk about them. Referring to Section 33, I have seen some ping-pong-ball in a tube controllers, using F.L., and they were pretty good at some places, but not at other places. Demanding perfection from F.L. is not a Sure Thing.

Referring to Section 38, Dave Brubaker has proposed the name "Zadehan Logic," in honor of its originator. It's not clear how long that will take to catch on.... even though it's a good idea.

No, this is not "the last word on F.L." But it was a pretty good status report as of 1993. To see a pretty good status report as of 1995, keep reading the Columns in this reprint. And look at my WEB SITE—go to URL = http://national.com/rap/ , and then hit *technical material* to get to http://www.national.com/rap/Application/0,1127,25,00.html , to see my "Third Thoughts on Fuzzy Logic," which I wrote for the *IEEE Micro Magazine*. If you aren't on the WEB, send me a SASE. I don't say *only* bad things about F.L....—*rap*

ΔΣ A/D Converters Offer Speed, Resolution, Low Power Options



ADS1212/ADS1213

A Winning Solution for IPC Applications

ADS1212 and **ADS1213** are complete, wide dynamic range, 22-bit delta-sigma converters operating from a single +5V supply. ADS1212 is a single channel A/D; ADS1213 is a 4-channel multiplexed version. Both include a flexible synchronous serial interface which is SPI compatible, and a 2-wire mode for low-cost isolation. Burr-Brown's proprietary "Turbo" modulator mode of operation allows the ADS1212 and ADS1213 to achieve effective resolutions of 16 bits at a sample rate of 1kHz. Effective resolution of 22 bits is achieved by using a low-noise input amplifier at conversion rates up to 10Hz. V_{BIAS} generated from V_{REF} allow drift characteristics to track over temperature thus providing high accuracy for the complete application over temperature extremes found in industrial environments.

Key Specifications

- Differential Inputs
- Internal or External Reference
- 20 Bits Effective Resolution at 10Hz: 16 Bits at 1kHz
- Package Options:
  ADS1212—18-pin DIP, 18-lead SOIC
  ADS1213—24-pin DIP, 24-lead SOIC, 28-lead SSOP
- ADS1212 is priced from **$7.25** in 1000s;
  ADS1213 from **$8.15** in 1000s

Model	INL (%FSR)	DNL (Bits)	Resolution (Bits at 10Hz)	Resolution (Bits at 1kHz)	Power Dissipation (mW)	FAX*LINE*#	Reader Service #
ADS1210	±0.0015	No Missing Codes	24	20	26	11284	89
ADS1211	±0.0015	No Missing Codes	24	20	26	11284	90
ADS1212	±0.0015	No Missing Codes	22	16	1.4	11360	91
ADS1213	±0.0015	No Missing Codes	22	16	1.4	11360	92

For Technical Information: http://www.burr-brown.com/Ads/ADS1212-Ad.html

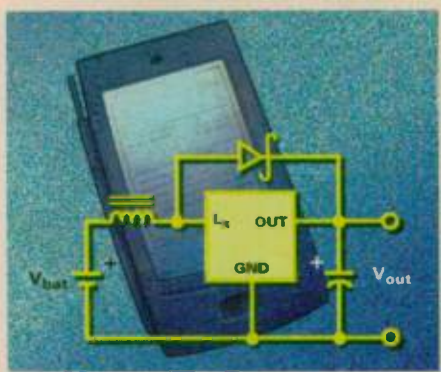
BURR-BROWN®

Burr-Brown Corporation

Burr-Brown Corporation • P.O. Box 11400 • Tucson, AZ • 85734-1400 • Call **(800) 548-6132** or use **FAX*LINE* (800) 548-6133** • **http://www.burr-brown.com/**

Distributors: Anthem: (800) 826-8436 • **Digi-Key Corp:** (800) 338-4105 • **Insight Electronics:** (800) 677-7716 • **J.I.T. Supply:** (800) 246-9000 • **Sager Electronics:** (800) 724-3780 • **SEMAD (Canada):** (800) 567-3623

Motorola Analog



Micropower CMOS DC-DC Converters Simplify Design of Portable Products

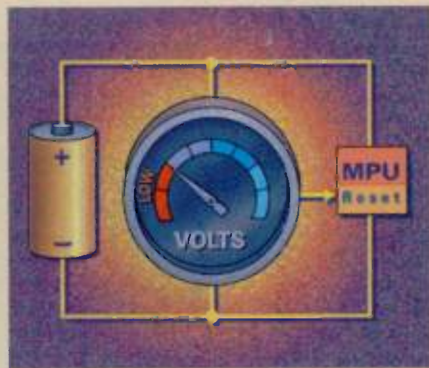
The MC33463/33466 series of micropower switching voltage regulators are available in 3.0, 3.3 and 5.0 V options, and are ideally suited for battery powered computer, consumer and industrial equipment. Both families are available in three-pin SOT-89 packages, with either an on-chip switch transistor or provisions for an external switch. The MC33463 devices are Variable Frequency Modulation controllers with a quiescent bias current of 4 µA, while the MC33466 devices are Fixed Frequency PWM switchers with a quiescent current of 15 µA.

✓ *Box A on coupon*

Three Families of CMOS Micropower Linear Regulators have Ultra-Low I_Q

MC78LCxx/78FCxx/78BCxx. Three series of micropower linear voltage regulators are designed for use in cameras, camcorders, VCRs, and hand-held communication products, and include voltage options of 3.0, 3.3, 4.0 or 5.0 V. The MC78LCxx series has an 80 mA output current, a dropout voltage of 0.7 V at 40 mA, and is available in SOT-23 or SOT-89 packages. The MC78FCxx family has an output current of 120 mA, dropout of 0.2 V, in a SOT-89. The MC78BCxx series is available in a SOT-23 and is designed for use with an external power transistor for higher output currents.

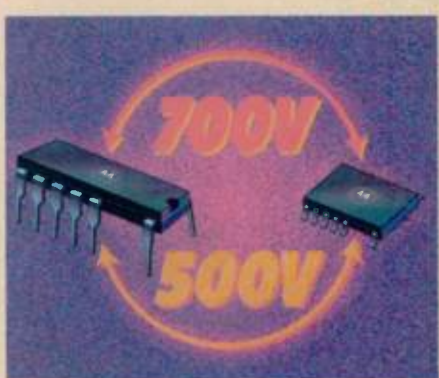
✓ *Box B on coupon*



CMOS Micropower Undervoltage Sensing Circuits Monitor MPU/Logic Supplies

The MC33464/33465 families of micropower undervoltage sensing ICs are designed for direct monitoring of MPU/logic power supplies in portable, appliance, automotive and industrial equipment. Both series are available with threshold voltages of 0.9, 2.0, 2.7, 3.0 and 4.5 V with a choice of open drain or complementary CMOS reset output configurations. The MC33464 family has a low quiescent current of 0.8 µA and is available in SOT-23 or SOT-89 packages. The MC33465 series adds a programmable time delayed output, has a quiescent current of 1.0 µA, and is packaged in a SOT-23.

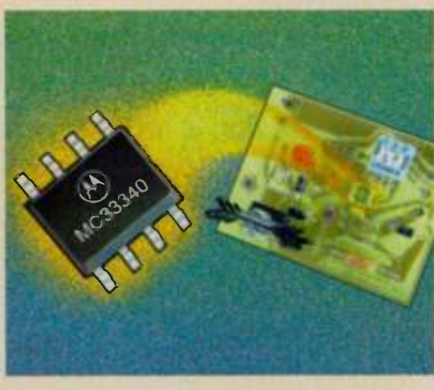
✓ *Box C on coupon*



High Voltage Switching Regulators Simplify Design of Off-Line Supplies

MC33362/33363. These ICs are designed to operate from a rectified AC line source for off-line power supplies, or from a high voltage source for DC-DC converter applications. The MC33362 is designed for rectified 120 Vac line operation and features an on-chip 500 V, 2.0 amp SenseFET™ power switch. The MC33363 is designed for 240 Vac rectified line operation with a 700 V, 1.0 amp SenseFET. Both devices are available in 16-lead through-hole and surface mount packages with pins eliminated to achieve high voltage spacing requirements.

✓ *Box G on coupon*



Battery Fast Charge Controller Simplifies NiCd and NiMH Charging

The MC33340 is specifically designed for fast charging of Nickel Cadmium (NiCd) and Nickel Metal Hydride (NiMH) batteries using negative slope voltage detection. Accurate charge termination is ensured by an output that momentarily interrupts the charge current for precise voltage sampling. The IC also supports secondary charging methods of either programmable time or temperature limits. Protective features include battery over and undervoltage detection, latched over temperature detection, and power supply input undervoltage lockout. A rapid test mode enhances end product testing.

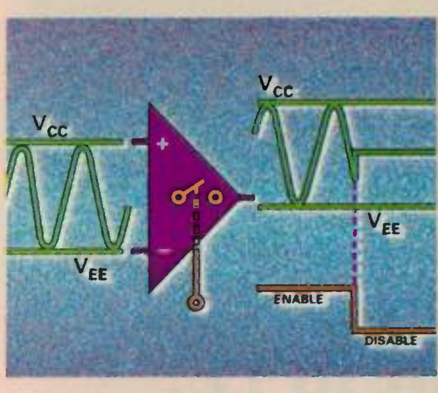
✓ *Box H on coupon*

Subminiature Package Trims Board Space

We offer a variety of products in the new Micro-8 subminiature surface mount package. This package uses 50% of the board area of a traditional SO-8 surface mount package, and is narrower than TSSOP miniature packages. The LP2951 adjustable micropower low dropout voltage regulators, and MC33264 low dropout micropower regulators with on/off control are available in the Micro-8 package. The MC34064/34164 undervoltage sensing/micropower undervoltage sensing circuits, and the TL431,A,B programmable precision references are also available in this space-saving package.

✓ *Box I on coupon*

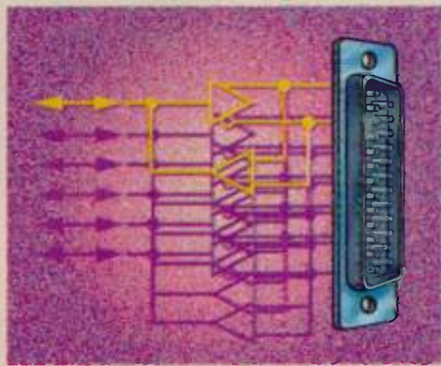
Product Review #3



Dual/Quad 1.8 V Rail-to-Rail Op Amps have Enable Feature to Extend Battery Life

MC33206/33207. These dual/quad op amps not only have input *and* output rail-to-rail capability, but also an enable mode that can be controlled externally. Typical drain current is ≤1.0 µA per amplifier in the standby mode, saving power and extending battery life. Each op amp in the MC33206 has its own enable pin, and the op amps in the MC33207 are enabled in two pairs. These amplifiers can operate with supplies as low as 1.8 V and ground, yet can still operate with a single supply voltage as high as +12 V.

✓ *Box D on coupon*



Hex Transceiver Meets SCSI-3 Fast-20 Specs

The new MC34059 contains six differential driver and receiver pairs in a 48-pin QFP for transmission of differential signals at 20 MBPS, meeting the requirements for SCSI-3 Fast-20 transmission systems. Control lines can enable/disable each driver and receiver as required, and an over-temperature sensing circuit will shut down any driver that gets too hot due to ambient temperature or a prolonged short circuit. The low quiescent current of 18 mA saves power in hard disk drive, backplane communications, and computer-to-computer data transmission applications.

✓ *Box E on coupon*

Low Cost FM Communications Receivers

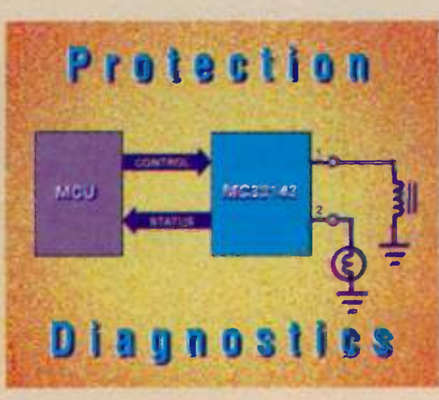
MC13135/13136. These low cost, single chip, dual conversion FM receivers can be used as stand-alone VHF receivers or as the lower IF of a triple conversion system, with a low 2.0 V supply. The MC13135 is designed for use with an LC quadrature detector, while the MC13136 can be used with either a ceramic discriminator or an LC quad coil. Applications include cordless phones, radio controlled toys, baby monitors, walkie-talkies and scanners.

✓ *Box F on coupon*

New PIP IC Enables TV Feature Versatility

The MC44463 Picture-In-Picture (PIP) controller IC provides a wide variety of feature options that are all *software programmable,* requiring no printed circuit board changes. When combined with external memory, the device controls a replay mode of up to eight seconds that can be played back at four different speeds. The IC provides options of a single PIP, in either active or replay mode; and three or four PIPs, with one active and the remaining PIPs in a freeze-frame mode. In the multi-PIP mode, the user can choose which of the three or four PIPs is active.

✓ *Box J on coupon*



Dual High Side Switch has Protection and Diagnostic Features

The MC33143 dual high side switch is designed for solenoid control in harsh automotive applications, but can also be used to control incandescent lamps, relays, and small motors. This SMARTMOS™ IC has an on-chip charge pump to enhance switch performance, and an externally controlled Sleep-Mode™ for power savings. Each output has individual overcurrent and over temperature shutdown with automatic retry. The device detects and shuts down globally with any overvoltage condition. It also detects and indicates an open load or output short to the supply.

✓ *Box K on coupon*

Call or Write Today

For more information on these Motorola products, please contact your local sales office, or return the coupon below to:
Motorola Semiconductor Products,
P.O. Box 20912, Phoenix, AZ 85036
Or call 1-800-441-2447

0147ED080497

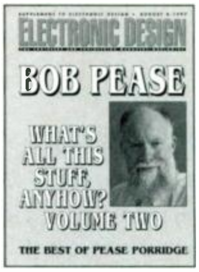
To: Motorola Semiconductor Products
P.O. Box 20912, Phoenix, AZ 85036.
Please send me more information on the Motorola Analog Products checked below.

☐ **A** MC33463/D	☐ **D** MC33206/D	☐ **I** LP2950/D
MC33466/D	☐ **E** MC34058/D	MC33264/D
☐ **B** MC78LC00/D	☐ **F** MC13135/D	MC34064/D
MC78FC00/D	☐ **G** MC33362/D	MC34164/D
MC78BC00/D	MC33363/D	TL431/D
☐ **C** MC33464/D	☐ **H** MC33340/D	☐ **J** MC44463/D
MC33465/D		☐ **K** MC33143/D

Name
Title
Company
Address
City
State Zip
Call Me ( )

MOTOROLA
Analog IC Division

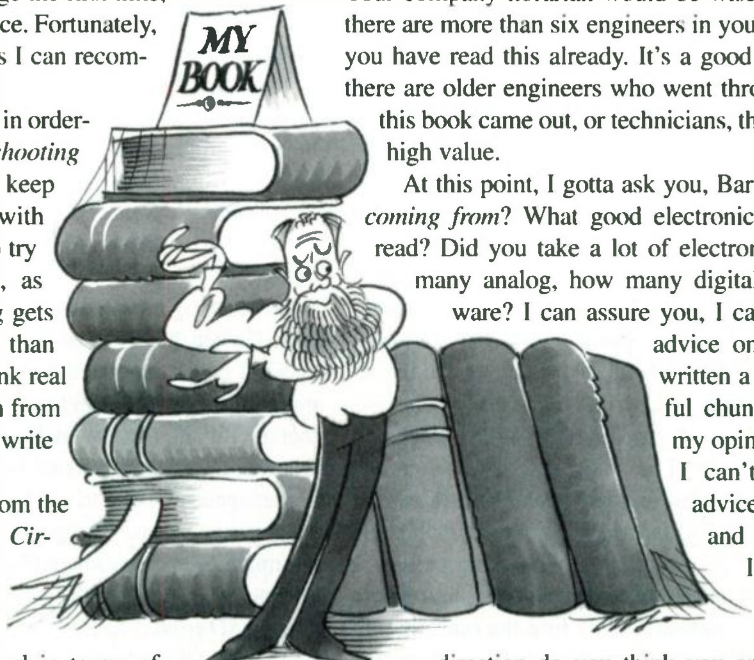
What you never thought possible.™



What's All This Technical Reading Stuff, Anyhow?

