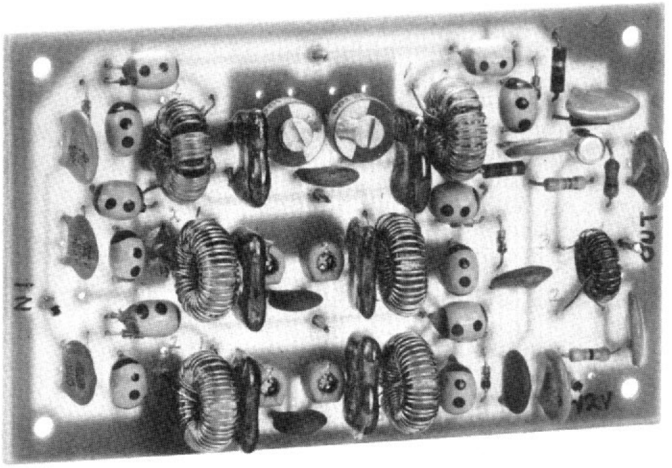
A Diode-Switched Band-Pass Filter



High-speed silicon diodes work well as RF switches. This article describes how to use diodes for selecting two or more filters.

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There's nothing new about analog switching with diodes or transistors. If you have not used diodes for this application, there may be some stumbling blocks for you to overcome. The purpose of this article is to provide simple guidelines you can apply when using diodes to switch audio and RF circuits. It's easy, and often less expensive than working with mechanical switches.

Solid-state switching enables us to use dc voltage to actuate the diode switches, thereby negating the need to use several coaxial leads between a conventional switch and the circuits to be switched. In essence, we end up with a neater package when we use diodes.

How the Switches Function

Fig 1 shows three band-pass filters that are selected remotely by means of a dc control voltage that causes four diodes to conduct each time a different filter is switched into the circuit. Forward (positive) bias is applied to the diode anodes to make this occur. D2 and D3, along with D4 and D5, are in series with the signal lines for FL2. The other two filters and their diodes are configured the same way. A dc path to ground is needed for each of the diodes when we want them to turn on. Using FL2 as our example, D2 and D5 return to ground via RFC2 and RFC5, respectively. D3 and D4 obtain their paths to ground through the links on T6 and T7. RFC2 through RFC5 prevent the signal from being routed to ground.

R43 acts as a current-limiting resistor for all the diodes in Fig 1. Without it the diodes would draw excessive current and burn out. The value of R43 must be chosen to regulate the amount of current that flows through each of the switching diodes.

This circuit calls for 1N914 silicon diodes. In my version, approximately 10 mA of current flows through the diodes, ensuring that they are completely turned on. Too little junction current causes them to conduct partially; this results in high signal loss through the switches. The diodes remain cool at 10 mA of current. I do not recommend more than 20 mA of sustained current through the 1N914 family of diodes, even though they are rated for 50 mA of maximum current.

