

## CHAPTER 5

### RESULTS AND DISCUSSION

#### 5.1 INTRODUCTION

In this chapter, we present the results obtained from the pulsar observations at 34.5 MHz made using the two schemes, namely the **single** frequency channel scheme (SCS) and the swept frequency dedispersion scheme (SFDS), described in the earlier chapters. Three pulsars, namely PSR 0628-28, PSR 0942-13 and PSR 0943+10, have been detected for the first time **at a** decametric wavelength. The average pulse profiles and the energy spectra are presented for the detected pulsars. The theoretical implications of these results are not discussed here as it is beyond the scope of the present work.

The profiles obtained using the SFDS are smoothed additionally over 3 bins for PSR 1919+21 and over 10 bins in other cases. The error bars correspond to five times the standard deviations due to noise.

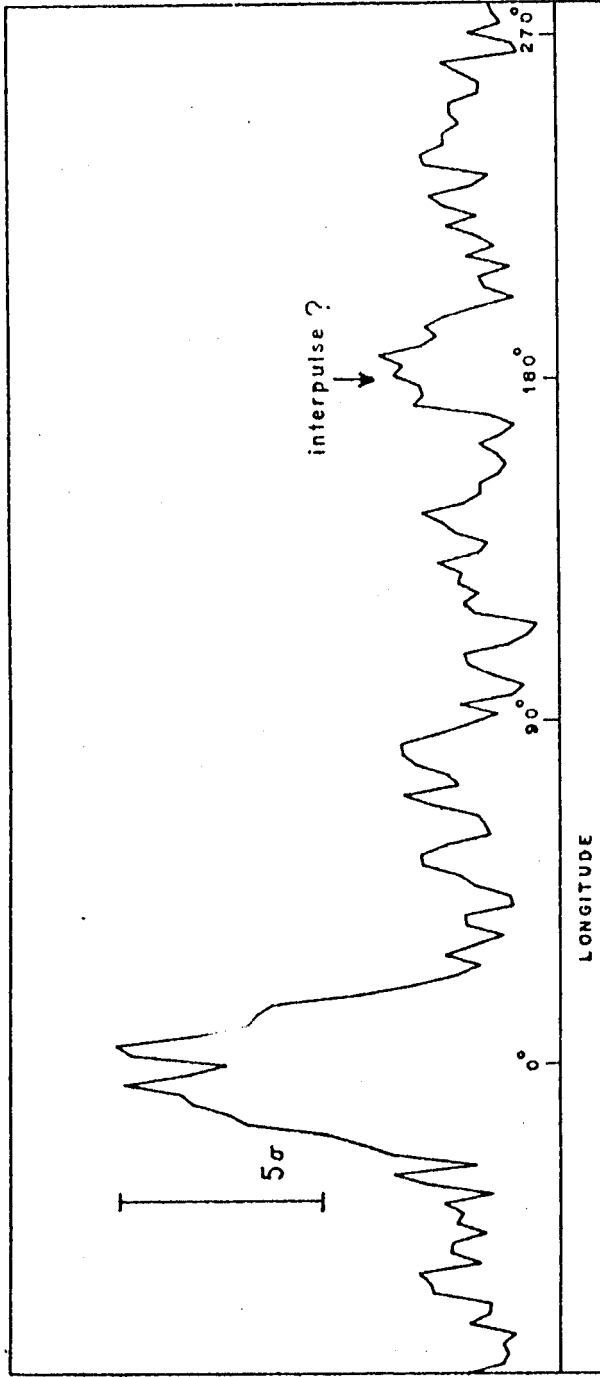
## 5.2 PSR 0628-28

This pulsar with high dispersion measure of  $34.36 \text{ cm}^{-3} \text{ pc}$  is detected at such a low frequency for the first time. The average pulse profiles obtained from both the schemes (SCS, SFDS) are shown in Fig. 5.1. The profile presented in Fig. 5.1(a) is obtained using SFDS. Note the weak emission feature at about  $185^\circ$  longitude, which can be easily distinguished from the rest of the off-pulse baseline. This feature is probably due to interpulse emission. If so, the ratio of the energy of the interpulse to that of the main pulse is about 0.15. More observations are necessary to confirm the possible interpulse emission. The observed width at half-maximum of the main pulse is 125 milliseconds.

The spectrum of the pulse energy of this pulsar is found to be straight in the frequency range 61 to 1420 MHz (Kuzmin et al., 1978) [51]. However, an extension of the spectrum to frequencies below 60 MHz, using our estimate for the main pulse energy, shows a turnover in the spectrum (Fig. 5.2). The emission intensity appears to peak at frequencies close to 60 MHz.

