Hugh Wells W6WTU
1411 18th St.
Manhattan Beach CA 90266

The Ins and Outs of Parts Substitution

Part 2: Specific devices.

With the diminishing availability of common semiconductors, hams are faced with substituting parts in order to implement circuits from the past. Many of the older circuit designs were excellent and provided a strong technical base for use in ham projects of today.

To implement older circuits, we as hams must be ingenious in our ability to locate and install available replacement semiconductors. Part 1 of this series discussed the steps involved in the substitution process; from searching for the "specific" part to examining the circuit parameters to enable the selection of a suitable replacement part. Specific transistor characteristics were obtained from available sources to create a table of device information in order to demonstrate how device parameters are compared for similarity. Knowing and matching the characteristics of both the old and new device greatly improves the likelihood of a successful device substitution.

Part 2 continues with those tools in mind and applies the process for substituting or replacing an FET. Because FETs are used in RF circuits as well as at low frequencies, the selection process involves a few more steps than those required for a junction transistor. In addition, ICs, op amps, and special devices will be discussed.

FETs

When it comes to substituting one FET for another, we really have our work cut out for us. FETs are designed in six different configurations, with most operating in a depletion mode and with some operating in the enhancement mode — making up a total of ten FET device configurations. A basic FET device configuration can be one of the following: JFET, single-gate MOSFET, or a dual-gate MOSFET. JFETs are depletion devices and function in a manner similar to a vacuum tube, except that the gate impedance isn't quite as high as the grid of a tube. Device current conduction increases when the gate swings toward the drain and decreases when the gate swings toward the source. Because of the reverse-biased gate of an FET, the input impedance is very high. In general, the output or drain impedance is similar to that of a junction transistor.

Many older circuit designs called for the use of a 2N3819, 2N4416, 2N5245, etc., junction FET. These can be replaced with an NTE 452 because the electrical parameters closely overlay. The replacement device supports both DC and RF functions closely matching the performance characteristics of the replaced device. Keep in mind that these FETs are interchangeable and will substitute for each other.

Some FETs are designed to function as a switch. When "turned on," the resistance between source and drain is very low, or high when "off." As a result the switch device is a very poor candidate for use in an amplifier circuit. Likewise, an amplifier-type FET would make a poor substitute for an FET switch. NTE does provide a series of suitable replacement devices for FET switches. Some enhancement FETs are used in a switch function when the R_{ds} (resistance, drain-to-source) value is low enough during a hard turn-on condition. Another parameter of an enhancement device to be considered during the selection of a replacement is the biased gate turn-on voltage. When used in an analog/linear function, the bias voltage is set to place the quiescent drain-to-source voltage at approximately the center of the operating swing between cutoff and saturation. Shifting the bias point to accommodate the application may be required if a direct replacement part is not available.

Perhaps the most common application for an enhancement FET is for use in audio, and coupled with a low R_{ds} parameter it is capable of controlling high-power circuits. The internal chip structure is made very large, allowing the FET to handle a very large current. With a resulting large internal gate structure to support the FET control feature, the gate exhibits a high capacitance between the gate and source terminals. The capacitance value can be in the 1,000 pF range, creating a reactance value that effectively eliminates the power enhancement FET from being used in an RF environment.

Fig. 1 shows a junction FET used in a basic linear amplifier circuit. Knowing that an FET is used, the gate impedance can be surmised by examining the value of the R1 resistor. R1 effectively establishes the circuit's input impedance as long as the gate junction is reverse-biased. The circuit's output impedance will be approximately half the value of R2. The value of R3 is selected to adjust the gate bias value for linear operation. Substituting one FET for another in the circuit shown requires only the adjustment of R2 to achieve the desired gain and to adjust the value of R3 to set the bias for the desired linear operating point. Substituting a MOSFET for another in an audio/linear-type circuit follows the same logic and can be replaced using the NTE guide.

RF devices

Both RF transistors and RF FETs become the most difficult to substitute because of the numerous circuit parameters that are directly dependent upon a specific device when used in an RF environment. The most difficult devices to substitute are RF power transistors used in transmitter circuits. As a result, to consider substituting one device for another in an RF power circuit, one must be prepared to change the circuit design parameters to accommodate the "new" device. In general, the RF active board circuit traces, called striplines, are adjusted in length to be resonant at a given frequency and become the "impedance transformer" for a specified transistor.