Recently a young engineer, Barrett L. of Poughkeepsie N.Y., wrote me a letter. He not only ordered one of my books, but he asked my advice and opinion: "I'm a recent E.E. graduate, and if you could please supply me with a list of suggested reading (i.e. books, periodicals, columns) it would be greatly appreciated." Well, I *had* to reply:

"Dear Mr. L.——Darn it, you are the second person this week to ask me this question, and while I was stupid enough not to get the message the first time, I won't miss the message twice. Fortunately, there are several good books I can recommend.



You have not gone wrong in ordering my book on *Troubleshooting Analog Circuits.*[1] I try to keep things light and breezy, with REAL examples. And I also try to minimize the platitudes, as you have noted that nothing gets me TICKED OFF faster than meaningless platitudes. I think real engineers get their education from EXAMPLES, and I try to write accordingly.

A second related book, from the same publishers, is *Analog Circuit Design*[2], edited by Jim Williams. It consists of about 33 chapters from 23 authors. It, too, is educational in terms of EXAMPLES. Some of the chapters are so-so (in my opinion) and then they get better and better, up to *great*. The chapters by John Addis and Derek Bowers are great. I wrote two good chapters.

NOW, if you laid hands on this book you might decide that you wanted to buy it, OR you might read a few chapters and then put it back on the shelf. So get your librarian—your town librarian or your company librarian—to order it. If you ain't on good terms with your librarian, you should be. After the librarian buys it, it can be shared by a good number of people.

Nextly, there's Horowitz and Hill's *The Art of Electronics*.[3] Any bookstore will order it for you. It's in its second edition—very popular, fun to read, good insights. Your company librarian would be wise to buy this one if there are more than six engineers in your company. Maybe you have read this already. It's a good reference book. If there are older engineers who went through school before this book came out, or technicians, they may find this of high value.

At this point, I gotta ask you, Barrett, where are you *coming from*? What good electronics books have you read? Did you take a lot of electronics courses? How many analog, how many digital, how many software? I can assure you, I can give you ZERO advice on software. I have written a couple of successful chunks of BASIC, but my opinions are worthless. I can't give you much advice on digital circuits, and books thereon, but I'll ask my friends.

Next question for you—in which direction do you think you are *going*?? Analog, ADCs, or systems? Low power? High speed? Lotsa processors and a little analog? Just trying to get a broader education? That will make some difference. Or, if you're not sure where you're headed, well, the broad perception from reading a lot will be good for you.

OF COURSE you gotta keep reading *Electronic Design*.[4] It gives you a good clear presentation of some of the newer ideas, circuits. concepts, and trends, with intelligent guys from the industry trying to make good explanations—trying to play teacher. One item of advice: Read and mark the hell out of any stories that are interesting. Xerox or cross-index the stories that are of good interest, but don't throw the magazines away for at least five years. You can go back in several years and see what's interesting, what's trivial, and what's passe. Note, a five-year stack of ED just fills two "Xerox-paper boxes," about 2.5 cubic feet....

Read hobby magazines—*Popular Electronics*[5] or similar publications. Some of the stuff is trivial, but that's OK—sometimes it's good to read stuff where you're smarter than the authors, and you can see if they're doing something stupid.

James Roberge of MIT wrote an excellent book about op amps in general, and about the LM301A in particular.[6] The first half explains how the '301 chip was engineered; the second half goes into how you can *apply* a '301. I asked James and he said it's still in print. It's a very good read.

The advanced, expert book on op amps is by Jiri Dostal—*Operational Amplifiers (second edition)*.[7] I was selling these for $53. This used to sell for $113 from Elsevier Scientific, and was worth it. Now at $55, it's a bargain. Serious, thoughtful. NOT your FIRST primer on op amps, but any serious user of op amps should read this about once a year. You'll learn something new every time. However, that statement is true for almost every one of these books: All of these books are well worth rereading every year or two.

Now, darn near your first primer on op amps is Tom Frederiksen's *Intuitive IC Op Amps*.[8] Heck of a fine book. Where is it sold? Tom still has some to sell. If you want to use op amps, you want to do it intuitively. No fancy formulae, no matrices, no Taguchi optimization. Just common-sense engineering with good intuitive insights. Tom's an excellent teacher for that.

The NEXT primer on op amps is NSC's linear databook on op amps.[9] The history of op amps was written there.

NOW, Analog Devices' op-amp databook might be almost as good as NSC's, *but* they usually don't include device schematics. If you want an AD databook, call them up.[10] You can request and study databooks from anybody in the whole electronics industry, but I find the ones that do include schematic diagrams (of the devices themselves) are the most useful and educational.

NEXT, NSC's *Linear Applications Handbook*.[11] Some of the better early linear IC applications breakthroughs have gone into there. It's indexed pretty well, so you can find what you want.

NSC's databook on regulators and power ICs[12] is quite good—a useful basic reference book. Also falling into that category is the *Data Acquisition Databook*,[13] which covers DACs, ADCs, voltage references, and temperature sensors. Another is the *Linear Applications-Specific ICs Databook*,[14] which includes several strange but useful ICs.

The list price for these NSC handbooks is usually about $10 or $15 each. But our marketing guys agreed that we ought to make a special offer to readers of *Electronic Design*—serious engineers. If you want any or all five of those linear databooks, just call and ask for the set.[15] Not a bad deal.

If you ever have to do "optimization" or quality problem-solving, buy the books that cite "Taguchi" in them the *fewest* number of times. I just got around to reading Keki Bhote's book,[16] full of excellent common sense. I started out skeptical, but eventually decided I really liked his style and common-sense approaches. Hans Bajaria has a good book.[17] So does Forrest Breyfogle.[18] And Diamond's book[19] is good, too. Just keep away from books by Genichi Taguchi, and all his friends who tell you how great it is to use orthogonal matrices to solve any problem and you don't have to think... (if you know what I mean, and I think you do).

Recently, I was introduced to a new book by Dennis Feucht, *Handbook of Analog Circuit Design*.[20] It really covers lots of the things a designer needs to know about analog circuits. I'm favorably impressed, and I recommend it. It has good chapters on wideband amplification, precision amplification, feedback circuits, frequency compensation, signal-processing circuits, etc. There's some overlap with Hill and Horowitz, but that's *good*, not bad.

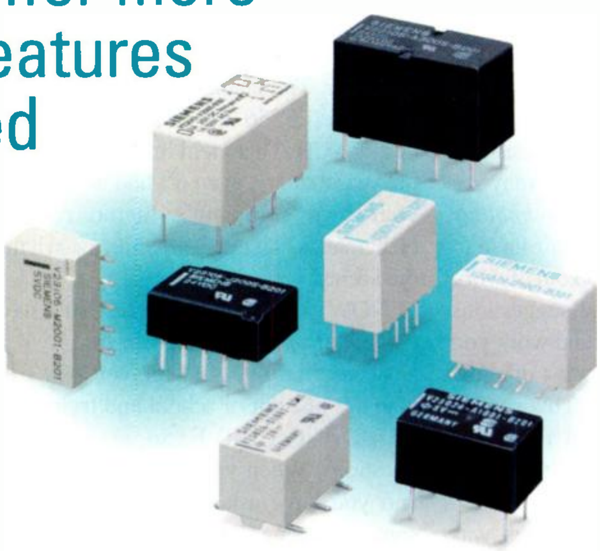
Another good new book is *High-speed Digital Design*, by Howard Johnson, subtitled *A Handbook of Black Magic*.[21] I thought it was pretty good, so I loaned this to one of our best digital/mixed-signal designers. I was a little surprised when he returned it right away. He said that was because he had gone out and bought several copies for the guys in his group. It treats the gray area between signals that are digital, and the analog aspects that are so important when you want your digital buses to behave at higher and higher speeds—not a trivial task. This book is there to help, with serious advice and good philosophy. You ain't gonna get much of that anywhere else these days.

One of my old fans, Reg Neale, recommended a book on ESD, *ESD from A to Z*, by John Kolyer.[22] I discovered the book in our library, read through it, and found a number of thoughtful observations. Just as my book is the "best" book on Troubleshooting, so this book may well be the "best" on ESD, and *partly* for the same reason—it's the only one.

When I wrote about Ground Noise in June, I recommended the excellent book by John Barnes, *Electronic*

SIEMENS

Our new low-signal relays offer more of the features you need



You wanted more, and we've got it

Your designs demand more, so we're providing more! We've expanded our line of low-signal relays. New models provide just the features you need for application in telecommunications equipment, computer peripherals, security systems, office automation and more. These relays offer:

- Through-hole and surface mount termination options.
- Choice of low-profile or minimal PC board area types.
- Isolation meeting FCC Part 68 and Bellcore specs.
- Single-pole as well as double-pole designs.
- Load carrying capability to 150W or 250VA.
- Non-latching, single-coil latching and dual-coil latching models.
- Ultra-sensitive coils.

There's still more

Great product features are just the beginning. You're assured of consistent quality, as these relays are produced on fully automated lines. Of course, we support you with the same level of service you've come to expect from Potter & Brumfield Products Division, an ISO9001/QS9000 registered company that's been delivering dependable, innovative switching solutions for more than 60 years.

Series	V23026	V23106	V23079	V23105	V23042
Contacts	SPDT	DPDT	DPDT	DPDT	DPDT
Dim. (mm)	13 x 7.9 x 6.9h	14 x 9 x 5h	14.5 x 7.2 x 9.9h	20 x 9.8 x 12h	20.1 x 10 x 10.6h
Contact Rating	30W 60VA	30W 62.5VA	60W 62.5VA	60W 125VA	50-150W 250VA
Nominal Coil Power	30-150mW	100-200mW	70-140mW	150-300mW	75-360mW
Terminals	Pin or SMD	Pin or SMD	Pin or SMD	Pin	Pin
Fax Doc. #	8026	8106	8079	8105	8042

Find out more...

From the U.S. or Canada, use a touchtone phone and our automated fax-response system. Simply dial 812.386.2561 and request the appropriate fax document number. Or follow the prompts to speak with your sales representative.

TUV Rheinland of North America, Inc.

ISO 9001/QS-9000 Registered Company

Potter & Brumfield Products Division
Siemens Electromechanical Components, Inc.

Siemens Electromechanical Components, Inc.
200 S. Richland Creek Drive
Princeton, IN 47671-0001
Fax 812-386-2072
e-mail: info@sec.siemens.com

READER SERVICE 111

System Design,[23] and I still do. Also, a friend recommended *Noise Reduction Techniques in Electronic Systems*, by Henry Ott.[24] Its second edition just came out, and it, too, covers many topics that aren't taught in schools. If you work with RFI and EMI in real systems, you'll probably profit by buying and reading *both* of these books.

Recently, Barrett, a reader asked me what book can I recommend to teach about designing printed-circuit boards? I asked several friends—no ideas, no recommendation. Maybe some of our readers can recommend a book? There *ought* to be something beyond the literature of the pc-board-design software people...

Also, you and other readers who recall the question and debate of the value of a Bachelor's Degree versus an Associate's Degree in Electronics Technology may be interested in a new book by Joel Butler, *High-Technology Degree Alternatives*.[25] He observes that you don't have to go to school at night for a dozen years, nor drop out of work and pay tuition for four years. He has several suggestions on how you can get credit for school courses and work you have already accomplished. He recommends a list of a few dozen schools where you can apply by mail. This sounds kind of unlikely, except Mr. Butler points out that these schools actually are ACCREDITED, which isn't a trivial statement.

One last "book," actually some stories on floppies, was sent to me by Geoff Harries, a reader located in Munich, Germany. They are Science Fiction, sort of high-tech and time-travel, and good historical stuff, too. He's still trying to get a publisher. Meanwhile he gave me permission to sell you his book, *ChronDisp I* (about 700 kbytes) on a high-density IBM-type floppy for about the same price as a paperback book. I will repatriate all proceeds to Geoff. I enjoyed the book, and I recommend it to you, too. It's kind of fun to sit there in the evening, hitting "Page Down," again and again, reading Geoff's stories.[26]

Well, there is my list. This may not be a DEFINITIVE list, but it's a good start. Ask your buddies. Borrow some of their hobby magazines. Also, you will probably want to read one or two general-purpose science magazines. I used to read *Scientific American*,[27] but a year ago I gave up on them and changed over to *Discover*.[28] Maybe *Sci Am* is coming back, but I still think *Discover* is excellent. Try *Machine Design*.[29] You can spend a lot of time reading this, but it's fun and educational. You'll see several kinds of good engineering.

Ah—yes, let's not overlook the obvious. You should also read *your own company's* catalog or data sheets. Look at what it says to your customers, and look at the circuits "behind the front panel." I don't know what your company does or makes, but let's assume there are PRODUCTS somewhere. When I joined Philbrick in '61, I studied the heck out of all its schematics and data sheets, op amps, and analog computing products. Then I would say to myself, "Why did they do *that*?" I surely couldn't understand everything, but by asking all questions that came to mind, I got a *heck* of an education.

Similarly, when I came to NSC in 1976, I studied all of the op amps, data sheets, schematics, AND layouts. I'm sure you will agree that in an IC, the layout can be even more important than the schematic. In my first year at NSC, I spotted a philosophical error in the layout of a popular amplifier. The changes I suggested caused the yield to go up on the LF356, the LF256, AND the LF156, by a factor of 2, EACH. That yield improvement paid for my first couple years' salary, even if I had done nothing else.... So, read your own company's literature, and the serious art (schematics, layout, software, or whatever) that's behind the scenes.

NOW you can plainly see that I have written a whole *column* around your request, for pity's sake! I hope I have answered the question for you *and* for many other guys who are just out of school and trying to get going—up the LEARNING CURVE. So, read books and think of good questions. When you have answered as many as you can, and you have asked your colleagues, and there are still some you cannot answer, write down some notes and ask one of your Senior Engineers. He'll probably be flattered to get thoughtful questions from a *serious* student. If you ask reasonably, he/she may provide some (priceless) mentoring. Have fun, Barrett!!"

Comments invited! / RAP
Robert A. Pease / Engineer

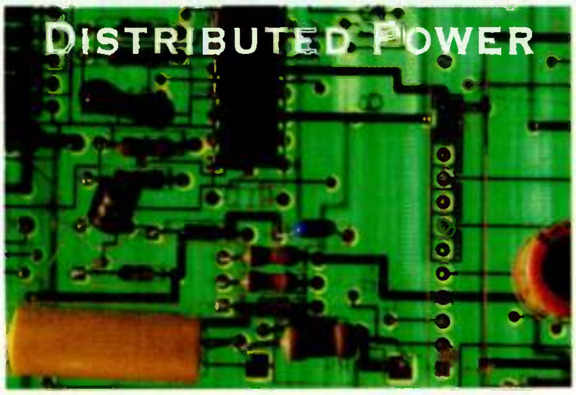
1. *Troubleshooting Analog Circuits*, 7th Printing, Robert A. Pease, 1992, 208 pages. Butterworth-Heinemann. Order from Robert Pease, 682 Miramar Ave., San Francisco, CA 94112. $31.95 including tax & shipping.

2. *Analog Circuit Design: Art, Science, and Personalities*, edited by Jim Williams, 1992, 222 pages. Order from Robert Pease, (see address in reference 1) $33.00 includes tax & shipping; or order it from the publishers, Butterworth-Heinemann, Newton, MA; (800) 366-2665 or (617) 928-2500.

3. *The Art of Electronics* (2nd Edition), Paul Horowitz and Winfield Hill, 1989, 800 pages. About $65. Cambridge University Press, NY; (914) 937-9600 or (800) 872-7423.

4. *Electronic Design*, Penton Publishing. To apply for a free subscription, write to Electronic Design, Reader Service Dept., 1100 Superior Ave., Cleveland, Ohio 44197-8132. You also can go to *Electronic Design*'s web site at http://www.penton.com , hit sub, fill out the form, then

HIGH PERFORMANCE *and* HIGH DENSITY.



Power Convertibles is your source for high density DC to DC converters when you need:

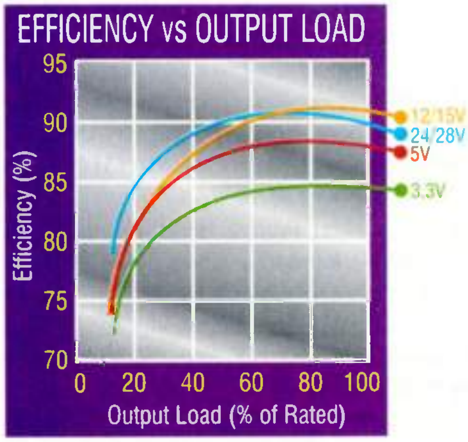
PERFORMANCE - The VKP Series is tops in its class when it comes to delivering peak efficiency in a fixed frequency design. Our output transient response is tough to beat, making it ideal in applications where loads are switching at high speed.

