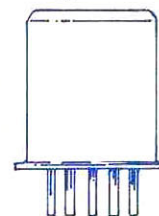


FETRON, solid state vacuum tube replacement

fet·ron (fet' rän) *n.* [ModE. < L. — *semiconductus* < *fetum* (? akin to *FET*, transistor), + *RON* (< Molaysian), orig. with reference to a solid state tube replacement introduced by Teledyne Semiconductor in 1972] 1. An answer to improved performance and 100 year life of existing vacuum tube electronics gear 2. A cost reduction for companies maintaining large vacuum tube systems 3. A method of reducing the cooling requirements in buildings containing large quantities of vacuum tubes 4. A method of reducing electric bills due to elimination of filament current 5. [Adv.] The greatest thing since the winning of the West

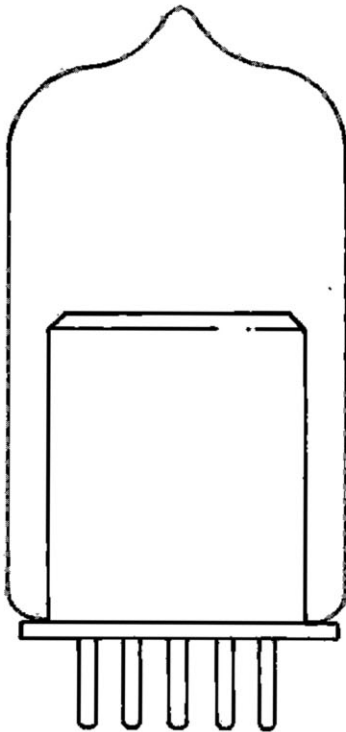


FETRON



**TELEDYNE
SEMICONDUCTOR**

FETRON,^{T.M.} solid state vacuum tube replacement



VACUUM TUBE TO FETRON

Prior to the development of the transistor, and particularly the high voltage JFET, electronic equipment for many applications was engineered with the vacuum tube as the principle active element. In spite of the instabilities and short life of the vacuum tube, much existing equipment, particularly telephone carrier equipment, is well designed and will last for many more years if properly serviced.

However, the servicing cycle for vacuum tube equipment is very expensive, requiring frequent adjustment and periodic tube replacement to minimize down time. As a result, most existing vacuum tube equipment is scheduled to be replaced by new all solid state equipment. But new equipment is also very expensive and requires large capitalization in most cases. Replacement of obsolete vacuum tube equipment has therefore been delayed.

As a solution to this problem, Teledyne has developed the FETRON for direct plug-in replacement of vacuum tubes in the field. This allows the vacuum tube equipment user to reap many of the benefits of all solid-state equipment without having to incur the expense of complete new systems. The FETRON provides improved equipment performance, and drastically reduces servicing costs and electric bills from the date of installation.

In high utilization equipment, such as telephone carriers, the FETRON can pay for itself within six months of installation. Dollar savings from the first year can then be applied toward more sensible long term equipment plans and for greater return on investment.

FETRON NOW

To date, the FETRON has been developed for replacement of pentodes and twin triodes. FETRONs are now available to replace many common tube types such as the 6AK5 and the 12AT7, described in a feature article of *Electronics Magazine*, April 10, 1972. Now in development are replacement types for thyratrons, tetrodes, various high frequency tubes like the 6BA6, and power pentodes such as the 6AQ5 and the 6V6.

The FETRON is not a universal replacement for vacuum tubes, and must be configured differently for certain applications. For example, the FETRON configuration will generally be different for a pentode amplifier and an oscillator. However, the number of replacement tube types and specific applications is growing rapidly, and may one day cover virtually every tube type and application.

The FETRON is currently used mainly in telephone communications systems. Several hundred thousand are now operating in telephone carrier equipment. FETRONs in the field have replaced the 407A, 408A, and similar types. Replacement types are under development for the 403A, 404A,

415A, and 396A tubes. Other replacement types will be developed as requirements are made known by potential users.

INSIDE THE FETRON

The FETRON is composed of one or more JFETs, a protective fuse, and R/C networks for tailoring to the required circuit performance parameters. The JFETs used in the FETRON are also used in high reliability missile systems, and many other applications. These are high volume, proven devices. A tantalum fuse is used, and thick film methods are employed for the R/C networks.

Using standard hybrid circuit techniques, the FETRON elements are assembled under ultra clean conditions. The FETRON elements are then attached to a substrate, after which the substrate is soldered to the header. Using gold wires, the chips and substrate pads are attached to the posts on the header. These posts extend through the header as the socket pins.

