Pulse Compression with Very Low Sidelobes in an Airborne Rain Mapping Radar

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Abstract

The pulse compression system for an airborne rain mapping radar is described. This system uses time domain weighting of the transmit pulse and is able to achieve a pulse compression sidelobe level of -55 dB. This is significantly lower than any values previously reported in the open literature.

1 Introduction

Pulse compression allows a substantial reduction in the peak transmitted power of a radar, without loss of signal-to-noise ratio [1]. Because of the expense involved in the construction of high peak power supplies, pulse compression is attractive for spaceborne radar remote sensing applications, including rain measurement. Its disadvantage is the presence of range compression sidelobes, which can mask returns in other range bins. in the case of a downward looking rain mapping radar, return from the surface can be much stronger (up to 60 dB or more) than return from rain, and sidelobes from surface return could potentially mask the return from rain. Consequently, the sidelobe level must be near -60 dB for light rain to be measurable. The achievement of such low sidelobe levels is not straightforward. Sidelobe levels of -30 to -40 dB are common, and the best compression sidelobe level reported in the open literature appears to be -45 dB for the Apollo lunar sounder, which operated in the 5-150 MHz region [2]. A sidelobe level of -55 dB level has now been achieved in the NASA/Jet Propulsion Laboratory Airborne Rain Mapping Radar (ARMA R).

ARMAR has been developed for the purpose of supporting future spaceborne rain radar systems, such as the radar for the Tropical Rain Measuring Mission (TRMM) [3], and also for longterm use as a research tool for radar meteorology and atmospheric science. It operates at 13.8 GHz and flies on the NASA Ames DC-8 aircraft. Table 1 summarizes the characteristics of ARMAR. ARMAR looks down at rain through the clouds and scans its antenna beam $\pm 20^0$ from boresight in the vertical plane normal to the flight direction. This geometry was chosen to simulate the spaceborne rain mapping radar case. ARMAR achieves its vertical resolution using pulse compression of a 4 MHz linear FM chirp. ARMAR was completed in 1991, and the first airborne testing was accomplished in May of 1992.

2 Pulse Compression Approach

Our approach to sidelobe suppression is time domain amplitude weighting of the transmitted chirp. The transmitted chirp is multiplied by a smooth envelope function, resulting in very low pulse compression sidelobes. In the past this has been difficult because of hardware limitations. As described in Cook and Bernfield [1] (p. 189), weighting of the amplitude of the transmitted signal is ordinarily "not attempted, since the final amplifier stages inherently operate class C and are not subject to amplitude control." This has led to use of other methods, such as frequency domain weighting and predistortion [I]. These methods, however, cannot reliably suppress range sidelobes to below -55 dB; consequently, wc decided to use amplitude weighting of the transmitted chirp and to operate the final transmit amplifier under linear rather than saturated conditions.

Figure 1 shows a block diagram of ARMAR. The system digitally synthesizes a chirp with a desired envelope shape, transmits, receives, and digitizes the received signal. The digitized received signals are then compressed in computer software by correlating with a reference chirp. The radar is capable of producing arbitrary chirp waveforms of 4 MHz bandwidth centered about an RF frequency of 13.8 GHz. The chirp generator utilizes a programmable frequency synthesizer to generate an IF chirp of constant amplitude and frequency near 70 Ml] z; following this, the chirp amplitude is shaped by the system described below. A computer looli-up-table (l, UT) drives both the frequency synthesizer and the amplitude shaping system. The amplitude and frequency information arc loaded into the LUT during initialization. During the transmit cycle, the information is sent to the synthesizer and amplitude shaping system at a rate of 6.7 MHz. The resulting chirp is then upconverted to RF by mixing with a 13.8 GHz oscillator.