POWER - We have a broad range of input/output combinations through 100 watts, ideal for on-board distributed power architectures.

PACKAGE - Our high density products are packaged in industry standard half-packs... Perfect for low board pitch applications.

PRICE - Competitive pricing is a MUST in today's demanding electronics markets.

Call Power Convertibles today and learn how our high density products can perform in your applications.



ISO9001 CERTIFIED

POWER CONVERTIBLES™

Tucson, Arizona • 520-628-8292 • FAX 520-770-9369 • email: sales@pcc1.com
Data sheets are available through our DATAFAX system @ 520-628-8691

Internet: www.pcc1.com

print it out, and mail it in..

5. *Popular Electronics*, about $19 per year. Call (800) 827-0383 or (815) 734-4151.

6. *Operational Amplifiers: Theory and Practice*, James Roberge, 1975, 678 pages. Wiley/Krieger. (407) 724-9542 (Out of print).

7. *Operational Amplifiers (Second Edition)*, Jiri Dostal, .1993, 555 pages. Butterworth-Heinemann. About $55. See phone numbers in footnote 2.

8. *Intuitive IC Op Amps*, Thomas M. Frederiksen, McGraw-Hill, 1988, 352 pages. Order from Thomas Frederiksen, 24705 Spanish Oaks, Los Gatos, CA 95030; $15.04 including tax & shipping.

9. *Operational Amplifiers Databook*, National Semiconductor Corp., 1995. Publication No. 400036.

10. Analog Devices Inc., Literature Dept. (617) 461-3392.

11. *Linear Applications Handbook*, National Semiconductor Corp., 1994. Publication No. 400043.

12. *Power ICs Databook*, NSC 1993. Publication No. 400037.

13. *Data Acquisition Databook*, NSC, 1995. Publication No. 400035.

14. *Linear Application-Specific ICs Databook*, NSC 1995. Publication No. 400034.

15. Set of 5 NSC linear databooks—items 9, 11, 12, 13, and 14 above—call the NSC Customer Response Center, (800) 272-9959 or (817) 468-6811.

16. *World Class Quality: Using Design of Experiments to Make It Happen*, Keki R. Bhote, AMACOM, 135 W. 50th St. NY, NY 10020; (518) 891-5510. About $28.

17. *Statistical Problem Solving—A Team Process for Identifying and Resolving Problems*, Hans Bajaria & Richard Copp, 1991, 300 pages. About $45. Multiface Publishing Co., Garden City, MI; (313) 421-6330.

18. *Statistical Methods for Testing, Development, and Manufacturing*, Forrest Breyfogle, John Wiley & Sons, 1992; (908) 469-4400. About $90.

19. *Practical Experiment Designs for Engineers and Scientists*, William Diamond, 1981, 347 pages. Van Nostrand Reinhold, NY. About $58. Call (800) 842-3636 or (606) 525-6600.

20. *Handbook of Analog Circuit Design*, Dennis L. Feucht, 1990, 685 pages. About $22.23. Order from the author, 14554 Maplewood Road, Townville, PA 16360.

21. *High-speed Digital Design (A Handbook of Black Magic)*, Howard Johnson and Martin Graham, 1993. About $47. Prentice-Hall, Englewood Cliffs, NJ; (800) 947-7700 or (515) 284-6751.

22. *ESD from A to Z*, John Kolyer and Donald E. Watson, 1990, Van Nostrand Reinhold, NY; (800) 842-3636 or (606) 525-6600. About $72.

23. *Electronic System Design: Interference and Noise-Control Techniques*, John R. Barnes, 1987, 144 pages. About $48. Prentice-Hall, NY; (800) 947-7700 (out of print).

24. *Noise Reduction Techniques in Electronic Systems*, (2nd edition), Henry Ott, 1988, 426 pages. About $79. John Wiley & Sons, NY; (908) 469-4400.

25. *High-Technology Degree Alternatives*, Joel Butler, 1994, Professional Publications, 1250 Fifth Ave., Belmont, CA 94002; (415) 593-9119. About $22.

26. *ChronDisp I: The Gun From The Past*, Geoff Harries, 1993, Munich, Germany. Can be ordered on a high-density IBM-compatible floppy disk for $4.00 (including tax & shipping) from Robert A. Pease, 682 Miramar Ave., San Francisco, CA 94112.

27. *Scientific American*, about $35/year. Call (800) 333-1199 or (515) 247-7500.

28. *Discover*, Family Media, NY. About $35/year. P.O. Box 420105, Palm Coast FL 32142; (800) 829-9132.

29. *Machine Design*, a Penton Publication. Write on letterhead to 1100 Superior Ave., Cleveland Ohio, 44114.

Originally published in
Electronic Design, March 7, 1994

RAP's 1997 comments: The first comment is: if you liked Jim Williams' *first* collection (footnote 2), you will also like his second collection: "The Art and Science of Analog Circuit Design," Butterworths, 1995. ISBN = 0-7506-9505-6. Order from the same places as footnote 2. About $50.

Jim Smith wrote a good book on electronics manufacturing and assembly. If you are skeptical about the hyped claims for "six-sigma quality" or "Taguchi methods," and you are in the board-manufacturing business, this is a good $50 investment. Call (toll-free) to 1-888-866-6502, x52 for more info, including how to order. "Optimizing Quality in Electronics Assembly," from Cambridge Management Sciences, 4285 45th Street S., St. Petersburg FL 33711.

I've run into some books on the WEB. Not technical books, maybe not great books. But check out the shareware at http://www.teleport.com/~ammon/gn/cover.htm or samples of a novel at www.greatamerican.com . I think the presentation is well-done, technically. I hope to have sample Chapters of my books on the web, soon.

See also "The Goal," by Elihu Goldratt, at the end of the next column.

It took me about 5 hours to re-check all the 1997 prices and phone numbers in here. By the time you read this, probably one of them is already incorrect. I just can't tell you which one.—*rap*

From backplanes to fully wired systems...

everything you need, exactly how you need it.

That's Pure VERO.

From components to systems, VERO has the product and the expertise to solve just about every electronic packaging problem – *standard, modified, full custom*... you name it!

Our extensive range of standard, configurable products includes:

- High performance backplanes – VME, VXI and custom
- Card cages and enclosures
- Power supplies
- IMRAK cabinets
- Off-the-shelf or designed to your specs

Or, let us design and configure a fully wired, custom system to your exact specifications...and reduce your development costs and "hassle factor." Either way, you'll benefit from VERO's quality, experience and expertise.

Call us at 1-800-631-VERO to turn your packaging problem into a Pure VERO solution – for *any* and *every* requirement.

Call 1-888-549-8376

VERO

VERO ELECTRONICS

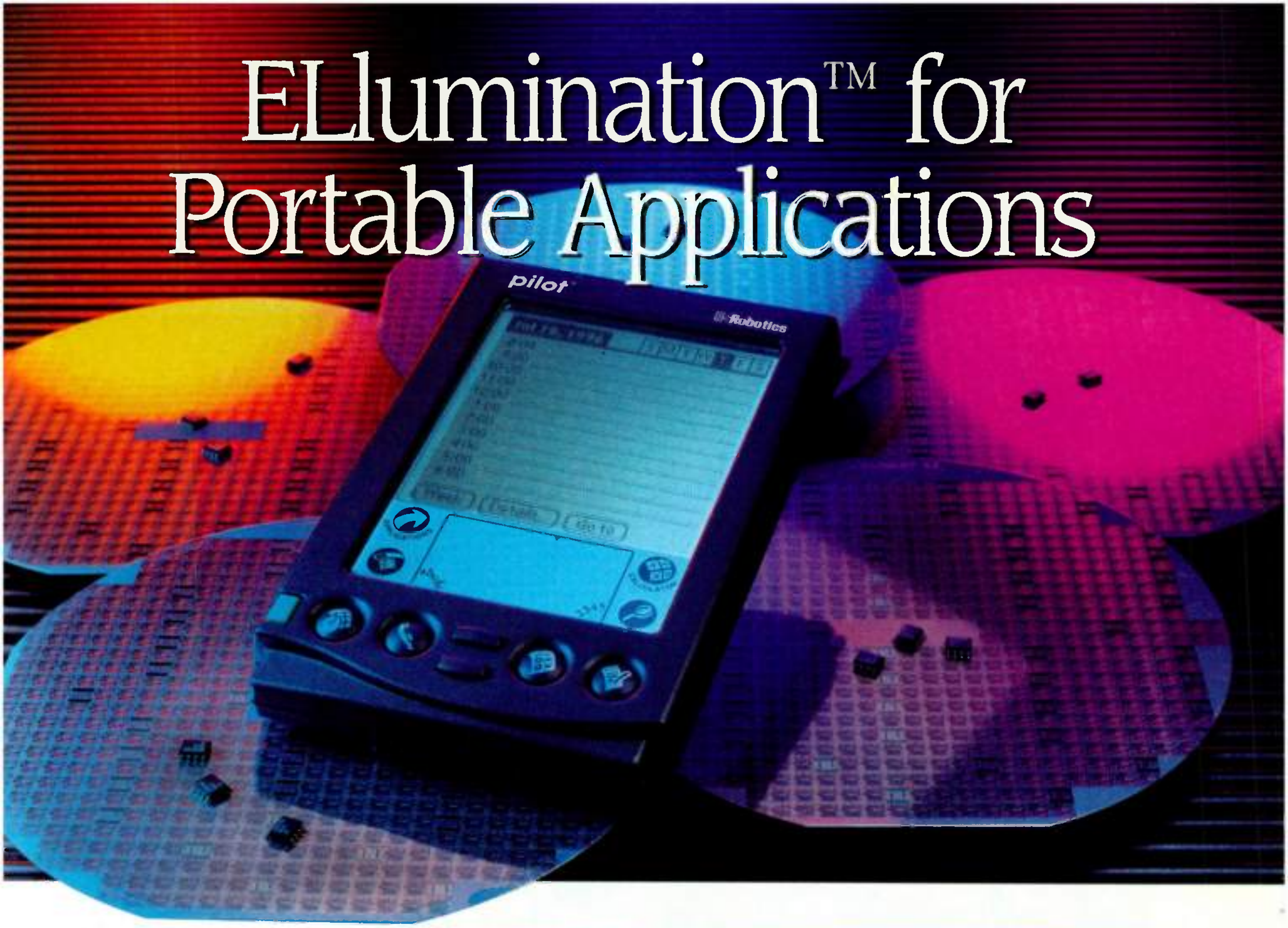
VERO Electronics, Inc.
5 Sterling Drive
Wallingford, CT 06492
Fax: 203-287-0062
email: vero@vero-usa.com

Your Packaging Partner.

Come see us at www.vero-usa.com

✓ An ISO 9002 Certified Company

ELlumination™ for Portable Applications



ELluminate your next portable application with the SP4400 series of EL lamp driver IC's from Sipex. With the largest selection of EL driver chips in the industry, Sipex has the right solution for a variety of applications. From TIMEX® watches with INDIGLO® night-lights to the U.S. Robotics Pilot™ PDA, Sipex driver chips offer the smallest, lowest power back-lighting technology available.

For more information, contact Sipex Corporation for data sheets, samples, or pricing.

Product	Supply Voltage	Supply Current (typical)	Internal Osc	Features	Applications
SP4412A	2.2V to 3.6V	5mA		Ultra low power	Watches, Small LCD Displays
SP4415	2.2V to 3.6V	5mA[1]		4 selectable light levels	Watches, Games, Apparel, Small LCD Displays
SP4422A	2.2V to 6V	8mA[1]	•	Requires minimal board space	Remote Control Units, Portable Instruments, POS Terminals, LCD Displays
SP4423	2.2V to 6V	5mA[1]	•	Low Power	PDA's, Calculators, LCD Displays
SP4424	1V to 6V	6mA[2]	•	Dual oscillator for coil and lamp control	Pagers, Digital Watches, LCD Displays
SP4425	1V to 6V	37mA[2]	•	Max light output @ low voltages	Pagers, Cell Phones, LCD Displays
SP4430	1V to 3V	75mA[3]	•	DC/DC converter	Cell Phones, PDA's, Pagers

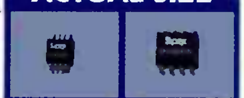
1. Vdd = 3.0V 2. Vdd = 1.5V 3. Vdd = 1.0V

Sipex

NEW

Available in both 8-pin NSOIC and new USOIC

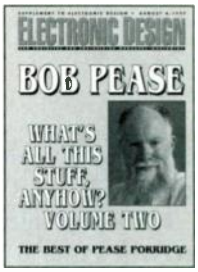
ACTUAL SIZE



USOIC NSOIC

22 Linnell Circle, Billerica, MA 01821 Tel. 508-667-8700 Fax 508-670-9001 web site: www.sipex.com

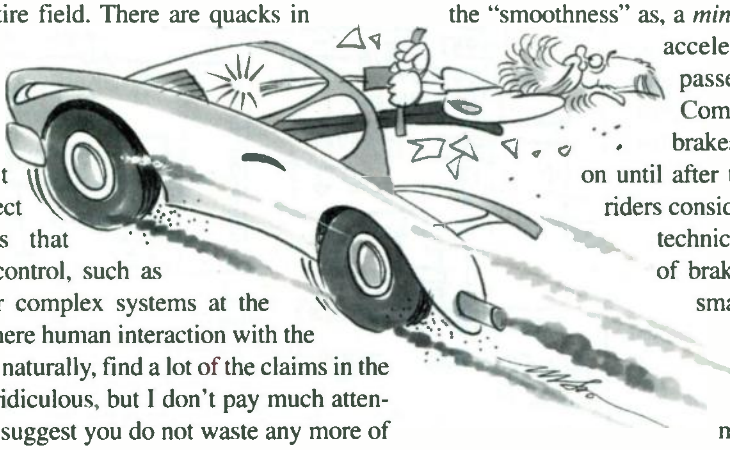
READER SERVICE 112



What's All This Acceleration Stuff, Anyhow?

A while back, I got a letter from a Scientist at a major U.S. electronics corporation: "Dear Mr. Pease, I read, with equal degrees of amusement and irritation, your articles on Fuzzy Logic in the May 13 and Nov. 1, 1993 issues of Electronic Design. You threw out a challenge to the world at large to show you a *real* application of Fuzzy Logic. So here it is, the Sendai and now, Tokyo, subway controller using fuzzy logic (technical paper by S. Yasunobu & S. Miyamoto, 1985). These are real, actual working systems that thousands of people ride on everyday. The enclosed paper, though dated, provides some technical details on the system.

'You have adopted the somewhat silly approach of taking what the lunatic fringe of Fuzzy Logic say, and using that to brand the entire field. There are quacks in every field.



'I have worked for quite a few years in the field, and have found it useful in either direct control of systems that don't need precise control, such as dishwashers, etc., or complex systems at the supervisory level, where human interaction with the system is required. I, naturally, find a lot of the claims in the trade journals quite ridiculous, but I don't pay much attention to them either. I suggest you do not waste any more of your time reading press reports on Fuzzy Logic, but instead attend a serious technical conference such as the IEEE Fuzzy Logic Conference, or just go to Japan and take a ride on the Sendai subway. Regards, V. B."

I looked at the paper by Seiji Yasunobu and Shoji Miyamoto of Hitachi, published in the *Industrial Applications of Fuzzy Control*, (Elsevier, Holland, 1985). I spotted some simulated curves where the authors thought it was a great idea for the train to start out at full acceleration, without first coming up gradually through moderate acceleration. Then, after accelerating up to the outrageous speed of 40 mph (top speed), the authors thought it was a great idea for the F.L. controller to CHOP power and just let it coast. After a while, it was time to STOP, so the fuzzy controller put on the brakes pretty hard and came to a hard stop at about 0.12 G. The brakes were just left on hard, all the way to zero speed. THIS causes a lot of JERK (da/dt). Why did these engineers brag about the smoothness of the Sendai subway when the acceleration, cut-off of acceleration, and final braking were causing severe JERK?

My conclusions are simple:

(1) Originally the authors defined the figure of merit for the "smoothness" as, a *minimum number of changes* of acceleration. Unfortunately, the passengers weren't consulted! Coming into the station with the brakes on hard and leaving them on until after the train stops is NOT what riders consider comfortable, even though technically the *number* of changes of brake setting (brake notch) was small. I tried driving this morning with my brakes held constant all the way down to a stop, and my wife asked me, "Why are you driving like a madman?" I explained I was just driving "smoothly," using a F.L. guy's definition of "smoothly."