PSR 0628-28

SFDS



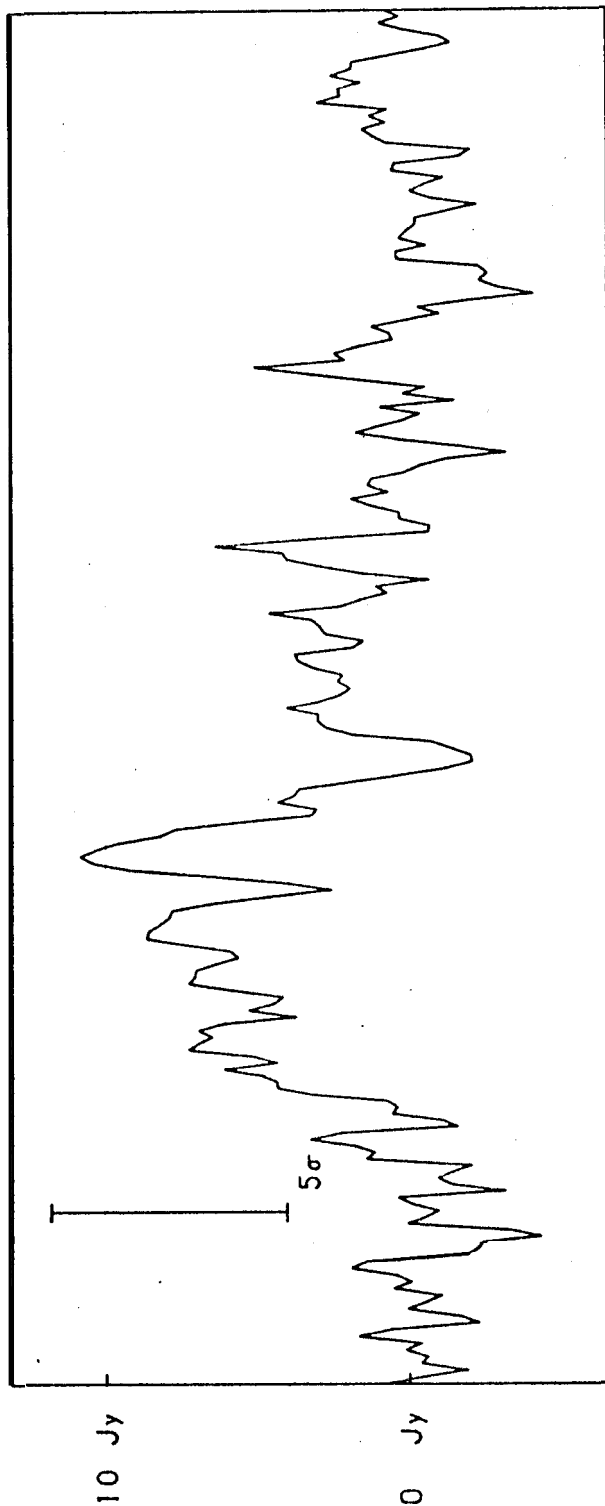
EFFECTIVE INTEGRATION : 77 minutes.

(  $P=1.244417s$  and  $DM=34.36 \text{ cm}^{-3} \text{ pc}$  )

FIG. 5.1a AVERAGE PROFILE OF PSR 0628-28 USING THE SWEPT-FREQUENCY DEDISPERSION SCHEME

PSR 0628-28

SCS



AVERAGE OF 4000 PULSES  
(  $P=1.244417s$  and  $DM=34.36 \text{ cm}^{-3} \text{ pc}$  )

