Superconducting Imaging Array Receiver at 500 GHz with Internal Local Oscillators

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ABSTRACT

A focal plane Imaging Array Receiver has been designed and built based on an extensive study of Superconducting Integrated Receiver, a chip sized device containing a quasioptical SIS mixer and a Josephson type flux-flow oscillator (FFO) as a local oscillator. The fly's eye concept is used whereby all 9 pixels of the imaging receiver are designed to be identical and easily exchangeable units with individual antireflection-coated elliptical silicon optics and individually controlled local oscillators. The pixels are arranged in two rows (4+5) using honeycomb packaging resulting in an equal distance of about 13 mm between all adjacent units. The antenna beam of about F/9 with typical sidelobes less than –16 dB was measured and is close to the theoretical limit for this type of optics. The complete Imaging Array Receiver was tested in the vacuum dewar with a large optical window of 10 cm diameter. A noise temperature of about 150 K DSB was measured for the array, caused mainly by loss in the infrared filter. Neither evidence of degradation of the beam quality nor essential mutual interference between pixels was found when units were combined. The PLL-FFO tested recently in a separate experiment is up-to-date the first practicable, well-controlled Josephson effect oscillator within frequency range 270-440 GHz. All these open very good prospects for use the device in multi-receiver applications.

INTRODUCTION

Lightweight and compact Superconducting Integrated Receiver (SIR) with low power consumption is very attractive for the radio-astronomical research at sub-millimeters and for distant monitoring of the Earth atmosphere, Koshelets et al (1), Shitov et al (2). New projects for radio-astronomy or remote sensing which are based on a multi-receiver approach (e. g. ALMA) would gain considerably by using single-chip SIR due to its lower price and better serviceability as compared to conventional approach employing SIS mixers and varactor multipliers. It is important to note that ultimate performance of the quasi-optical SIR is basically the same as for wave-guide SIS receivers in the frequency range 400-600 GHz while the convenience of electronically controlled local oscillator is quite advantageous. Frequency resolution of a receiver is one of the major parameters in spectral radio-astronomy. The resolution is determined mainly by stability of the local oscillator which frequency deviation should be less than 1 ppm of the center frequency. The feasibility of phase locking the FFO to an external reference oscillator has been demonstrated recently by Koshelets et al (4) with a resulting linewidth of few kHz. In this report we review mainly data obtained with SIR as an element of the Imaging Array Receiver.

RECEIVER CHIP

The integrated circuit is fabricated on a silicon substrate from the Nb-AlO_x-Nb trilayer. Each individual chip of sizes of 4 mm × 4 mm × 0.5 mm contains a SIS mixer and FFO (long SIS junction) as a local oscillator that presented in. Figure 1. The micron size tunnel SIS junction is placed in the center of the double-dipole antenna array which supply the signal. The local oscillator power at 500 GHz is supplied to the mixer via a microstrip line which contains both *rf* impedance transformers and *dc*/IF breaks. The receiver chip is mounted back-to-back with the lens, forming a single optical system. A quarter-wave back reflector is mounted manually directly onto the antenna. The lenses and their anti-reflection coating from epoxy are manufactured using diamond turning. The control of the chip is realized with IRTECON system which performs the qualification tests starting from *dc* and finishing with receiver noise temperature.

ARRAY DESIGN

The pixel unit presented in Figure 2 passed a full-performance qualification test prior combining into the array. The imaging sensor is arranged as a two-row hexagonal array of 9 identical units as shown in Figure 3. The array block is mounted on the cold plate of a liquid helium (LHe) cryostat equipped with a 150 micron Mylar window at 300 K and a 6 mm thick IR filter from Teflon at 80 K, and a Zitex membrane at LHe stage to reduce the heat load on the LHe vessel and array mount. A cryoperm shield enclosing the array block reduces the influence of external magnetic interference onto the FFO, Koshelets et al (1).