(2) This paper just presents the engineers' INITIAL proposals. The computer said the system was great. But when real tests were made, the JERK was found unacceptable. So the engineers obviously had to go back and do it right. I'm sure they did some very good engineering, adding S-curves for acceleration and braking, so the braking is feathered off

as the stop is approached. And I have no doubt that the Sendai train, as it's now operating, is very smooth indeed.

The basic problem is NOT that it took the Japanese engineers a few tries to get it right. The problem is that all of the wonderful advantages of the Fuzzy Control system—faster station-to-station time, smoother ride, 10% less power needed (more on this later), more precise stopping accuracy—were ALL based on the computer simulations in this 1985 paper, which would have jerked badly (a jerk of 1 G per second for 1/14 second seems pretty lurchy).

I searched to find out if any more technical information on the Sendai train is available, representing operation of the trains AFTER the subway was put into service—not just computer simulations. And I inquired with the people who engineer these train systems, at Hitachi, and they said there weren't any other papers published subsequently.

I'll try to set up a comparison with Bay Area Rapid Transit (BART), which accelerates pretty smoothly these days. Does BART use F.L.? No, John Slama at BART says they do not. So I explained to Mr. B., the letter writer, "If Japanese trains actually ran the way that technical paper said, half of the people in Tokyo would just fall down from the JERK (*da/dt*), and the other half would fall down from laughing."

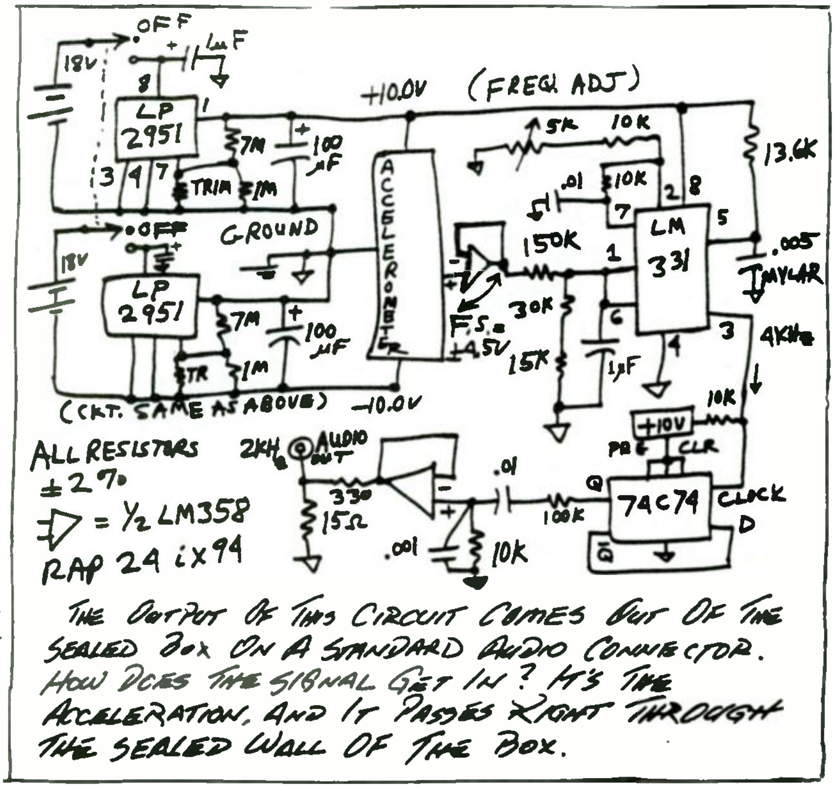
The Hitachi engineers are quite correct when they observe that in any vehicle-control system, you can make a trade-off (or compromise) between fastest run time, *or* lowest power usage. However, all things being equal, any train that adds smooth S-curves in its acceleration/deceleration, for greater smoothness and comfort, will inherently take *more* time to run from one station to another, compared to a train with high JERK. If you still want to maintain a fast schedule, *then* you have to run at a higher top speed, which will take more energy. This is true for any controller, whether it uses Fuzzy Logic or not.

If the Sendai train runs smoother, then it will have to be either SLOWER, or waste MORE ENERGY, or have BOTH those disadvantages—NOT both ADVANTAGES—compared to a system that accelerates sharply and has more jerk. It's IMPOSSIBLE for Sendai's F.L. controller to have all of those advantages claimed for it back in 1985.

Now that I had rebutted the Fuzzy claims—I had to go out and design a recording accelerometer. I asked several friends, and Jim Williams gave me an accelerometer, Model DE-14440, from Columbia Research Laboratory, Woodlyn, Pa.; (215) 872-3900. He had picked up five of them at the electronics flea market for $10. It was easy to calibrate at ±1 G = ±4.5 V. I built it up with a little V-to-F converter, as shown in the figure. I scaled it so –1 G would give 1 kHz, 0 G of acceleration would give 2 kHz, and +1 G would give 3 kHz. This made it easy to calibrate by turning the box on its ends. You can also pull the jack out of the tape recorder's mike input, and add voice along with the data, such as, "Just arrived at Shinjuku station."

Then I built an F-to-V converter, similar to the one I described in the July 8, 1993 issue (p.81), to convert the tape-recorded data back to a voltage that represents acceleration. I followed that with filters and a differentiator to compute the JERK. (I could also have added an integrator to integrate the acceleration to speed, and another integrator to indicate distance, but I decided that wasn't really essential information.) I ran this audio signal into a small tape recorder (actually, my camcorder gives much better WOW and stability).

So far, I've gotten pretty good data from this on various vehicles, including BART trains, San Francisco Municipal Railway trains, on my VWs, and on a Mustang. Because I've accumulated enough data, I'm about ready to send the



accelerometer to a friend in Japan.

I wish I could recommend the Columbia accelerometer. Unfortunately, the price on a new one is about $960. So, if you have to work in this field, you may want to check out the $60 ADXL50 from Analog Devices, Norwood, Mass.; (617) 329-4700 (see *Electronic Design Analog Applications Supplement,* June 27, 1994, pp. 54-56).

Likewise, I won't say that the Fuzzy Logic controllers in these Japanese trains don't represent good, perhaps excellent engineering. But everybody attributes miraculous advantages to Fuzzy Logic based on those imperfect computer simulations of 1985. If we could just cut out the hype, we could evaluate Fuzzy Logic's advantages on the basis of facts, not wishful thinking.

Will the Sendai train be smoother than BART? Or, vice versa? Note, just because one has less JERK than the other doesn't necessarily mean it's better. You have to have a certain amount of JERK, or it will take FOREVER to get your train up to speed.

My pet theory says you'd want to get started with a constant amount of JERK, which means the acceleration will RAMP up smoothly from zero to its maximum value. If you start *ramping* the JERK, it's going to take a long time to get up to speed. Maybe about a 1-second taper on the JERK would be OK.

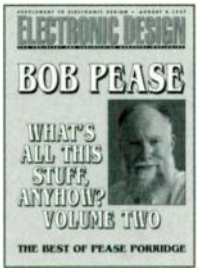
But, if you want to meet a schedule, every second spent dawdling along at 0.02 G will either make you fall behind schedule or require you to accelerate up to a much higher top speed compared to a system with more JERK. In other words, I'd accelerate as if I were driving my elderly aunt around town, with low jerk but plenty of acceleration.

I've heard that most of the trains in Japan run very smoothly, but a few older ones still have a harsh ride with heavy acceleration and jerk. Maybe I'll be able to get a recording of their acceleration profiles before they're gone.

Comments invited! / RAP
Robert A. Pease / Engineer

Originally published in
Electronic Design, November 7, 1994

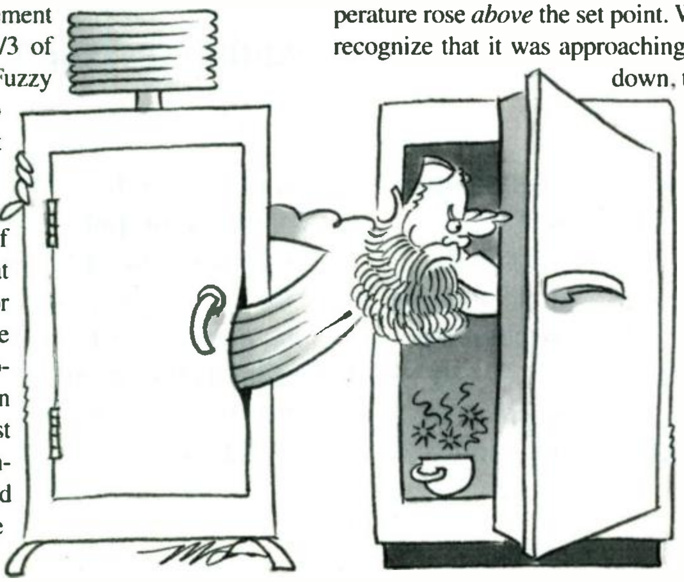
RAP's 1997 comments: I put good data into my camcorder, but when it came out, it was rough and ragged. If you put in *square waves*, I know that makes the time-base grouchy. So I put in triangle waves, and the time-scales of the signals coming out were still rough and ragged. So the outputs of the FVC were jumpy and lurchy. I'm not sure why. Because the camcorder does have a crystal-controlled time base. One of these days I'll try again. I'd like to get it working right.--*rap*



What's All This Refrigerator Stuff, Anyhow?

I plan to write about four refrigerators and an icebox; let's see what happens.... About a year ago, the radio said that Whirlpool had won the $30 million contest for an Efficient Refrigerator. "They used Fuzzy Logic to improve the compressor, and the efficiency was improved by a factor of 3." Wow! How did they do that? A few months later, I read in *Machine Design* that Whirlpool's machine was 29% more efficient than the 1993 Federal standards. Well, that's not 3:1, but it's still quite an improvement.

I later read in *Popular Science* that the basic old refrigerator design was *already* 20% better than the Federal specs, so they only had to make an additional 9% improvement to win the contest. Well, an improvement from –20% to –29% is a relative improvement of about 11%. And about 1/3 of this was attributed to the Fuzzy Logic, which was *not* used to improve the compressor, but only to set the best time for the defrost cycle.



Then Mr. R. Shattuck of Gillette, Pa., suggested that you can connect the wiring for the defrost timer over to the *switched* side of the thermostat. This is an old refrigeration engineer's trick, so the defrost timer only runs when the compressor is running. If it's a cold day and nobody opens the refrigerator's door, then the time between defrost cycles is extended. If it's hot and the kids are opening the door a lot, the compressor will run a lot, and the time between defrost cycles will decrease. This may provide as much gain in efficiency as is claimed by Fuzzy Logic. The alleged advantages of F.L. are kind of Fuzzy when you compare it to this old trick.

Now, I was still looking for a case that had a really serious debate between a good F.L. system and a good "conventional" system. A friend sent me a data sheet on a Fuzzy-Logic-based oven controller made by Space Industries in Texas. It claimed to provide a 10X advantage—0.3° C accuracy vs. 3° C for the "conventional" oven controller.

But I saw some data showing that this controller didn't just approach the set point and then slow down and stop. It kept cooling long after the oven temperature fell *below* the set point, and it kept the heater turned on long after the temperature rose *above* the set point. Why didn't this controller recognize that it was approaching the set point, then slow down, turn off the heat, and settle promptly? An engineer at this company said that if the mass of the oven was nominal, the overshoot was negligible. But I observed that the data sheet for this oven said that it was rated at full accuracy with large or small thermal mass. This controller appeared to ring and oscillate for *hours* at any light amount of mass.

I volunteered to help redesign this oven controller, because I know how to make a good controller for a simple case like this. I volunteered to do this with an analog controller (a quad op amp), *or* a digital controller, *or* a Fuzzy controller. The company

responded that since the controller met specs, they had no interest in further improvements. I knew I could make some serious improvements, because the Fuzzy controller responded only to the temperature error and that error's rate of change. Thus, it was like a *P-D* controller—*Proportional* and *Derivative* terms. I knew how to make a *PID* controller, which added an *Integral* term. By adding an integrating term to increase the gain for long-term errors, I could cut back on the Proportional Gain and improve the damping a lot. (If you don't have any Integral Term, it forces you to turn up the proportional gain to get good accuracy, which causes the ringing.) In fact, I bet I could meet 0.03° C....

Well, the engineer at this company decided he didn't want to be helped. That reminds me of the old lady who had to be helped across the street by five Boy Scouts because she did not *want* to cross the street.

I studied this some more. Some people—even guys at USC—claim that there's an inordinate number of Fuzzy Rules you have to write in Fuzzy Logic if you advance from 2 dimensions to 3 or 4 variables. If you want to write 7 rules for each dimension, then you'd have to increase the number of rules you write from 49 to 343 to 2401. Wow, that's a heavy load. I mean, the Fuzzy Logic enthusiasts always say it's fun and easy to write the rules for Fuzzy Logic. Oh, yeah, but it gets tedious when you have to write 300 rules, and when you have to write 2400, that really gets to be hard work. So most Fuzzy engineers decide that they don't have to use 3 variables—they can get perfectly fine results with 2 variables (they may be wrong....).

Well, there's no real reason that you have to write 7 rules in any one dimension, for any one parameter. So, maybe you can write $3 \times 2 \times 3$ rules, rather than $7 \times 7 \times 7$. Now, you might not be able to do this if the system is heavily nonlinear. You might have to write $7 \times 3 \times 2$ rules, which still isn't more than 49. SO, a person could write the rules for a fairly linear PID F.L. controller and still not run out of ink. (Note, you might want to avoid getting into a hissing contest with a guy who buys his ink by the barrel.) So, the "explosion of rules" may turn out to be no big deal. And a Fuzzy PID controller can be easy and effective to accomplish—and can perform lots of tasks much better than a simple PD type.

One of the rules I saw for a heater written in Fuzzy Logic went: "If the temperature in the chamber is very cold, turn on the heat very high." My comment on this is: How many of you guys ever owned a VW, Beetle or Bus? I have put on over 10^6 miles in VW Buses and Beetles, and I know darn well: "If the temperature in the chamber is very cold, you turn on the heat very high." Of course, you can turn up the heat in one of these old VWs all the way, and even at full throttle, the heater doesn't kick out enough heat to keep you warm when it's below zero outside. Is that a refrigerator? Or is it just an icebox?

It's not the fault of the controller, it's the fault of the heater's capacity. BUT, even if the heater does have enough heating capacity at +40° F outside, you could only get the heat to turn on to full heat when the inside temperature had already gotten too cold, if you used that Fuzzy rule.

Then you could never get the controller to give good results. The weakness there is, if you trust the conventional way that rules are written for F.L., most engineers don't understand the limitations of PD controllers, and they don't understand the advantages of PID, but they think they can beat the game. They might be wrong. (I don't mind the weak heater in my '68 Beetle, because I make sure to bring along plenty of warm clothes for cold-weather travel.)

Recently, we got a letter from an engineer asking, if he buys a "Greenplug," can he use this NASA-based technology to save on energy running his refrigerator? I got several letters from readers. One of them pointed out that the "Greenplug" does NOT use the old NASA technology, but is just a switch-mode voltage regulator. If the line voltage at your house is typically 124 V, you might save some energy. But if your line is at 106 V, you may not save anything.

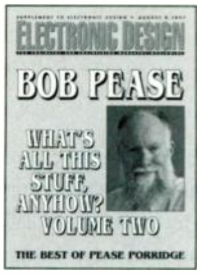
Another guy sent in the results of Consumer Reports' testing which revealed that on old refrigerators you could save a *few* percent, but on a newer refrigerator, you might not save any electricity at all—or, you might get *less* efficiency than without. Then someone else said his Greenplug had failed, and he found out only after several days when the contents of his warm freezer let him know. (Send me a SASE for the schematic of an updated low-power detector/alarm for freezer failure.)

Other people sent in glowing claims for other "economizer" controllers that would save energy "by not letting the refrigerator's motor get too much voltage or too much current." BUT then I began to see a scary problem: If a refrigerator is running, and power is lost for a few seconds and then restored, the compressor can usually start, even against the back pressure. But if the line voltage is low, and the line's impedance is soft, the compressor may stall. It might even blow a fuse, or blow out the "economizer." And this is all compounded by the fact that the "economizer" is *trying* to provide a soft startup voltage and a small startup current.

If you want to buy an "economizer" for *your* refrigerator, make sure that the "economizer" is approved by the manufacturer of your refrigerator. They would be best qualified to certify that restart under low-line conditions won't cause stalls or damage.

