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FOUR PORT FUSED TAPER ACOUSTO-OPTIC DEVICES USING STANDARD SINGLE-MODE TELECOMMUNICATIONS FIBRE

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Abstract

Tapered fibre null couplers are used to form high performance acousto-optic devices for 1.55 μm operation. Standard single-mode telecommunications fibre is used throughout, yielding devices with identical ports. The two devices described are shown to have acousto-optic resonances at 1.5 MHz and 10.6 MHz, with greater than 99% acousto-optic coupling for RF drive powers of 0.5 mW and 2.6 mW.

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Introduction

All-fibre acousto-optic devices have important applications as frequency shifters, switches, modulators and tunable filters [1]. We have already shown how a null coupler (an asymmetric fused taper coupler with broad band zero splitting) can be used to form an effective low power acousto-optic device [2]. In that previous work, two dissimilar non-standard fibres were used; here we report the successful construction of a null coupler using standard telecom fibre. The procedure involves pretapering one of a pair of identical fibres to provide the necessary dissimilarity [3]. In this way an acousto-optic device can be constructed entirely from one fibre type with four identical ports, and be made compatible with any existing network. The advantages of low RF drive power, low insertion loss and high conversion efficiencies are retained. Standard 125 μm single mode telecom fibre is used throughout, for operation at a wavelength of 1.55 μm.

Referring to Figure 1a, light in the pretapered fibre evolves adiabatically through the null coupler, exciting the second mode of the coupler waist and returning to the same fibre at the far end. Similarly, light in the other fibre evolves into the fundamental mode of the waist. When a flexural acoustic wave is applied to the waist such that its wavelength matches the beat-length between the fundamental and second modes, light is coupled between the modes with a frequency shift, as shown in Figure 1b. When light enters in one fibre, a pure frequency-shifted wave leaves in the other fibre if the acoustic amplitude is appropriate. The device functions as a switch when the acoustic wave is switched on and off, as a modulator when the acoustic amplitude is varied, and as a tunable filter when the acoustic frequency is varied.

Results

The versatility of this design was demonstrated by manufacturing two separate devices (A and B) designed for operation at acoustic frequencies of respectively 1.5 MHz and 10 MHz. The only difference between them is the diameter of the final coupler waist; for a 1.5 MHz resonant frequency the necessary diameter can be calculated [4] to be 11 μm, and for a resonant frequency of 10 MHz a narrower waist of 6 μm diameter is required. In each case a 40 mm length of standard telecommunications fibre was initially pretapered from 125 μm to 90 μm. This fibre was held in parallel contact with an unstretched length of the same fibre, and then heated and stretched together in a travelling flame. The final coupler waist was 25 mm long, uniform, and had short taper transitions each 25 mm in length. Control of these dimensions was achieved by varying the flame's travel distance during coupler elongation. The excess loss of both couplers was less than 0.05 dB, and the maximum splitting ratios were 1:8000 and 1:23000 respectively (maximum coupling ratios as small as 1:70 000 have been seen in other null couplers). Light from a 1.55μm DFB laser was launched into the pretapered fibre via a polarisation controller. For each device a co-propagating flexural acoustic wave was excited in the coupler waist in the plane of the two fibres, using a PZT disc attached to the fibres via a concentrator horn [2].

Acousto-optic resonances were found at 1.55 MHz (device A) and 10.6 MHz (device B) respectively. In Figure 2, the optical powers emerging from the two output ports of device A are plotted against the $\sqrt{}$RF drive power $(mW)^{1/2}$ (proportional to the voltage across the PZT disc) with the polarisation controller adjusted for maximum acousto-optic coupling. Greater than 99.4% acousto-optic coupling was possible for an RF drive power of 0.5 mW. The same response was observed when light was launched in the other fibre. A similar response was obtained for device B, with 99.8% acousto-optic coupling for an RF drive power of 2.6 mW. Theoretically, the acoustic powers required for these devices are 4.6μW and 2.7 μW, so there is still sufficient scope for improvement. In both cases, the total insertion loss was less than 0.05 dB.

We measured the frequency shift by inserting each device (with the input in the pretapered fibre and the output from the other fibre) into one arm of an all fibre Mach-Zender interferometer. A Bragg cell downshifted the wave in the other arm by 80 MHz. The detected beat signal at the output was monitored on a RF spectrum analyser; the spectra are shown in Figures 3 and 4. The main beat components are offset from 80 MHz by about 1.5 MHz and 10.5 MHz respectively, corresponding to frequency upshifts equal to the acoustic frequency. In Figure 3, the image sideband near 78.5 MHz is visible above the noise floor and is 30 dB below the principal component. In both Figures 3 and 4, the carrier frequency is not visible above the noise floor, and so is suppressed by at least 30 dB in each case. Optical back reflections from the device were less than the measurement limit of 45 dB under all circumstances.