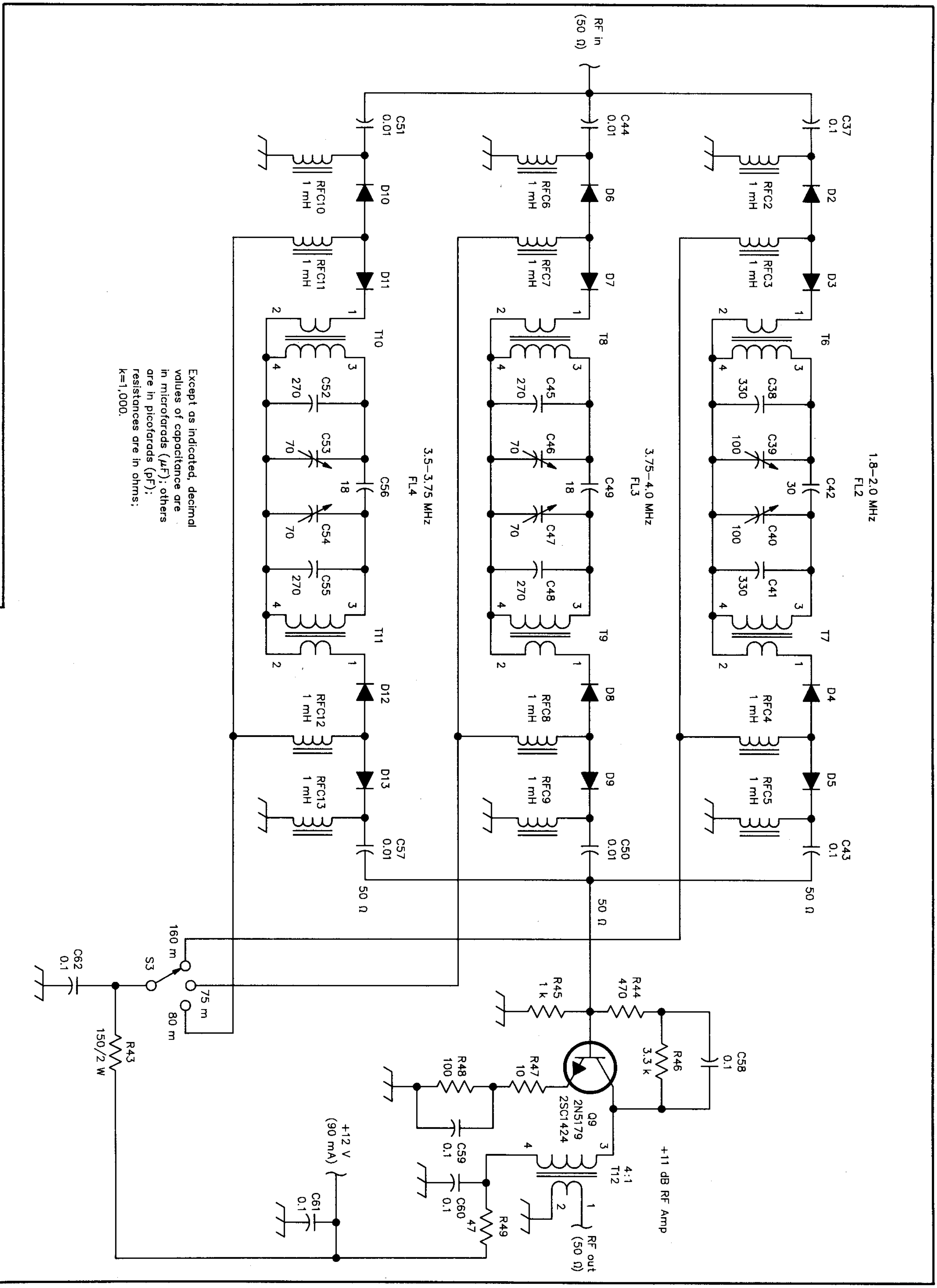
Although a single diode can be used for filter input-output switching, the isolation between filters would be poor. With the back-to-back diodes in Fig 1, I am able to measure 26 dB of isolation between any two input or output ports on the circuit board. I used a scope (a Tektronix 453A at 50 ohms) for all my Fig 1 measurements, which is not the most precise way to make critical measurements. Therefore, the isolation may be somewhat better than 26 dB.

The RF chokes associated with the switching diodes need to have an inductive reactance (X_L) of no less than 4 times the circuit impedance. In other words, make sure your RF chokes have an X_L of at least 200 or, preferably, much higher. The required inductance for the chokes is found from $L(\mu H) = X_L/2\pi f(MHz)$. Thus, if we want an X_L that is 10 times 50 ohms, the RF choke must provide an X_L of 500 ohms. Using the foregoing equation, we find that for 1.8 MHz we need an inductance of 44.2 μH. A choke of this value (500 X_L) in parallel with 50 ohms lowers the effective input-circuit impedance to 45 ohms, and this is what we must keep an eye on if we are to maintain an impedance match between mating circuits. An X_L of 11,500 results in an RF choke of roughly 1000 μH or 1 mH. The 1-mH choke in parallel with the 50-ohm filter input impedance results in an effective impedance of 49.78 ohms, which is entirely acceptable.

In our circuit we have two 1-mH RF chokes that are effectively in parallel when

Fig 1—Schematic diagram of the diode-switched band-pass filters. Fixed-value capacitors within the filter circuits are silver mica or NP0 disc ceramic. All other fixed-value capacitors are disc ceramic, 50 V. Resistors are ¼-W carbon film or carbon composition, except for R43. This circuit was originally designed to be part of an SSB exciter, so some components are numbered as they are in that project.