Finally, I must say that I smile every time I hear about

(Continued—See "Refrigerator" on page 64)

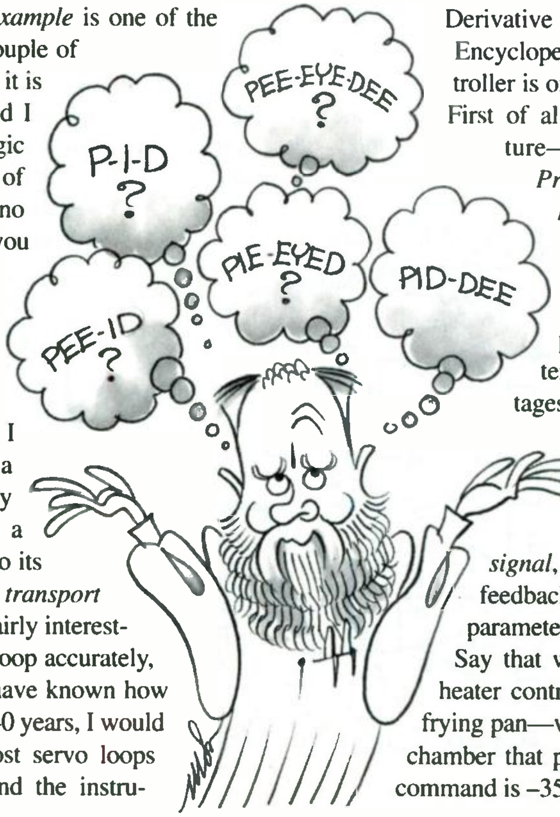


What's All This P-I-D Stuff, Anyhow?

Recently, I wrote about refrigerators,[1] pointing out that there are several ways to control a servo loop, such as a temperature chamber, or an oven, or a refrigerator using thermoelectric coolers (let's leave bang-bang controllers and on-off heat-movers out of this). Fuzzy Logic controllers can work pretty well, and so can a P-I-D (or PID) controller. That's pronounced "pee-eye-dee," not "pid." Several readers said that they were not very knowledgeable about PID controllers. They don't teach very much about them in schools these days, I guess. They asked me, "Please show us a good example of a PID controller." Well, I agree completely that an *example* is one of the most powerful tools. I'll show a couple of examples, so you can see how easy it is to come up with one yourself. And I will point out that, after a Fuzzy Logic expert showed us his best example of a nice simple F.L. controller, I had no idea how to make it myself. Do you know how to run a F.L. controller after seeing an example of one? I don't. I hope that would not be true for my examples.

One example is found in my book on Troubleshooting,[2] where I had to control the temperature of a blast of heated air. When you apply more watts to the heater, there's a delay before the sensor warms up to its new temperature. In fact, there are *transport delays* and *thermal lags*. This is a fairly interesting kind of system for closing the loop accurately, but not really difficult. Engineers have known how to do this for many years—about 140 years, I would say. Back in the 1880s, when most servo loops were mechanical or pneumatic, and the instrumentation was crude, it was a wise person who understood how to close a loop with it good accuracy and loop stability. But for the last 40 years, when a good operational amplifier costs $22 or even less, it's been a piece of cake.

Note, a wise old colleague observed that the introduction of the Integral term to Control Theory is credited to the 1930s. But I found good documentation in my Encyclopedia Britannica[3] that a flyball governor with an *added* integral term was invented by Sir W. Siemens in 1853.[4] Never bet that the British didn't get there first. However, I can't say that I've seen the Derivative effect exploited in that 1894 Encyclopedia. So maybe the PID controller is only about 60 years old....



First of all, let's discuss the nomenclature—"PID." That stands for *Proportional*, and *Integral*, and *Derivative*. You can build some controllers using only P and I, and others using only P and D, but when you need good performance, using all three terms can provide REAL advantages. Let's see how these terms are made, and how they are used.

First, these functions are used to operate on the *error signal*, the difference between the feedback parameter and the desired parameter. Let's spell out an example. Say that we want to define a precision heater controller—perhaps for an electric frying pan—with a sensor for the controlled chamber that puts out 10 mV/°C. The input command is –350 mV (which corresponds to a desired temperature or "set point" of +35°C), the output of the temperature sensor is +250 mV (which corresponds to a temperature of 25°C), and the load must be heated to get the feedback voltage to track (equal but with opposite sign). What's needed, then, is a circuit to operate on the error, namely (V_{out} + V_{in}), or –0.1 V. Op amp A1 does just that (*Fig. 1*). (Let's keep things simple by considering primarily linear systems; if the system actually has some nonlinearities, we can address them later.)

After we generate that error term, you will want to generate a correction signal that's a function of the Error Signal. As I discussed back in December, you might design your system so that a heater has its watts linearly Proportional to the temperature error. "If chamber temperature is very cold, turn heat up high" is how the Fuzzy Logic guys like to say this. This is partly wise, because if the temperature really is too cold, turning on the heat is one of the good things to do. That is the *Proportional* term.

Referring to Figure, we follow the error-detector amplifier A1 with a Proportional amplifier A2. We can control the gain of the Proportional path by adjusting the pot P2 at its output, so as to get the right gain going to the power amplifier A5. Eventually, we will figure out what to do with A3 and A4, but right now we can set their trim pots to ZERO, and then they're out of the picture. Let's keep things simple, one step at a time.

Now, let's say you pour a bucket of very cold water into this electric frying pan, where the controller is set for +35°C. The sensor soon says it's much too cold, so the heater turns on pretty hard. As the temperature of the sensor gets near the desired temperature—the *set point*—the heater will eventually be turned off. The problem is that any heater has a delay before its heat gets to the chamber and load and sensor. So, when the error gets to zero, and you turn off power to the heater, the chamber still keeps on heating for a while and overshoot occurs. If you turn the gain down low, this overshoot may be minor. But if you decide that you must have very high accuracy and turn up the gain, overshoot is certain, and oscillation or bad ringing is likely.

Now, how can we avoid this overshoot by foreseeing this situation and recognizing that the power needs to be shut down a little early? The best solution is to add in A3 to compute the Derivative of the temperature error—the rate of change—while the Proportional amplifier is computing when the error becomes small. When these two signals are combined properly, the Derivative signal lets the controller decide, "Whoa, we are getting very close to the set point, *and* the sensor's temperature is still rising pretty rapidly—time to cut back on the power." In practice, this works quite well. This is called P-D control, using just A2 and A3 for the Proportional and Derivative terms. You trim P3 to the setting that gives good results—not too much overshoot (not enough derivative) and not too slow (too much derivative term). The Fuzzy Logic guys achieve this same function by using the words: "If the temperature error is small (negative) and the rate-of-change is small (positive), heating power should be small." This works, too.

In theory, you can make a differentiator—a rate-of-change computer—by taking op amp A3 and just connecting an input capacitor C_{in} and a feedback resistor R_f. But in practice, with real op-amps, this will cause a local oscillation of the amplifier, due to the lag in the feedback loop. The fix is fairly simple—for most cases, to prevent local oscillations, add a small resistor R_{111} in series with C_{in}, and add a small capacitor (C_f) in parallel with R_f. In practice, if you make R_{111} about 1/10 or 1/100 of R_f, and C_f about 1/20 or 1/200 of C_{in}, that works pretty well. In other cases, it may be a bit more critical which value you choose, either to prevent local oscillation or avoid degradation of loop stability.

The P-D controller is quite good for many servo control applications. To a large extent, many Fuzzy Logic controllers are quite analogous to a P-D loop, and often they work well. NOW let me invent a case where the P-D controller (and the simple F.L. controller) begins to work *lousy* (that's a technical term). Let's take this +35°C controller

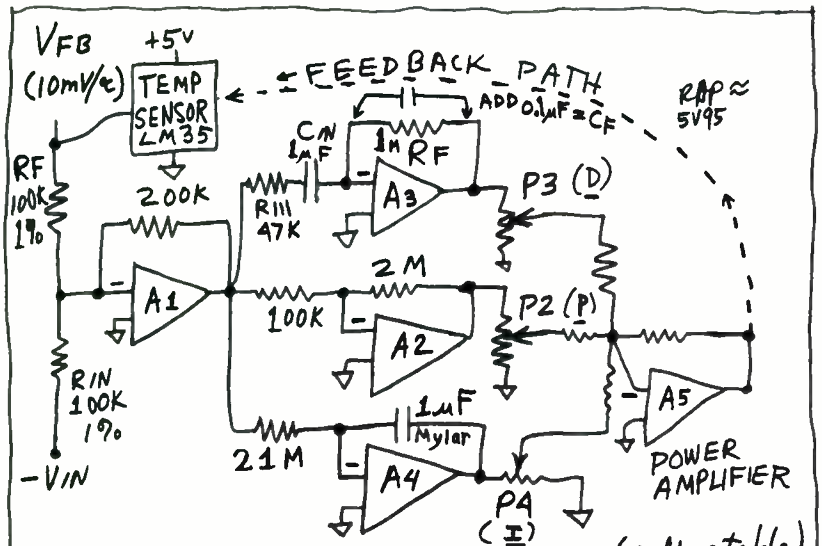


FIGURE 1. BASIC P-I-D Controller (Adjustable)

REDUNDANT POWER

REDUNDANT POWER

MP1350 Series

- -48V/25A
- +24V/50A
- 110/220VAC Input
- 5.25" (3U) Height

MP3600 Series

- -48V/65A
- +24V/125A
- 220VAC Input
- 7" (4U) Height
- 16" Depth
- DC-DC Models

MP Series Features

- Power Factor Correction
- Active Current Sharing
- Hot Bus Plug-In
- Monitoring and Alarms
- Optional Metering
- Racking Systems
- Standard Products
- Tailored Solutions

MODULAR POWER SYSTEMS

36 Newburgh Road
Hackettstown, NJ 07840
Phone: 908-850-5088
www.transdev.com
info@mailer.transdev.com
Fax: 908-850-1607

A Division of Transistor Devices, Inc.

CERTIFIED ISO 9001 QUALITY SYSTEM

outside on a cold day. The water stays warm for a while, but the air starts to cool it off. After a while, the Proportional path turns up the heater. But there's still an error—*always* an error. If the fry-pan needs 50 W to keep the water at about 35°C, then the error will be 50 W divided by the gain.

To avoid a large error, it's natural to just turn up the gain—which is what some people propose to do. But when you turn up the gain, the loop stability is hurt. How badly? Ahhhh, that is hard to predict—hard to model. The reason is that the thermal transfer from the heater to the water and the sensor isn't a simple model. It's not a simple lag. The transfer might be similar to a cascade of 5 or 10 lags, so that a step of heat causes a slow change of the sensor temperature. It's *possible* to do this in a computer—or within SPICE—but it's not really easy. Furthermore, you basically have to measure some real response of the system. You can guess, but it's not really easy. Anyhow, if you take enough data and generate an accurate-enough model, you can show that you can turn up the Proportional Gain a certain amount. But, if you go any higher your loop will oscillate, or ring severely. Let's say that you can only set the Proportional gain as high as 50 W/5°C, without oscillation. Your need is for less than 1°C of error. But there remains about 5°.

FIRSTLY, you might add as much insulation as you can to cut down the amounts of watts needed. But let's say there is *still* more than 2° of error. What can we do?

One alternative (secondly) is to sense the outside temperature. We could then use that to *predict* that 20 or 40 W of power will be needed. We could add that information into the controller—which does work at times, sometimes very well. This is known as *feedforward.*

Another thing we could do (thirdly) is add not just extra insulation, but a heated shell around the experiment—perhaps at 30°C. That could greatly improve the accuracy, but often this amount of complexity is unacceptable.

Okay, the fourth option—and a fairly popular and inexpensive one—is to look at that error signal (the output of A1), and if there's any dc error, just INTEGRATE that signal using A4. Then feed that output through its adjustment pot (P4) and sum it with the other signals. This beats the conundrum: to get full accuracy in view of the rule, "You can only turn on the heat high when the error signal is large." In this case, you can turn on the heat high even if the error signal is NOT large—but you may have to wait a while for the integrator to do its job. Why not just turn up the GAIN for the Integrator? You can do that to some extent. If you overdo it, that makes the loop unstable. So don't overdo it.

The best thing about using the Integrator is that it lets you turn down the gain of the Proportional amplifier. If you turned up the Proportional gain too high to try to cut down the error, that will cause instability as I mentioned earlier. When you have the integrator working, you can turn down the Proportional Gain and improve the loop stability a LOT, yet still have infinite gain at dc. You can have ZERO static error.

But, don't turn the Proportional Gain down TOO FAR. If you did that, the I and D terms would act like an L-C filter with no damping. So if you turn P2 down to zero, that's sure to cause oscillation, too. Now that you have the Integral path working, the gain setting for the Proportional term acts as a DAMPING FACTOR to prevent the loop from ringing. As you can imagine, the optimization of such a loop isn't trivial. Also, in many cases, these loops may be slow, so it's hard to see if any changes you're making are doing more good than harm.

•Hint 1: Use a slow strip-chart recorder so that you can see the shape of the loop's step response, and if you're making any improvements. Or use a storage scope. Or a Rustrak meter.

•Hint 2: Take a little open-loop data to show the delay from a step of heat to a change of output temperature. Build up a cascaded R-C network to simulate that slow lag (*Fig. 2*). Then change the lag's response by a factor of 100 by decreasing all of the capacitors by a factor of 100. *Then* design your controller to make that loop stable at a speed that's easy to observe. Then scale that controller 100:1 slower, and you're fairly close to having a controller that will work. This is one form of Analog Computer.

•Hint 3: If the system changes—if the amount of water in the fry-pan decreases—you will probably need to change the coefficients of your system. You could turn those pots, or you could use multiplying DACs in place of P2, P3, and P4, to get the coefficients you want. Not trivial—because the system won't do it for you—you have to tell it what you want. But, this IS feasible.

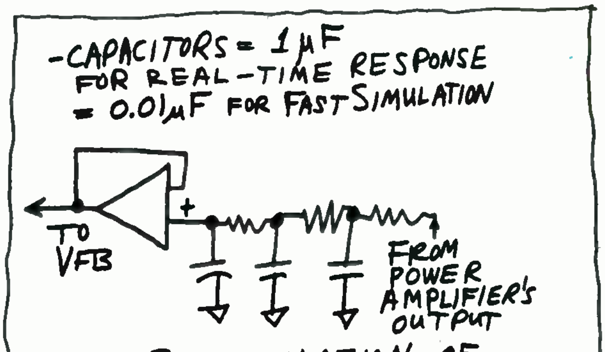


FIGURE 2. SIMULATION OF LAGS FOR LOOP STABILITY ANALYSIS

•Hint 4: This circuit won't work well at all with general-purpose op amps. An LM741 at A3 or A4 would cause HORRIBLE errors, because the resistors in the differentiator and in the integrator will be quite high—perhaps 2 or 5 MΩ —forcing you to get op amps with low bias currents. But, fortunately, good op amps with low input current (50 pA or 0.05 pA) aren't expensive these days.

•Hint 5: When you have all of this worked out and optimized pretty well, you can do the whole thing with one op amp—you may not need five amplifiers. In Figure 3, op amp A6 does the whole thing. Of course, you don't have the flexibility of three independent controls, but in many cases you don't need that. In this case, the output of A6 is a summation of the Derivative and the Integral terms, with a Proportional (damping factor) term also included.

Can Fuzzy Logic likewise take advantage of an Integrator to convert from PD to PID? Yes, and pretty easily, if you figure out the right trick. Of course, if the system is REALLY nonlinear, or a nonlinear controller is really needed, then nothing is simple, and you might have to write 125 or 343 rules. Still, a small Integral term could let you effectively turn down the "gain" of the Proportional path and greatly improve the dc accuracy AND the loop stability. Of course, this doesn't mean that you can easily get fast settling under difficult conditions, such as "we have no idea how much water is in the pan." But there's still a definite opportunity for improvement by adding in the integrator.[5]

As I mentioned in '93, F.L. does not, by itself, compute a derivative. So if you want a derivative term, you have to generate a derivative and digitize it, then present it to the F.L. controller: OR, you digitize the proportional signal and take a DIFFERENCE every few seconds, then present THAT as a derivative signal to the F.L. controller: So, in exactly the same way, the F.L. controller can't generate an integral. But, you can program a subroutine to compute the integral of the Error Signal and present it to the F.L. OR, you could compute the Integral term and just ADD it to the Proportional term, and then process that total without any fanfare. If the system is fairly linear, nobody will ever know that you cheated, and it will probably work perfectly. You may not have to write 343 rules—maybe 25 or 49 will work just fine!

So, if you have a few bucks worth of op amps and a little time, you can make a pretty darned good controller: Much better than a bang-bang controller. When I came to NSC back in '76, I found several Applications Notes where we had recommended a temperature controller. But either the controller had finite gain (i.e., poor *low* gain) or else ran bang-bang, with various kinds of noise and inaccuracy—and bad error!! In my App notes. I recommend that a proportional controller with stability enhanced by the PID terms, can be fairly simple and effective.