The chirp amplitude shape is critical as far as pulse compression sidelobe levels are concerned. Simulations have shown that a smooth transition from zero to full amplitude is needed. Any sharp jumps in the chirp amplitude, including quantization steps that are too large, can increase sidelobes above the -55 dB level. In specifying the shape of the transmitted pulse, wc were faced with a tradeoff between range sidelobe levels and sigual-to-noise ratio (SNR). Maximum SNR is achieved by a constant amplitude pulse. Optimal sidelobe performance is achieved, however, by using a smooth envelope over the entire transmitted chirp. Based on computer simulations, we decided to usc a sinusoidal function which varies from zero at the start of the chirp to unity during the first third of the chirp. The middle third of the chirp has constant amplitude, and the final third of the chirp is again multiplied by a sinusoid to vary smoothly from unity to zero. In using this amplitude weighting, wc 100SC approximately 2 dB in SNR, but we get a 40 db reduction in sidelobes in ***our*** simulations,

To implement this amplitude shape, we initially tried a commercially available programmable attenuator in laboratory testing, Minimum step size for this attenuator was 0.25 dB and the resulting quantization step in the chirp amplitude was found, both in tests and in computer simulation, to limit the compression range sidelobes to about -50 dB. "Jo improve upon this, an attenuator with 0.1 dB quantization was tried. However, sidelobes remained around -50 dB because switching transients which occurred when changing from onc attenuation to the next were nearly as significant as the 0.25 dB step size. The problem was solved by using a double balanced mixer in place of the attenuator to control the chirp amplitude. This is shown in Figure 2. The signal from a D/A converter is used to drive the mixer IF port with a voltage proportional to the desired chirp amplitude. The frequency synthesizer was fed to the LO port, and the 70 MHz IF chirp was taken from the RF port. This technique produced transient free chirp waveforms with -60 dB sidelobes in laboratory testing with no traveling wave tube (TWT) amplifier. in subsequent testing wc found that the TWT increased sidelobes to the -55 dB level.

To determine the operational sidelobe performance of the system, wc examined the return from the ocean surface acquired during a test flight in May 1992. Figure 3 shows the results for 5, 20, and 40 μsec chirps. Each plot corresponds to the (incoherent) average of approximately 6000 compressed chirps. It can be seen that the sidelobe levels are approximately -55 to -60 dB. These measurements arc typical.

The system's rain mesurement ability can be determined by comparing surface return with rain return; wc consider a worst case situation with rainfall over a smooth ocean at nadir. A relatively smooth ocean might have a nadir cross section σ^o of 15 dB [4]. For a -55 dB sidelobe level, the ocean surface clutter return would thus have a cross section of -40 dB. This can be converted to a cross section pcr unit volume, or reflectivity, by dividing by the radar range resolution of 100 m (after range averaging), giving $\eta = 10^{-6}$. Assuming a Marshall-Palmer drop size distribution and Rayleigh scattering, this reflectivity corresponds to a rainrate of approximately 2 mm/hr [5], [6]. Rainrates of less than 2 mm/hr will have return that is less than the sidelobes due to surface return.

3 Conclusions

A pulse compression radar which has range sidelobes of-55 dB or better has been built and demonstrated in flight tests over the ocean. The pulse compression technique relics on weighting of the time domain amplitude of the transmitted signal, This weighting is accomplished by mixing an IF chirp of constant amplitude with a signal having the desired amplitude. The success of this system is quite significant for future spaceborne rain radars, since minimization of peak power is critical. With a limited peak power the SNR can be significantly increased using long pulses with pulse compression.

Acknowlegment

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References

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Table 1: ARMAR System Characteristics

Operating Frequency (GHz)	13.8
Polarization	HH,VV,HV
Antenna Size (m)	.41
Antenna Gain (dB)	34
Antenna Scan Angle (deg)	±20
Transmitter Power (W)	250
Chirp Duration (μsec)	5-45
PRF (KHz)	1-4
Chirp Bandwidth (MHz)	4
System Noise Temperature (K)	700

Figure Captions

Figure 1. Block diagram of ARMAR.

Figure 2. Block diagram of chirp generator.

Figure 3. Average of 6000 compressed chirps from the ocean surface. Chirp length of (a) 5 μsec, (b) 20 μsec, and (c.) 40 μsec.