ATENNA BEAM

Only two channels were monitored during the test of array. Figure 4 presents data obtained for two neighboring pixels. The level of the first-order sidelobe is about - 16 dB, the beam width is 3.7° and 6.7° at the -3 dB and -10 dB levels respectively. The first minimum in the radiation pattern occurs at approximately 4.5°. This corresponds roughly to a f/9.4 beam with a waist size $w_0 \approx 3.6$ mm. Both antenna beam patterns are, within the accuracy of the measurement, the same as in the qualification test. The comparison with reference mixer, Shitov et al (2) showed that complex LO circuitry located in the antenna-mixer has a minor effect on the antenna beam pattern. The separation of beams indicated in Figure 4 corresponds well to the mechanical position of pixels. The cross-polarization component as calculated and measured is approximately 20 dB below the co-polar level. All these mean that regarding the main beam the alignment accuracy is such that it could be used on a telescope. No *rf* cross-talk within the array mount or cryostat has been found, unless a blocking mirror-like obstacle is installed in front of the cryostat in a very precise position that can direct a little LO signal from one pixel to another.

MIXER SENSITIVITY AND LO STABILITY

A double-side band noise temperature about 100 K was measured in qualification test at 500 GHz with 3-dB bandwidth of 15% while the internal LO was in free-running regime. The typical noise figure for the array is presented in Figure 5. Some degradation is associated with loss in the thick infrared filter and with coupling of scattered infrared radiation to the antenna sidelobes. Experiments on the FFO phase locking has been performed recently by Koshelets et al (4). Figure 6 presents linewidth of 1 Hz that is determined by the resolution of the spectrum analyzer. These data were measured relative to a reference oscillator by down-converting the FFO signal from 270-440 GHz to about 400 MHz. The measured linewidth is far below the “fundamental” value given by shot and thermal noise for a superconducting tunnel junction.

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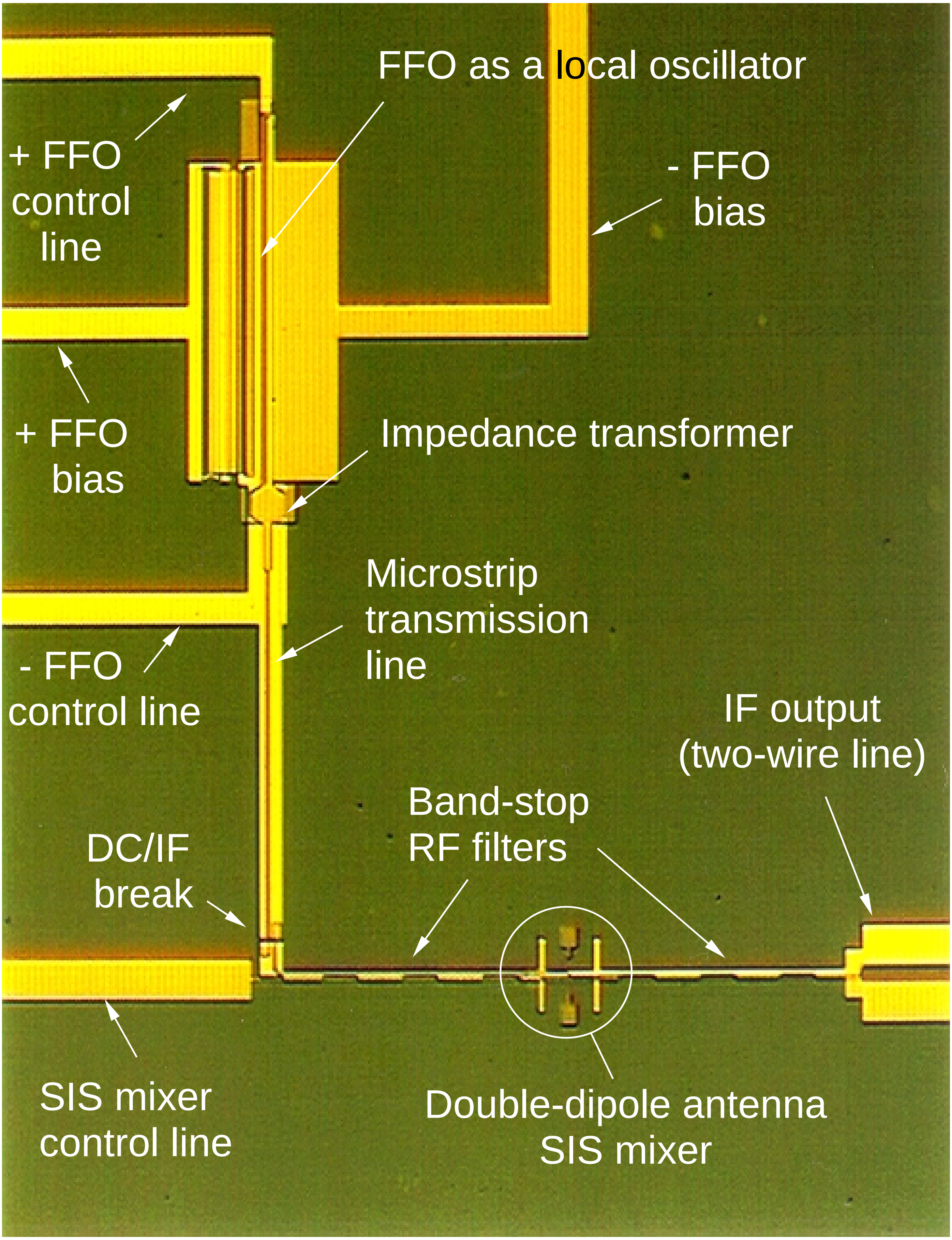


