Use Transmitting Power FETs For Antenna Switching

This novel design uses a transceiver's power-amplifier devices for antenna switching, reducing parts count, mismatch, and insertion loss.

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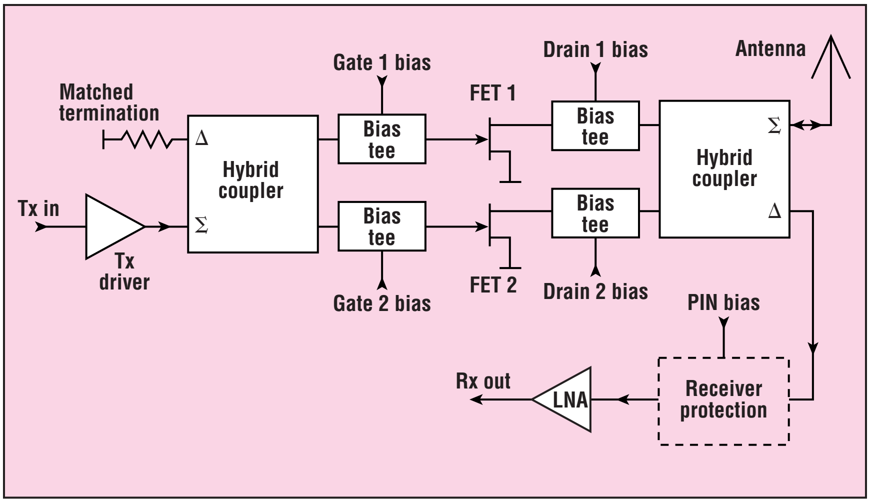
IN transceivers that do not use a non-reciprocal device (i.e., a circulator), the antenna switch requires at least two switching devices—one for transmit mode and one for receive mode—regardless of the technology used to build the switch. For example, a mechanical antenna relay requires at least two contacts, a positive-intrinsic-negative (PIN)-diode antenna switch requires at least two diodes, and a gallium-arsenide field-effect-transistor (GaAs FET) antenna switch requires at least two FETs. Even more switching devices may be required for higher power handling or improved switch isolation. But every switching device contributes some impedance mismatch and increases the insertion loss of the antenna switch. Therefore, it makes sense to look for solutions with a reduced number of switching devices to improve the electrical performance of the transceiver.

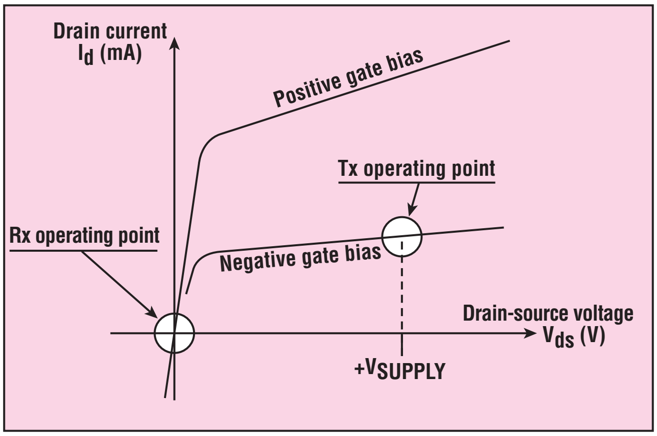
This article presents a K-band receive/transmit module design that does not require any additional components for antenna switching. In this design, the same transmitter power devices are biased in a different way during reception to route the RF signal from the antenna to the Rx input. In addition to reducing the number of switching components, this design can reduce the insertion loss in receive and transmit modes.

In most simplex radio transmitters, it is possible to control the out-



1. This schematic demonstrates antenna switching with transmitting power devices.

put impedance or reflection coefficient by properly adjusting the bias point of the output-power device(s) in the power-off state during Rx operation. This technique has often been used at low frequencies (below 30 MHz) to save one switching component in the antenna switch. The same technique can be used at microwave frequencies[1] by making the Tx output fully reflective when powered off.



