

YSAR: A Compact, Low-Cost Synthetic Aperture Radar

Douglas G. Thompson, David V. Arnold, David G. Long,
Gayle F. Miner, Thomas W. Karlinsey

Brigham Young University
459 CB, Provo, UT 84602

voice: 801-378-3262, FAX: 801-378-6586, e-mail: arnold@ee.byu.edu

Abstract: We have developed a relatively inexpensive, experimental Synthetic Aperture Radar (SAR) system which can be flown on small aircraft. The entire unit weighs approximately 360 lbs with most of the weight in the battery-power supply. The system cost is kept low by using a simple RF subsystem with an all-digital IF and commercial components for the chirp generation, analog-to-digital conversion, and digital signal processing. The system has been successfully operated from a truck and an aircraft and has exhibited a range resolution of 1.5 m and an azimuth resolution of 0.5 m. The system is described and images from the tests are shown.

INTRODUCTION

A Synthetic Aperture Radar (SAR) is an imaging radar which uses signal processing to improve the resolution beyond the limitation of the physical antenna aperture. Typical SAR systems are complex, expensive and difficult to transport. The BYU SAR (YSAR) is a relatively inexpensive, lightweight system. The system is designed to be flown in a four or six passenger aircraft at altitudes up to 2000 feet.

The system cost and complexity are kept low by using commercially available parts for most of the components. A standard PC system is used, with plug-in cards for the analog-to-digital conversion and digital signal processing. The chirp is generated by a low-cost 200 MHz Arbitrary Waveform Generator (AWG). A simple RF subsystem up-converts the transmitted chirp using double-sideband modulation and down-converts the received signal. The YSAR system has been successfully tested from a truck and an aircraft. The system has a range resolution of 1.5 m and an azimuth resolution of 0.5 m.

This paper describes the YSAR system and presents results obtained from system tests. The first section shows the block diagram and describes each component. The next section describes the deployment of the system. The third section presents test results.

SYSTEM DESCRIPTION

The YSAR system is composed of an RF subsystem, a chirp generation subsystem, a digital subsystem, and an antenna subsystem. A block diagram of the system is shown in Fig. 1. The entire system weighs approximately 360 lbs, with over half that coming from the battery-power supply. Each of the subsystems is described below.

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RF Subsystem

The RF subsystem consists of a transmitter, receiver, and offset local oscillator and weighs approximately 70 lbs. The transmitter mixes the 100 MHz bandwidth chirp up to 2.1 GHz for transmission. The receiver and local oscillator are used to mix the RF radar return from the antenna to an offset baseband and amplify it so it can be sampled by the digital subsystem.

Chirp Generation

To reduce cost, the chirp is transmitted and received with double-sideband (DSB) modulation, as shown in Fig. 2. This avoids the cost associated with single-sideband chirp generation and increases the effective bandwidth of the chirp.

The baseband chirp signal is generated by a commercial Arbitrary Waveform Generator (AWG). The chirp is first calculated by the PC and then downloaded with timing information to the AWG's memory over an RS-232 channel. The AWG is synchronized to the local oscillator in the RF unit and is used to control the timing for the entire system. The chirp bandwidth, the delay before triggering the digital sampling, and the pulse repetition frequency (PRF) are all software selectable. The LFM chirp may be windowed with 6 different windows to allow tradeoffs between range sidelobes and resolution. The AWG is the smallest system component at about 25 lbs.

Digital Subsystem

The digital subsystem consists of a 486-based Personal Computer system which has a total weight of 55 lbs. A high performance analog-to-digital converter operates at a sampling rate of 500 MHz. The software can be configured to do the range compression and display in real-time or to simply collect and store the raw data. In order to meet timing constraints, the data is collected into memory and dumped to the disk after a maximum sample length of about 100 seconds. The data can be

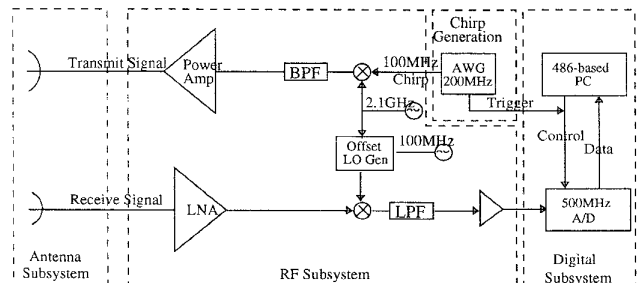


Figure 1: YSAR Block Diagram

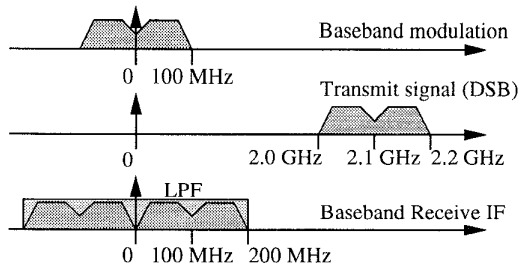


Figure 2: YSAR Frequency Plan

compressed onboard or downloaded to high-end workstations for further processing.

