Extended Abstracts of the 1991 International Conference on Solid State Devices and Materials, Yokohama, 1991, pp. 753-754

A Quantum Flux Parametron (QFP) Based 12-bit Shift Register Capable of Microwave Operation

J. Casas, R. Kamikawai, N. Miyamoto* and E. Goto, Research Development Corp. of Japan (JRDC),
1-280 Higashi Koigakubo, Kokubunji-Tokyo 185, Japan.
Phone: +81 - 423 - 25 7881 Fax: +81 - 423 - 25 1783

The QFP is a superconducting gate capable of very fast operation with very little power dissipation. A QFP circuit has been found to be able to operate at clock frequencies as high as 16.2 GHz [1] in spite of the fabrication process (Josephson junctions are fabricated with NbN-Pb alloy and 5 μm minimum feature size). In this work a 12-bit shift register using QFP gates is presented. At the present time it is the largest QFP circuit: it is made by using 48 QFPs and one dc Squid (See Figures 1-2).

The 12-bit shift register is wired around a closed loop. This device is capable of memorizing any 12-bit logic pattern. It can operate either as a programmable pattern generator or programmable frequency prescaler. The frequency prescaling factor can be either 2, 4, 6 or 12. A new QFP current sensor has been implemented in order to extract the 12-bit logic pattern. A pattern, its complementary and period shift can be easily recognized (this is not the case with detectors previously reported [2]). The output current is sensed by using a dc Squid attached magnetically to the load of one of the QFPs (Figure 1).

A standing wave is used for applying the clock current to the QFPs (Figure 1). Then the clock current amplitude forwarded to the first and last QFPs along a given clock branch differs more and more as the clock frequency is increased. Thus the QFP margins can limit the maximum operating frequency of a circuit [1]. In order to increase the clock frequency of the 12-bit shift register, the clock current is applied in parallel. The power is distributed by inductive division. Because no resistors are used, this power distribution scheme dissipates no power. The total on-chip power consumption with a clock frequency of 2.5 GHz is estimated to be in the range of 1 nW. This power consumption is well below the power consumed by any equivalent circuit reported to date [1] (either semiconductor or superconductor).

Until now most of the measurements of QFP circuits operating at high frequencies have been done in the frequency domain [1]. The 12-bit shift register output can also be analyzed in frequency domain but its resulting data is difficult to interpret (Figure 3). The low typical output signal amplitude of the QFP circuits make time domain measurements difficult. The output signal is masked by very wideband white noise and by crosstalk with the clock frequency. In order to circumvent these problems an active crosstalk cancelation technique and an averaging oscilloscope are used for signal acquisition [3]. With this technique the output of a single-bit shift register working at 5 GHz has been reported [3]. In this work the output waveform of the 12-bit shift register is obtained with a clock frequency of 2.4 GHz (Figure 4).

The 12-bit shift register can also be used to test the stability of the QFP gate. For this a 12-bit logic pattern is stored in the device and the stability in time of this pattern is assessed. If an error occurs one or more bits are inverted. This event is easily recognized. The 12-bit shift register has been able to run without the observation of an error during 2 1/2 hours and at a clock frequency of 2.4 GHz. With this experiment 10^{15} error free operations per QFP has been confirmed. A larger number of error free operations per QFP is difficult to show with the 12-bit shift register because of the unreasonably long experimental time.

References

[1] J. Casas, R. Kamikawai and E. Goto, "High frequency operation of Quantum Flux Parametron (QFP) based shift registers and frequency prescalers", accepted for publication in *IEEE J. Solid-State Circuits* (1991).

[2] J. Casas, R. Kamikawai, Y. Harada and E. Goto, "Subharmonic generators and error detection by using the Quantum Flux Parametron (QFP)", *IEEE Trans. Magn.*, MAG-27, pp. 2851-2854, March 1991.

[3] J. Casas, R. Kamikawai, N. Miyamoto and E. Goto, "Multigigahertz Time-Domain Testing of the Quantum Flux Parametron (QFP)", extended abstracts of *3rd International Superconductive Electronics Conf.*, pp. 179-182, Glasgow 1991.

* In charge of NbN-Pb alloy fabrication process at Hitachi Central Research Laboratory.

