

# RESEARCH TRAINING IN WIRELESS COMMUNICATION FOR EXTRATERRESTRIAL EXPLORATION

Aaron Ohta  
Department of Electrical Engineering  
University of Hawai'i at Manoa  
Mentor: Dr. Wayne Shiroma

## ABSTRACT

The basic operation of a 5-GHz wireless transmitter is presented, along with the characterization of Fujitsu FHX35LG high electron mobility transistors (HEMTs) for use in a transmit/receive (T/R) switch. To allow switching at high frequencies, chip inductors are used to compensate for the parasitic capacitances inherent in the transistors. A single FHX35LG HEMT provides 17.0 dB of isolation at 5 GHz, with an insertion loss of 1.2 dB.

## INTRODUCTION - WIRELESS COMMUNICATIONS

In space exploration, wireless transmission of data is a key link to many important pieces of equipment. This technology has been applied to past space expeditions, and continues to be improved for use in future missions. For example, the Sojourner rover used in the 1997 Mars Pathfinder mission, as well as the Marie Curie rover that is to be launched on the Mars Surveyor 2003 mission, both receive and transmit wireless data. (A larger lander "control center" "talks" to the rovers via a UHF radio modem, at a speed of 9600 baud [1]).

In order to gain understanding and experience in the field of wireless communications, a wireless transceiver project was undertaken, in conjunction with Dr. Wayne Shiroma's students. (A transceiver consists of a transmitter and receiver unit.) This researcher's main contribution to the project included assisting in the design and fabrication of a transmit/receive (T/R) switch. In addition, in order to understand the concepts involved in the wireless transmission of data, research training was undertaken in the design of a wireless transmitter. To contribute to the clarity of this report, the basic operation of a wireless transmitter is explained first, followed by a description of the work done on the T/R switch.

The fundamental elements of a wireless transmitter are shown in Fig. 1 below:

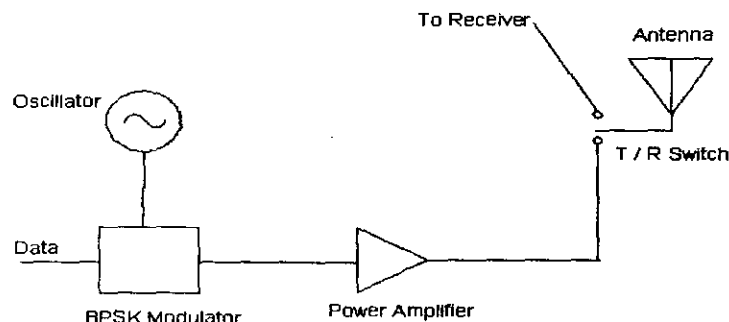


Fig. 1: Transmitter block diagram

The oscillator provides the signal upon which the data is carried. It does this by converting a direct-current (DC) voltage into a sinusoidal output at a certain frequency. The output frequency of the transmitter that was designed and built is 5 gigahertz (GHz). The operating frequency was chosen as 5 GHz because of future wireless applications. Currently, personal communication devices (e.g. cordless phones) operate at frequencies ranging from 900 MHz to 2.4 GHz, but in the near future the frequency allocation of these devices will probably shift to the 5 GHz range. Thus, the design of a 5 GHz transmitter may soon have mass-consumer applications as well.

The modulator is the mechanism by which the data is put onto the 5-GHz signal. A binary phase shift key (BPSK) modulator is implemented for this transmitter. The function of the modulator is to place data onto the outgoing signal from the transmitter. This is achieved by altering the phase of the sinusoidal output signal by 180 degrees. Thus, depending upon the degree of the phase shift (0 or 180 degrees), the receiver can decode the data signal, in the form of digital bits.

The power amplifier's main purpose is to boost the power of the output signal, in order for the transmitter to have the longest range possible. It does this in three stages, using MESFETs (metal semiconductor field effect transistors).

## INTRODUCTION - TRANSMIT/RECEIVE (T/R) SWITCH

As mentioned above, this transmitter design was just one portion of an overall wireless transceiver project. In order to integrate a wireless transmitter and receiver operating in half-duplex mode, a T/R switch is necessary. (A half-duplex transceiver allows only transmission or reception of data at any given time, and never simultaneously.)