A 3/4" nickel-plated cap is cold welded to give the standard semiconductor type hermetic seal. The cap also minimizes device temperature and allows easy plug-in to tube sockets.

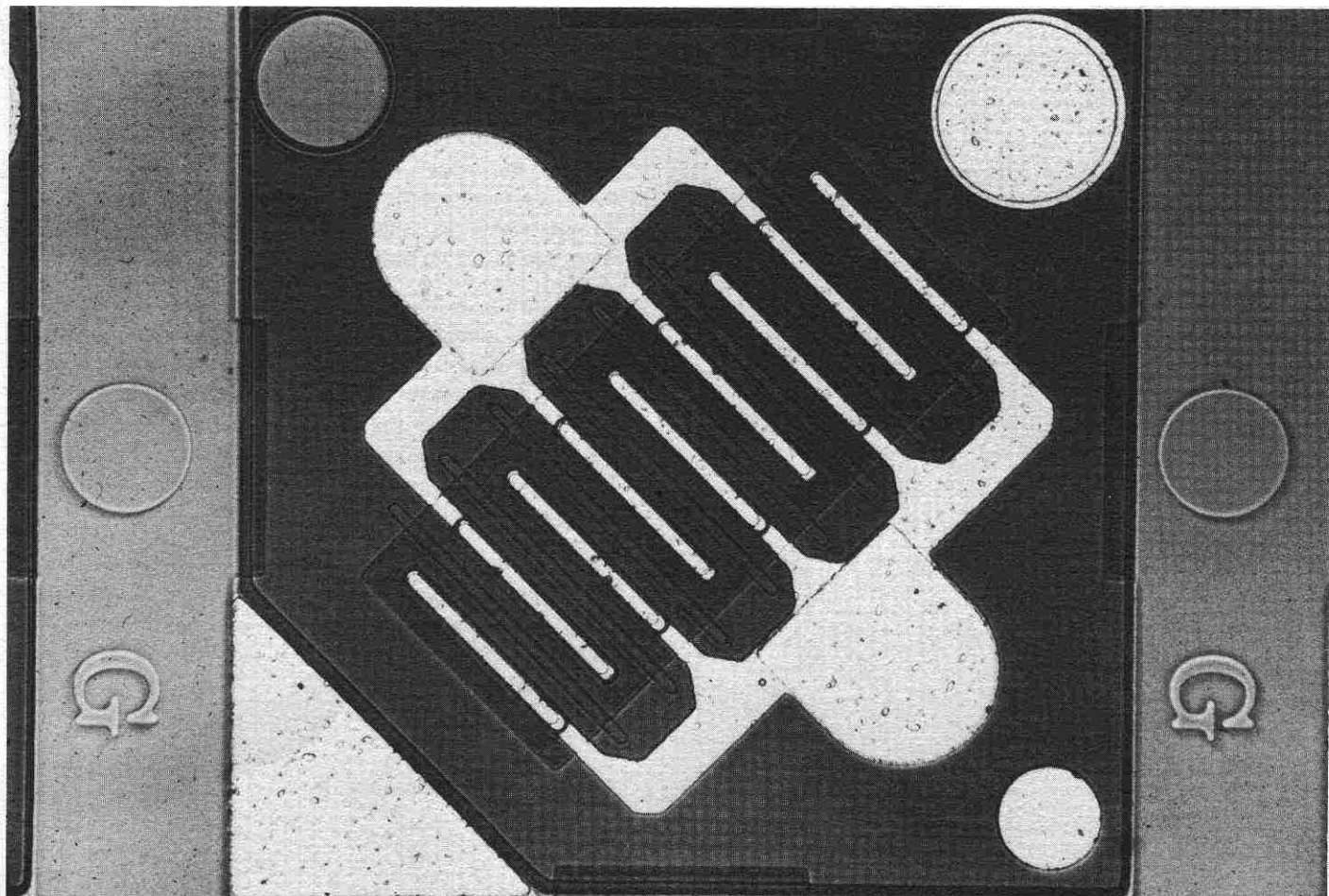


Figure 1. A Junction Field Effect Transistor (JFET). One of the JFETs used in the FETRON, and in volume production for high reliability missile systems and many other applications.