FIG. 5.1b AVERAGE PROFILE OF PSR 0628-28 USING THE SINGLE FREQUENCY CHANNEL SCHEME

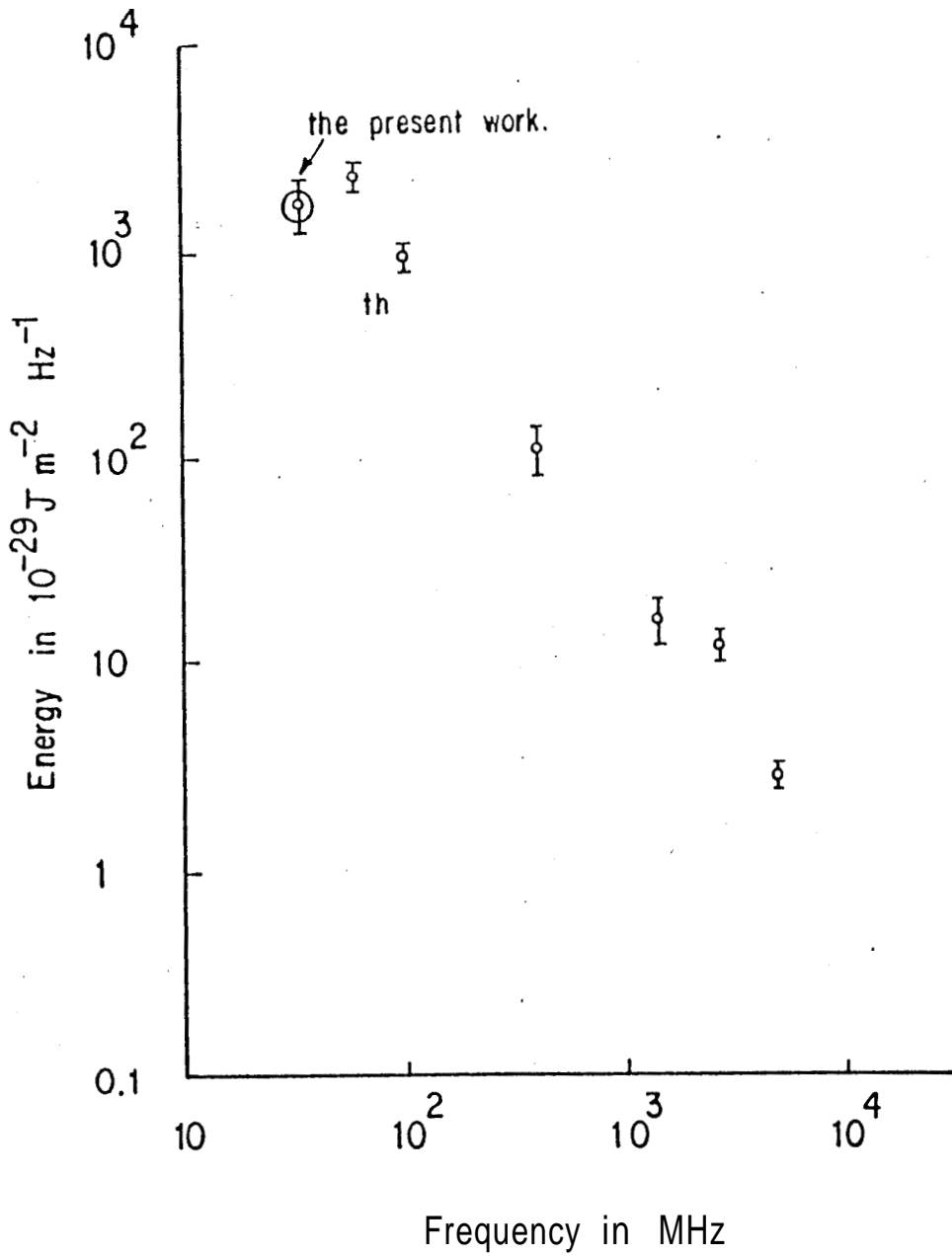


FIG. 5.2 Energy spectrum of PSR.0628-28

### 5.3 PSR 0809+74

This is the only pulsar that was observed extensively down to a very low frequency of **10 MHz** (**Bruck and Ustimenko, 1973**) [61]. Although, this is one of the strongest pulsars at the frequency of our observation, the signal-to-noise ratio that could be obtained **is** rather poor. The telescope sensitivity in the direction of this pulsar is very much reduced due to its large zenith angle. However, the increased tracking time for this pulsar, by virtue of its high declination, has made integration of more number of pulses possible leading to a partial improvement in the signal-to-noise ratio. The pulse profile obtained using the SCS is shown in Fig. 5.3. The average pulse energy estimated using this profile is consistent with the turnover in the spectrum [53]. However, it may have large calibration errors due to lack of suitable calibration sources at nearby declinations. Fig. 5.4 shows the spectrum of the average pulse energy using our **estimate** along with other observations [53].

### 5.4 PSR 0834+06

Using the SCS, data were obtained for this pulsar on 11 days. After combining the data on all days, we are able to obtain a very high signal-to-noise ratio for its average profile (Fig. 5.5a). A high time-resolution profile obtained

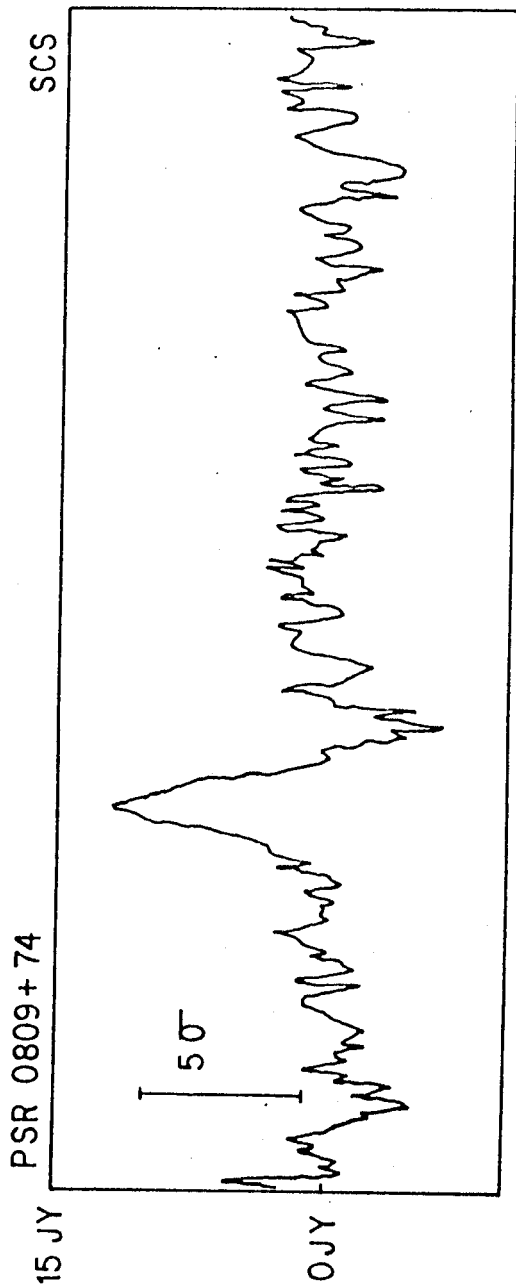


FIG.5.3 Average profile of PSR 0809 +74 using the single frequency channel scheme.