The T/R switch performs the equivalent function of a simple switch. As shown in Fig. 1 above, both the transmitter and receiver share the same antenna in the final transceiver design. However, the transmitter is designed to output high levels of power, while the receiver is designed to receive signals with very low power levels. Therefore, if the receiver is connected to the antenna at the same time the transmitter is transmitting a signal, the excessive power may cause the receiver components to fail. Thus, a switch is needed so that only one side of the transceiver (either the transmitter or receiver) is connected to the antenna at any given time. Although such a switch may seem simple, at high frequencies the transmitter signal will not be completely cut off by a mechanical switch (so a switch such as a light switch will not work). Therefore, this switch will be implemented using transistors configured to act as switches. Since a field effect transistor (FET) can be modeled as a single-pole, single-throw switch (similar to a light switch), test fixtures to characterize the FET for this type of operation were created. Gallium arsenide (GaAs) FETs were chosen for the T/R switch as they have been shown to provide fast switching times, multi-watt capability, and low insertion loss when used as switching elements. Since GaAs FETs are often used as economical, high-performance microwave switches in phased-array systems and electronic warfare applications, they are ideal devices for a T/R switch [2].

FETs contain three terminals: drain, source, and gate. The FET can operate as a switch by allowing electrical current to flow from the drain to the source, with the gate acting as the controller of the drain-to-source current. Normally, when the gate and source of the FET are at the same electrical potential, current flows freely from drain to source. When a negative DC bias

voltage is applied across the gate and source of the transistor, an electrical “depletion region” is formed, blocking current from flowing. Thus, the FET is switched on by applying zero voltage across the gate and source, and switched off by applying a negative voltage across the gate and source.

### SERIES TEST CONFIGURATION

Networks can be characterized by a set of standards called S-parameters, which are measured in decibels (dB). A two port network (containing an input, port one, and an output, port two) is characterized by four S-parameters: S11, S12, S21, and S22. S11 is the input reflection coefficient: it represents the amount of a signal reflected back to port one when a signal enters that port. S21 represents the forward gain of a network. Correspondingly, S22 is the output reflection coefficient, while S12 is the reverse gain [3].

The S-parameter of most concern in testing a switch is S21. When the switch is closed, a negative value of S21 represents the amount of the signal lost due to the switch. This is referred to as the insertion loss. When the switch is open, S21, again negative, represents the amount of the signal that “leaks” through, otherwise known as the isolation. Thus, for the T/R switch, high isolation was needed, on the order of -30 dB, along with as low insertion loss as possible (preferably less than -1 dB).

The test fixture shown in Fig. 2.1 was constructed to characterize a transistor’s switch properties. This test fixture consisted of a single transistor with its drain and source leads connected to 50-Ω transmission lines made of copper tape. The width of the 50-Ω lines was found to be 96 mil for Rogers Duroid 5880 (31 mil thick), using Microwave Office, a microwave simulation program. A 50-Ω through line was also fabricated to ensure that the transmission line width was correct. Initially, the Agilent ATF-10736 transistor was chosen due to its excellent performance at high frequencies.

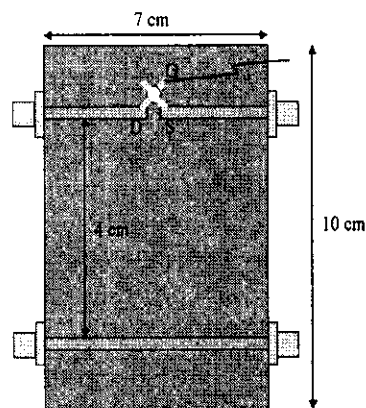


Fig. 2.1: The transistor / 50-Ω through line test fixture used in initial tests. Note: Blue line represents 30-gauge wire used to give DC bias to transistor gate lead. Drain, gate, and source are labeled as D, G, and S respectively.

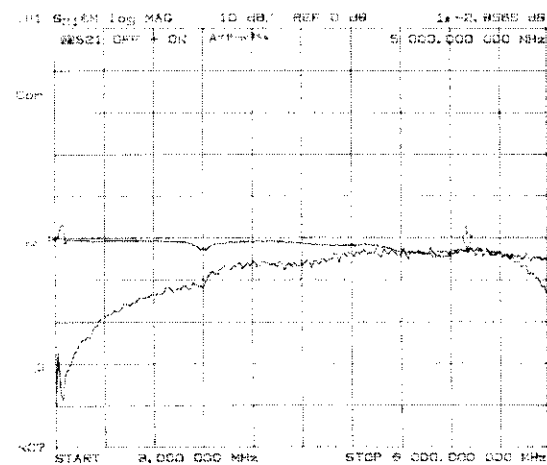


Fig. 2.2: S21 plot (both on and off states) of the setup seen in Fig. 2.2 using an ATF-10736 transistor. The off state is the lower curve, and the on state is the higher curve.