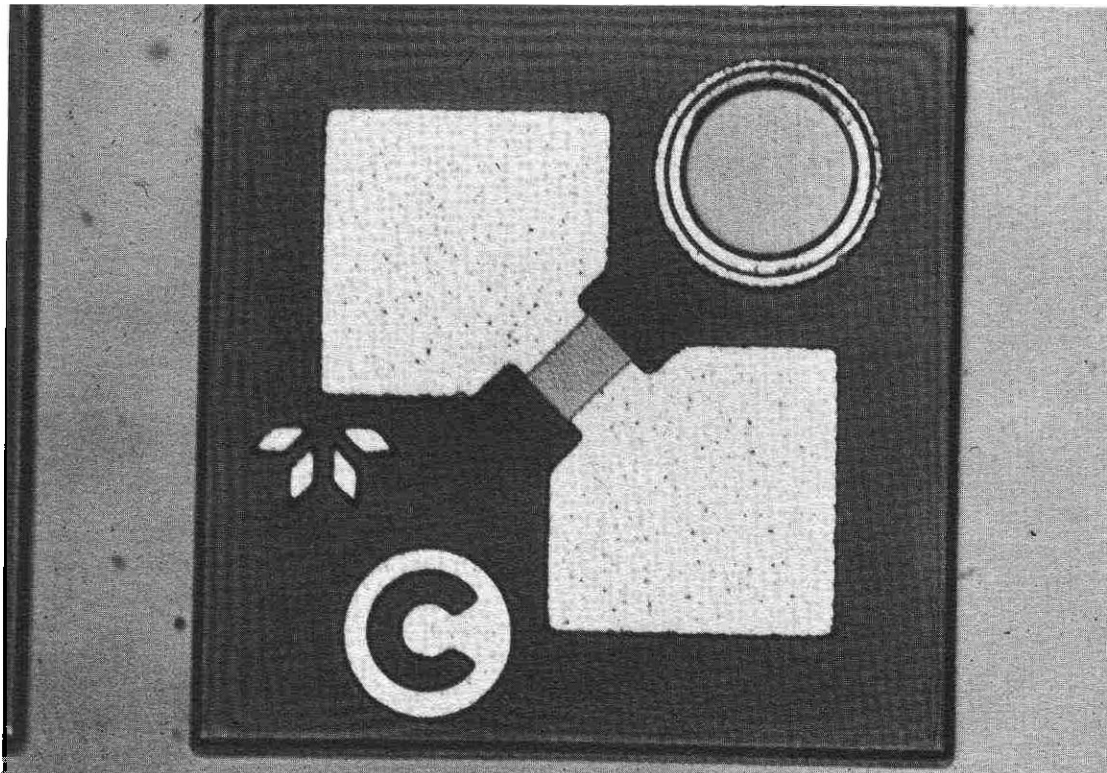


Figure 2. A Tantalum Fuse. The fusing device used for protection of other components in case of failure due to overload. The tantalum fuse, like other FETRON circuit elements, is made by well-established integrated circuit methods.