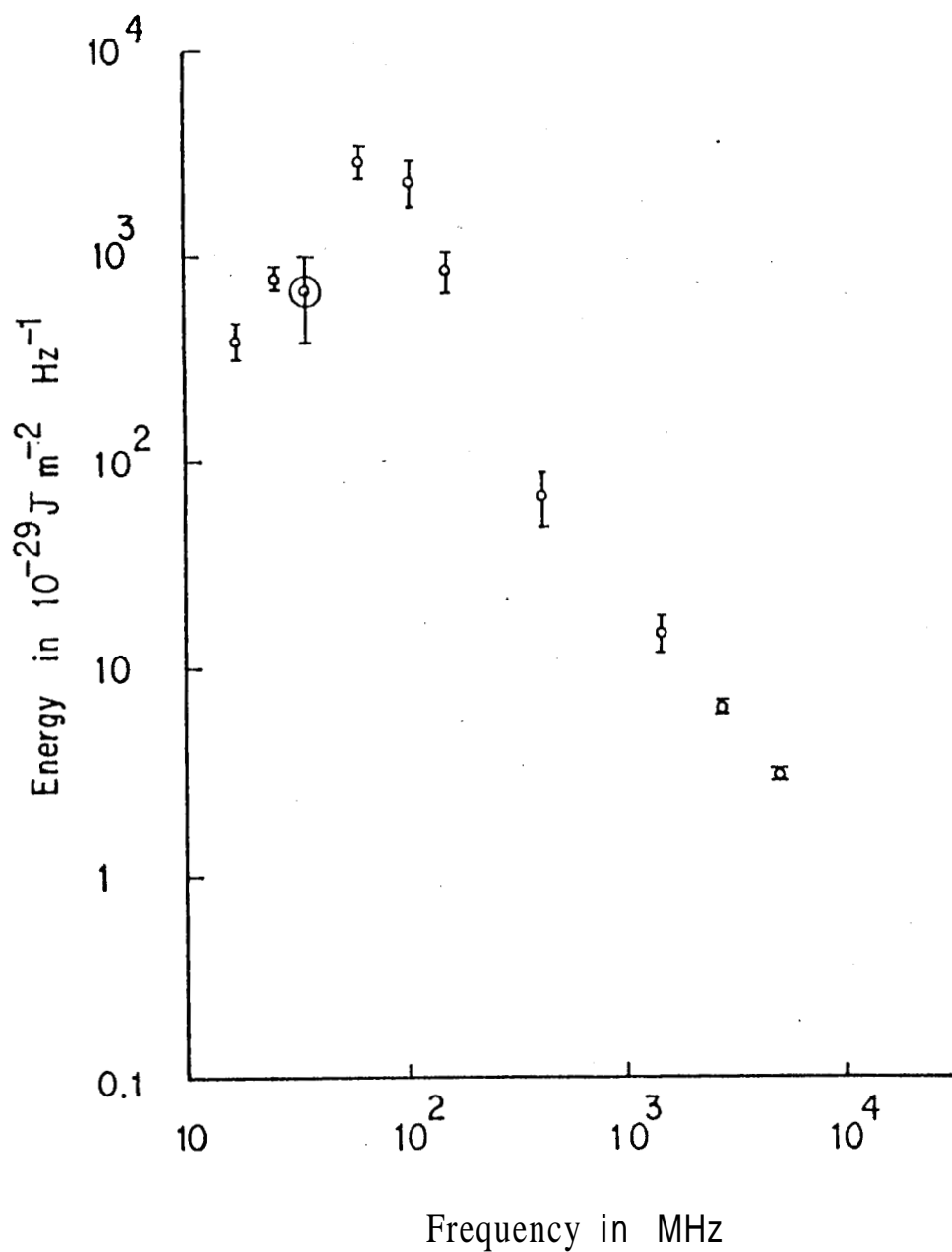
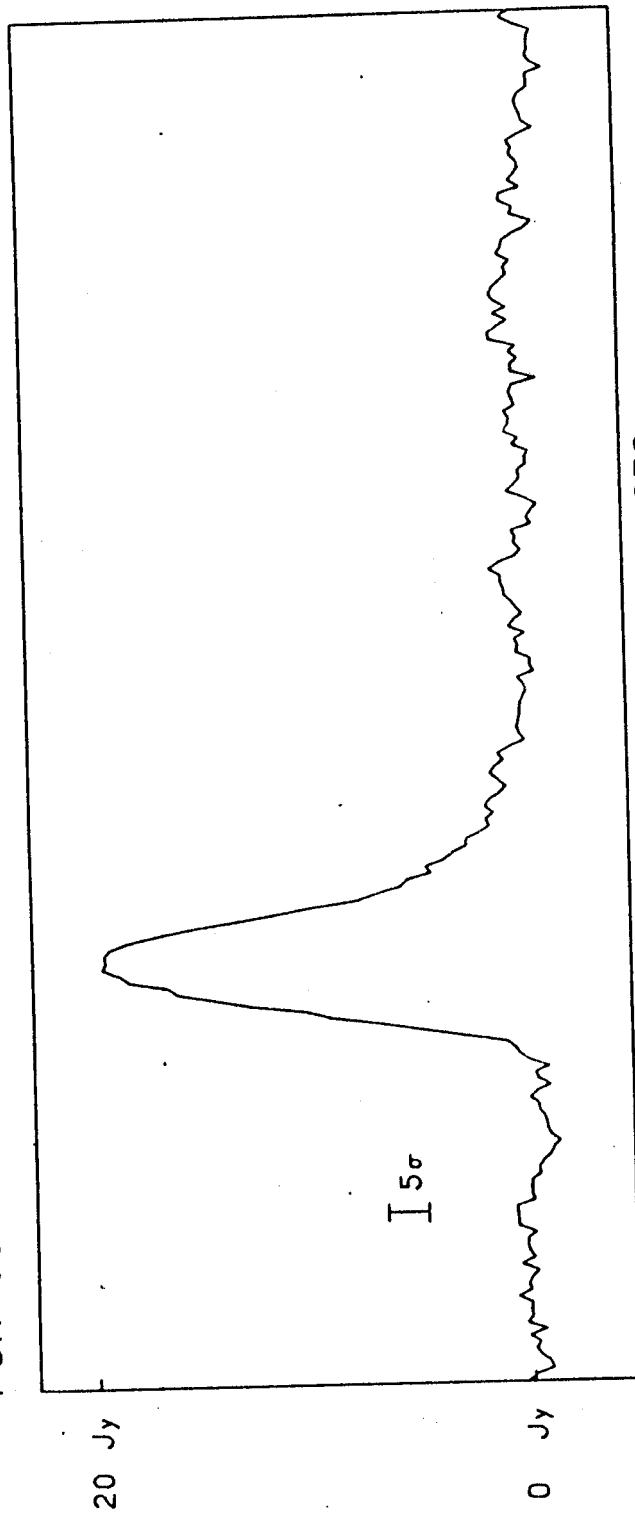