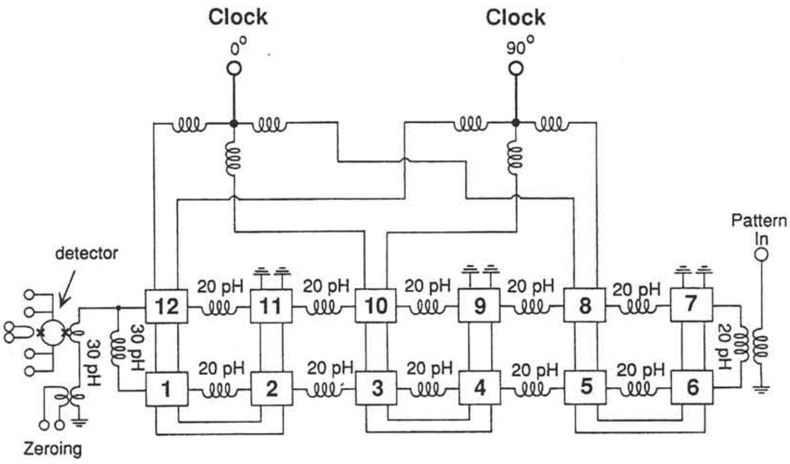

Figure 1: 12-bit shift register. Shorts at the clock microstrip lines produce the standing wave. Multi-phase clocking is necessary because the QFP is a two terminal device.

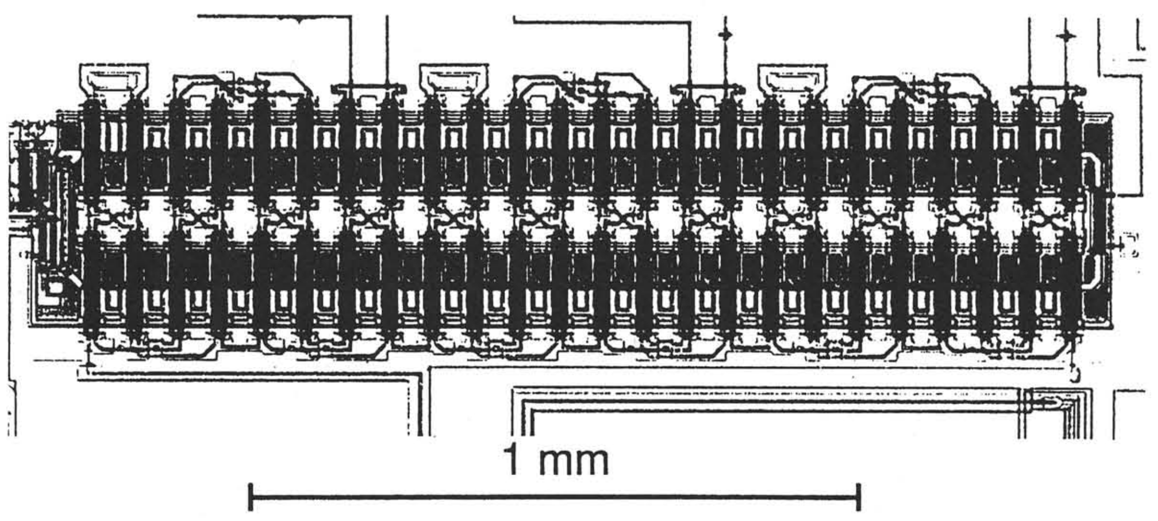

Figure 2: Fabricated 12-bit shift register. The 48 QFPs can be recognized.

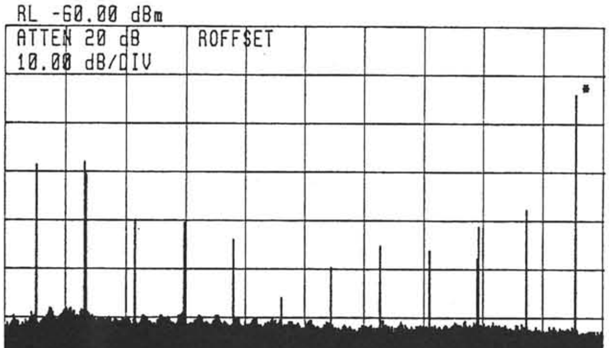

Figure 3: Power spectra obtained at the output of the 12-bit shift register. The clock frequency is 3.16 GHz. It is difficult to know which 12-bit logic pattern is stored. The harmonics seen are 1/12, 2/12, 3/12, 4/12, 5/12, 6/12, 7/12, 8/12, 9/12, 10/12, 11/12 and 12/12 of the clock frequency.

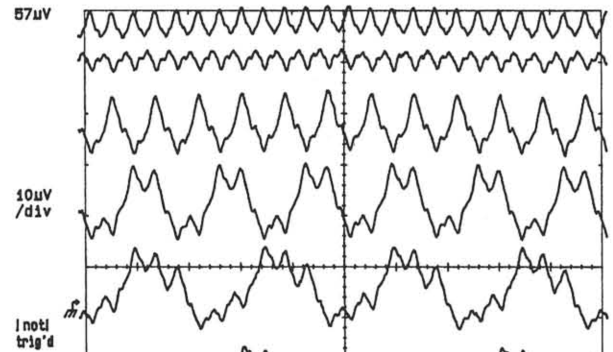

Figure 4: Some stored 12-bit patterns at 2.4 GHz. From top to bottom the patterns are: 111111111111, 000000000000, 010101010101, 001100110011, 001110001110, 100000011111 and 000000100000.