The Design and Construction of Inexpensive RF Circuitry for an S-band Synthetic Aperture Radar

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Abstract— Recent advances in digital technology have made possible the implementation of compact and inexpensive synthetic aperture radar (SAR). This paper presents a design for a compact and inexpensive S-band RF system for use with such a SAR. The design discussed in this paper is made using commercially available surface mount components and is a master's student project. This design is much more compact, and more reliable than the previous prototype design which was implemented in coaxial components.

The circuitry consists of isolated transmit and receive channels. The function of these channels and their schematics are presented as well as a discussion on the design techniques used and a description of the physical construction of the circuitry. Measurements are also presented.

INTRODUCTION

Compact and inexpensive synthetic aperture radar (SAR) are quickly becoming a reality due to advances in digital technology. The RF transceiver for SAR is a significant portion of the size and cost of the system. This paper will present the design, construction, and measurement of an inexpensive RF transceiver for use with the BYU SAR (YSAR). This radar has been deployed over several sites [1]. The transceiver used during these tests was constructed from individual coaxial components. The simple design described in this paper is a master's student project and exhibits a great improvement over the previous prototype. The design is implemented using microstrip and coplanar geometries and commercially available surface mount components. The function and RF schematics of the transceiver is presented in the following section. The second section includes a brief description of the design techniques used and in the third section the physical construction of the system is presented. Results of a constructed transmit channel are presented in the fourth section.

RF SCHEMATICS

This section describes the function of the RF transceiver. The schematic for the YSAR transmitter and receiver is shown in figure 1. Mini-Circuits part numbers are included in the schematic. The local oscillator (LO) at 2.2 GHz is provided by a voltage controlled oscillator (VCO).

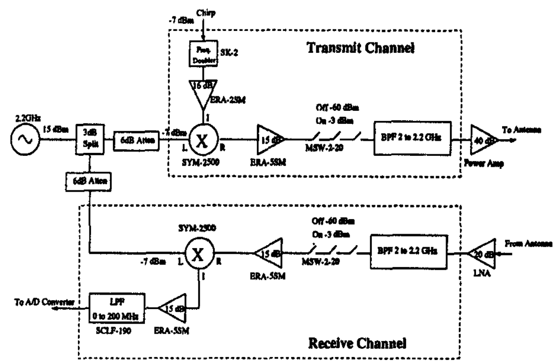

Figure 1: Transmit and Receive RF Block Diagram

The IF input comes from a digital to analog converter (D/A) which generates a 10-100 MHz linear frequency modulated (LFM) chirp. The only other inputs to the transmit RF circuitry are DC voltage supply for the amplifiers and control signals for the switches. The inputs into the receive channel include the RF signal from the antenna, the LO signal for mixing down, DC voltage, and control signals. The output is a baseband signal which is digitized and then processed.

A functional description of the transmit and receive channels follow. The LFM chirp enters the transmit channel and is frequency doubled and amplified. It is then mixed up with the local oscillator tone provided by the VCO. The signal then passes through amplifiers and switches. The switches provide 60 dB of isolation when no transmission is needed. A bandpass filter is used to remove the upper frequency sideband. An external high power amplifier is used to increase the final transmit power to +40 dBm.

The receive channel uses the same bandpass filter as the transmit channel. This serves to filter noise out of the radar's frequency band and increases the signal to noise ratio (SNR). The receiver mixes this filtered signal with the same 2.2 GHz tone as was used in the transmit channel. This passband signal is then lowpass filtered to remove any high frequency harmonics. Switches are also used in the receive channel to provide isolation while the transmitter is on.

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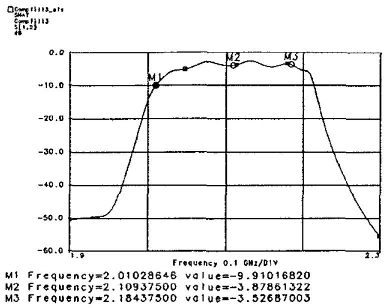

Figure 2: Simulated Filter Response

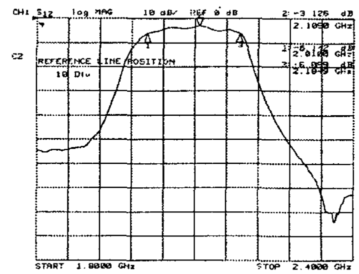

Figure 3: Measured Filter Response

DESIGN TECHNIQUES

This section will present the design techniques used in the design of the RF transceiver. The topics presented will include the design of the coupled microstrip bandpass filter, the integration of surface mount devices into the system, and the tradeoffs between using microstrip or coplanar waveguide (cpw) transmission lines.