Figure 1. Microphotograph of the central part of the silicon chip of sizes 4 mm by 4 mm. All main elements of the Integrated Receiver are presented; the back reflector is not yet installed on the double-dipole antenna. Some details of wiring and contact pads are out of the field of view, which is about 1 mm by 1.5 mm.

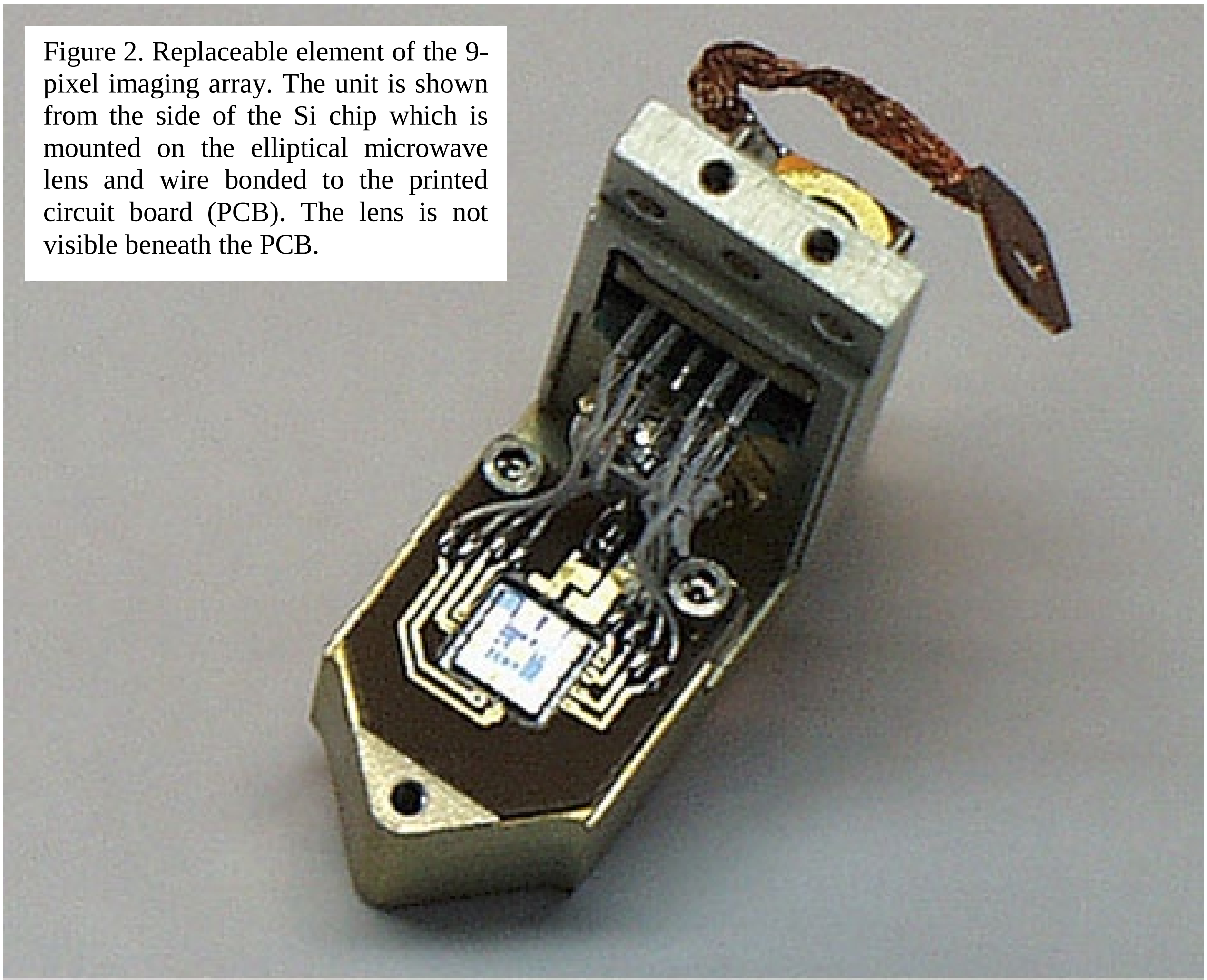


Figure 2. Replaceable element of the 9-pixel imaging array. The unit is shown from the side of the Si chip which is mounted on the elliptical microwave lens and wire bonded to the printed circuit board (PCB). The lens is not visible beneath the PCB.