FIG. 5.4 Energy spectrum of PSR0809+74



SCS

PSR 0834+06



AVERAGE OF 20000 PULSES

(  $P=1.273764s$  and  $DM=12.855 \text{ cm}^{-3} \text{ pc}$  )

FIG. 5.5a AVERAGE PROFILE OF PSR 0834+06 USING THE SINGLE FREQUENCY CHANNEL SCHEME

using the SFDS on one day is shown in Fig. 5.5b. The improvement in the time-resolution due to the SFDS is quite striking. The observed width in this case is approximately 36 milliseconds.

We estimate the average energy per pulse to be  $(2100 \pm 100) \times 10^{-29}$  J/m<sup>2</sup>/Hz. This estimate is in very good agreement with the estimates at other frequencies (see Fig. 5.6). The average profile (Fig. 5.5a) does not show any significant interpulse emission contrary to that reported at 25 MHz [78]. This may suggest a steep spectrum for the interpulse energy.

### 5.5 PSR 0942-13

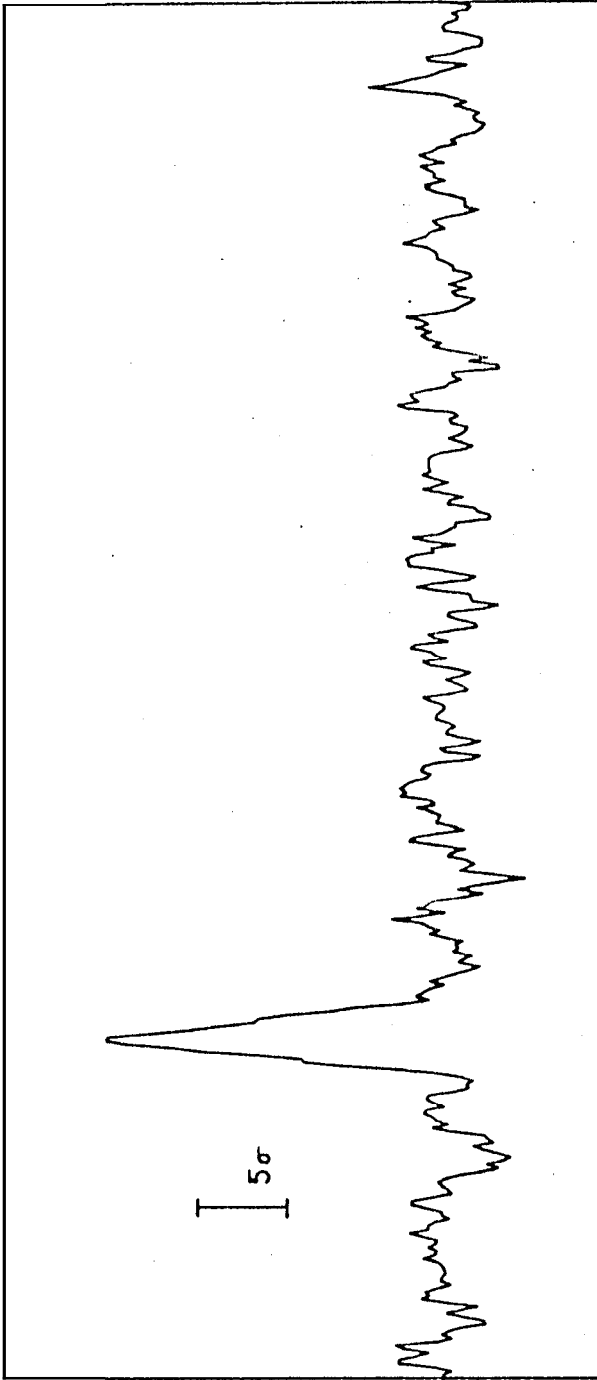
Observations of this pulsar were made on two days using the SCS. The final average profile is shown in Fig. 5.7. The pulse energy is estimated to be  $(110 \pm 67) \times 10^{-29}$  J/m<sup>2</sup>/Hz. Using the value for the average flux at 400 MHz [94], we estimate a spectral index of  $-0.76 \pm 0.28$ . Due to the large gap in the measured points on the spectrum, it is difficult to comment about the existence of a turnover in the spectrum in the frequency range 34.5 MHz to 400 MHz.

### 5.6 PSR 0943+10

The average profile obtained using the SCS is presented

PSR 0834+06

SFDS



EFFECTIVE INTEGRATION : 24 minutes.