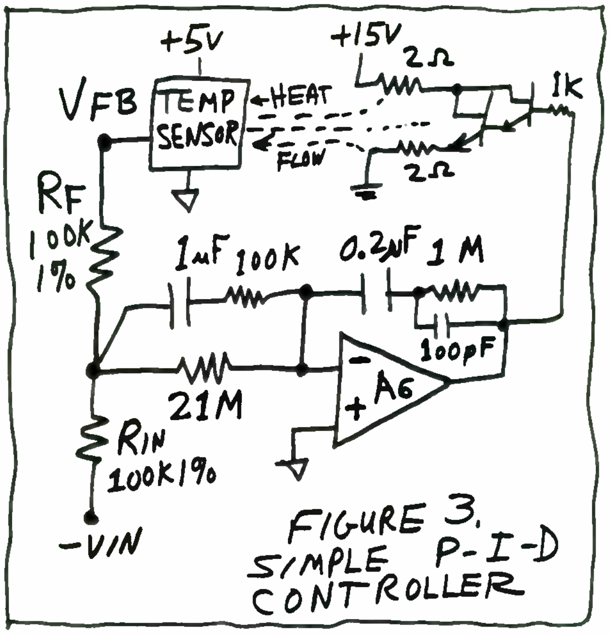


FIGURE 3. SIMPLE P-I-D CONTROLLER

OF COURSE, if the delay from the heat to the sensor is *just too slow*, that makes everything much harder. Locating the sensor where it gets a prompt response to the heat can help a lot. Also, you may get better results from having two sensors. The one that drives the Differentiator may be located very close to the heater as an aid to stability. But the one that drives the integrator may live in the "sweet spot"—the exact place where highest precision is needed. If there's an extra lag there, that will certainly make the loop difficult to engineer.

Then the other tricks mentioned above—the feedforward path and the oven-within-the-oven—may be justifiable. In all of the cases where transport delays occur, system design can be very challenging. But it needn't be considered impossible or even very difficult. And it's usually not a situation where Fuzzy Logic has any inherent advantages. In fact, PID usually has advantages over a Fuzzy Logic controller if that controller tries to do without any Integral term.

Comments invited! / RAP
Robert A. Pease / Engineer

P.S. If you have a heater—such as a gas furnace—you do not want to be turning it ON and OFF every few seconds because you would wear it out. The same is true for an electromechanical refrigerator. But if you have a thermoelectric cooler, you can turn that ON to any desired extent by driving the number of amperes the loop calls for. The same thing applies with dc resistive heaters, but

NEW!

BIG POWER 10 WATTS

small price.

FEATURES

- 2:1 Input Voltage Ranges
- Single and Dual Outputs
- Extended Temperature Range
- Industry Standard Pinouts
- Industry Standard Package
- Low Profile 0.4 Inch
- Short Circuit Protection
- Temperature Shutdown
- Remote ON/OFF (Optional)
- Metal Case for Reduced EMI

The WPC10R is a family of high performance DC/DC converters that offer regulated outputs over three input voltage ranges of 9 to 18V, 18 to 36V, and 34 to 75V. This converter family features no power derating over a wide operating temperature range of -25°C to +71°C.

This series features EN 60950 approval and will meet the requirements of 1) EN 41003, 2) EN 55022A for radiated and conducted noise levels (level B with external filter) and 3) IEC 801X.

ISO9001 CERTIFIED

POWER CONVERTIBLES™

Tucson, Arizona • 520-628-8292 • FAX 520-770-9369 • e-mail: sales@pcc1.com
Data sheets are available through our DATAFAX system @ 520-628-8691

Internet: www.pcc1.com

BEWARE—the amount of heat is normally proportional to the SQUARE of the current. If you use the power transistor AND the resistor as heaters, the total watts is about linearly proportional to the current, but you have to be careful where you locate the transistor (a small source) compared to the power resistor, which often is made of wire wrapped all around the temperature chamber. The management of thermal flow is a very important and tricky subject; I can't give any easy answers—you really have to study it.

Modulating or controlling a high-power heater, such as a kilowatt of 115-V line power, sounds like it would be much harder, but actually it's easy. You can drive a power Triac using a MOC3030 (zero-crossing firing circuit) and add a dither circuit to ensure that the average heating of the power resistor is linearly proportional to the duty cycle. In my book, I showed a 17-Hz dither that turned the Triac ON and OFF about 17 times per second. Averaged over the internal time constant of the heater, you can hardly see any noise, and the duty cycle is very well controlled without much heating in the control circuit. (You certainly don't want to control a kilowatt of resistive heat with a linear amplifier.)

References:

1. "What's All This Refrigerator Stuff, Anyhow?," *Electronic Design*, Dec. 19, 1994, p. 122.

2. *Troubleshooting Analog Circuits*, Robert A. Pease, 1991, p. 109. Butterworth-Heinemann. Available from the author for $31.95 (inc. tax and mailing).

3. *Encyclopaedia Britannica*, London, 1894, Vol. XXII, "The Steam Engine," pp. 508-509.

4. "A Differential Governor," Sir W. Siemens, *Proceedings of the Royal Institute of Mechanical Engineering*, 1853.

5. "The Basics of PID on the NLX220," by Adaptive Logic, Address: 800 Charcot Ave., Suite 112, San Jose, CA 95131. This arrived recently and shows easy techniques to get full PID control with F.L. Ask for info at (408) 383-7200.

Originally published in
Electronic Design, June 26, 1995

RAP's 1997 comments: THIS is not just about PID. THIS is not just about Analog Computers. THIS is not just about Op-Amps. THIS is not just about Fuzzy Logic. This is about THE REAL WORLD. The whole world. If you ask for something, and you get it, are you happy? If not, why not? I have seen some F.L. scientists who were wise enough to agree that they could make do with a LOT LESS than 343 rules, by adding the I term or the D term to the P term. Of course, this works best when there is not much nonlinearity. And when there is not much nonlinearity, F.L. does not have much advantage over PID controllers.

Minor correction on the circuit referenced in my book: on page 109, I show a good circuit with a "17 Hz triangle wave." The main function of the triangle wave is so you can see the LED blinking, and guess when the loop is pegged, or whether the duty cycle is high or low. I built another copy of this, recently. The LED did not seem to blink right. I checked, and the frequency was 170 Hz. So please mark up that schematic, to change the capacitor that is connected to "17 Hz" from 0.01 μF to 0.1 μF, so you would see the right kind of blinking. This is the only *error* I have found in my book. I think we can get the 1998 printing to have the correct C value.—*rap*

"Stop Noise Two Ways"

Most people know that a pacifier will stop noise, sometimes very quickly, other times it takes a little longer. The method, however, works. Add a little sweetness and it works even faster. And for certain applications the pacifiers come in different shapes and sizes.

Conec Filter Connectors stop noise as well. Noise created by EMI/RFI in today's high speed digital systems. And just like pacifiers, Conec Filter Connectors come in different configurations - industry standard d-sub, high density d-sub, filltered adapters, modular jacks and combo d-sub, with power filtering and signal filtering. We don't add any sweeteners. What we do add is our patented planar filters. The technology with a proven track record, combined with the industry's best connectors—ours. Both technologies fully integrated, for best results in filtering.

Contact us today and put a little sweetness in your life. You can find us at our website:
http://www.conec.com, or
e-mail 24926@ican.net

CONEC

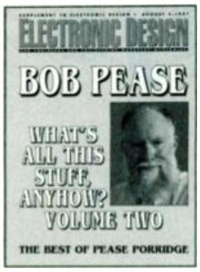
"TECHNOLOGY IN CONNECTORS"

72 Devon Rd., Unit 1, Brampton, Ontario Canada L6T 5B4
Tel: 905-790-2200 • Fax: 905-790-2201

CONEC QUALITY
"PEACE OF MIND"

• ISO 9001 CERTIFIED •

READER SERVICE 95



What's All This Frequency-To-Voltage Converter Stuff, Anyhow?

Once upon a time—my gosh, it was 30 years ago—a guy asked me if I could show him how to make a Frequency-to-Voltage converter (FVC). Well, at that time, at George A. Philbrick Researches, we knew a lot about analog computers and we figured we could convert almost any signal to any other form or mode. So I designed a charge-dispenser made of a voltage limiter, a capacitor, and diodes. I built it up, and it worked pretty well.

And in 1964 we put this into the old Philbrick Applications Manual.[1] (*Fig. 1*).

The first amplifier has a limited output voltage. The p-p voltage across the capacitor is pretty well established:

$$V_{p\text{-}p} = 2V_z + 2V_d - 2V_d$$

So, the charge ($Q = C \times V_{p\text{-}p}$) flows through the feedback resistor of the second amplifier. The output voltage will be, on the average:

$$V_{out} = R_f \times C \times V_{p\text{-}p} \times f$$

A few years later, we got into the Voltage-to-Frequency Converter (VFC) business. At the same time, I came up with an improved circuit for an FVC (*Fig. 2*). The input comparator is set up to accommodate TTL signals, but if you put a resistor from the + input to −15 V, you can accommodate symmetrical signals; a resistor from the + input to ground will cut down the hysteresis and let you handle small signals.

But the real improvement in this FVC is the bleeder resistor, the 3.3 MΩ added to the right end of the capacitor. If you want a charge dispenser to dispense a constant amount of charge, no matter what the rep rate of the pulses, you can't let the voltage at the right end of the capacitor just sit there unattended. That's because it will be charged (through the nonlinear impedance of the diodes) to a different voltage, depending on how long you wait. The 3.3-MΩ resistor helps pull charge off that node, so the p-p voltage is always constant at high or low speeds.

That is what's required for good linearity—for minimum deviation from the straight line of:

$$V_{out} = k \times F_{in} + (\text{error})$$

Also, note the symmetrical Zener clamp.[2]

Another cute feature was the adaptive filter at the summing point of the second amplifier. The conductance of the diode is linearly proportional to the current through it, so the 1-µF capacitor gives an adaptive time constant and helps filter the signal more at low frequencies, less at high frequencies. That's the classical problem with most F-to-V converters: If you want to get low ripple, you get slow response due to the heavy filtering. If you want fast response, it's hard to get low ripple.

After I left Philbrick, I joined National and designed the LM131 voltage-to-frequency converter,[3] using completely different ideas than any of the Philbrick circuits. It used $Q = I \times T$, rather than the $Q = C \times V$ employed by all of the Philbrick ones. It didn't need ±15 V; it could run on +15 or +30 or +12 or +5 V—much easier to apply. BUT, it still had the same constraint when you used it as an F-to-V converter: If you want low ripple, it's hard to get fast response.

In 1978, I wrote an application note on how to improve the response time of an FVC—in the Linear Apps

Handbook.[4] I showed how to cascade two or more fast Sallen-Key filters to give reasonably quick response, yet filter out the ripple at 24 dB per octave. For example, if you have a frequency in the range 5 to 10 kHz and the frequency suddenly changes, you can get the output voltage to settle to the new level (within 1%) in about 40 ms—that's about 200 cycles—yet the ripple will be less than 5 mV p-p. That's about a 10:1 improvement over a single R-C filter. Good, but not good enough for some applications.

In 1979, I wrote another App Note[5] showing how to use a phase-locked loop to make a quicker F-to-V converter, about 2 ms. That's about 10 cycles of the new frequency—a further 20:1 improvement.

Not bad—but still not fast enough for everybody. For example, in a control loop, you may need a voltage that represents the frequency, and any delay or lag in the information may cause loop instability. So a fast response can be very important.

Recently, a guy asked me how to make a 60-Hz FVC with quick response and negligible lag or delay. I told him that the standard procedure is to use a fast clock and a digital counter. But the number of counts collected during one period is linearly proportional to the *period* of the signal, and you might have to do some digital computations to convert that to a signal representing the *frequency*. Then I realized that a "multiplying" DAC can be used to divide in a reciprocal mode.

I built it up and it worked. This Frequency-to-Voltage converter settles in *one cycle* of the frequency. Besides that, it uses only a small number of parts (*Fig. 3*)

The digital logic generates a couple of pulses at the time of each rising edge of the incoming frequency (you could use some kind of dual one-shot multivibrator, but I didn't have any of those around). The first pulse loads the data from the CD4040 into the DAC (the pulse also disables the path from the clock to the counter to avoid any confusion

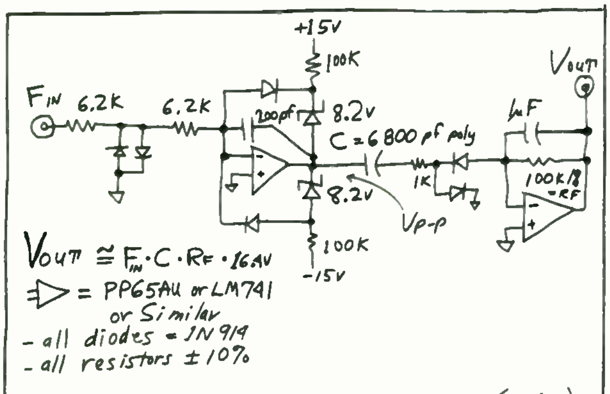


FIGURE 1, 1KHz F→V Converter (1965)

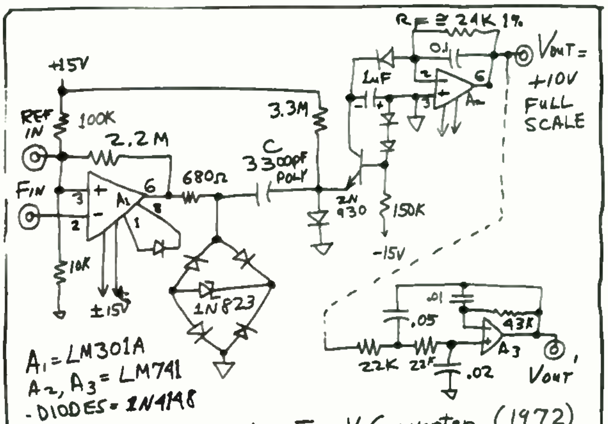


FIGURE 2, 10KHz F→V Converter (1972) WITH OPTIONAL SALLEN-KEY POST FILTER

from rippling in the counter). Then the second pulse resets the counter.

The MDAC has storage registers built in, so the data from the counter is fed right in to the DAC when the WRITE-2-bar pulse is applied. The MDAC isn't connected in the normal way, with the variable resistance in the input path. The fixed resistor is in the *input*, and the impedance controlled by the Digital code is connected as the *feedback resistor*. This permits the *multiplying* DAC to act as a *divider*, so the reciprocal function is done neatly—not in the digital realm, and not in the analog world, but on the cusp between them. (More on this in a few months). The LM607BN was chosen for the op amp because you need low offset. It's cheap, V_{os} is only 25 μV typical (60 μV max.), and you don't need a trimmer pot.

The guy who asked me for this function was quite pleased, as he said there are several suppliers who are happy to sell you this function for a couple hundred dollars.

But it's really not that big a deal. You can do the whole thing yourself. All it takes is just a few dollars worth of parts and a little labor.

The main limitation of this scheme is getting a decent resolution on the output voltage if you must cover a wide range of frequencies. For example, if you have to cover a 10:1 range, let's say from 20 to 200 Hz, then you can only use a clock frequency of 20 kHz with a 10-bit counter (or the clock counter would overflow, giving unacceptable false answers).[6] Then at 60 Hz, the number of counts would be just 333. The resolution would be only one part out of 333, or one-third percent.

So, if 200 Hz is scaled for 10 V, 60 Hz for 3 V, and 20 Hz for 1 V, then the FVC can only resolve the difference between 60.18 Hz and 60.000 Hz—for example, 3.000 V and 3.009 V. The resolution at 200 Hz would be even worse, about 100 mV per step, because there are so few COUNTS there.

If you need to get better resolution, you can get a 4X improvement by using a more expensive 12-bit MDAC and a 80 kHz clock. An 8-bit MDAC, even though the price is right, can't give much better than 1% resolution, even if you use it in a dynamic range of just one octave.

So, there's the limitation to this counting method. But you have to admit it is fast and has low ripple! (Of course, the other limitation is that if you wanted a fast computation for a 60-kHz frequency, you might need a 20 or 80 MHz clock and counter, not impossible, but not so easy....)

Comments invited! / RAP
Robert A. Pease / Engineer

p.s. And in an upcoming column, I plan to write about Voltage-to-Frequency converters, too.