Below 50 MHz, lumped inductors and capacitors are used in both the input and output matching networks. The input and output impedances of the transistor are known during the board's design phase and are accommodated by the impedance matching networks (lumped or stripline) connected to the transistor. The objective is to create a desired signal current drive level into the transistor's base circuit. As a simple example, if a replacement transistor is mounted into the circuit location designed for a different device, then the input and output impedances may be sufficiently different, preventing the stage to function as designed. As another example, should the substitute transistor exhibit a higher base inductance (L), a correction will be required to shift the reactance toward a resistive (R) condition. The shift can be accomplished by adding more capacitance directly at the transistor base resulting in a reactive shift from L toward R. When a match is achieved, the base drive current will be the highest at the operating frequency. Of course, the collector impedance value will have to be "corrected" in a similar manner to create an output match for maximum power transfer into the next circuit.

Receiver front-end circuits are a little more forgiving for part substitution than are transmitter circuits. One of the very early RF FET choices was the MPF 102 JFET. Being a VHF device, it opened the door for development of sensitive converter and receiver front ends. Some MPF 102 devices are still available from surplus sources. If desired, an MPF 102 may be replaced with an NTE 451 device.

To demonstrate the substitution process for a MOSFET, let's use the circuit shown in **Fig. 2a** as an example. Take note that the single-gate depletion MOSFET (may also be a GaAsFET) is used in a receiver's RF stage. After doing our extensive search for a replacement, we've determined that only a dual-gate GaAsFET is available. The spec parameters of the dual-gate GaAsFET may surpass those of the older single-gate FET, so that the substitution could be for the better. So our only recourse to "save" the receiver is to replace the single-gate FET with the dual-gate GaAsFET, and that means some mechanical and electrical design changes would be required in