C39, C40—100-pF ceramic or mini mica compression trimmer. Mouser Electronics no. 24AA034 used in this project.
C46, C47, C53, C54—Miniature 70-pF trimmer. Murata brand used in this project.
D2-D13, incl—1N914 or equivalent silicon small-signal diode.
Q9—High f_T NPN transistor, 2N5179, 2SC1424 or 2N5770.
RFC3-RFC13, incl—Miniature encapsulated RF choke, 100 μH. Mouser Electronics no. 43LR103 or equiv.
S3—Single-pole, three-position rotary switch.
T6, T7—17.68-μH toroidal transformer. 30 turns no. 26 enam wire on an Amidon Assoc FT50-63 ferrite toroid. Link has 4 turns of no. 26 wire over grounded end of main winding.
T8, T9—5.3-μH toroidal transformer. 36 turns of no. 26 enam wire on an Amidon Assoc T-50-6 powdered-iron toroid. Link has 5 turns of no. 26 enam wire.
T10, T11—6-μH toroidal transformer. 38 turns of no. 26 enam wire on an Amidon Assoc T-50-6 powdered-iron toroid. Link has 6 turns of no. 26 enam wire.
T12—20 turns of no. 28 enam wire on an Amidon Assoc FT37-43 ferrite toroid. Secondary (output) winding has 10 turns of no. 28 enam wire.



RF in (50 Ω)
C37 0.1
C44 0.01
C51 0.01
RFC2 1 mH
RFC6 1 mH
RFC10 1 mH
D2
D6
D10
RFC3 1 mH
RFC7 1 mH
RFC11 1 mH
D3
D7
D11
T6
T8
T10
1.8–2.0 MHz FL2
3.75–4.0 MHz FL3
3.5–3.75 MHz FL4
C38 330
C39 100
C42 30
C40 100
C41 330
C45 270
C46 70
C49 18
C47 70
C48 270
C52 270
C53 70
C56 18
C54 70
C55 270
T7
T9
T11
D4
D8
D12
RFC4 1 mH
RFC8 1 mH
RFC12 1 mH
D5
D9
D13
RFC5 1 mH
RFC9 1 mH
RFC13 1 mH
C43 0.1
C50 0.01
C57 0.01
50 Ω
50 Ω
50 Ω
Except as indicated, decimal values of capacitance are in microfarads (μF); others are in picofarads (pF); resistances are in ohms; k=1,000.
160 m
75 m
80 m
S3
C62 0.1
R43 150/2 W
R45 1 k
R44 470
R46 3.3 k
C58 0.1
R47 10
R48 100
C59 0.1
Q9 2N5179 2SC1424
+11 dB RF Amp
4:1 T12
C60 0.1
R49 47
+12 V (90 mA)
C61 0.1
RF out (50 Ω)

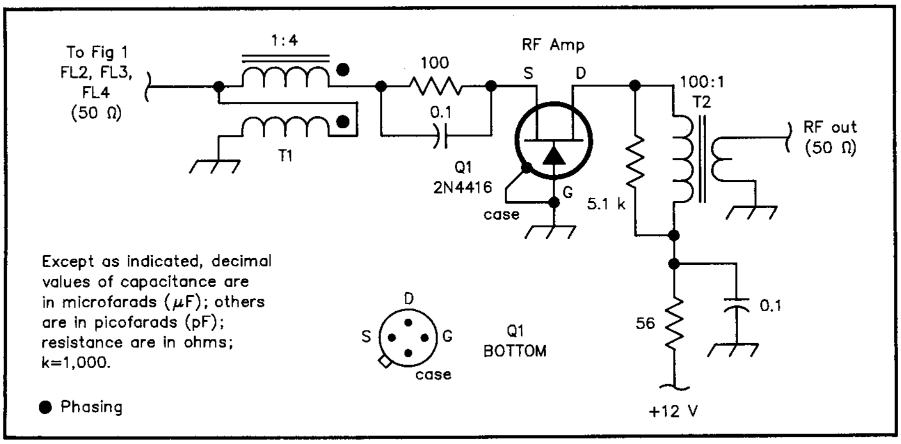


Fig 2—Schematic diagram of a common-gate JFET amplifier that may be substituted for Q9 of Fig 1 when the filter module is used as a receiver front end. Capacitors are disc ceramic and resistors are ¼-W carbon-film or carbon-composition types.

T1—4:1 broadband transformer. Use 15 bifilar turns of no. 28 enam wire on an Amidon FT37-42 ferrite toroid.