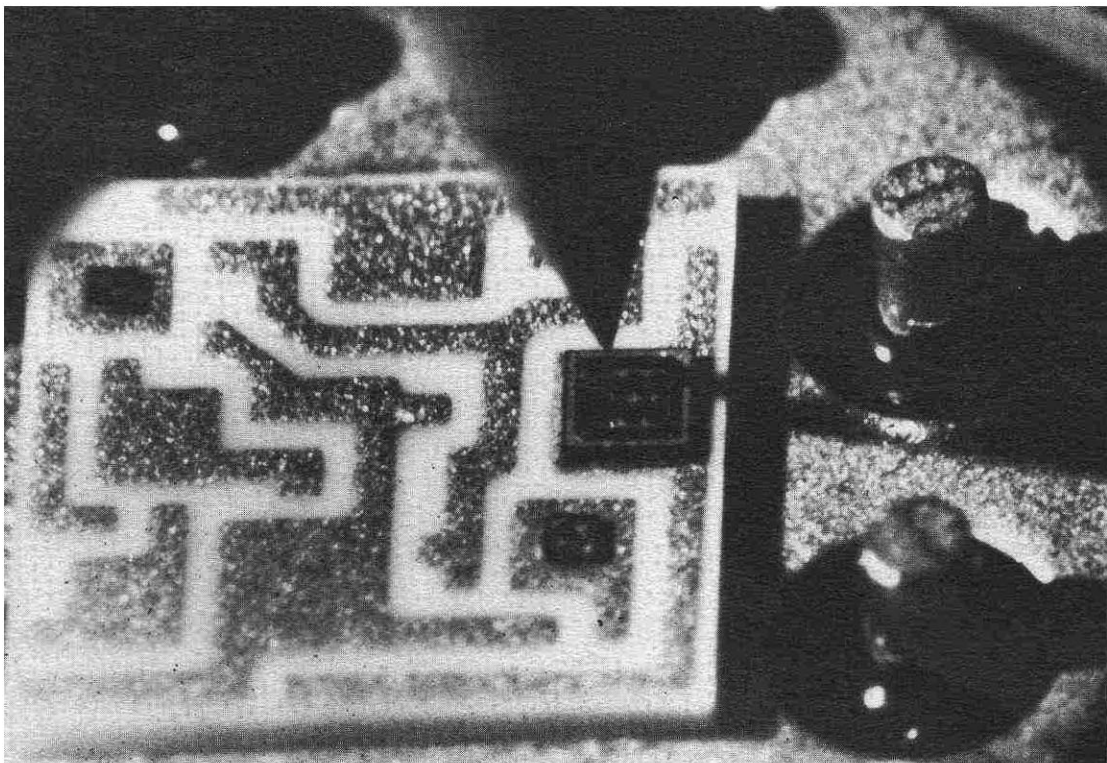


Figure 3. FETRON Circuit Assembly. FETRONs are assembled on a thick film substrate by well-established hybrid circuit methods. After bonding to the header, gold wires are connected from its pads to posts which extend through the header as pins for the vacuum tube socket.

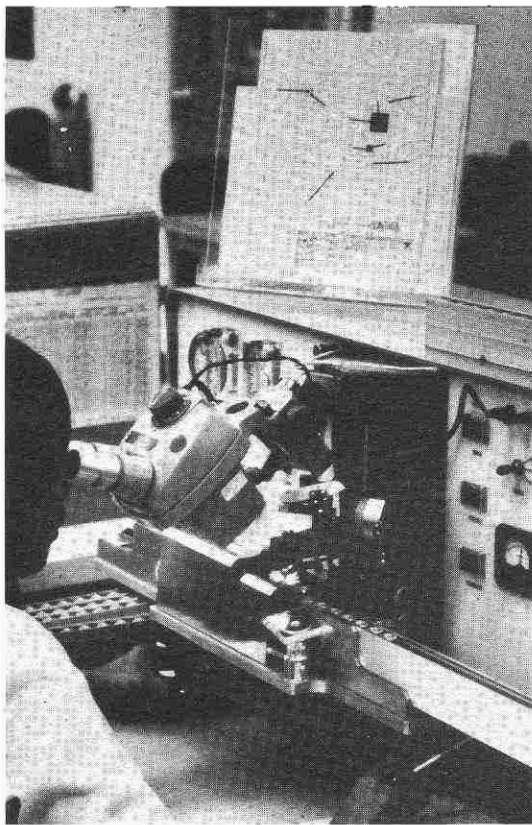


Figure 4. FETRON Production. Methods used for assembly are the best industry quality control standards, MIL-STD-883. Assembly procedures are carefully planned and carried out under ultra-clean conditions to maximize FETRON reliability.



Figure 5. FETRON Assembly Steps. The FETRON thick film circuit is shown (1) as a clean substrate, (2) with conductive film, (3) with circuit etched, and (4) with circuit chips attached. The completed circuit is then soldered to the header and connected to the posts with gold wires. The header is then hermetically sealed with a nickel-plated cap.

HOW THE FETRON WORKS

The FETRON usually contains two JFETs connected in cascode to simulate the actual performance of a pentode or triode vacuum tube. The advantages of this configuration are:

1. The input characteristics are determined by the first device,
2. The plate voltage rating is determined by the second device, and
3. The Miller capacitance is minimized.

Since a screen grid is not needed by a FETRON, some circuits include R/C networks to simulate the equivalent circuit of the screen-plate circuit. A tantalum fuse is connected in the plate circuit to protect other circuit components in case of failure.

Using cascoded JFETs in combination with other elements, any number of different tube types can be simulated. The FETRON is most like a pentode in that the plate current is essentially independent of the plate to cathode voltage. The plate current of a triode, and its transconductance, are very much dependent on the plate to cathode voltage. The FETRON is therefore superior in principle to the triode, and usually provides improvement in circuit performance upon replacement.

However, the proper FETRON must be selected and trimmed for each application, to avoid saturation effects as determined from the load line analysis.

Because of characteristic similarity, a FETRON can very closely simulate the function of a pentode tube. The gain/phase relationships are almost identical for a FETRON and a

pentode. However, there are three important circuit improvements obtained with the FETRON. These are:

1. Reduced noise by several dB, and no microphonics,
2. Higher gain which is independent of screen voltage, and;
3. Lower distortion by typically 15dB.