Discussion

A figure of merit can be defined by dividing the linearised percentage conversion by the required RF drive power and the square of the interaction length. For our device A, this is 79%/mWcm^2. A perfect 2.5 cm device would require a theoretical acoustic power of 4.6 μW for 100% conversion, giving an upper limit to the figure of merit of 8600 %/mWcm^2 to serve as an indication of the potential of such a device. This can be compared to values calculated by us for devices reported by other authors. For example, Smith et al. [5] use SAW coupling (at 1550 nm) between TE and TM modes of a planar waveguide, with a figure of merit of 0.85 %/mWcm^2. Blake et al. [6] describe coupling between spatial modes of a two mode fibre, with a figure of merit of 0.18 %/mWcm^2. Torsional acoustic wave coupling between the eigen modes of a highly birefringent fibre was described by Berwick et al. [7] with a figure of merit of 0.000002 %/mWcm^2. This highlights the fundamental efficiency of our device.

Conclusion

We have reported the repeatible construction of high performance null couplers using standard telecom fibre. These null couplers can be used to form an effective all-fibre four-port acousto-optic device. The devices reported yield >30 dB carrier and image sideband suppression, < 0.05 dB insertion loss and ~ 1 mW RF drive power for 100% conversion.

References

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Figure Captions

1. a) Evolution of the single (fundamental) mode of the pretapered fibre as it passes through the null coupler.

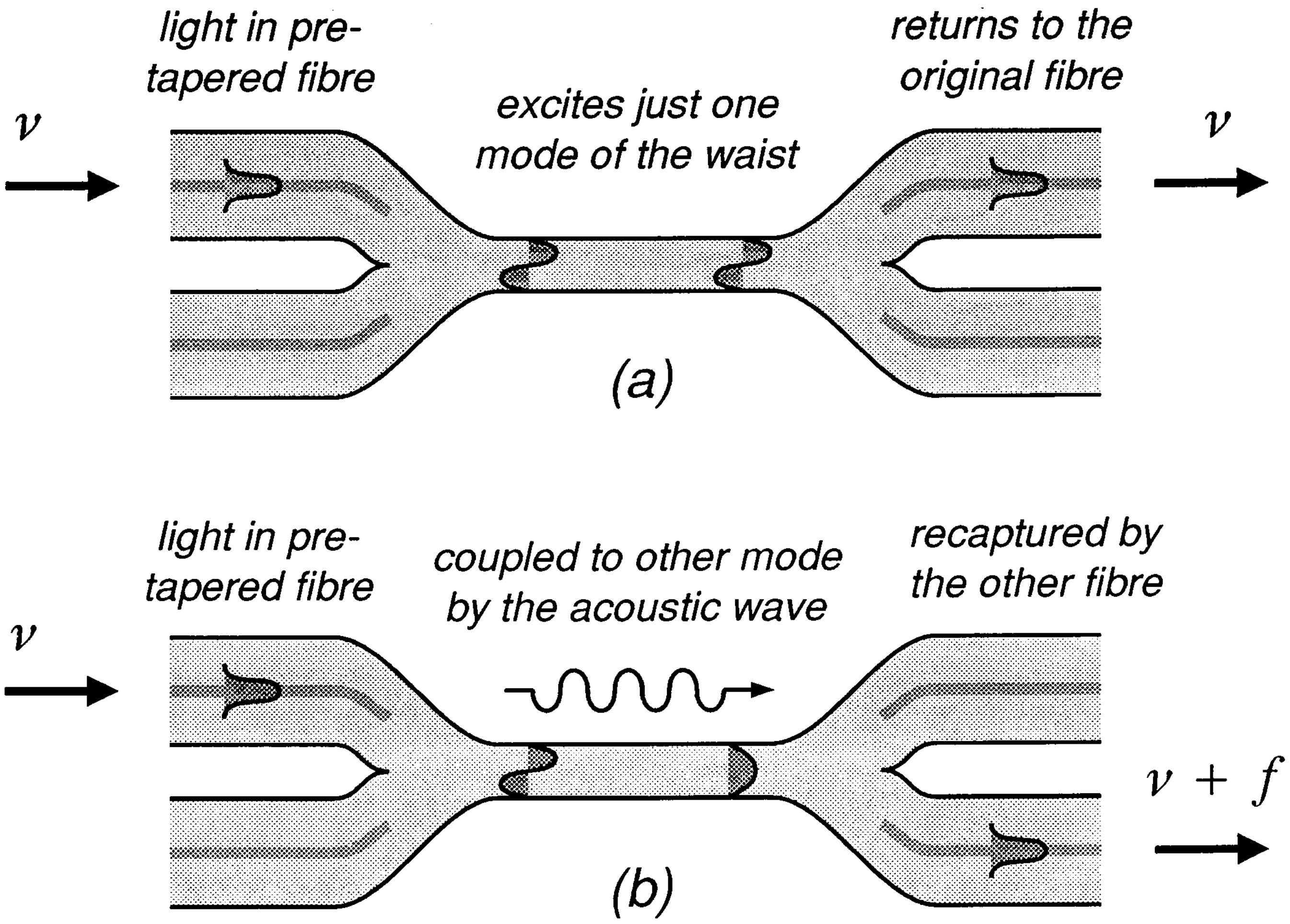
   b) Schematic diagram of the acousto-optic interaction in a null coupler.