The 2 GHz to 2.2 GHz bandpass filter performs sideband cancelation in the transmit path and filters out unwanted signals in the receive path so as to improve the systems signal to noise ratio. This filter is implemented using a custom microstrip coupled line filter. The design of the filter follows the technique presented in [2]. Element values for a maximally flat filter response were chosen. A 0.5 dB ripple in the passband and a sharp roll off were achieved by using 6 elements. After measuring the response of the first filter, the second was designed with a 2.16 GHz center frequency and a 203 MHz bandwidth in order to compensate for discrepancies between design and measurement. The filter design was simulated in the EEsof Momentum full wave analysis software. This analysis predicted a filter response which is very similar to the measured response. The numerical analysis consistently predicted the passband about 20 MHz high. The simulated filter response is shown in figure 2 and the measured response is shown in figure 3.

A very simple design was used for the transceiver. This served to reduce the number of surface mount components necessary and to reduce developmental time but also degraded system performance. All portions of the transceiver other than the bandpass filter were implemented using Mini-Circuits surface mount devices. These include frequency doubler, mixer, amplifiers, switches, and low pass filters. Each individual device was put on a microstrip or coplanar waveguide layout and tested using a spectrum analyzer and signal generator for the nonlinear devices or a network analyzer for the linear devices. The testing of the individual components facilitated the fine tuning of RF power levels. The equations describing the characteristic impedance of the microstrip lines can be found in [2] and the equations governing characteristic impedance of cpw are found in [3].

Coplanar waveguide has some basic advantages over microstrip transmission lines for the integration of surface mount components. It is easier to construct and requires fewer through holes to ground. Microstrip, however, is better understood and the governing equations for microstrip geometries are more available in literature. Up to this point, the design has been implemented in microstrip only. The final transceiver design will be implemented using cpw. Tests have revealed that the cpw implementation results in improved performance for the amplifiers. It should also provide increased isolation between components.

PHYSICAL CONSTRUCTION

This section will present a description of the process used in the physical construction of the RF transceiver and will present the monetary cost of the system as well as the final size.

The layout for the microstrip or cpw board is made using the EEsof Libra layout software and is ported to a numerically controlled milling machine via HPGL file format. The milling machine generates a completed board in approximately $\frac{1}{2}$ hour. The board is then populated with the surface mount components using solder paste and a convection oven. Aluminum cases are used as enclosures for the circuitry to prevent frequency leakage between transmit and receive channels or between other sources of RF. These cases consist of a single piece of aluminum with a milled cavity for the circuit and a flat plate as a cover.

The substrate for the circuitry is Gil 1000 which costs approximately \$10 per square foot. Total cost for the Mini-Circuits surface mount components for both transmit and receive channels is \$92.57 and the aluminum cases can be constructed for approximately $100. The transmit and receive channels are approximately 2 in by 6 in by 9 in each. These dimensions do not include external devices such as the LNA, power amplifier, and DC power supplies.

RESULTS

The final system was tested by injecting a single IF tone into the transmit channel in place of the chirp and then measuring the output on a spectrum analyzer. The measurements presented in this section were made on the transmit channel implemented in microstrip. The final coplanar waveguide implementation, when completed, will exhibit improved performance due to better isolation between components and better component performance. The output of the transmit channel with a 75 MHz tone injected is shown in figure 4. The circuit exhibits its best performance for IF tones above 50 MHz, where the highest intermodulation product (IP) level is 19 dB below the signal level.

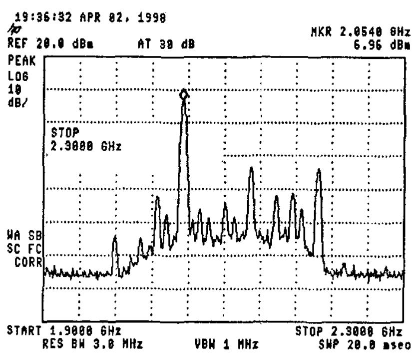

Figure 4: Transmit Channel Output with 75 MHz IF

For a constant IF input signal strength of 10 dBm across the frequency range, the output signal level varies from 3.2 dBm at 2.014 GHz to 9.9 dBm at 2.124 GHz. The 3 dB points from the max output power at 2.124 GHz occur at 2.185 GHz and 2.054 GHz. The 2.2 GHz LO feed through is around -14 dBm across the frequency range.

CONCLUSION

Surface mount components are commercially available which can be used to construct transmit and receive RF circuitry. These components are inexpensive and are simple to incorporate into a design. This technology is useful in the development of SAR which is rapidly becoming less expensive and more compact. The student transceiver design presented in this paper is for use with an S-band SAR developed at BYU.

References

[1] D. G. Thompson, D. V. Arnold, D. G. Long, G. F. Miner, and T. W. Karlinsey. Ysar: A compact, low-cost synthetic aperture radar. In *Proceedings of the 1996 International Geoscience and Remote Sensing Symposium*, pages 1892–1894, Lincoln, Nebraska, May 1996.

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[3] I. Bahl and P. Bhartia. *Microwave Solid State Circuit Design*. John Wiley & Sons, Inc., 1988.