The pentode generates distortion by cross modulation of higher harmonics, a result of its three-halves response relationship. The FETRON, however, is close to being a perfect square law device over most of its usable range, and generates almost no harmonics above the second. The FETRON must also be tailored for pentode operating conditions, but less critically than for the triode.

In general, the choice of FETRON depends on operating voltage and power levels, frequency range and whether an oscillator or an amplifier. Teledyne has analyzed the circuits on most telephone carrier equipment and other instruments such as Hewlett Packard VTVMs. Worst case analyses have been done on the carrier equipment by Teledyne together with different telephone companies. Teledyne has also formalized simple conversion procedures in most cases. The target ground rules for specific applications are:

1. No external components.
2. No re-wiring of equipment.
3. No power supply changes.
4. Plug directly into the tube socket.

These objectives have been achieved in almost every case. They make it easy for you to reap the benefits of the FETRON.

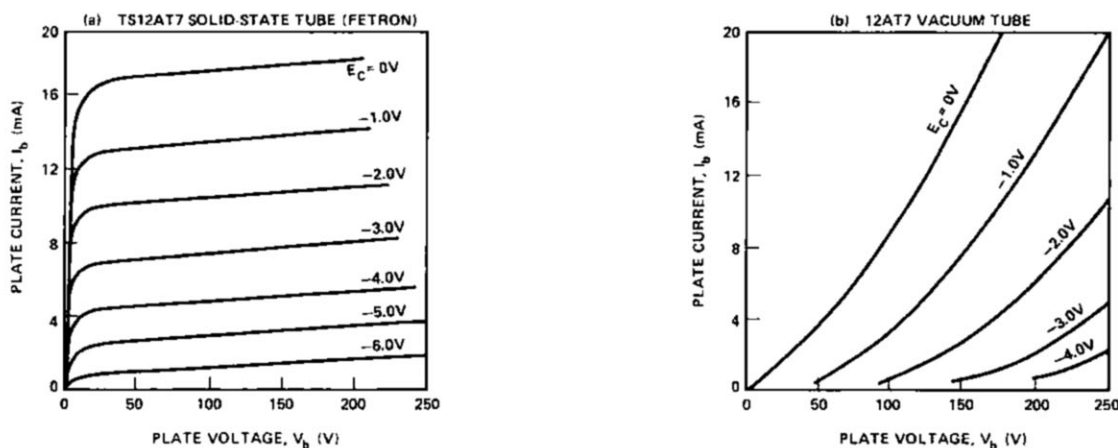


Figure 6. FETRON Compared with Vacuum Triode. The FETRON provides a plate current/voltage characteristic that is superior to the triode. Plate current in the FETRON is virtually independent of plate voltage. The plate current and transconductance of a vacuum triode is very much dependent on plate voltage. For example, with a 240 ohm load, a plate voltage change from 130V to 60V results in a plate current change from 8mA to 2.5mA. The same voltage excursion results in only μ A in the FETRON.

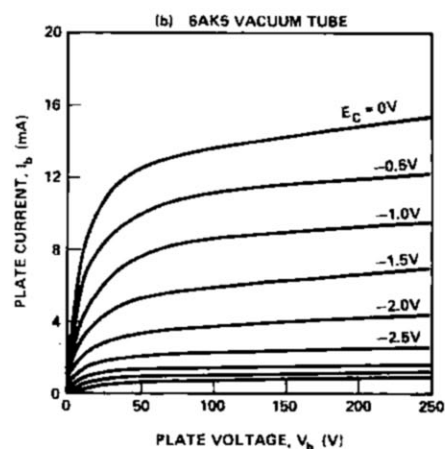
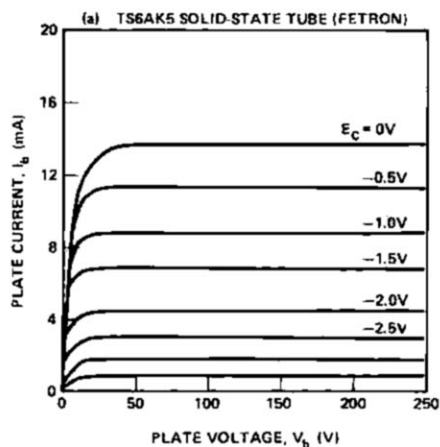


Figure 7. FETRON Compared with Vacuum Pentode. The FETRON is most like a pentode, but provides a superior plate current/voltage curve. The transconductance at the pentode is nearly independent of plate voltage, but depends on screen to plate voltage. The FETRON is independent of both. A plate voltage change from 130V to 60V causes a pentode plate current change from 10mA to 4mA. The corresponding FETRON current change is negligible.