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AIRBORNE RAIN MAPPING RADAR
14 GHz BLOCK DIAGRAM

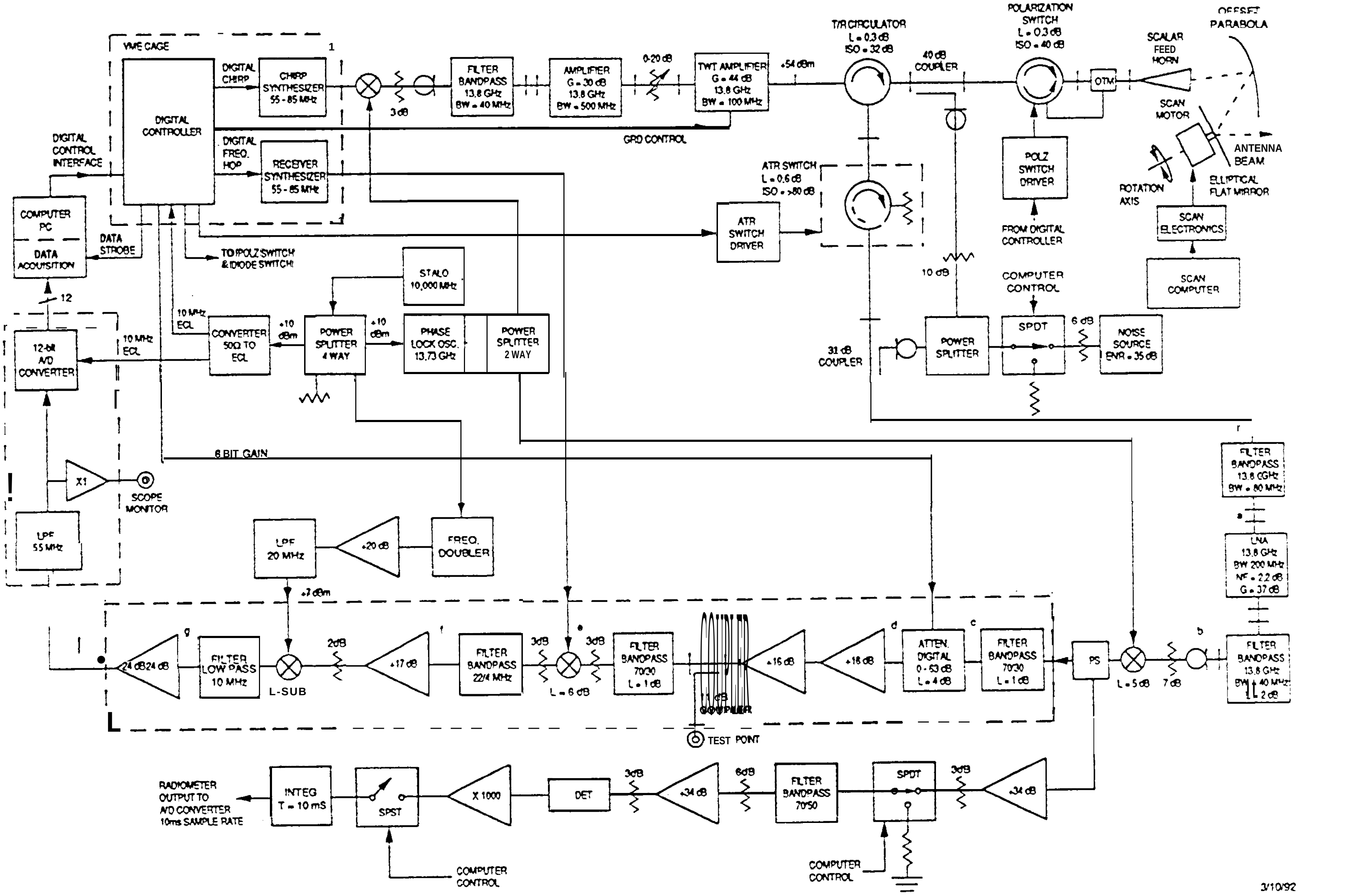

Fig 1

AIRBORNE RAIN MAPPING RADAR

CHIRP GENERATOR