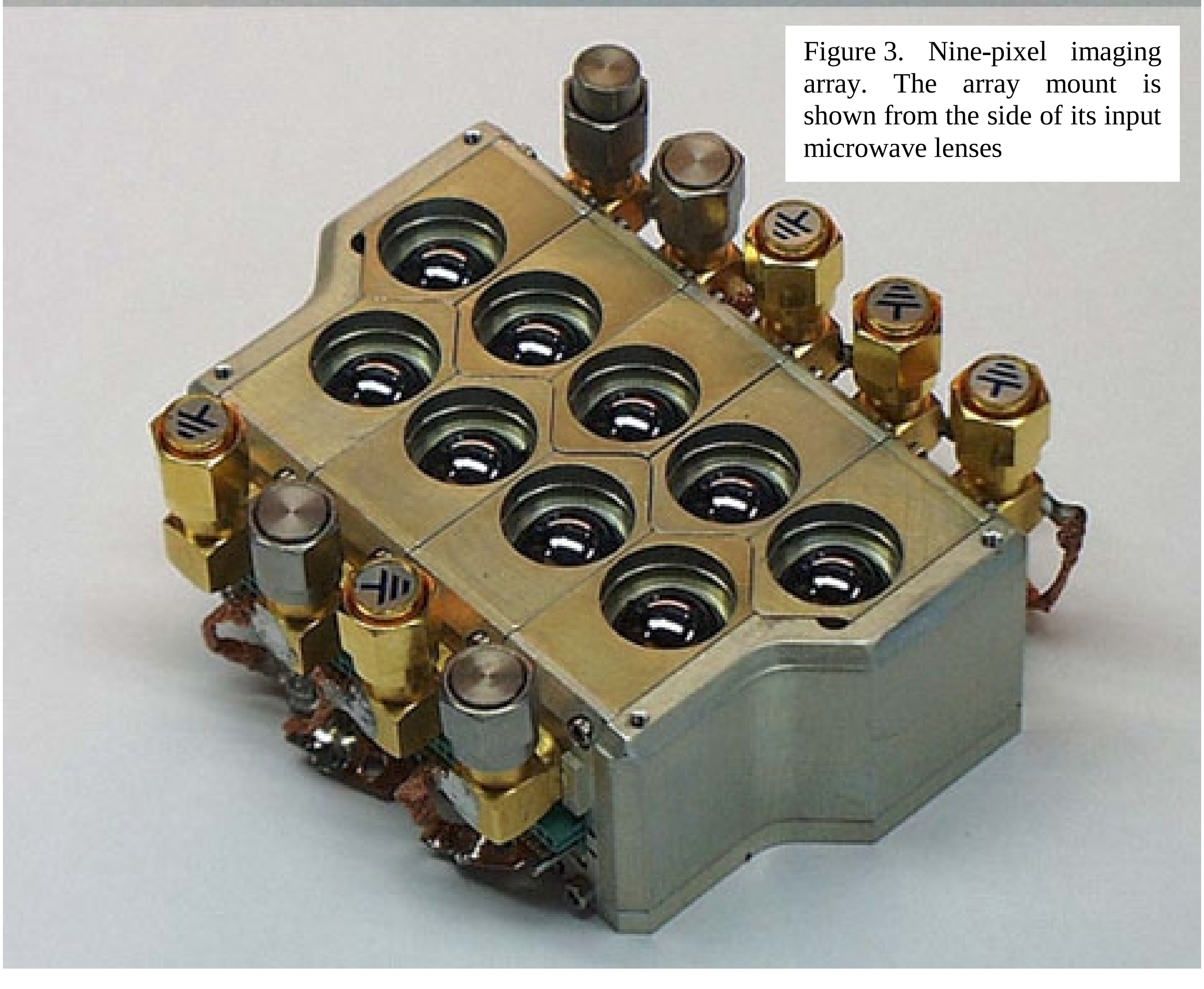


Figure 3. Nine-pixel imaging array. The array mount is shown from the side of its input microwave lenses