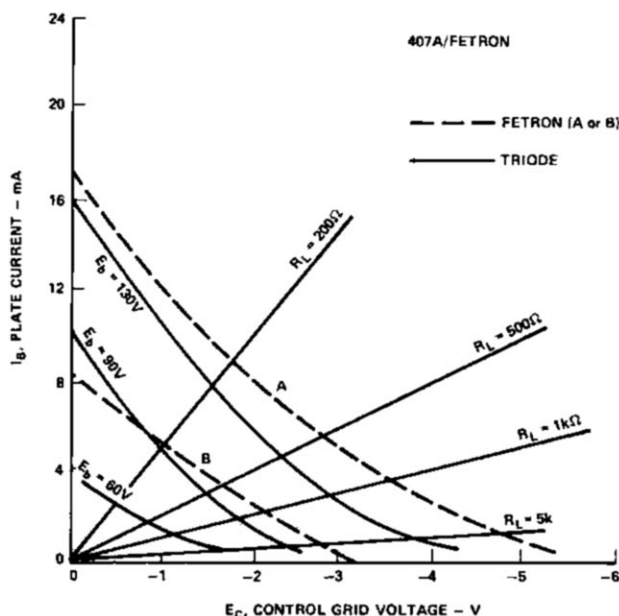


Figure 8. Transfer Characteristic, FETRON vs. Vacuum Triode. By JFET selection and trimming, any triode function can be generated. A load line analysis is conducted by Teledyne to prevent saturation when the FETRON is plugged into the tube socket. A 50kΩ load would saturate FETRON A, but not FETRON B.

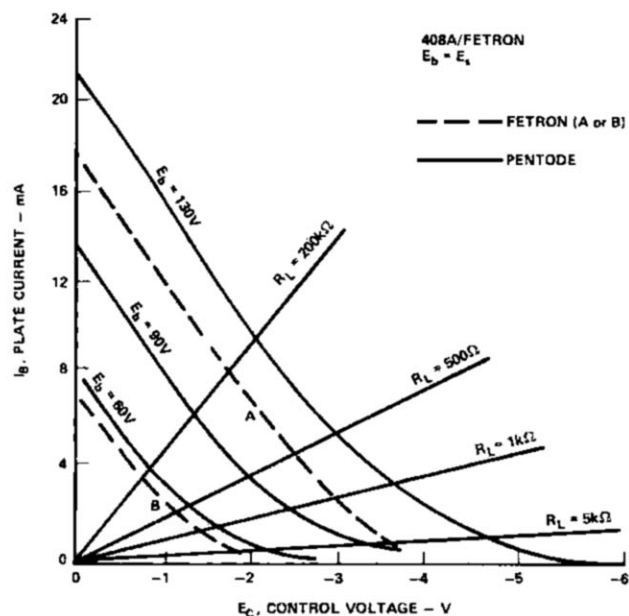


Figure 9. Transfer Characteristic, FETRON vs. Vacuum Pentode. Most vacuum pentode functions can be generated with a FETRON. The FETRON is less dependent on circuit voltage and generates less noise and microphonics.