2. This graph shows the power FET operating points.

In radio transmitters with more than one power device in the output stage, the designer has more degrees of freedom to adjust the bias points of the single power devices independently in the power-off state, as shown in Fig. 1. During transmission, the two power FETs are combined with two hybrid couplers. During reception, the bias points of the two power FETs are adjusted so that the signal coming from the antenna is reflected into the Rx.

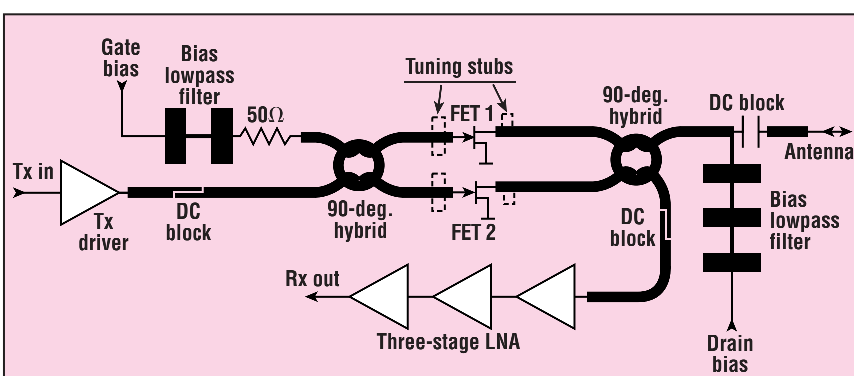
Reflecting the incoming signal from the antenna into the Rx during reception can be achieved by using in-phase power dividers and combiners, or by using quadrature hybrids. Using in-phase power dividers and combiners (like rat-race hybrids), the two FETs have to be biased in a different way to provide a 180-deg. difference in the phases of their output refection coefficients. For example, one FET is turned on while the other FET is turned off. Using quadrature hybrids, the two FETs have to present the same output reflection coefficient with the same phase during reception. The quadrature hybrid splits the received signal from the antenna into two signals with a 90-deg. phase shift. After these two signals are reflected in the same way by the two power FETs, the quadrature hybrid introduces yet another 90-deg. phase shift so that the two reflected signals subtract on the antenna port and sum on the Rx input.

In both cases, a Rx-protection circuit may be required if the expected transmitter unbalance power is high enough to damage the receiver's front end. Of course, worst-case conditions have to be considered. These conditions can include maximum device mismatch and load conditions, such as a disconnected or obstructed antenna. The receiver protection may include a limiter and/or a shunt PIN-diode switch. In low-power transceivers with less than 200-mW transmitter power, the maximum unbalance power is usually too low to damage the receiver, so no special receiver-protection circuit is required.

Although the geometry of popular transmitting-power FETs is probably not optimized for operation as RF switches, most GaAs FETs provide useful switch performance, as shown in Fig. 2. During transmission, the dynamic-channel resistance is closely matched to the system's characteristic impedance (usually 50 Ω). With the drain bias removed, the I_d-versus-V_{ds} curve becomes much steeper, resulting in a ten-fold decrease of the channel resistance. If a small positive bias is applied to the gate, the channel resistance is further halved, resulting in an output reflection coefficient close to –1. On the other hand, if a highly negative bias is applied to the gate, the FET channel resistance will increase to very high values, resulting in a reflection coefficient close to +1 at low frequencies. In either case (FETs on or off), not much additional noise is generated with the drain bias removed, resulting in very little reduction in the sensitivity of the receiver.

To demonstrate the feasibility of the proposed antenna-switching design, the author built and tested a practical low-power transceiver front end for the 24-GHz industrial-scientific-medical (ISM) band. It includes a Tx driver stage, an output stage with two FETs, and a three-stage low-noise amplifier (LNA). While easy-to-use and inexpensive packaged pseudomorphic high-electron mobility transistors (PHEMTs) originally designed for 12-GHz TVRO downconverters still provide useful performance at 24 GHz, finding cheap and easy-to-use RF switching components for 24-GHz applications is more difficult. An efficient alternative was finally found by performing the Rx/Tx antenna switching with the same Tx power devices.