(  $P = 1.273764\text{s}$  and  $\mu M = 12.855 \text{ cm}^{-3} \text{ pc}$  )

FIG. 5.5b AVERAGE PROFILE OF PSR 0834+06 USING THE SWEEP-FREQUENCY DEDISPERSION SCHEME

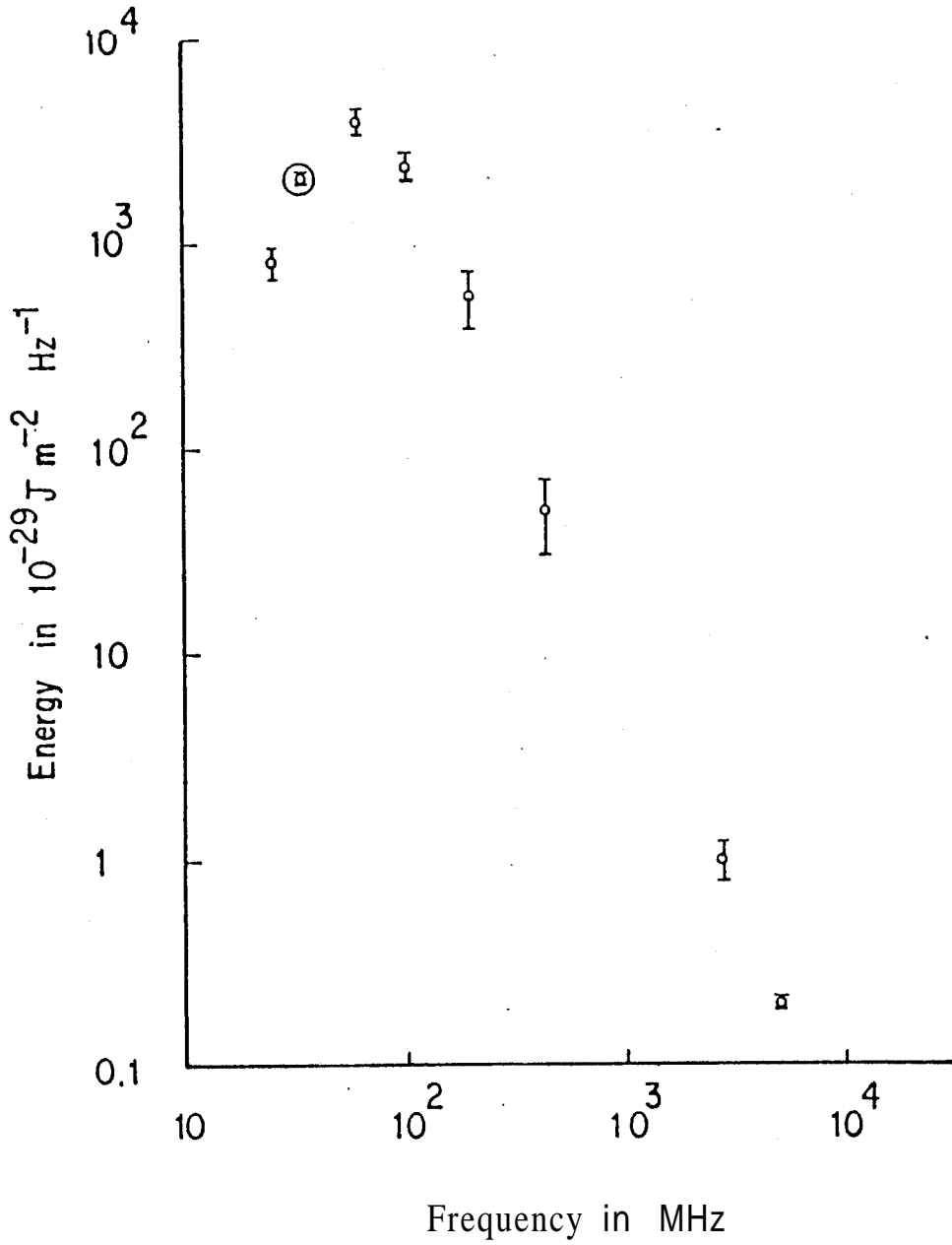
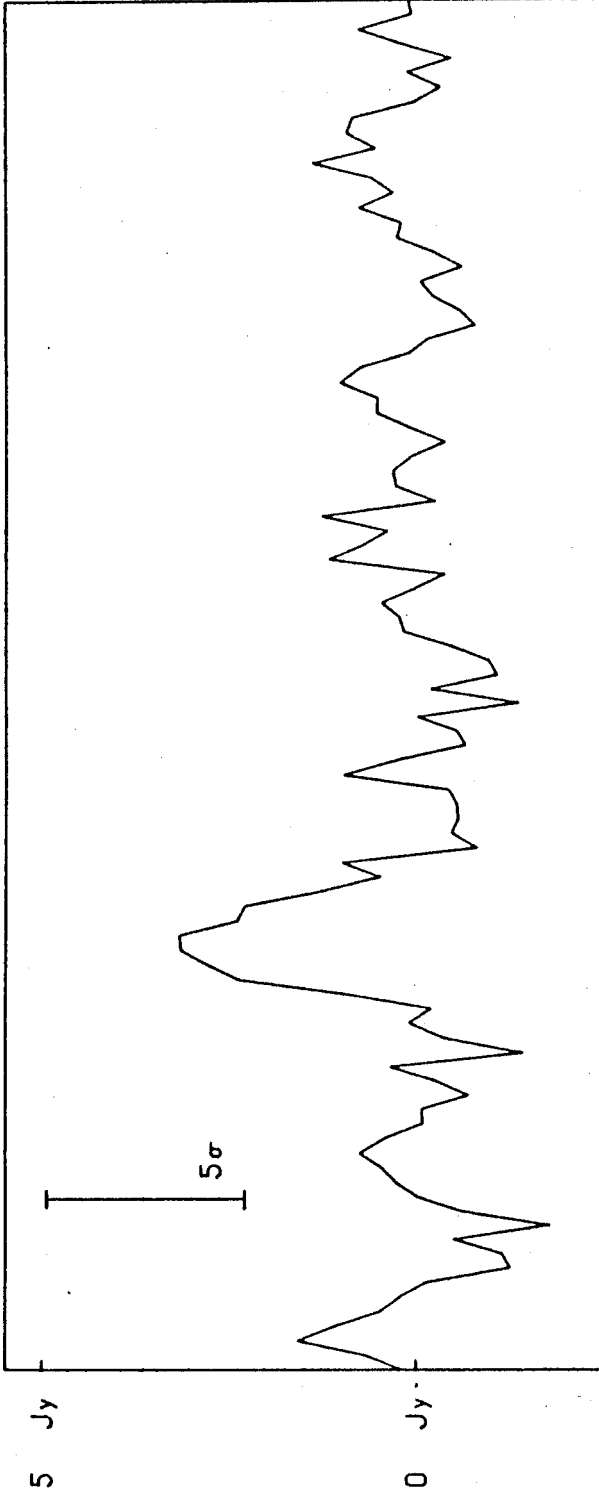