T2—Broadband transformer, 10:1 turns ratio. Primary has 30 turns of no. 28 enam wire on an Amidon FT50-43 ferrite toroid. Secondary has 3 turns of no. 28 enam wire.

the diodes are conducting. Therefore, the effective X_L of the chokes is 5750 ohms. This leaves us with a filter input and output impedance (effective) of 49.56 ohms. This is still okay for ensuring that our filters have a 50-ohm termination. These considerations are more than subtle. Some hams overlook them when designing a circuit, and performance can be less than desired when the impedances are too low.

Better port-to-port isolation is possible by changing the diode-switching circuit so that when the switches are in the OFF mode their anodes are grounded and their cathodes have reverse voltage applied to them (+12 V). This complicates the mechanical switching at S3. The reverse bias on the diodes turns them off more completely than with the arrangement shown in Fig 1.

The Overall Filter Board

You are probably wondering what the filter module is used for. I designed it for use in an SSB exciter I am developing. The Fig 1 circuit follows the mixer in my exciter. (This accounts for the nonstandard component numbering.) A string of RF power amplifiers is used after the filter assembly. The board accommodates 160, 80 and 75 meters. There is no reason filters could not be added for all the HF bands. Q9 is a fed-back, broadband class-A linear amplifier. It has a gain of 11 dB. I tried a 2N2222A and a 2N4401 at Q9. Those devices worked fine, but provided 2 dB less gain than the 2SC1424, which is similar to the more common 2N5179 transistor.

FL2 through FL4 are based on the Butterworth-filter equations. Ripple is 0.5 dB and the insertion loss is 2 dB or less. The end impedance of the three filters is about 3900 ohms. FL2 is 3900 ohms, FL3 is 3895 ohms and FL4 is 3860 ohms. This provides the information needed to determine how many turns are required for the input and output links of the filter input and output transformers. The links are calculated to provide a match between 50 ohms and the characteristic impedances of the filters.

The circuit in Fig 1 is adaptable for use as a broadband input circuit for a ham receiver. It can be used as shown, but Q9 is a tad noisy for a receiver front end. I would modify the Q9 amplifier to a grounded-gate 2N4416 JFET. The stage gain would be on par with that for the circuit shown, but the noise figure would be substantially lower. Fig 2 shows a 2N4416 as an RF amplifier.

The overall gain for the filter module is approximately 8 dB on each band. The losses occur in the filters and the diode switches. Some losses occur also in the input and output transformers of the filters.

Q9 of Fig 1 uses a broadband 4:1 transformer in the output circuit. This transformer is used to match 50 ohms to the 200-ohm collector impedance of Q9. Owing to the feedback used at Q9, its input (base) impedance is 50 ohms, making it suitable for terminating the three filters.

Practical Considerations

The filter module is assembled on a single-sided PC board that measures 2½ × 4¼ inches. PC boards, the circuit-board etching pattern and the part overlay for this project are available from FAR Circuits.[1]

T6 through T12 are mounted vertically on the PC board. Following circuit check-out you may wish to affix the bottom of each transformer to the PC board by applying epoxy cement. This prevents stress on the transformer leads during handling or vibration, such as in mobile service.

I hope these tips are helpful to you. Certainly, the use of diode switches is practical and inexpensive. If nothing more, it enables you to locate the band switch any convenient distance from the circuits that are switched.

[1]FAR Circuits, 18N460 Field Ct, Dundee, IL 60118, tel 708-426-2431 after 6 PM Central Time. Price: $5, plus $1.50 shipping per order to US addresses.

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□ Solid-state amplifier maker RF Concepts has introduced the rfc 2/70, a dual-band class-C amplifier intended for use with 144/440-MHz hand-held transceivers. Featuring 30 W output on 2 meters and 25 W output on 70 cm (5 W drive per band) and automatic band switching, the amplifier measures 2 × 3.5 × 8 inches (HWD). A version with dual, RF-sensed-switching GaAsFET preamplifiers (rfc 2/70G) is also available. PIN diodes protect the GaAsFET preamps from transmitter RF. Both models feature fast TR switching (less than 20 ms) for packet-radio compatibility.

Manufacturer's suggested retail prices: rfc 2/70, $239; rfc 2/70G, $269. For more information, contact RF Concepts, PO Box 11039, Reno, NV 89510-1039, tel 702-827-0133, fax 702-827-0134.—*NJ2L*

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