After the preliminary test of the ATF-10736 test configuration, no change was measured in the s-parameters as the transistor changed from the on state to the off state (Fig. 2.2), which meant the FET was unable to shut off signal flow at 5 GHz. It was then noticed that the ATF-10736 was indeed switching states, but only at frequencies below 1 GHz.

To determine whether the problem was due to the ATF-10736 transistor itself, it was replaced with a Fujitsu FHX35LG high-electron mobility transistor (HEMT). By using another type of transistor, it was hoped that the switching would take place at the design frequency. However, similar results were obtained as with the ATF-10736; this transistor also failed to switch at 5 GHz. Like the ATF-10736, the FHX35LG only had a switching response under 1 GHz.; it remained in the on state regardless of the gate bias (Fig. 3).

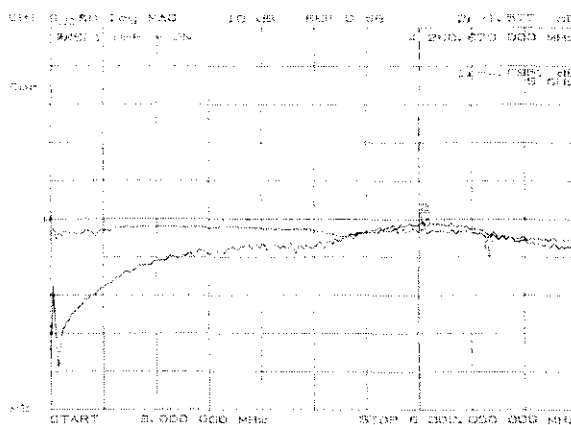


Fig. 3: S21 plot (both on and off states) of test fixture seen in Fig. 5.2.2 using an FHX35LG HEMT. The off state is the lower curve, and the on state is the higher curve.

### SERIES CONFIGURATION WITH CHIP INDUCTORS

After further study, it was determined that a possible cause of the series configuration problems was source-drain capacitance, due to the semi-insulating substrate of the transistor [2]. Since the transistor off state can be modeled as a parallel R-C combination from drain to source, it was concluded that the absence of high frequency switching was due to the capacitor shorting at high frequencies. This capacitance effectively prevents the transistor from being shut off, since it makes the source to drain impedance near zero for high frequencies, regardless of the transistor's gate bias. The impedance of a capacitor is characterized by:

$$Z = 1/(j\omega C) \quad (1)$$

where  $Z$  is the impedance,  $\omega$  is the frequency in radians per second, and  $C$  is the capacitance. From this equation, it can be seen that as the frequency increases, the impedance of the capacitor drops, reducing the isolation of the off state. Therefore, to eliminate this effect, it was determined that an inductance from drain to source should be added.

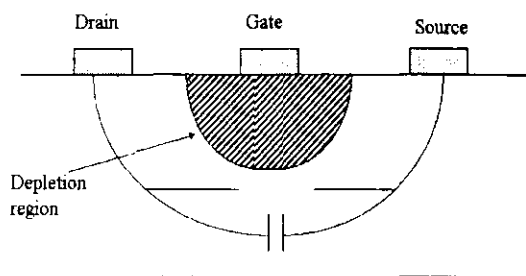


Fig. 4.1: Parasitic capacitance can cause an RF short between the drain and source.

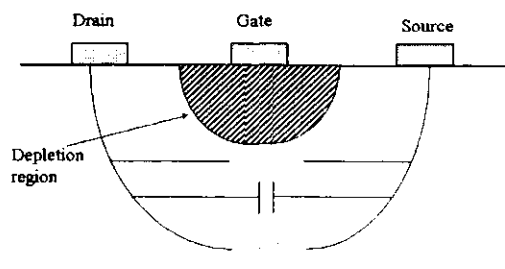


Fig. 4.2: Parasitic capacitance can be compensated for with an inductor in parallel.