Continued on page 28

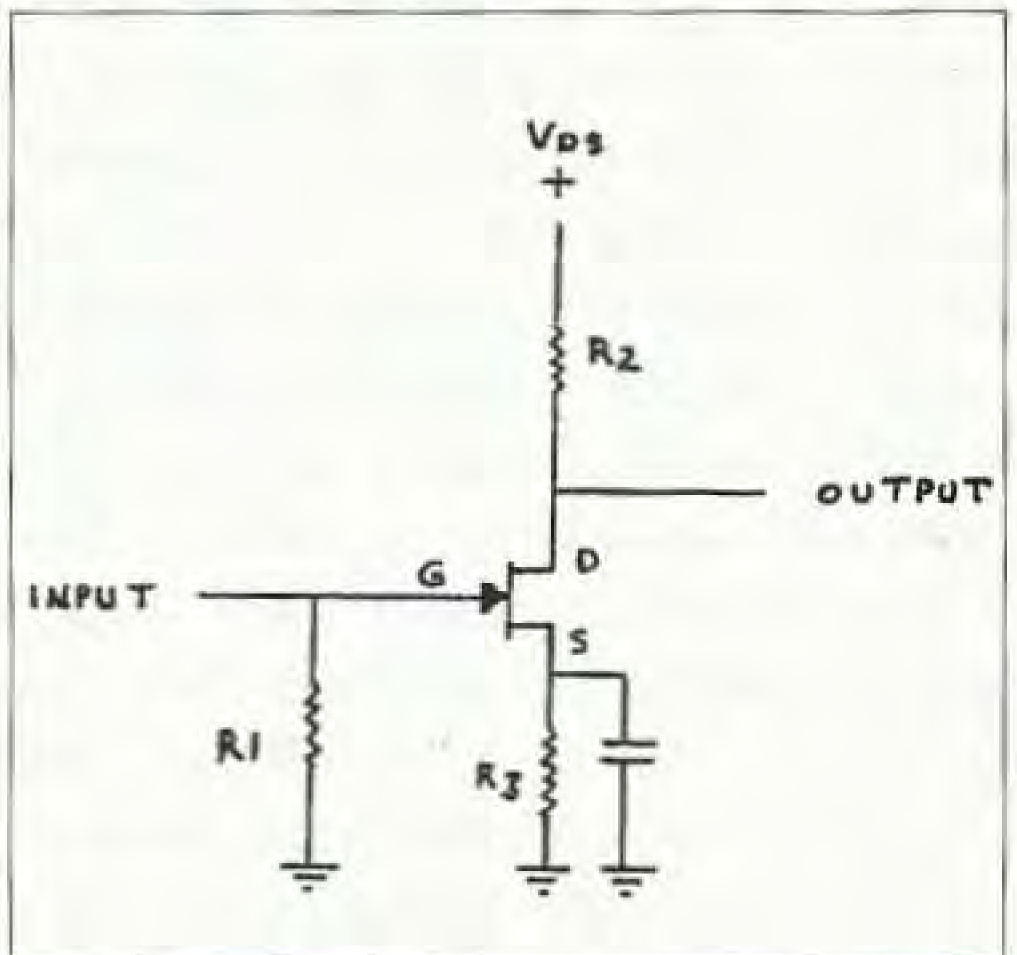
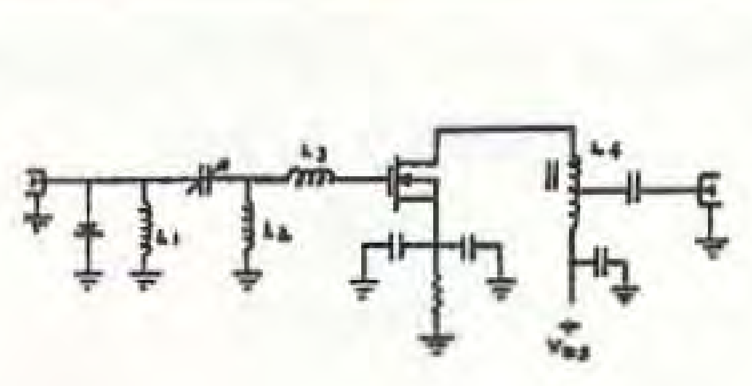
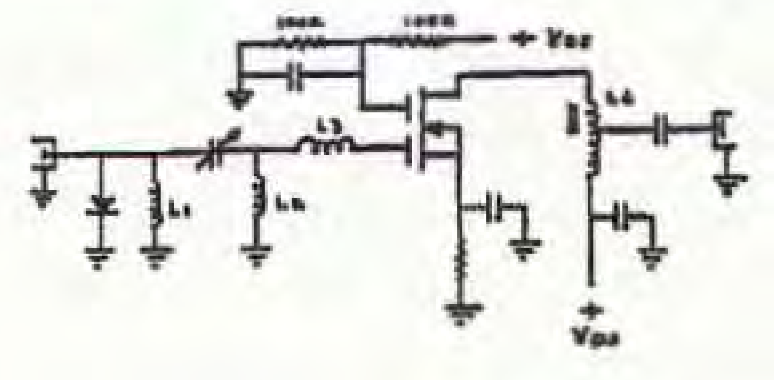


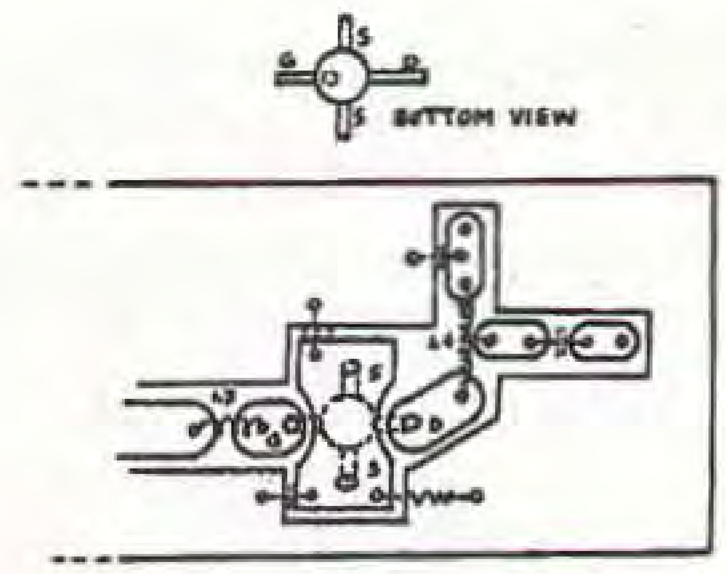
Fig. 1. *A simple depletion JFET as used in a low frequency amplifier circuit. The input impedance is approximately equal to the value of resistor R1. The output impedance is approximately equal to one-half of the R2 value.*