CIRCUIT GAIN PHASE vs. FREQUENCY

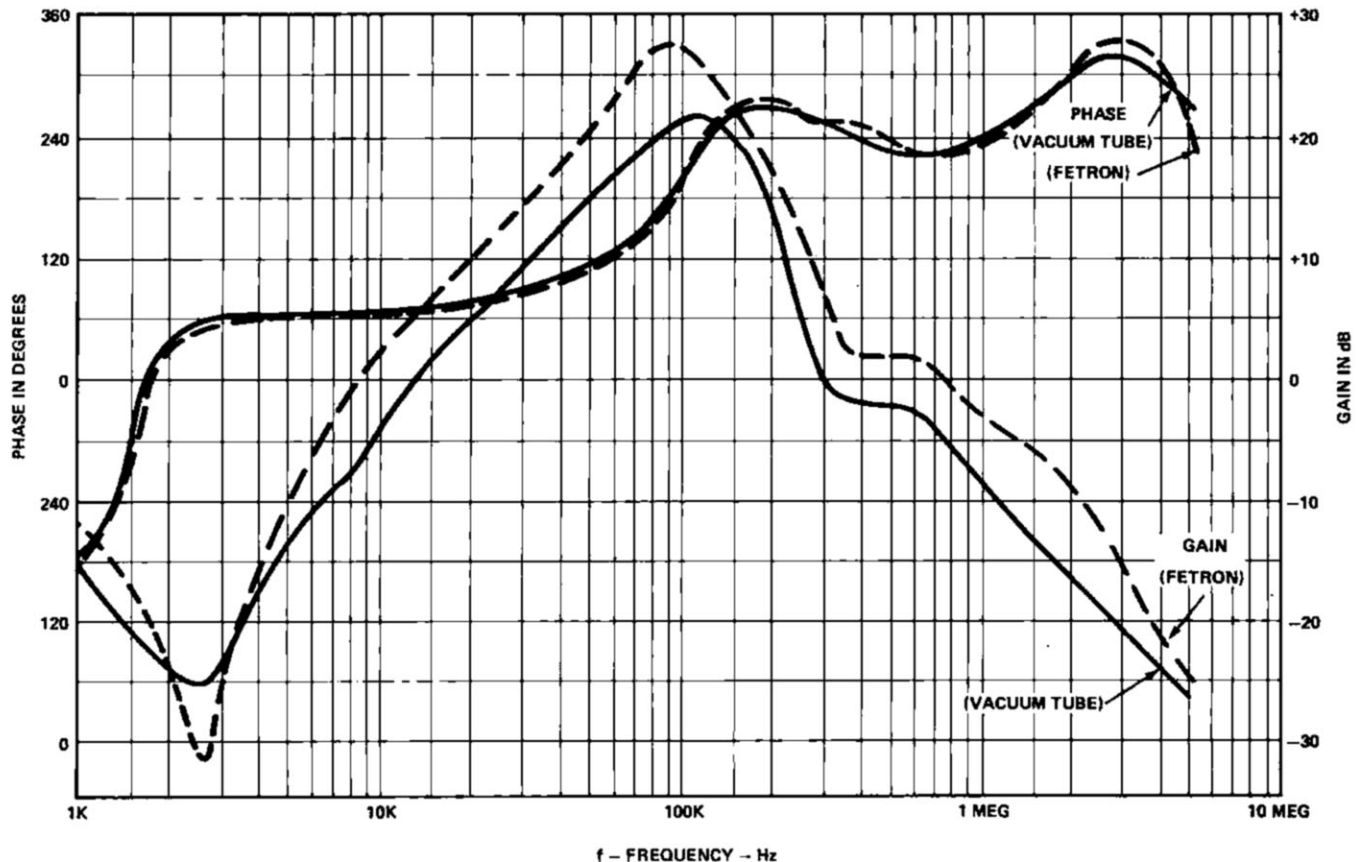


Figure 10. Frequency Response, FETRON vs. Vacuum Tube. The gain/phase curves for the FETRON and the vacuum tube are matched quite closely. No changes due to these functions are incurred. The FETRON reduces distortion due to upper harmonic by 15dB, a result of its true square law response.

FETRON BENEFITS

As a result of low initial cost of the FETRON and generous savings resulting from vacuum tube replacement, the FETRON is finding rapid and widespread acceptance. These cost savings result from the simple advantages the FETRON has over the vacuum tube. Primarily higher reliability, more stable operating characteristics, and lower power consumption. Add to this list the ease of replacement designed in by Teledyne, and the result is an irresistible opportunity for change.

Higher Equipment Reliability results from the lower operating temperature, less thermal wear on other parts, and the longer lifetime of the FETRON. Vacuum tubes have a useful life of only thousands of hours. Experience with FETRONs in the field has demonstrated a lifetime greater than one million hours, over a hundred years. The net result is extended equipment life, less down time and a savings of frayed nerves. The cost of standard industrial tube replace-

ments alone is about \$4.00 per year. Other components are estimated to be \$2.00 per year for each tube, resulting from thermal wear.

Maintenance Costs are drastically reduced since FETRONs do not require periodic replacement or frequent adjustment like the vacuum tube which begins to degrade immediately after installation. As a result, there is no change in signal transmission strength or quality degradation with time. A definite improvement in quality in most cases. Estimated savings for a typical thirty tube system are:

1. Local site — 3hrs x \$15/hr x 2 servicing/yr x 1/30 = \$3/tube/yr.
2. Remote site — 4hrs x \$25/hr x 2 servicing/yr x 1/30 = \$6.67/tube/yr.