Antenna Subsystem

The antenna subsystem consists of two custom microstrip patch arrays. Each antenna array is approximately 3 by 1.5 feet and is connected to the RF subsystem by standard SMA cables. Two such arrays are used to improved isolation between the transmitter and receiver portions of the RF subsystem. The two antenna arrays are identical and are mounted end to end.

The Sonnet Software electromagnetic analysis package was used in the design of the microstrip patch array. The patches in the array were designed to resonate at three different frequencies to improve the bandwidth of the antenna. The feed lines were matched to the port of the antenna using transmission line methods. The patches are fed in phase and with equal power. The arrays were fabricated on an inexpensive substrate, resulting in a somewhat lossy though well-matched antenna. The standing wave ratio (SWR) of the array is below 2 over the entire 200 MHz bandwidth and is 1.27 at the center frequency. The beam width is 8.8° in azimuth and 35.0° in elevation at the center frequency. The center fed antenna array layout is shown in Fig. 3.

DEPLOYMENT

The initial system tests were made with the system mounted on a truck in a nearby canyon. Corner reflectors were placed at strategic locations to aid in identifying items in the image. The images obtained from these tests are lower quality because of the grazing incidence. The speed and direction of travel were also not as constant in the truck as in an airplane.

In a recent series of test flights, the antennas were mounted below the airplane fuselage, and the rest of the hardware occupied the seat directly behind the pilot. The operator sat in

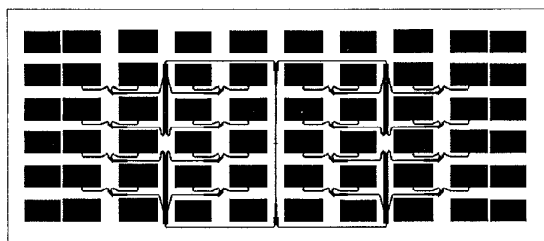


Figure 3: Layout of An Antenna Patch Array

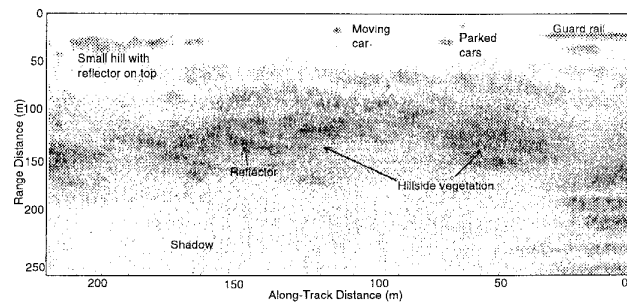


Figure 4: A one-look grazing-incidence image taken from a truck in Provo Canyon.

the rear seat. The initial test was in a rural area with corner reflectors placed in the primary target areas. Several passes were made to try different parameters and altitudes.

RESULTS

A representative image from the truck tests is shown in Fig. 4. This image was taken at approximately 22 m/s (50 mph) with an azimuth sample rate of 200 Hz and a chirp length of $1\mu s$. Several of the identified features are labeled in the figure. The radar was on the road at the top of the image (not seen), moving to the left and looking down the page. There is a short section of guardrail along the road to the right of the figure. Just behind that and a little further along the road are some parked cars. Near the left of the picture and close to the road is a set of small hills with a corner reflector on top of one of them. In the center of the image there are several tree-covered hills, with a corner reflector identified on one of them. In other images further up the canyon a pipeline can clearly be seen at about 200 m up the hillside.

Fig. 5 shows an image taken from the initial airplane test. An air photograph of the same area is shown in Fig. 6. The image was taken at approximately 52 m/s (100 knots) with an azimuth sample rate of 200 Hz and a chirp length of $1.5\mu s$. The altitude is 1000 ft. Important features are labeled in both figures. The airplane was flown parallel to the road seen near the bottom of the image (just below the edge of the photograph). A church building can be seen near the road at the right of the image. A parking lot surrounds the building, with a fence and concrete-lined ditch behind the parking lot. Just behind the fence and between the houses to the left are unplowed fields. Further left is a road perpendicular to the line of flight, with houses and other buildings along it. Further away from the flight path near the center of the image is a plowed field with a corner reflector pattern in it. The corner reflectors were arranged in the form of a line, with a large (1m) reflector in the center and smaller (0.6 m) reflectors at the ends. This reflector pattern can be seen more clearly in Fig. 7, which is a closer view of that portion of the image.