References:

1. Teledyne Philbrick, Applications Manual, 1965, 1985; p. 95; (out of print).

2. How do you like that little Zener bridge circuit that's inherently symmetrical in its swing? As near as I can tell, it was first published by NSC in an "Applications Corner" in *Electronic Design*, p. 69, July 5, 1976. I sort of invented it about 1971—has anybody ever seen it before 1976? I don't think I have ever seen any patent on it—and if there had been one, it would have expired by now....

3. LM131/LM231/LM331 Voltage-to-Frequency Converter data sheet; available on request. The LM331 data sheet is accessible at URL = http://www.national.com/pf/LM/LM331.html .

4. National Semiconductor Linear Applications Handbook; Appendix C, available on request. Appendix AN-C is accessible through Adobe Acrobat, half-way down the above noted LM331 page (145 kbytes).

5. Ibid., Application Note AN210, which is accessible through Adobe Acrobat, halfway down the above-noted LM331 page (183 kbytes).

6. That's the function of the trick circuit shown in Figure 3—to detect when the counter is nearly full, shutting off the clock. This prevents preposterous outputs when the frequency approaches zero.

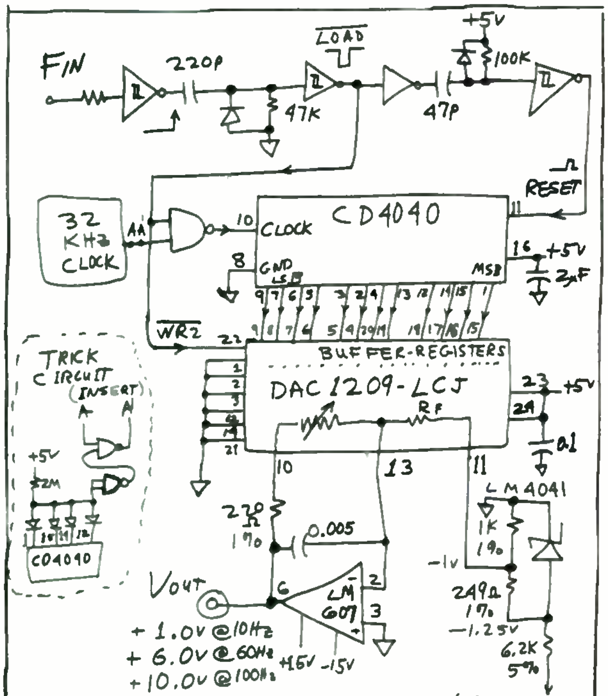
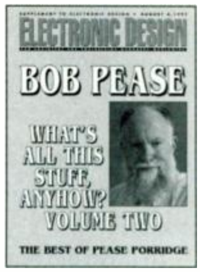


FIGURE 3. A COMPUTING F→VC.

= MM74C14 ; VARIOUS CMOS LOGIC

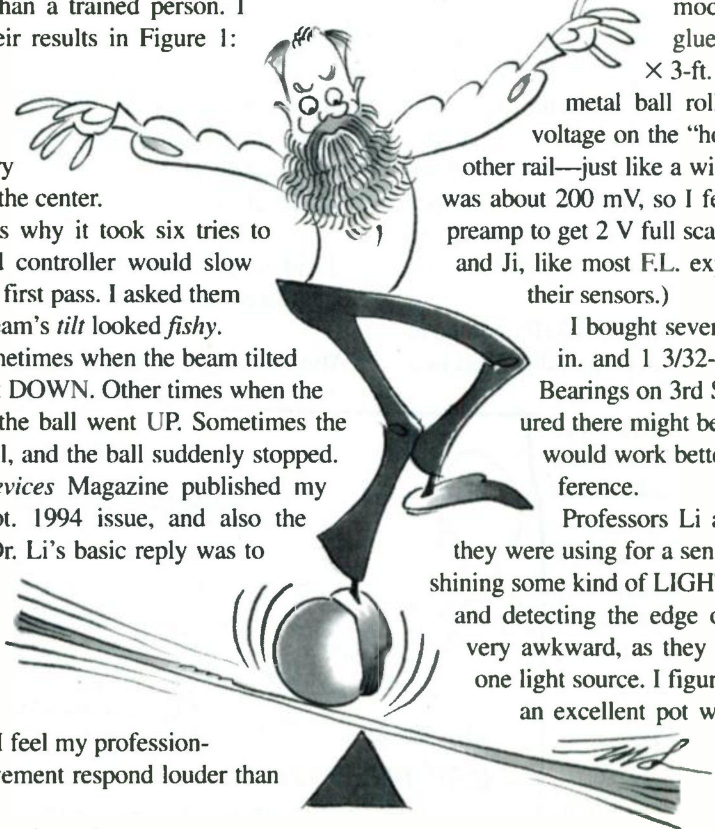
Originally published in
Electronic Design, July 8, 1993

RAP's 1997 comments: I said in footnote 2 that I had published that bridge circuit in 1976. Several readers wrote in that they had seen it a few years before that. Recently one of my fans gave me a copy of a December, 1971, English magazine, *Electronic Engineering*, where I had gotten this circuit published, *after* I published it first in the US in 1971. So maybe I can show I was one of the first inventors of that circuit. Gee, maybe I shoulda patented that one....—*rap*



What's All This Ball-On-Beam-Balancing Stuff, Anyhow?

Several months ago, a reader showed me an application of Fuzzy Logic, which claimed to be excellent. The IEEE *Circuits and Devices* Magazine (March 1994, pp. 30-35) published an article by Dr. Hua Li and Dr. Yuandong Ji, showing how to balance a ball on a tilting beam. They showed how easy it was to use a little computer (well, actually, a 50-MHz '486-based PC) to get a ball to move to the center of a tilting beam. They claimed that Fuzzy Logic made a much quicker and smoother controller than a trained person. I present a copy of their results in Figure 1: The ball starts out, lurches along, crosses zero five times, and on the sixth try finally gets to stop at the center.



I asked the authors why it took six tries to stop, when any good controller would slow down and stop on the first pass. I asked them why the plot of the beam's *tilt* looked *fishy*.

That's because sometimes when the beam tilted DOWN, the ball went DOWN. Other times when the beam tilted DOWN, the ball went UP. Sometimes the beam did not tilt at all, and the ball suddenly stopped. The *Circuits and Devices* Magazine published my questions in the Sept. 1994 issue, and also the authors' comments. Dr. Li's basic reply was to recommend that I ought to read a good book on Fuzzy Logic. And as for their results, Dr. Li could only respond, "I feel my professional practice and achievement respond louder than anything I can write".

After I researched this a little, and found almost no published information on a ball balanced on a beam, I felt challenged to make my own controller. After all, it isn't every day that I can replace a '486 with a simple $0.85 quad op amp. So when Bob Milne asked what I plan to do for a nice "Analog" column to run in the Special Analog issue in November, I knew this was the right topic.

First I had to design a sensor. There's hardly anything simpler than V = I × R. I forced 0.50 A down a 3-ft. length of brass model-railroad rail (Z-gauge) glued on top of a 1 in. × 1/4-in. × 3-ft. wooden beam (*Fig. 2*). As the metal ball rolled along on two rails, this voltage on the "hot" rail was transferred to the other rail—just like a wiper on a pot. The I × R drop was about 200 mV, so I fed that into a gain-of-plus-10 preamp to get 2 V full scale. (I mention this because Li and Ji, like most F.L. experts, do not like to mention their sensors.)

I bought several ball-bearings, 3/4-in., 7/8-in. and 1 3/32-in. diameter, at Performance Bearings on 3rd Street in San Francisco. I figured there might be some reason the larger balls would work better. Actually there was no difference.

Professors Li and Ji did not disclose what they were using for a sensor, but they were apparently shining some kind of LIGHTS onto their ping-pong ball, and detecting the edge of the shadow. That seemed very awkward, as they appeared to have more than one light source. I figured my steel ball would make an excellent pot wiper. And I was right. Note, a ping-pong ball has more air-friction—it's easier to make it stop, but harder to get it going. A ball-bearing has very little friction, so it's a tough test to get it to stop.

To drive the beam and control its tilt, I used a surplus dc motor with a lead-screw. (I could have clamped a piece of threaded rod onto the shaft of any motor, but this was easy.) I drove this motor with an LM3876 power op-amp running on ±18 V to get good speed. I used dental-floss (less stretchy than nylon cord) and pulleys to couple the horizontal motion of the lead-screw to the ends of the beam. I mention this because Li and Ji, like most Fuzzy Logic experts, never talk about their power amplifier or output transducer.

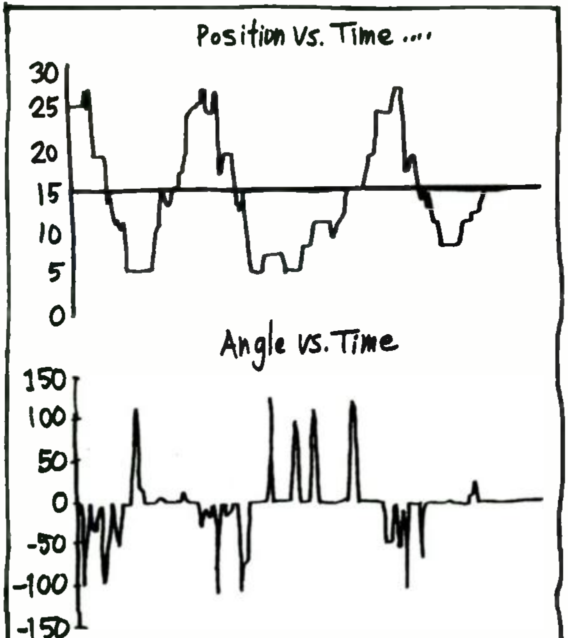


FIGURE 1.

The dc path for the control amplifier was easy. I took the voltage from the sensor preamp (A1) and fed it back through R2 to the main control op amp, A2. But, if I just hooked it up this way, it would oscillate like CRAZY, because there are three integrators in the feedback path, *not to mention* the integrator action of A3 *(Fig. 3)*. After all, the position of the ball is the integral of its velocity—and its velocity will be the integral of the beam's tilt! The dc gain will be INFINITE, and any roll-off of the gain with frequency will surely be at 18 dB per octave. Very bad phase shifts! This loop is sure to oscillate if I don't intervene and put in some special tricks to make this loop stable.

I knew I could not use just a simple PID (Proportional, Integral, Derivative) controller of the type I discussed in a recent column (June 26, 1995), because when there are two or three integrators in the loop, a simple PID controller can't control the loop. But my plan does look like a PID with the addition of extra circuits (differentiators).

First, I put the motor inside a feedback loop, so the motor's lag would be effectively decreased to a negligible amount (*Fig. 4*). Then we set up a pot to sense the tilt of the beam so we could close the loop. And then we built the tilt-servo. It worked the first time, but I had to make a couple changes:

1. I had to add a heat-sink for the power amplifier—the poor little amplifier kept going into thermal shutdown because I forgot to provide one!

2. I had to decrease one capacitor's value (C1, cut 1 μF to 0.15 μF) since it was causing a long tail in settling. (If I had put a pot in there, I could have just turned the knob.)

Then we added a joystick (just a pot with a lever) so we could control the beam's tilt manually. Making the ball move over from one spot to another spot is NOT a really easy loop to control by hand. It requires thought and planning. It's fun to try. And it's still possible to have it run smoother and faster than Li's Fuzzy Controller.

Then we built the main loop, with the dc path and a couple of differentiators added in (*Fig. 3, again*). These signals help us *anticipate* that the ball is approaching the right place, to help the controller slow it down and stop. It's just like the Differentiator effect in a PID loop, but we have a Derivative and a *Second Derivative*. You might call this a PID^2 controller.

We fired it up and it worked pretty well the first time, with most of the pots set at maximum damping. But it didn't damp out too well until I fixed two more items:

3. I had to cut down some friction in the pulleys.
4. One amplifier was wired wrong in the differentiator.

After that, it ran pretty well. The ball moves smoothly

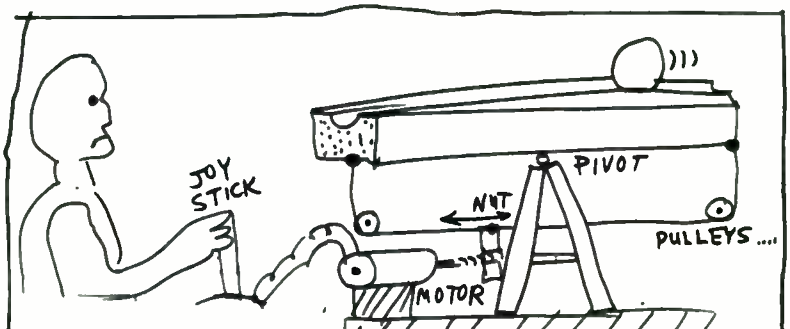


FIGURE 2.
- CAN YOU POSITION A BALL ON A TILTING BEAM?
- CAN YOU BE REPLACED BY A 50MHz '486?

and only overshoots a few percent. It rarely lurches or jitters. I can use it to position the ball at any point on the beam. As shown in the scope photo on the next page, the voltage that represents the ball position settles smoothly—just as the ball does.

I still don't know why my scheme is so slow; I want to figure out how to make it faster. There are several ideas I'd like to try out, and I've had several suggestions on making it servo and settle much faster. Maybe the integrator in the main servo loop is adding too much dc gain. I may be able to decrease friction with a dither, or a preload.

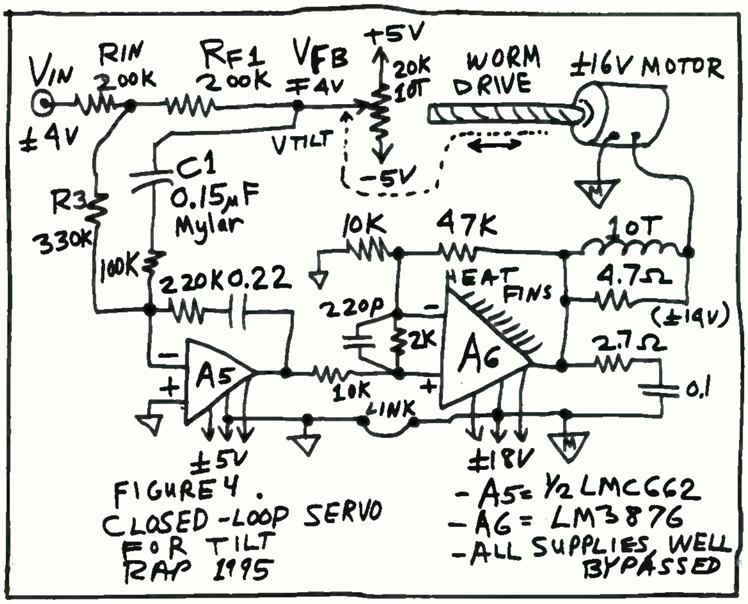


FIGURE 4. CLOSED-LOOP SERVO FOR TILT RAP 1995

When I do get this working really well, I'll send a videotape to Dr. Li and Dr. Ji—just to show them how a beam balancer can work *well*. They claimed they got their best results because they didn't use any models. Mine runs well because I was able to use simple models: a rolling ball is a double integrator. They claimed their Fuzzy Logic was able to triumph over the nonlinearities of a tilted beam. Well, the approximation that sine of tilt angle = tilt is only nonlinear by a few percent. They still can't servo the ball to any place on the beam as fast as my PID^2 controller.

If I get some time, I may be able to try out a deterministic solution: Bang the motor ON for a while, then when the ball has moved about half way, bang the motor to tilt the beam the other way. When the ball is nearly at its goal, then I'll servo the beam to be flat. This will require a bunch of tricky circuits, but if you're really in a hurry, this is surely the right way to do it.

Comments invited! / RAP
Robert A. Pease / Engineer

P.S. Thanks for Jay Friedman's and Kevin Thompson's help.

PPS. In case the position sensor got flaky, I was prepared to buy a tube of carbon-loaded lubricant that's made by Planned Products of Santa Cruz. But we never had any trouble with that, so there was no need to buy that stuff. It's a little pricey, about $13 at Fry's, but it's nice to know it's there.