2. Throughput (triangles) and coupled (circles) optical output powers of the 1.55 MHz acousto-optic device versus the square root of the peak to peak RF drive power in $(\mathrm{mW})^{1/2}$ across the PZT disc. The deviation from the expected $\sin^2$ curve is largely attributable to the non-uniformaties in the diameter of the interaction region.

3. RF spectrum of the detected beat signal between the frequency shifted coupled output of the 1.55 MHz device and light downshifted by 80 MHz in a Bragg cell.

4. RF spectrum of the detected beat signal between the frequency shifted coupled output of the 10.66 MHz device and light downshifted by 80 MHz in a Bragg cell.

Fig. 1.


light in pre-tapered fibre
ν
excites just one mode of the waist
returns to the original fibre
ν
(a)
light in pre-tapered fibre
ν
coupled to other mode by the acoustic wave
recaptured by the other fibre
$\nu + f$
(b)

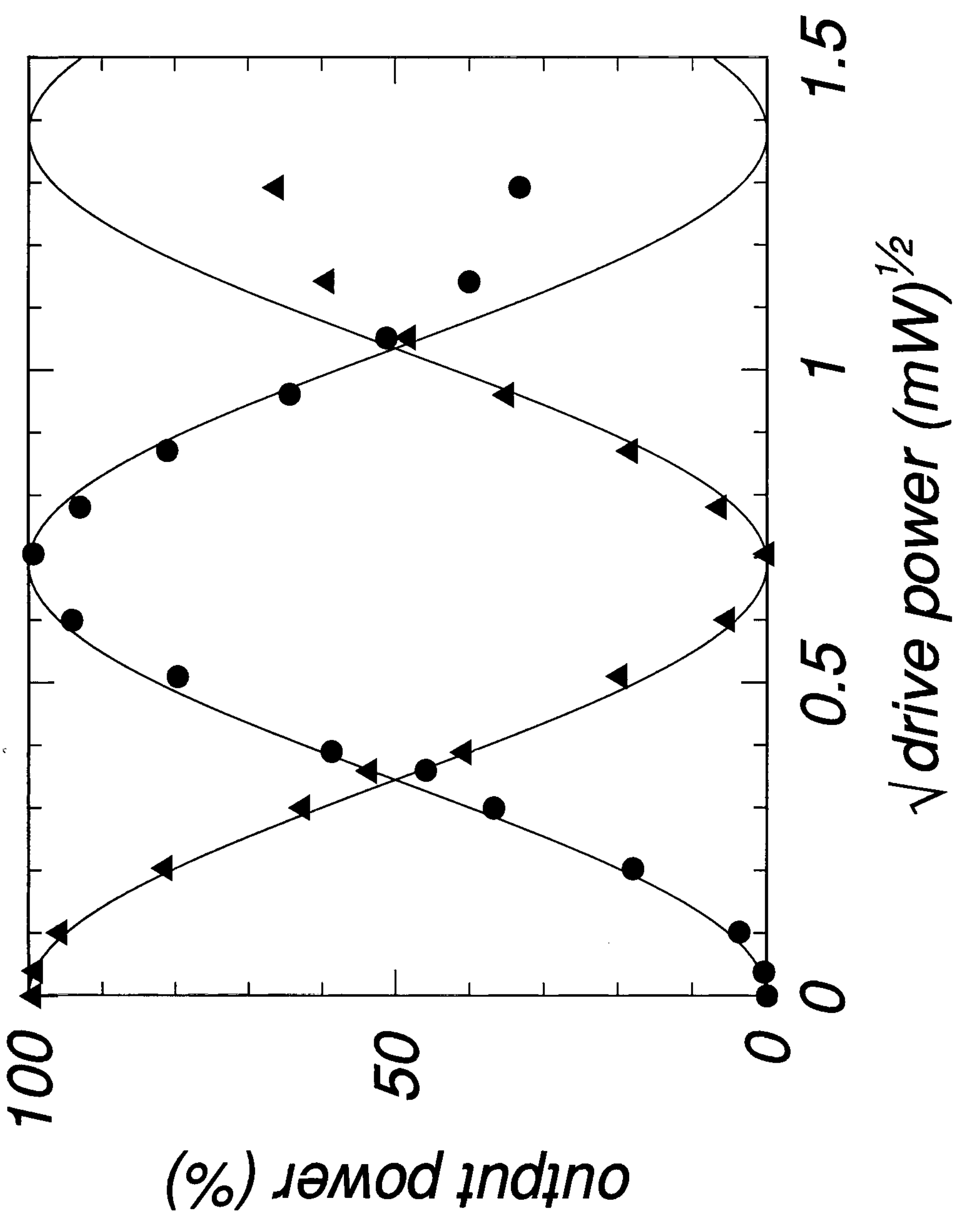


Fig.2.

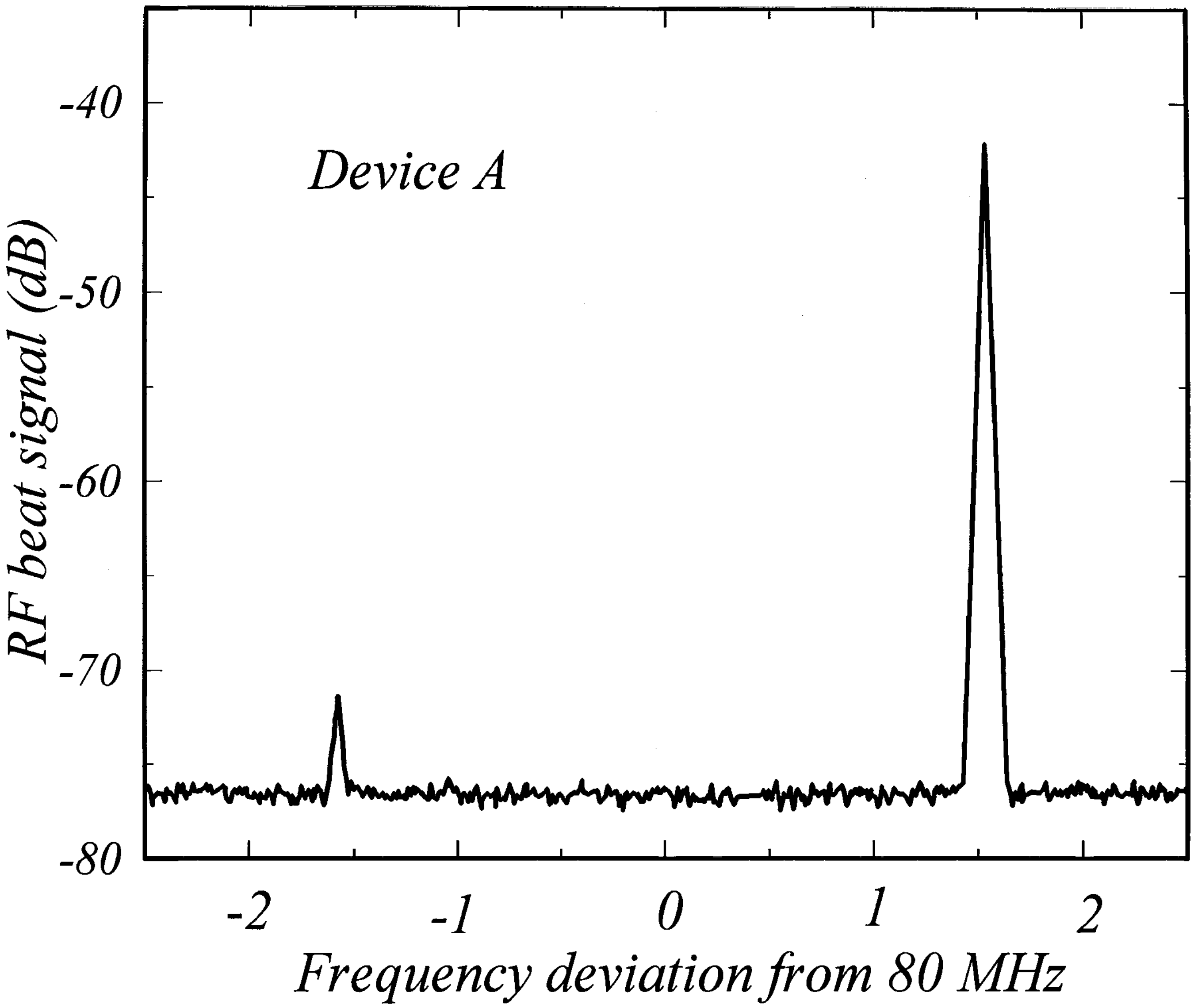

Device A
RF beat signal (dB)
-40
-50
-60
-70
-80
-2
-1
0
1
2
Frequency deviation from 80 MHz

Fig 3.