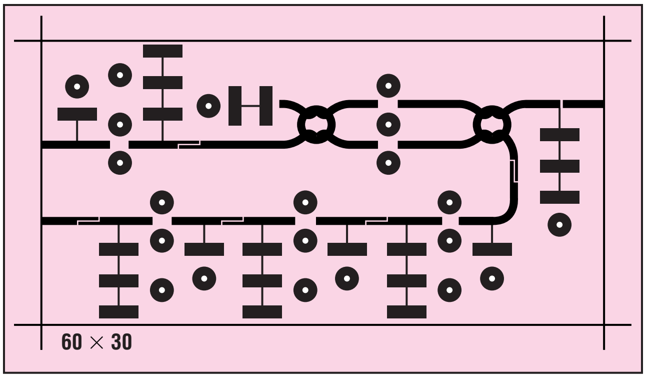
The simplified circuit diagram of the 24-GHz transceiver front end is shown in Fig. 3. Due to circuit parasitics, the phases of the reflection coefficients are difficult to control at 24 GHz. At high frequencies, it is simpler to obtain two reflections with the same phase rather than two reflections exactly 180 deg. out of



3. This is the simplified circuit diagram for a 24-GHz transceiver front end.

phase. Thus, the author decided to use quadrature hybrids and apply the same bias to both transmitter output FETs.

The practical circuit uses ATF35076 packaged PHEMTs in all stages. According to the manufacturer's data sheet,[2] these devices are not specified above 18 GHz, so tuning stubs are required to obtain 7 to 8 dB of small-signal gain at 24 GHz. With an input of +10 dBm (at 24 GHz) to the driver and +4-VDC output-stage drain bias, a saturated power of 95 mW could be measured with an HP8485A thermocouple and an HP435A power meter on the antenna connector.



4. The 24-GHz front-end microstrip board layout measures 60 × 30 mm on soft laminate.

The unbalance power on the LNA input can be made arbitrarily low with circuit tuning. Even without specific tuning, the unbalance power remained well below the +10-dBm input damage level[2] of the ATF35076 PHEMT. Therefore, no special receiver-protection circuit was required in this application. The three-stage LNA gain is approximately 22 dB, including the antenna-switch insertion loss.

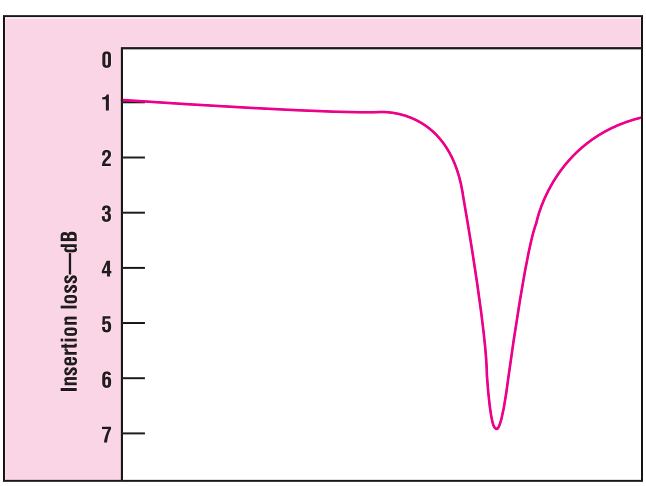
The 24-GHz transceiver front end is built as a microstrip circuit on 0.25-mm (10-mil)-thick, fiberglass-Teflon laminate with 35-µm copper on both sides (ARLON DiClad 870, which has a dielectric constant of 2.33). The microstrip-board pattern shown in Fig. 4 measures 60 × 30 mm. Since the Teflon board is quite soft, the bottom side is soldered to a 0.3-mm-thick brass plate for mechanical support.

The 1/8-in. (3.2-mm)-diameter holes in the microstrip board are used either for grounding the source leads of the PHEMTs to the brass-plate groundplane or for accommodating feedthrough capacitors required for the various supply voltages. Most DC blocks are built as quarter-wavelength coupled lines. Since it is difficult to etch very narrow slots in 35-µm-thick copper, the actual slots are too wide and the resulting mismatch has to be compensated with the tuning stubs.