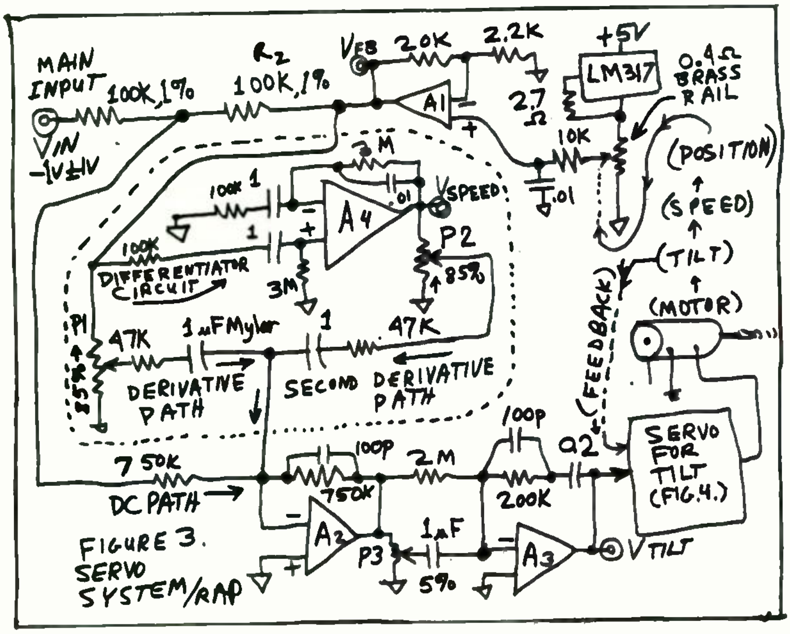


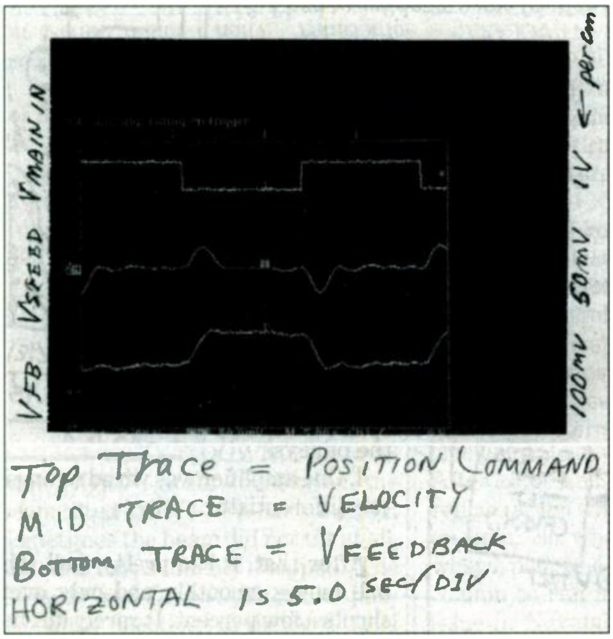
FIGURE 3. SERVO SYSTEM/RAP

Originally published in
Electronic Design, November 20, 1995

RAP's 1997 comments: My BOBB keeps on plugging. When I published this in '95, I had gotten the settling time down to 8 seconds. I added an R-C network from –Vin to the first summing point, and it didn't help. I added it again later, and it worked just fine, and helped me get the settling time down to 4 seconds, and 3.2 on a good day.

How am I going to get it down to less than 2 seconds? More on this, later.

I have seen a couple recent technical reports on BOBB using Fuzzy Logic. They are not bad at all. They seem rational. They are not hyped. And, surprisingly, they make no ref-



erence to the seminal Ji/Li article. More on this later.

Here I'll list three References from the magazine: *IEEE Transactions on Fuzzy Systems.*

(Isn't it funny that dozens of F.L. enthusiasts gather there to say good things about F.L., and I'm the only protection you have from them?)

1. "Designing Fuzzy Controllers from a Variable Structures Standpoint," J. Glower and J. Munighan, North Dakota State University, Fargo, N. Dak. pp. 138-144, Feb. 1997. They simulated a response of about 4 seconds, but had not built a model at the time of publication. Honest, realistic work. I'll add more comments later. They agree that adding P plus D terms before they are sent into the F.L. controller can improve and simplify the system, as I proposed above in my PID column.

2. "How to Design a Discrete Supervisory Controller for Real-Time Fuzzy Control Systems," N. Muskinja et al., University of Maribor, Slovenia, May 1997, pages 161-166. They show some curves with some not-entirely linear results, with settling in the range 4 to 8 seconds. They don't explain a lot about their analog-digital interface. But they use pulleys like I do.

3. "Adaptive Fuzzy Control: Experimental and Comparative Analyses." R. Ordonez et al., Ohio State University, May 1997, pp. 167-188. They show comparisons between computer simulations and the systems they BUILT. Very honest guys. They actually wrote about their sensors and their interfaces. Very honest. They got results in the 4 to 6 second range. More on this, later.—*rap*

Refrigerator
Continued from page 48

our Secretary of Defense, William Perry. Imagine that—a 340-lb. "refrigerator" in the Pentagon! (Even those of you who aren't football fans may know, with some prompting, about William "the Refrigerator" Perry who plays for Philadelphia....) But, maybe that was a different guy? Enough!

Comments invited! / RAP
Robert A. Pease / Engineer

Originally published in
Electronic Design, December 16, 1994

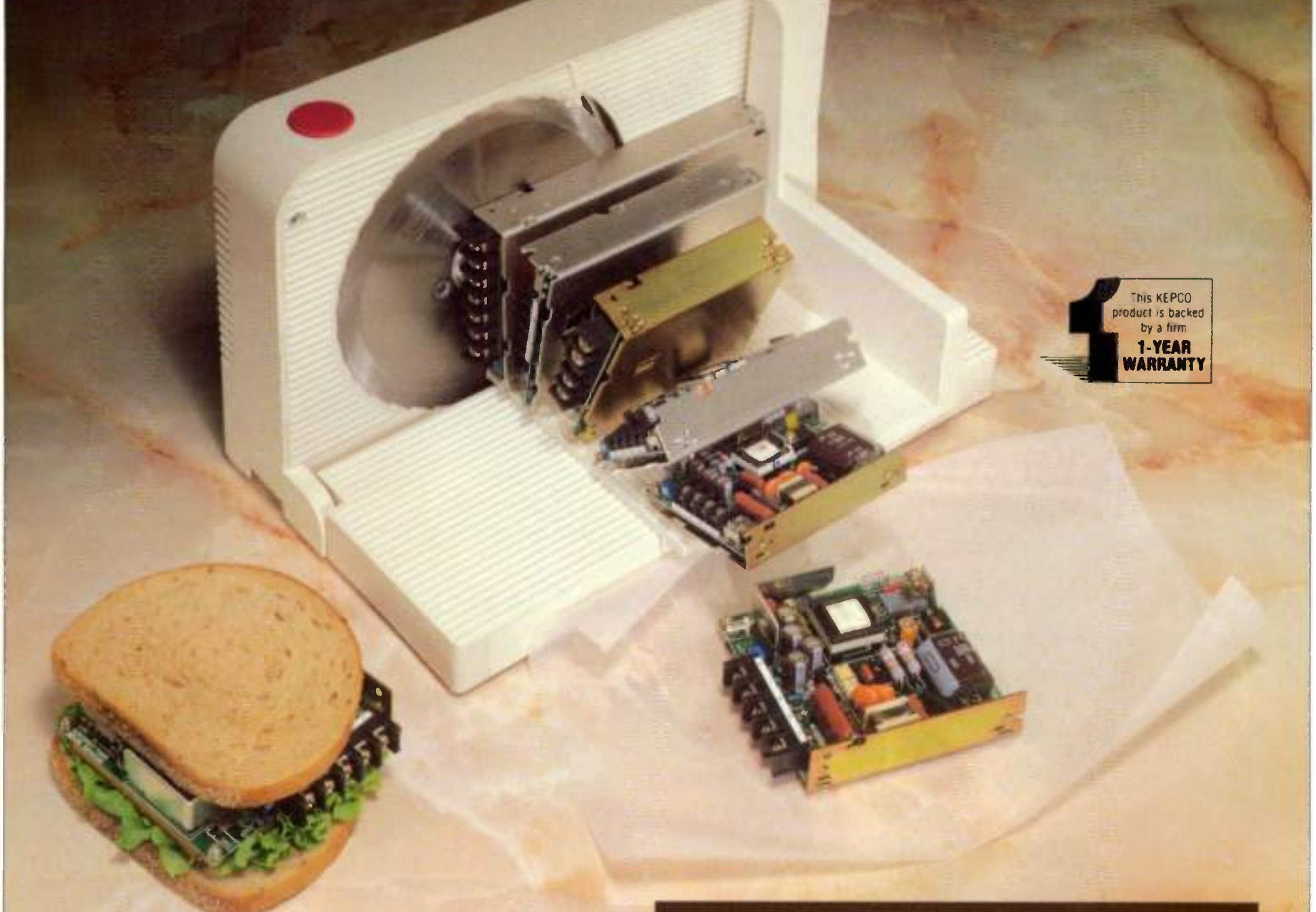
RAP's 1997 comments: I never did hear from anybody in the refrigerator business, saying that there was any "economizer" that is safe and reliable to use with any particular refrigerator, under all conditions. Of course, William Perry has retired from the position of Secretary of Defense. And William "the Refrigerator" Perry has retired from the NFL. I forget if that means "National Football League" or "No Fuzzy Logic."—*rap*

INDEX OF ADVERTISERS

Advertiser	RS #	Page
ALTERA CORPORATION	-	Cov4
AMKOR ELECTRONICS	126	43
ARIES	103	6
BIC VERRO	107	39
BURR-BROWN	80	25
BURR-BROWN	81-86	4
BURR-BROWN	88	1
BURR-BROWN	89-92	29
CONEC CORPORATION	95	57
CYPRESS SEMICONDUCTOR	-	15
DIGI-KEY CORPORATION	96	Cov2
DY 4 SYSTEMS	105	32
FAIRCHILD SEMICONDUCTOR	97	11
FORCE COMPUTERS	98	17-18
HARRIS SEMICONDUCTOR	124	13
KEPCO, INC.	99	Cov3
LAMDA ELECTRONIC	100	2-3
LECROY	101	8
LINEAR TECHNOLOGY	102	25
MOTOROLA	109	30-31
POWER CONVERSION	118	37
POWER CONVERSION	119	45
POWER CONVERSION	120	55
SIEMENS	111	35
SIPEX CORPORATION	112	40
SMART MODULAR	121	22
TRANSISTOR DEVICES	122	51
XICOR, INC.	123	47

Sliced Thin To Fit.

Kepco's FAW and FAK series skinny power supplies will fit your application. Available in ratings from 15~150 watts, these single-output models produce 5V to 48V of well-regulated d-c. The FAW are universal-input (85~264V a-c) models for international service.
FAK are 85~132V a-c models for domestic service.

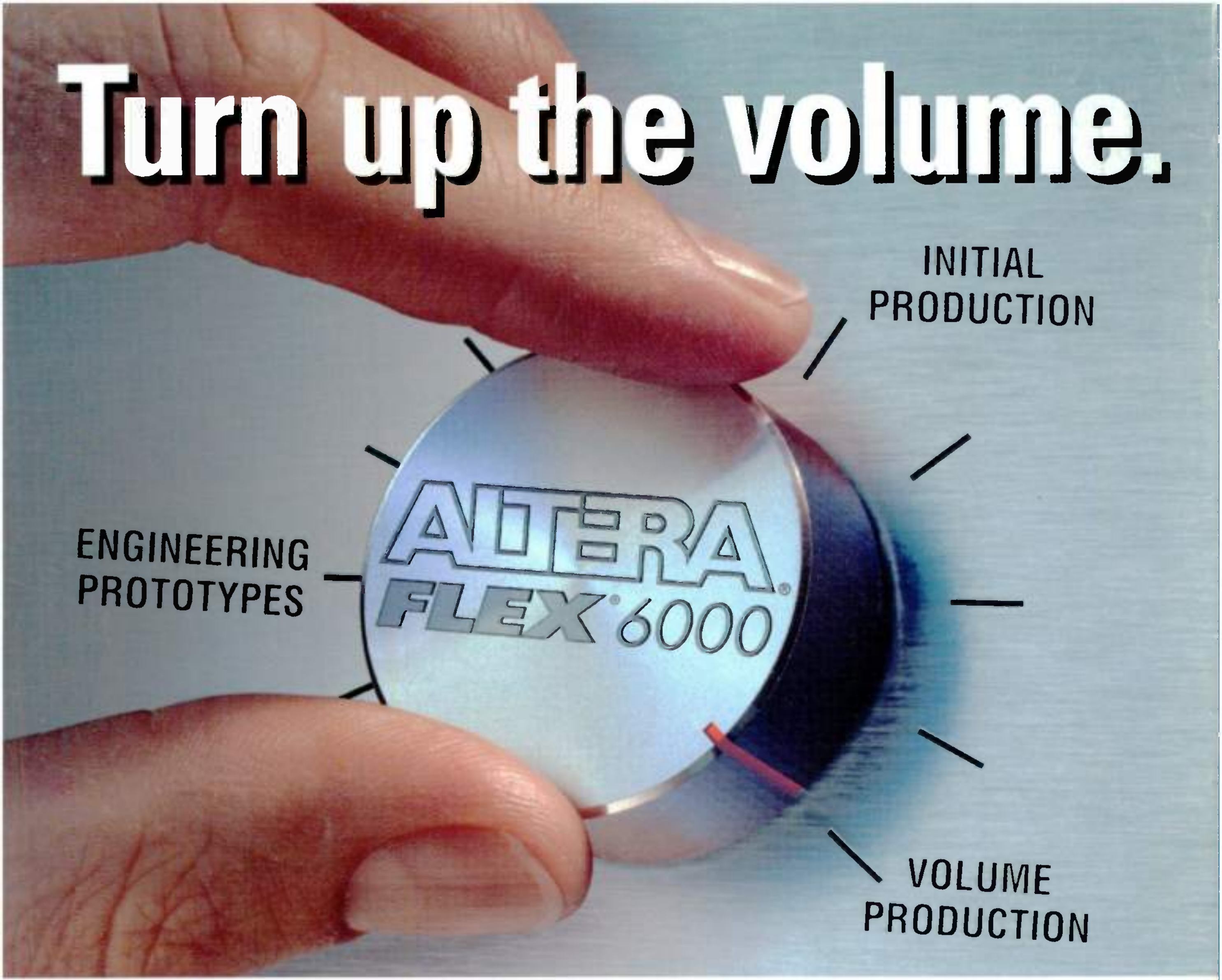


FAW/FAK POWER					
Nom. Volt	15W	25W	50W	100W	150W
5V	FAW, FAK	FAW, FAK	FAW, FAK	FAW	FAW
12V	FAW, FAK	FAW, FAK	FAW, FAK	FAW	FAW
15V	FAW, FAK	FAW, FAK	FAW, FAK	FAW	FAW
24V	FAW, FAK	FAW, FAK	FAW, FAK	FAW	FAW
28V				FAW	FAW
48V			FAW	FAW	FAW

AN ISO 9001 COMPANY
KEPCO®
THE POWER SUPPLIER™
SINCE 1946

Kepco, Inc. HQ / Eastern Region: Dept. PEF-05
131-38 Sanford Avenue, Flushing, NY 11352 USA
Tel: (718) 461-7000 • Fax: (718) 767-1102 • E-Mail: hq@kepcopower.com • URL: http://www.kepcopower.com • **Western Region:** 800 West Airport Freeway, Suite 320, LB 6018, Irving, TX 75062 USA • Tel: (972) 579-7746 • Fax: (972) 579-4608 • E-Mail: kepcotx@aol.com

READER SERVICE 99



Altera's FLEX® 6000 family signals a breakthrough in high-density programmable logic for volume production.

As the world leader in high-density programmable logic devices, Altera has broken through the cost barrier so you can use programmable logic for your highest volume production needs.

Say good-bye to low-density gate arrays because with the fast time-to-market, design flexibility, and low cost of FLEX 6000 devices you can afford to stay programmable throughout your product lifecycle.

The secret behind the low cost is Altera's enhanced OptiFLEX™ architecture. Our development focused on minimizing die size while maximizing performance and efficiency.

Turn to FLEX 6000 devices for your next ASIC design.

DEVICE	EPF6010	EPF6016	EPF6016A	EPF6024A
GATES	10,000	16,000	16,000	24,000
VOLTAGE	5 V	5 V	3.3 V	3.3 V
PRICE*	$6.00	$7.50	$7.00	$10.00

*Prices are in U.S. dollars and are projected for 1998 in volumes of 50,000 units. Prices are for standard speed grades and may vary for specific options or in different geographic regions. Contact your Altera representative or distributor for exact pricing and availability.

It's time to turn up your volume.

We'd like to tell you more about the FLEX 6000 family, which is why we've developed a cost calculator and special literature package. Just go to **www.altera.com/volume** for more information. It's time to let Altera's FLEX 6000 devices turn up the volume of your designs.

www.altera.com/volume

1-800-9-ALTERA

ALTERA®
The ASIC Alternative™

WRH