FIG. 5.6 Energy spectrum of PSR0834+06

PSR 0942-13

SCS



AVERAGE OF 9000 PULSES

(  $P=0.570264s$  and  $DM=12.4 \text{ cm}^{-3} \text{ pc}$  )

FIG. 5.7 AVERAGE PROFILE OF PSR 0942-13 USING THE SINGLE FREQUENCY CHANNEL SCHEME

in Fig. 5.8. Suleimanova and Izvekova (1984) [102] have reported mode changing for this pulsar at 62 and 102 MHz. The time-resolution in the profile shown in Fig. 5.8 is not adequate to see any details in the pulse profile. However, using the SFDS, it was possible to observe finer details of the pulse. Fig. 5.9 shows a high resolution profile obtained by combining the data on two days. The profile seems to suggest that only one of the two modes (namely, B and Q) discussed by Suleimanova and Izvekova [102] becomes prominent at decametric wavelengths. This (B) mode is observed to have two peaks with an intensity ratio of 3.5:1 at 102 MHz. This intensity ratio appears to be about the same at 34.5 MHz. However, the separation of the two components has increased to about 80 milliseconds at the present frequency from 31 milliseconds at 102 MHz. This suggests to us that the separation is proportional to  $(\text{wavelength})^{0.9}$ .

Our estimate of the average pulse energy, when compared with similar estimates in the range 53 to 606 MHz by Comella [52], suggests that the spectrum is still rising even upto 34.5 MHz. This happens to be the first case where the spectrum for a long period pulsar does not have a turnover even upto 34.5 MHz. Investigation of the spectrum at frequencies below 34.5 MHz may be of great interest. The spectral index computed using our estimate with that at 400 MHz [94] is about -1.65.