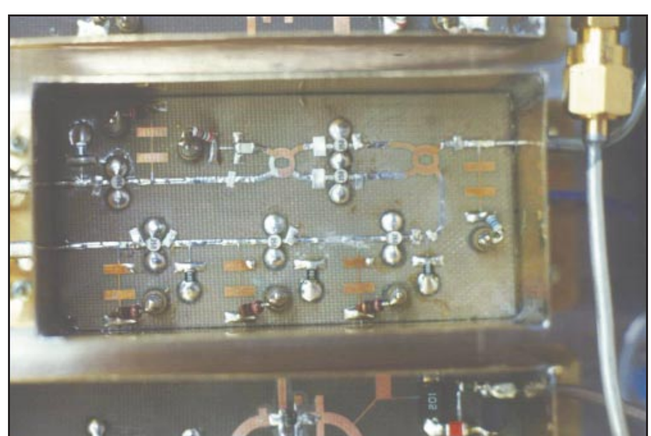
The only exception is the antenna's DC block, which is a discrete capacitor made from a small rectangular piece of double-clad, 0.13-mm (5-mil)-thick Teflon laminate soldered on top of the output microstrip line. The width of this capacitor matches the microstrip width, while the length is one-quarter wavelength. The top electrode is connected to a microstrip by a small piece of tinned-copper foil.

The microstrip circuit board includes a few additional components, including bias networks for all amplifier stages. All three stages of the receiving LNA and the transmitter driver operate at zero gate bias for maximum gain. Although the PHEMTs provide some useful gain at 24 GHz, their insertion gain increases quickly at lower frequencies. If no special countermeasures are taken, a 24-GHz amplifier design will most likely self-oscillate at or below 15 GHz. One must carefully design the bias networks to prevent these unwanted oscillations at low frequencies. Therefore, all bias networks include a lowpass structure terminated into a resistor toward ground or the bias feedthrough capacitor. The lowpass structure is designed to reflect K-band signals while terminating lower frequencies into the following resistor. The unwanted low-frequency gain is further reduced by the resonant quarter-wavelength, coupled-line DC blocks.

Unfortunately, the described countermeasures are not enough to ensure the stability of the transmitter output stage. Its two quadrature hybrids represent a near-perfect short circuit at frequencies below 5 GHz. Push-pull oscillations of the output stage are therefore possible below 5 GHz. These oscillations are



5. This graph shows the measured Rx insertion loss.



6. This photo shows the 24-GHz front end with cover and absorber removed.

suppressed by carefully selecting the lengths of the lines connecting both gates and drains to the corresponding hybrids. In particular, the drain lines must be longer than the gate lines.

The same drain- and gate-bias voltages are applied to both output PHEMTs through the quadrature hybrids. The drain-bias network includes a simple lowpass structure, while the gate bias is applied through the 50-Ω termination on the difference port of the hybrid. The 50-Ω termination is a 0805-size SMD resistor, installed "upside-down" with the resistive layer facing the printed-circuit board (PCB).

Figure 5 shows the measured receiver insertion loss as a function of the gate-bias voltage, with an estimated absolute accuracy of ±0.5 dB. As expected, the insertion loss is low (approximately 1 dB) for both a positive gate bias (approximately +0.65 VDC) as well as a large negative gate bias –2.5 VDC). The drain supply of the transmitter output stage is, of course, switched off during reception. The gate current is limited by a resistor when a positive bias is applied.

Figure 6 shows the entire 24-GHz front end with the cover and absorber removed. Since the whole microstrip board is rather large in terms of the operating wavelength, microwave-absorbing foam is required to kill high-Q cavity resonances when the microstrip board is installed in a shielded case. The best place to install the microwave-absorbing foam is on the entire underside surface of the cover.

THE DESCRIBED FRONT END REQUIRES NO ADDITIONAL COMPONENTS FOR ANTENNA SWITCHING

The positions of the tuning stubs were found to be reproducible when using the same transistors on the same circuit-board material. Of course, the construction tolerances have to be kept tight during the assembly of the circuit—especially the spacing of the coupled lines and the positioning of the PHEMTs on the board.

The described 24-GHz, ISM-band transceiver front end requires no additional components for antenna switching. There is no additional insertion loss for the transmitter, since all components used for antenna switching are already part of the transmitter. The receiver insertion loss is reasonably low and is comparable to conventional PIN-diode or GaAs-FET switches.••

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