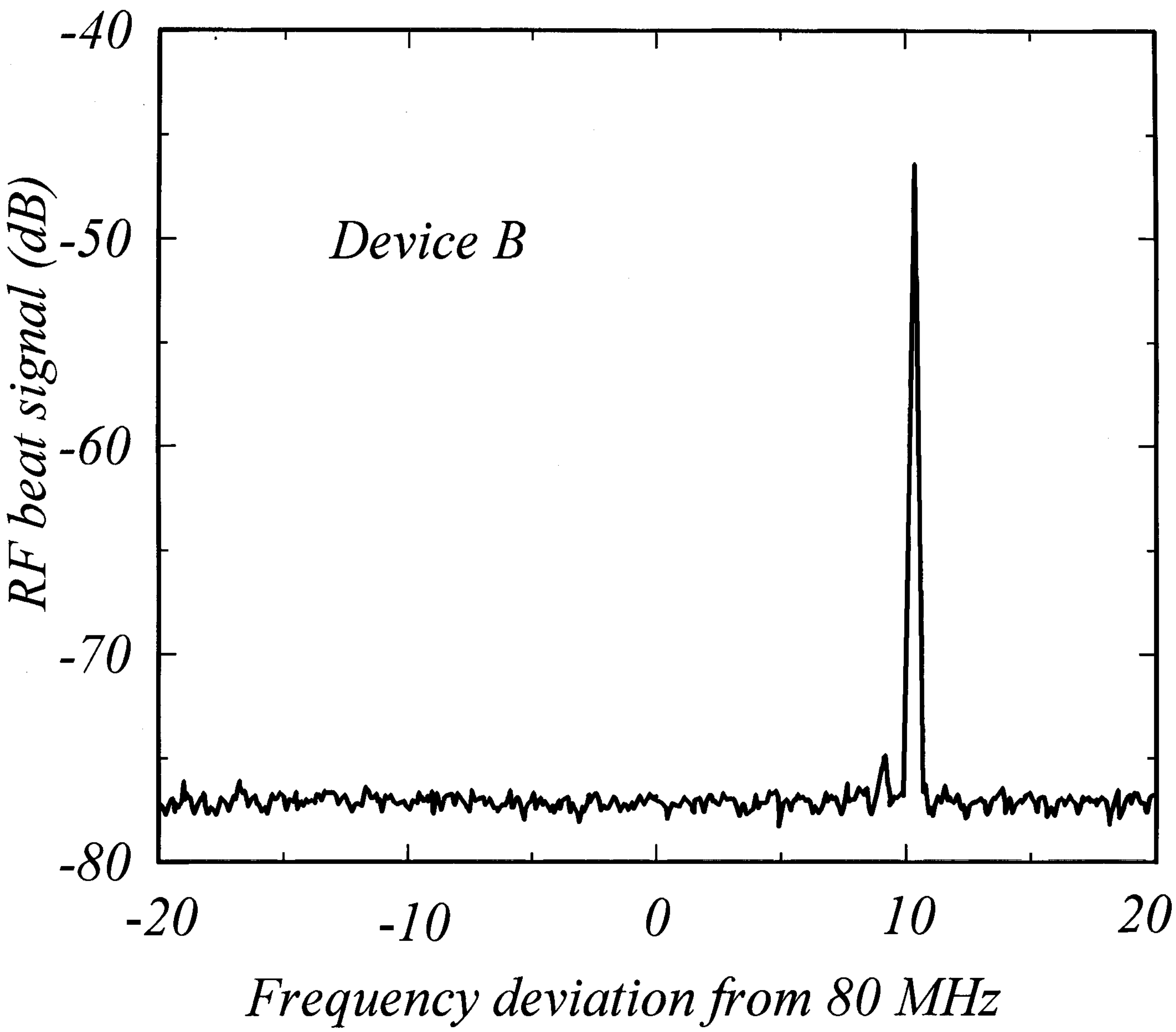

Device B
RF beat signal (dB)
-40
-50
-60
-70
-80
-20
-10
0
10
20
Frequency deviation from 80 MHz

Fig. 4.