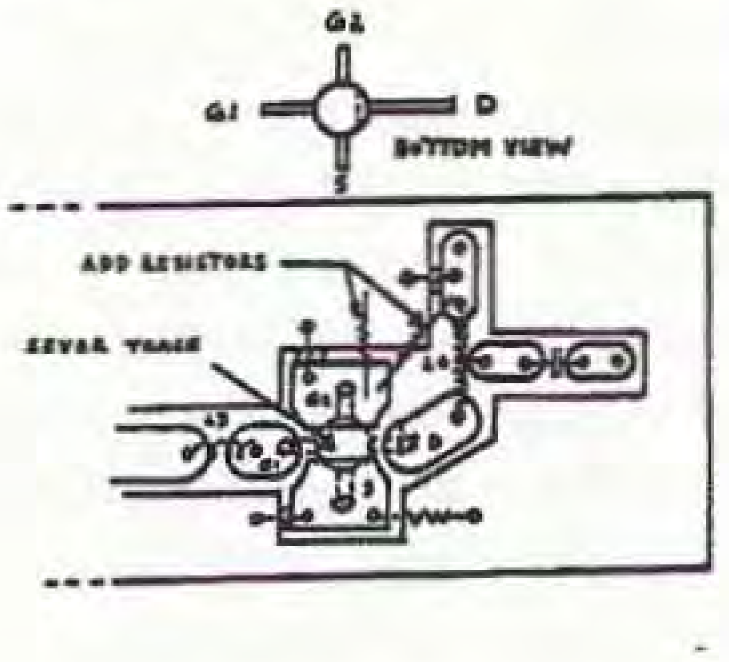
A
Original single-gate GaAs FET RF amplifier circuit.



B
Rf amplifier circuit modified to accept a dual-gate GaAs FET.



C
Typical PC board trace pattern for the single-gate circuit shown in "A".



D
PC board pattern modified to accept the dual-gate FET shown in "B". If the board is double sided, the trace area around the G2 terminal must be relieved, if necessary, to prevent the G2 pin from shorting to ground.

Fig. 2. *Steps involved in converting an RF amplifier circuit and PC board from a single-gate GaAsFET to accommodate dual-gate GaAsFET: **(a)** Original single-gate GaAsFET RF amplifier circuit. **(b)** RF amplifier circuit modified to accept a dual-gate GaAsFET. **(c)** Typical PC board trace pattern for the single-gate circuit shown in (a). **(d)** PC board pattern modified to accept the dual-gate FET shown in (b). If the board is double-sided, the trace area around the G2 terminal must be relieved, if necessary, to prevent the G2 pin from shorting to ground.*

The Ins and Outs of Parts Substitution

continued from page 27

the receiver for it to accept the GaAsFET installation.

Available GaAsFETs that will perform well in a receiver front end are a 3SK121 and a 3SK174. Both are dual-gate devices with an upper frequency cutoff of 2,000 MHz. Some caution must be taken when using a GaAsFET capable of 2,000 MHz in a low frequency circuit. Because of the wide bandwidth capability, long leads within a low frequency circuit could easily support sufficient feedback for the GaAsFET to oscillate. When the choice is available, it is better to more closely match the frequency response of the substitute device with that of the application. NTE provides two dual-gate MOSFETs suitable for most general circuit applications — they are an NTE 454 (200 MHz), and an NTE 455 (900 MHz).

When it becomes necessary to modify the original circuit to replace a single-gate FET with a dual-gate FET, as shown in **Fig. 2**, the following steps are suggested:

(1) Draw out a near to-scale picture of the current FET installation and the surrounding resistors, capacitors, and inductors (**Fig. 2c**).

(2) Draw out the electrical schematic for the existing FET circuit (**Fig. 2a**).

(3) Draw out the schematic for the GaAsFET circuit so as to "fit" or overlay the single-gate circuit with the dual-gate circuit (**Fig. 2b**).