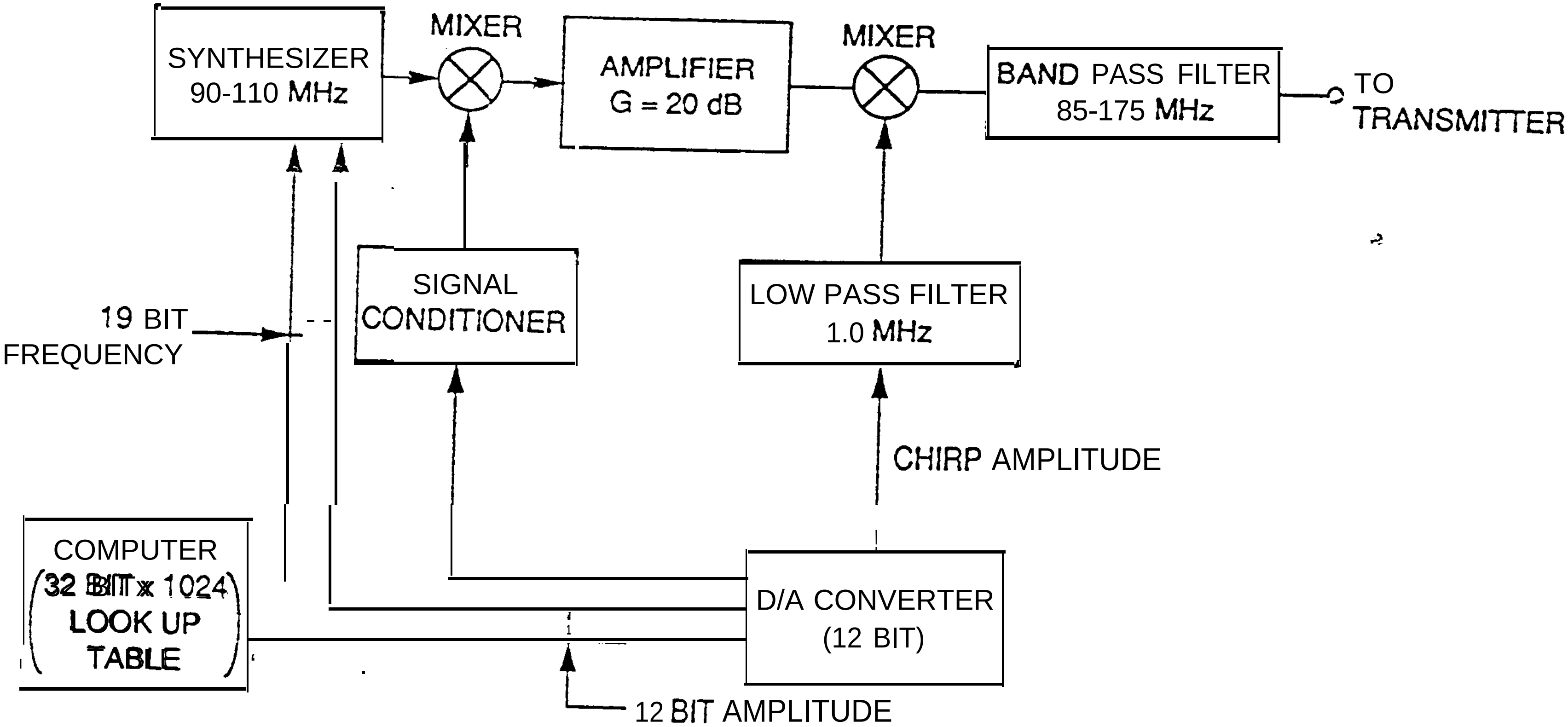

Fig 2

AIRBORNE RAIN MAPPING RADAR

PULSE COMPRESSION SIDELOBES

- Shown below are averages of approximately 6000 compressed chirps from the ocean at nadir for different chirp lengths.