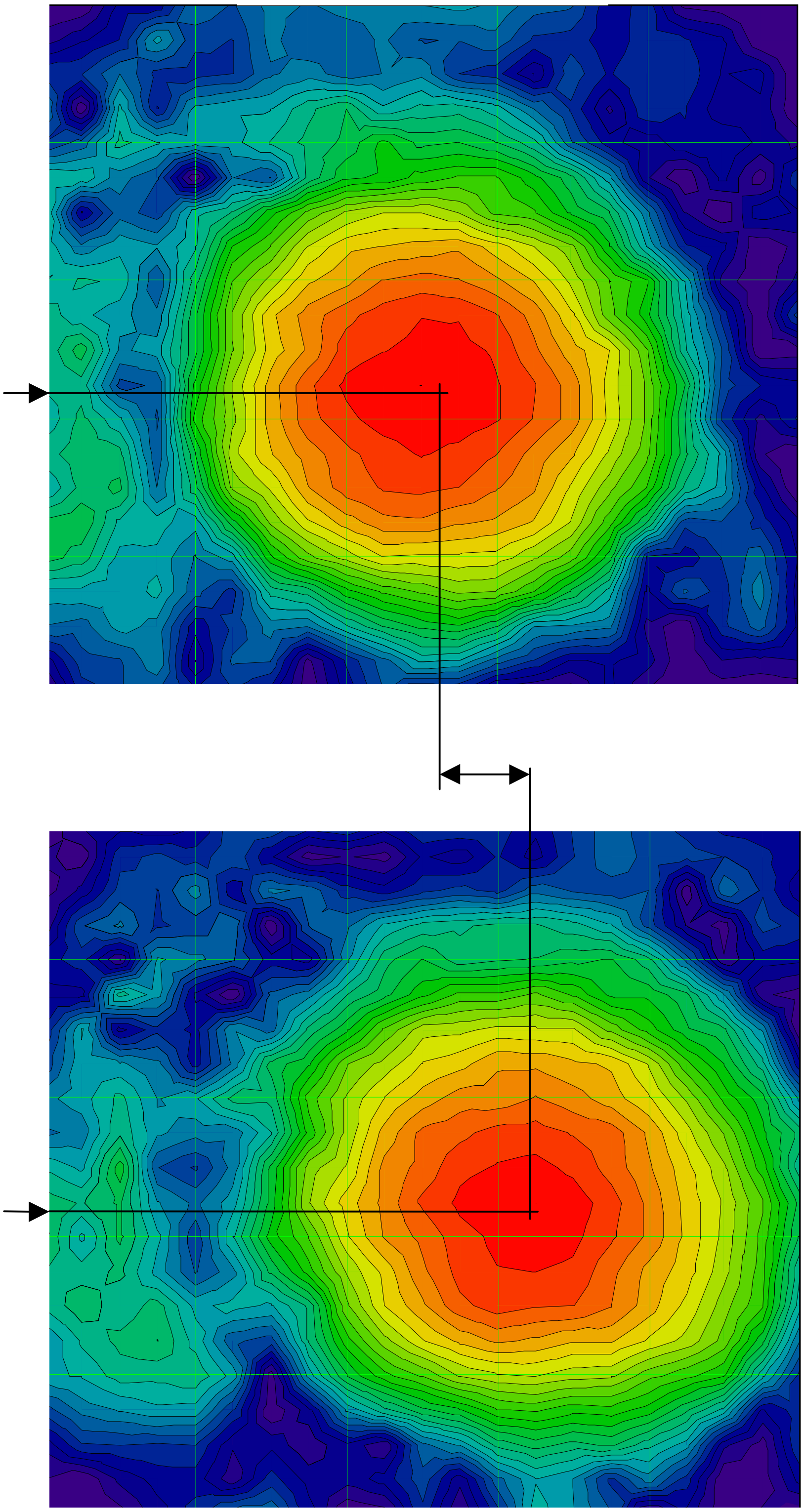
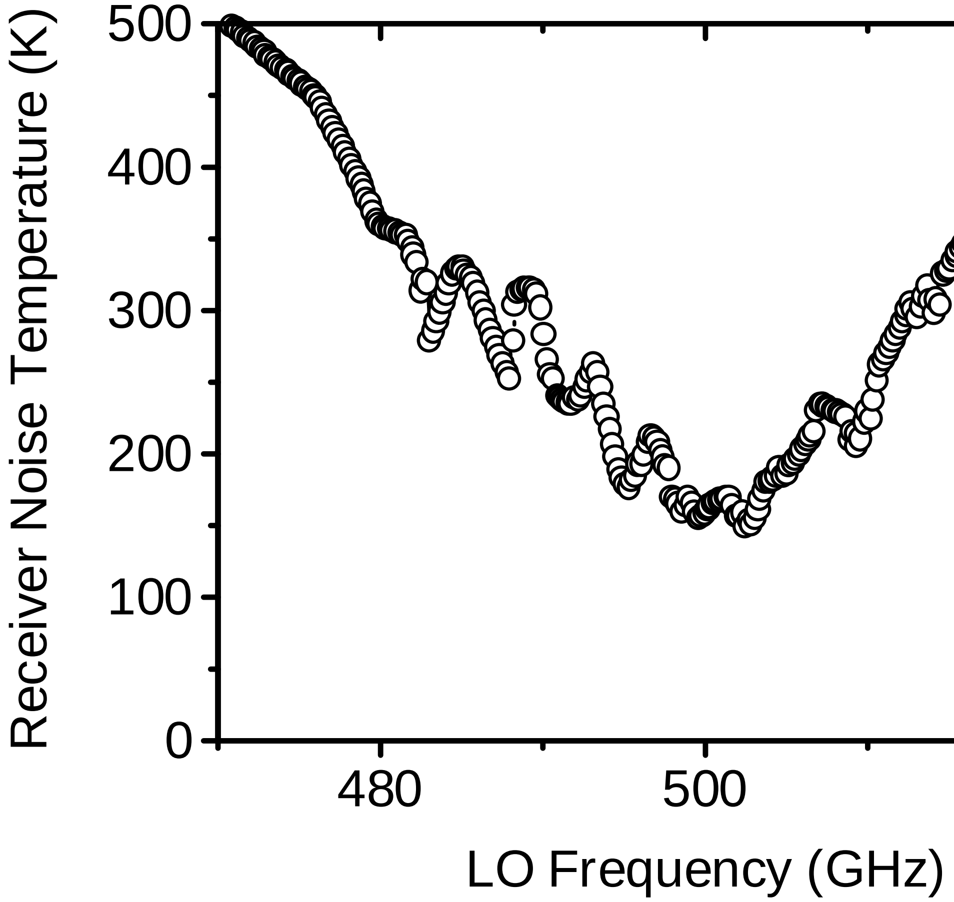


Figure 4. Antenna beam patterns measured at the distance of 400 mm from the cryostat window at 500 GHz for two adjacent pixels. Data for the raster image are collected from area 100 mm by 100 mm. The equal power contours are placed with step of 1 dB. The first sidelobe found at -15...-16 dB. Some asymmetry is assumed to be a result of sidelobes touching the shielding can. The shift between centers of the beams is about 13 mm that corresponds well to the geometrical (mechanical) position of the pixels within the array mount. It means that no essential tilt of the beams is present and the alignment accuracy.