(4) Lay the GaAsFET onto the drawing (#1 above) so that it overlays the single-gate FET footprint. Keep track of the top and bottom side of both the FET and the circuit board.

(5) Make note of the mechanical mounting differences between the two FETs.

(6) Plan the circuit board mechanical changes required to accommodate the GaAsFET (**Fig. 2d**).

(7) Plan where the additional bias resistors will be placed when the GaAsFET is installed.

In step 5, the major differences to be accommodated are the source pins of the flat-pack single-gate device. Both source pins are internally connected in parallel to balance the I/O reactances, and are connected externally to "ground," or through a bias network to ground. The footprint of the dual-gate FET exhibits only one source lead connected to "ground." The opposite lead from the source is the second gate (G2). To accommodate the device substitution process, one "ground" pad for the single-gate device must be isolated from ground, or the bias network, to accommodate the G2 gate of the dual-gate FET. With the pad isolated, the necessary resistor(s) and capacitor may be attached to the pad to support the second gate.

ICs

Substituting IC's is another story. IC's, better known as "integrated circuits," are complex circuits made up of a great number of semiconductors integrated onto a silicon chip with the whole to perform a designated function. Because of the unique function of each specific circuit, the opportunity of finding "another" IC that will function in a like manner is unlikely. However, the possibilities that exist are some basic functional parallels between the early RTL, DTL, and select few of the later TTL and CMOS IC's. With the technological differences between them, some supporting external circuit design considerations must be made for an application to function. When one considers the advancement in the TTL and CMOS series of IC's, there seems to be little need to implement an old RTL or DTL circuit utilizing the later technology since the later technology has so much more functional capability — including reliability.

There are some possible substitutes between the 74XX and 4XXX series of logic ICs should the "need" arise. If implementing a logic circuit from scratch, it is perhaps a better choice to choose one single family of ICs rather than to mix families, even though both may function well with a supply voltage of 5 VDC. Because of the logic threshold voltage differences between TTL and CMOS, though slight, the overall logic function might occasionally glitch when operating at clock speed. However, low speed and step functions are generally accommodated properly even though the families are mixed.

Operational amplifiers

Op amps, unlike digital ICs, are a little easier to substitute. Op amps differ in their performance characteristics, but the basic analog amplifier function of each will adapt to a great many applications. An obsolete or hard-to-find op amp indicated in a schematic can usually be replaced by a later part. The external biasing and feedback networks are fairly constant for most op amp circuits, providing for a routine substitution process as long as the mechanical footprint differences are accommodated.

One of the early op amps is the LM741. Though old in design, it is still a suitable building block for a lot of usable circuits. A dual version of the LM741 is the LM1458 with all of the variants that followed, including the 4558 that was called a precision op amp. The early versions of op amps suffered greatly from "noise" that could be heard as a hiss when the device was used in audio systems. Later versions incorporated JFET input circuits both to reduce the internally generated noise and to raise the input impedance. Because of the large manufacturing volume of the more common op amps, parts continue to remain available for ham applications. Should the need arise, NTE provides a variety of op amps that will replace many of the older part numbers.

Special purpose devices

Over the years, a great number of specialty parts have been developed and then abandoned. One that comes to mind is the tunnel diode. When it was first developed, applications flourished because it was so revolutionary, but being a two-lead device, the total number of applications was limited. The transistor, being more of a universal device, had a wider application capability, and as a result, the tunnel diode fell by the wayside. However, many older circuits still exist that call for a tunnel diode. The Heathkit Tunnel Dipper comes to mind, and because the tunnel diode is a two-lead device, there is no direct substitute for it. Should it be necessary to repair the dipper's function, it's possible that the circuit can be converted to accommodate a transistor.

Another device that is now considered as obsolete is the unijunction transistor. The uni was a very popular device used in oscillators and timing circuits, and for the making of sawtooth generators. Even though the familiar unijunction device is scarce these days, many of the circuits calling for the device can be modified slightly and made functional using a PUT. A PUT is a programmable unijunction transistor that will perform all of the same functions as the original uni, but with the addition of a bias voltage network that's used to establish the "firing" point.

Because of the wide variety of specialty semiconductor devices, it's difficult to provide a general "fix" for the substitution process. At best, I'd suggest that the circuit/application be examined to determine the requirements being imposed on the device. Once those requirements are understood, perhaps a replacement device can be identified along with any circuit changes that might be required to support the replacement device.