Electric Bills are much lower because FETRONs use less than half the power of vacuum tubes. Air conditioning bills are lower too, and personnel efficiency goes up along with the

Table 1. Typical FETRON Savings, \$/yr/FETRON

Item of Savings	Remote/Commercial Tube Installation	Local/ Commercial Tube Installation	Your Installation
1. Reliability — 100 year FETRON	\$4.00	\$1.00	
2. Power Savings — on going operation	\$2.40	2.40	
3. Power Savings — new addition	\$4.80 (first year)	—	
4. Maintenance	\$6.67	\$3.00	
5. Loss of Revenue (poor service, etc.)	\$1.50	\$1.50	
6. Other Components — thermal wear	\$2.00	\$2.00	
7. Extended life of present equipment	???	???	
Total FETRON savings	\$16.57+?	\$9.90+?	

plant comfort index. Estimated power savings by replacement of a vacuum tube by a FETRON are:

1. Operating tube power — $1.9 \text{ W/tube} \times 9\text{k hrs/yr} \times \$0.01/\text{kW hr} = \$1.70/\text{tube/yr}$.
2. Air conditioning, standby power, etc. — $0.9 \text{ W/tube} \times 9\text{k hrs/yr} \times \$0.01/\text{kW hr} = \$0.70/\text{tube/yr}$.

Each equipment user has found different FETRON conversion priority and cost savings. Here are some examples of cost savings to set the wheels in motion.

- One area had maintenance problems and loud customer complaints on some repeater lines. All was quiet after conversion to FETRONs.
- A costly power panel replacement program for handling high current loads was cancelled due to the low current drain of FETRONs.
- After observing no drift in equipment calibration for a year after installation, numerous maintenance people were assigned other jobs.
- Instead of salvaging tube equipment in favor of short-lived new equipment, the older equipment lives on with FETRONs.
- After learning about FETRONs, additional batteries and diesel generator requisitions were cancelled. FETRONs eliminated the need.
- "Do I spend \$20,000 for power supplies and building additions?" Just \$1,600 worth of FETRONs deferred this expenditure for at least 5 years.
- Power plant additions totaling \$80,000 were deferred several years. A result of —48 volt savings accrued by installation of \$20,000 worth of FETRONs.
- One sizable telephone company when asked why they were so anxious for their FETRON delivery, indicated that they would be saving \$5,000 a day with FETRONs.
- Several remote sites in the Midwest used a twin DC to DC converter (two in case one failed), working off the —48V system. They were able to avoid increasing the —48V drain since filament current was eliminated with

FETRONs. As a result, a +130 supply and standby batteries were pulled out, making room for new carrier systems.

- One group installed FETRONs in equipment scheduled for removal within two years, still realizing a substantial savings with FETRONs. Unlike vacuum tubes that wear out, the FETRONs will be used elsewhere when the equipment is turned down.
- All groups like the advantage of immediate write-off maintenance money, rather than having to capitalize new equipment.

"We can now meet the tighter standards imposed on us without huge expenditures."

These profitable success stories are a result of careful engineering, and cooperative effort to solve the problems involved. The solution to these individual problems has resulted in a catalog of FETRON conversion kits available from Teledyne Semiconductor.

FETRON KITS

Numerous systems have been converted to FETRONs throughout the North American Continent. Other systems are in a field trial stage. Still others are in the prototype stage. As a result, a number of FETRON conversion kits are available in various phases of development.

Conversion of these systems available immediately:

N1 Repeater (—130V or tandem)
 N1 Terminals (save > 200W)
 ON Carrier (stable, low W)
 O Carrier (stable, low W)
 O Repeater (low noise)
 HP 400 VTVM (low noise)
 E2, E3 Repeaters (simple conversion)
 V3 Voice Amplifiers (simple conversion)
 MF Receivers (all solid state)
 Lenkurt 45A Carrier (no drift)
 43A1 Teletype (all solid state)

These systems are in field trials, available June, 1973:

Lenkurt 45BN Cable Carrier
Lenkurt 45BX Radio Carrier
ANI Identifier
Lynch B510 Carrier

These systems are in the prototype stage, some available data:

ON Junction
TD2 70MHz IF
Lenkurt 74, 70MHz IF
Lenkurt 4564 Repeater

Begin your investigations with the systems we have now. Teledyne stands ready to work with you on systems in development, or new systems to suit individual needs.

MAKE FETRONS PAY

If you have vacuum tube equipment in your facility, FETRONS will save money for you. The following is a suggested approach to determine how. It has been compiled from experience by applications of FETRONS at Teledyne.

1. Survey your equipment for the number and types of tubes, and types of equipment.
2. Consider setting up trial locations for field tests for the most pressing needs. Evaluate the results.
3. Teledyne will support your investigation with applications assistance. Take an in-depth look at the savings achievable with the FETRON.
4. Let Teledyne know your needs. They have experience where it counts and are anxious to help.

For immediate information or assistance, contact:

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