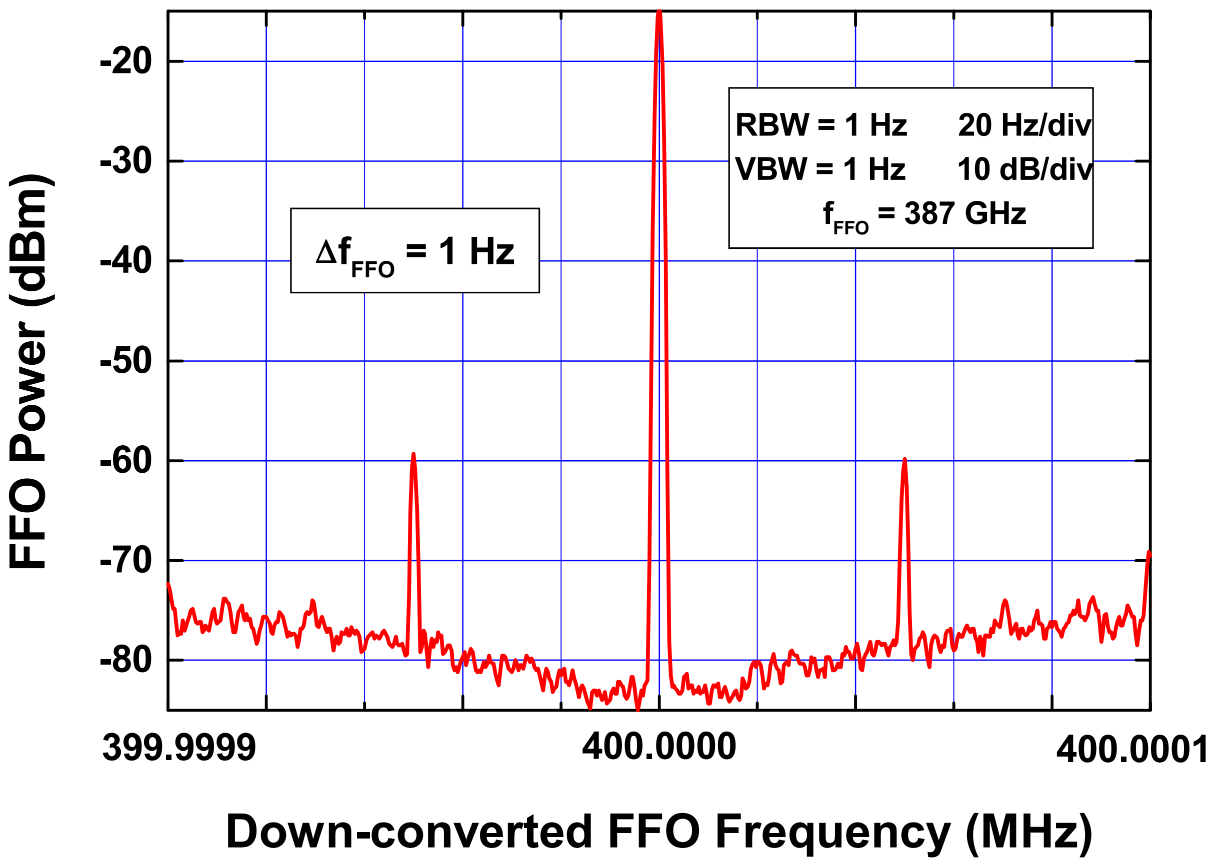


Figure 6. Power spectra of the FFO phase-locked at 387 GHz recorded at the intermediate frequency of 400 MHz and referred to a synthesized source. Some unwanted 50 Hz interference is clearly seen.