Conclusion

Over the years, many circuit designs have been developed to support radio and electronic circuits, with a great many being applicable to ham radio. As the years have passed, the active elements (tubes and semiconductors) used in radio and electronic circuits have evolved, yet very little in the basic circuit design has changed. However, the active element (semiconductor) has been improved, allowing the older circuit designs to perform with renewed vigor.

As we review many of the old circuits,

we occasionally find one of interest and desire to implement it into a project. But to implement the circuit we have to upgrade the active element to one that's available, and that's where we typically run into a problem.

How do we identify a modern device to replace the old device shown in the schematic of our desired project — particularly when our parts supply is shrinking. The "fun" begins with a journey through a search process leading us through catalogs, reading specification sheets, doing Internet searches, and doing design overlays to identify parallels between old and new parts. In some cases, it becomes necessary to make minor circuit and circuit board design changes to accommodate the newly selected replacement part.

From my observation, the person who gains the most from the substitution process is the person who learns how to work their way through the process maze. 73!

Reference and search information

(note: This is only a representative/ sample listing.)

Books

Cordura Co.
D.A.T.A. Reference Standards
9889 Willow Creek Rd.
PO Box 26875
San Diego, CA 92126
619-578-7600

Catalogs

Allied Electronics, 1-800-433-5700.

Digi-Key, 1-800-344-4539, [www.digikey.com].

Hosfelt Electronics, 1-800-524-6464.

Jameco, 1-800-831-4242, [www.jameco.com].

Mouser Electronics, [www.mouser.com].

Newark Electronics, [www.newark.com].

Radio Shack, [www.radioshack.com]

Internet forums

[http://listserv.lehigh.edu/lists/qrp-l/], group information.

[qrp-l@Lehigh.EDU], post messages to QRP-L.

[gqrp-subscribe@yahoogroups.com], GQRP message group.

[www.gqrp.com], GQRP Internet conference.

[http://groups.yahoo.com/group/Buddipole/].

[http://www.hfpack.com], group/information.

[hfpack@yahoogroups.com], post messages.

Internet parts searches

Appleton Electronics, [www.appletoneg.com].

Chip documents, [www.chipdocs. com].

NTE, [www.nteinc.com].

PartMiner, [www.freetradezone.com].

Questlink, [www.questlink.com].

Science Electronics, [www.repairfaq.org/REPAIR/F_Obsol_IC.html].

Transistors, [http://members.tripod.com/Malzev/comp/transist.htm].

Manufacturer data

Fairchild, [http://e-www.motorola.com].

Mitsubishi, [www.mitsubishi-chips.com/data/datasheets/hf-optic/vhf_discrete.htm].

Motorola, [http://e-www.motorola.com].

National Semiconductor, [www.national.com/design/index.html].

Texas Instruments, [www.ti.com/sc/docs/eedesign.htm].

Obsolete parts

— [http://www.aeri.com]

Circuit Solutions, [http://www.cirsolutions.com/head.htm]

Excess Electronics, [http://www.excesstrade.com/]

IhI Electronics, [http://www.ihielectronics.com]

Obsolete Semiconductors, [http://www.adsemi.com/]

Rochester Electronics, [http://www.rocelec.com/]

Star Electronics, [http://www.4star-electronics.com/]

Parts suppliers

1-Source Electronics, [www.1source-components.com].

All Electronics Corp., PO Box 567, Van Nuys CA 91408; 1-800-826-5432; [allcorp@allcorp.com].

B&D Enterprises, [www.bdent.com].

Circuit Solutions, [www.cirsolutions.com].

Dan's Small Parts, [www.danssmall-partsandkits.net].

Electronix On-line, [www.electronix.com/catalog].

Mitsubishi, [www.mitsubishi-chips.com/data/datasheets/hf-optic/vhf_discrete.htm].

NTE, [www.nteinc.com].

Radio Shack, [www.radioshack.com].

RF Parts, San Marcus CA, [www.rfparts.com].

Sanyo Semiconductors, [www.semic.sanyo.co.jp/index_e.htm].

Westgate, 1-800-213-4563. 73