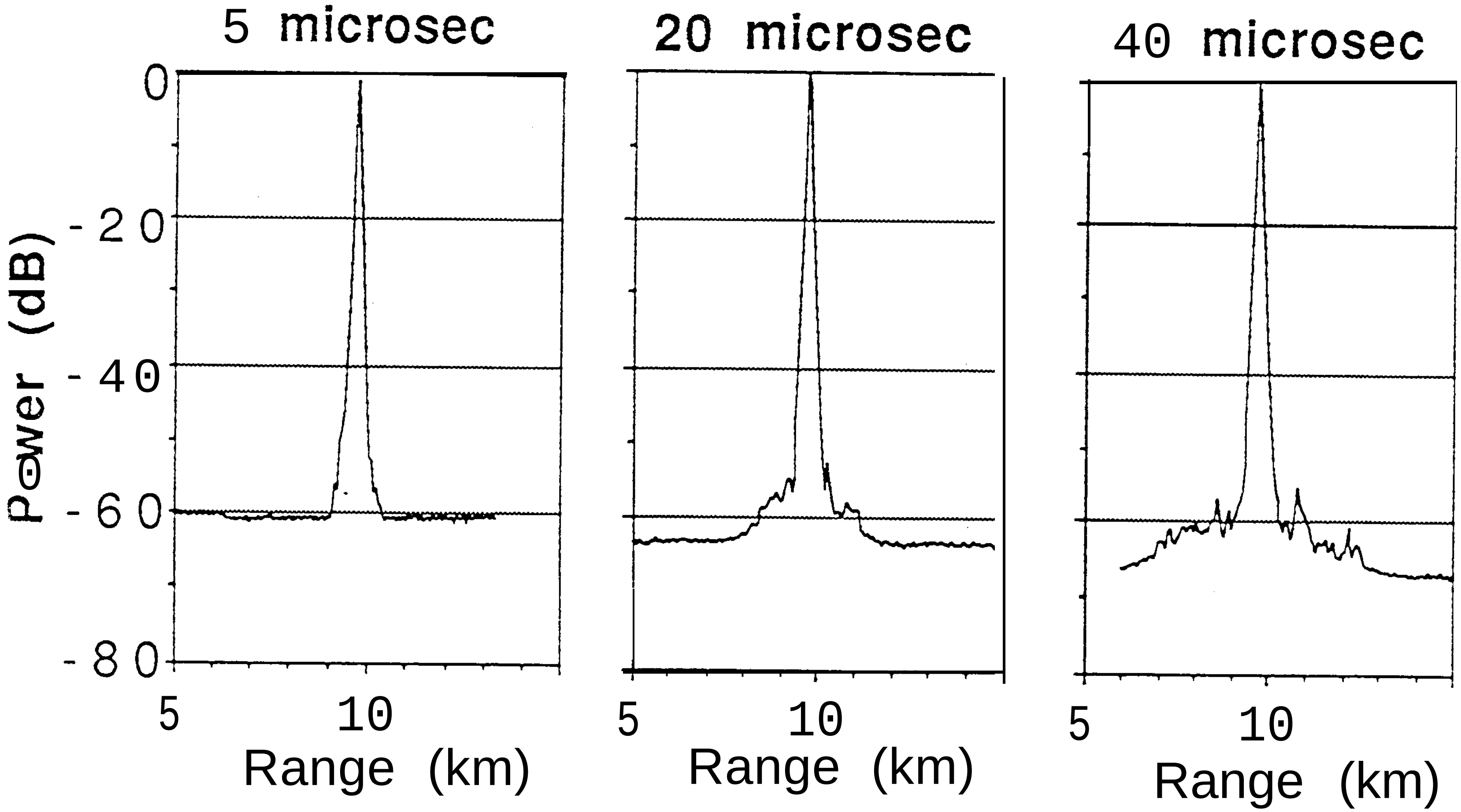

Fig 3