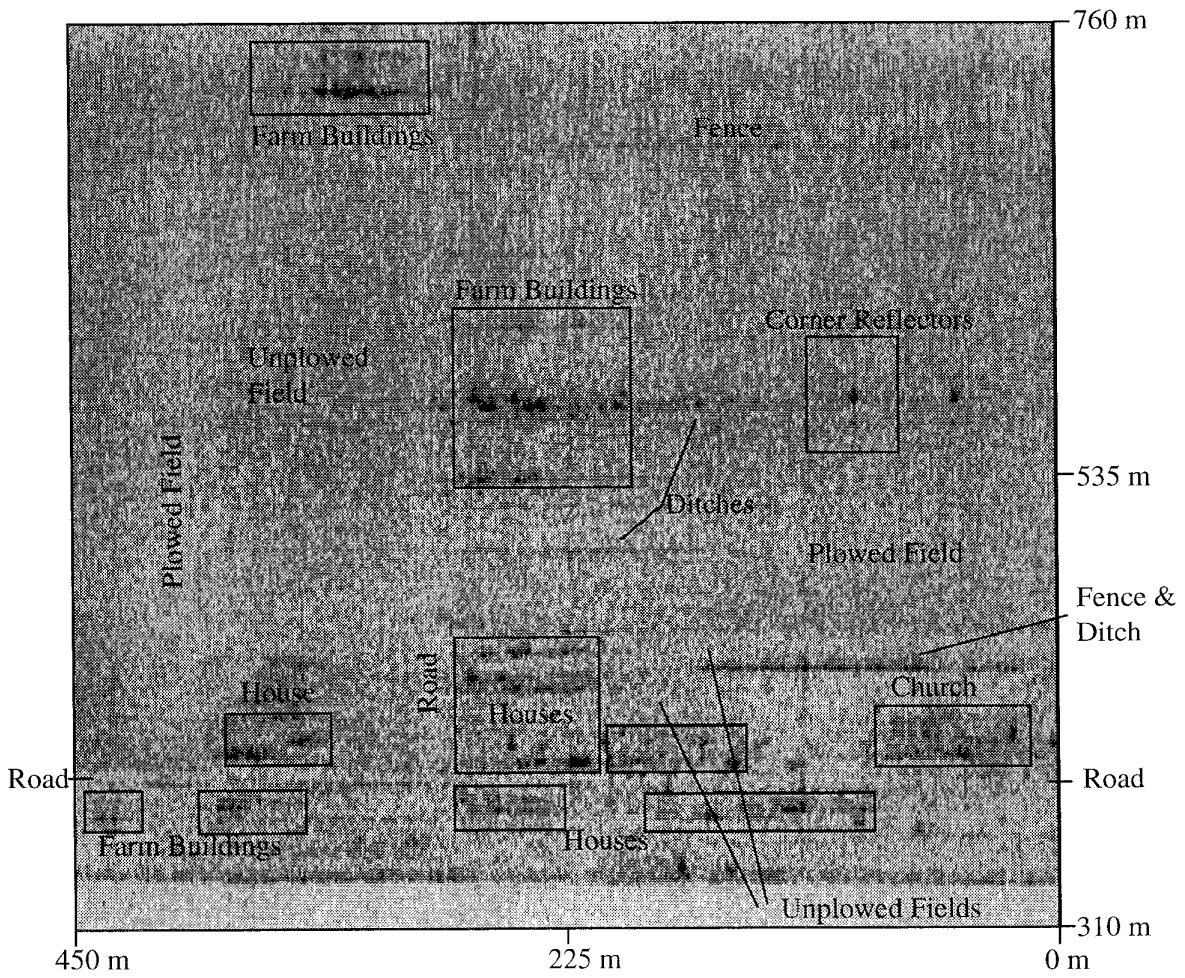


Figure 5: A one-look image taken from an airplane at 1000 ft. Darker shades are brighter in the radar image.

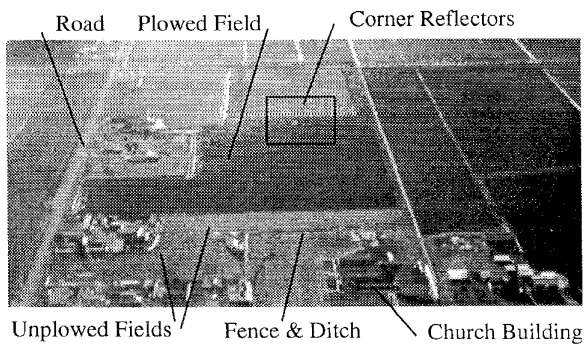


Figure 6: Air photograph of the target area.

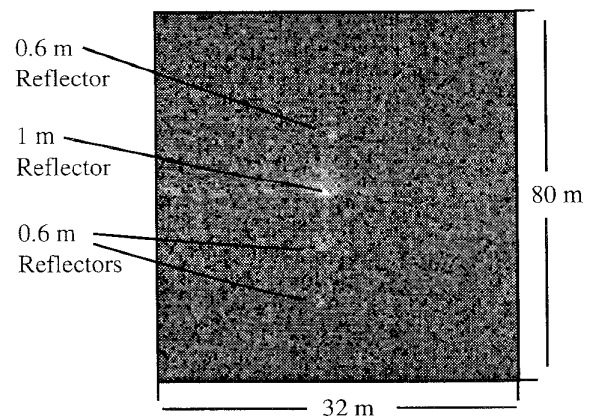


Figure 7: Close-up image of the corner reflectors. The grayscale is reversed with respect to Fig. 5.