Chip inductors were chosen as an accurate method of compensating the drain to source capacitance. The exact value of inductance needed to cancel out this parasitic capacitance is given by:

$$L_{DS} = 1/(\omega^2 C) \quad (2)$$

Some initial tests were made to determine the exact value of the drain to source capacitance in (2). Testing the FHX35LG with a 1.5-nH drain-to-source inductance ( $L_{DS}$ ) yielded the best isolation at 4.56 GHz. Substituting these values into equation (2) yielded  $C = 0.8$  pF, corresponding to an  $L_{DS}$  of 1.25 nH needed for operation at 5 GHz. However, when further tests were made with a  $L_{DS}$  of 1.32 nH (a 2.2-nH inductor in parallel with a 3.3-nH inductor), the recalculated, more accurate value of  $C$  was found to be 0.917 pF. The required  $L_{DS}$  for 5 GHz switching was 1.1 nH, achieved by placing two 2.2-nH inductors in parallel. With this setup, noticeable switching occurred around the 5 GHz design frequency (Fig. 5).

This process was repeated with the ATF-10736 transistors. However, testing showed that the off-state capacitance of these transistors was larger than that of the FHX35LG, at 1.20 pF. This made the necessary  $L_{DS}$  rather small at 0.844 nH; therefore, it was decided that the switch would be easier to implement using the FHX35LG HEMTs.

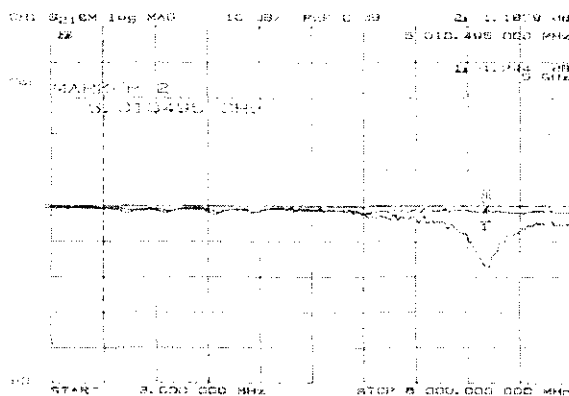


Fig. 5: Optimized FHX35LG transistor test setup ( $L_{DS} = 1.1$  nH). The off state is the lower curve, and the on state is the higher curve. The off state peak corresponds to an  $S_{21}$  of  $-17.3$  dB at 5.01 GHz.

## CONCLUSION

The basic design of a wireless transmitter was presented. In order to design the T/R switch component, it was necessary to characterize the switching properties of the Fujitsu FHX35LG HEMT. After a drain-to-source inductance was added to compensate for the parasitic capacitance of the transistor, its isolation at 5 GHz was found to be 17.0 dB, with an insertion loss of 1.2 dB. These results are summarized in the table below (Fig. 6).

Fig. 6: Fujitsu FHX35LG HEMT switching characteristics at 5 GHz

Off state	Isolation: 17.0 dB
On state	Insertion loss: 1.2 dB

To improve isolation of the Fujitsu FHX35LG for use in the T/R switch, the transistors could be placed in series on the same transmission line. While this may introduce more insertion loss, isolation is the most important factor in the design of the T/R switch. Furthermore, insertion loss could be improved with greater care in soldering the transistors, so as not to introduce inductance from the transistor leads. (At high frequencies, the transistor leads look like an inductance, which have high impedance to RF signals.) To a lesser degree, the addition of a  $V_{DS}$  of 0V would also improve insertion loss.

Finally, if an adjustable inductance was available to provide the  $L_{DS}$ , fabrication and testing time of the switch could be cut greatly. This may also improve performance slightly by allowing the optimum switching frequency to perfectly match the design frequency.

## ACKNOWLEDGEMENTS

I would like to thank NASA and the Hawai'i Space Grant College for providing the opportunity to participate in an undergraduate research project. I would also like to thank Dr. Wayne Shiroma for making this project possible, and for his patient and invaluable mentoring throughout the semester. In addition, I would like to thank all the students who I worked with on the wireless transceiver project: Mike Tamamoto, Kendall Ching, Wen Phan, Lito Caraang, Darren Goshi, Grant Shiroma, and Martian Binonwangan. Thanks also to Nathan Higuchi and William Forsyth, who gave up their time to give equipment tutorials. Last, but not least, much gratitude goes out to my family, who supported me throughout a very tiring semester.

## REFERENCES

- [1] NASA website, "Microver Radios and Antennas," <http://mars.jpl.nasa.gov/MPF/rovercom/itworks.html#rover-radio>
- [2] Yalcin, Ayasli, "Microwave Switching With GaAS FETs 'Device and Circuit Design Theory and Applications,' " *Microwave Journal*, pp.61-74, November 1982.
- [3] Papananos, Yannis E. Radio-Frequency Microelectronic Circuits for Telecommunication Applications. Boston: Kluwer Academic Publishers, 1999, pp. 101-102.