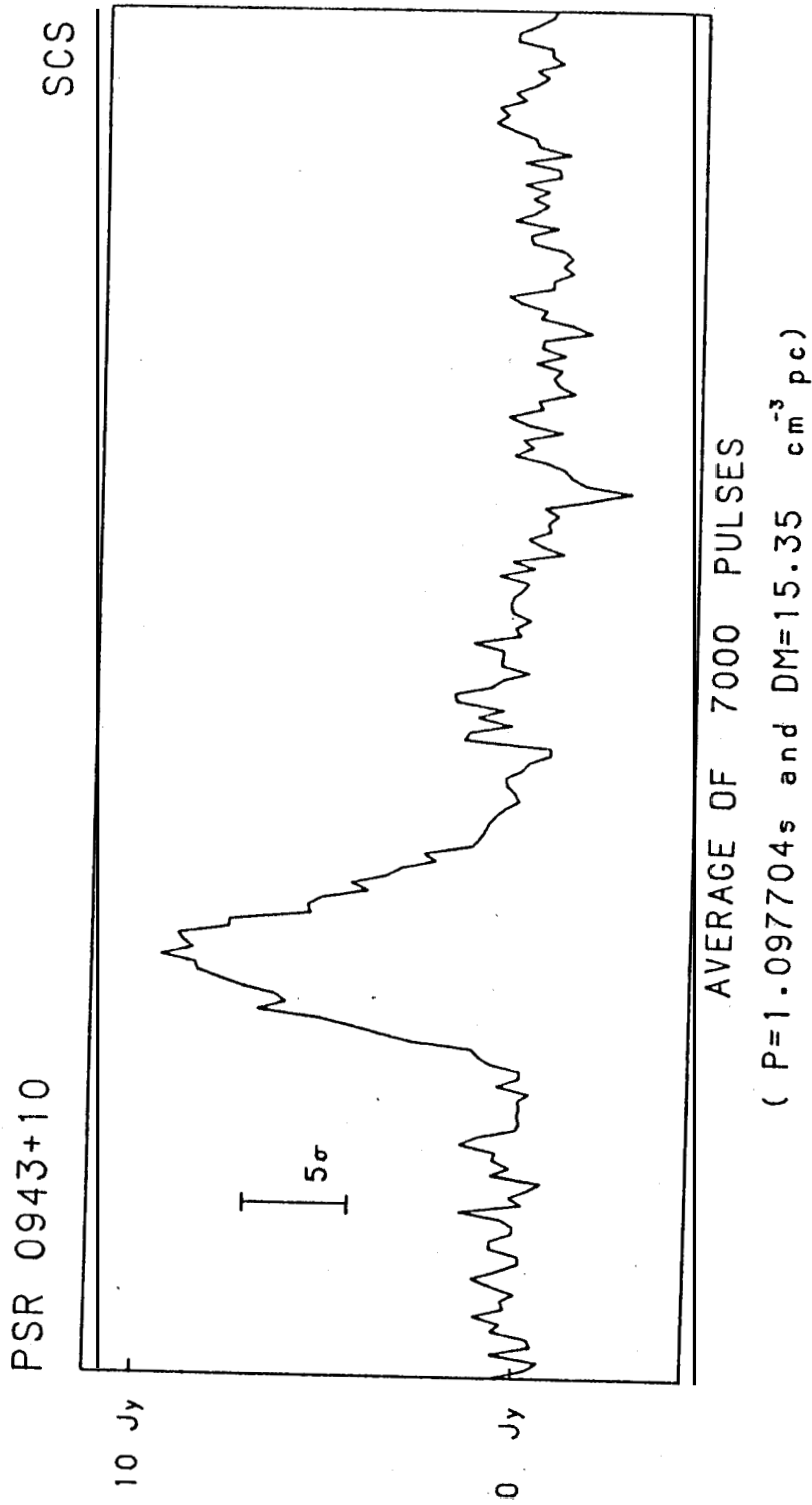
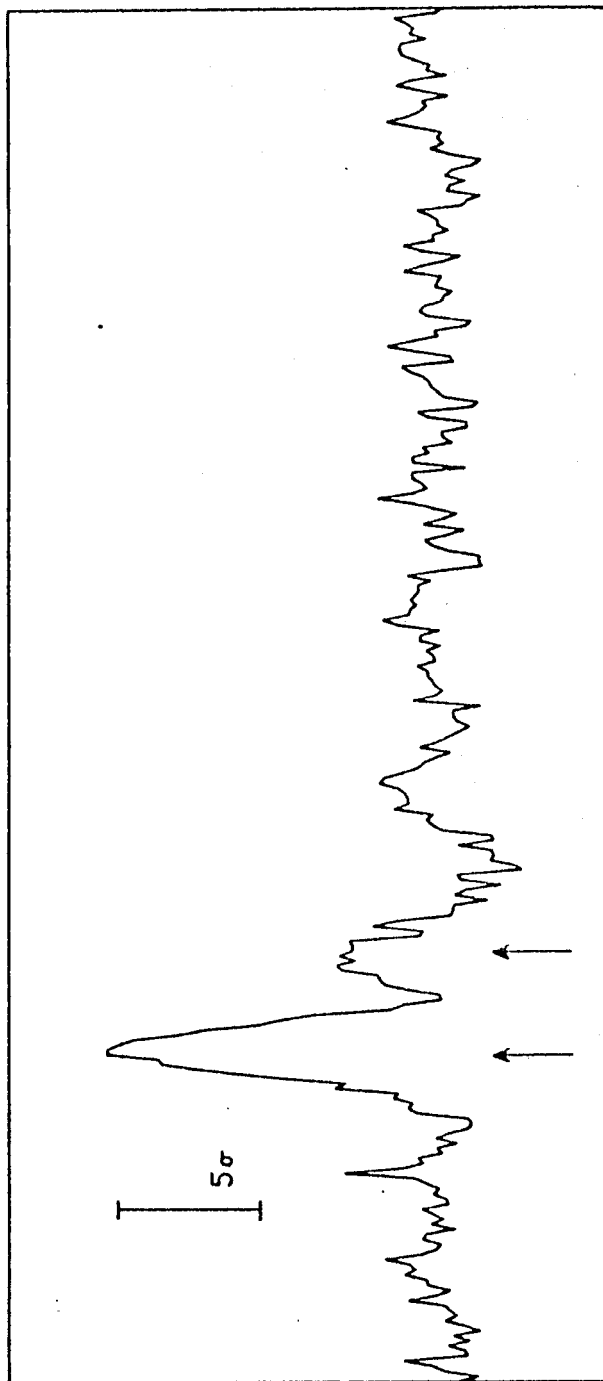


FIG. 5.8 AVERAGE PROFILE OF PSR 0943+10 USING THE SINGLE FREQUENCY CHANNEL SCHEME

PSR 0943+10

SFDS



EFFECTIVE INTEGRATION : 72 minutes.

( P=1.097704s and DM=15.35 cm<sup>-3</sup> pc )

FIG.5.9 AVERAGE PROFILE OF PSR 0943+10 USING THE SWEPT-FREQUENCY DEDISPERSION SCHEME



## 5.7 PSR 0950+08

PSR 0950+08 has the smallest dispersion measure among known pulsars. Due to its short period, it was possible to average a large number of pulses leading to better sensitivity. Fig. 5.10 shows a profile averaged over 54000 pulses using the data obtained from the SCS on six days. The longitude resolution in this case is not adequate to see finer details in the pulse. The average energy per pulse is estimated to be  $(420 \pm 60) \times 10^{-29} \text{ J/m}^2 / \text{Hz}$ . This estimate when compared with other observations [53] appears to suggest that the estimate at 61 MHz [51] may be in considerable error (see Fig. 5.11).

## 5.8 PSR 1133+16

Fig. 5.12 shows an average profile for PSR 1133+16 obtained using the SCS. The observations were made over 8 days. The two components which have been observed at and above 61 MHz [27,63] are just distinguishable in this profile. However, a predicted profile (see eq.3.12) assuming a single component in the intrinsic pulse could not give a good fit to the observed profile, during the estimation of the scattering width. Therefore, the intrinsic pulse is assumed to have two components of width 12 msec each with a separation of 45 msec. The widths and the separation of the components at 61 MHz are used after (wavelength)<sup>0.25</sup> scaling. With this assumption, it is

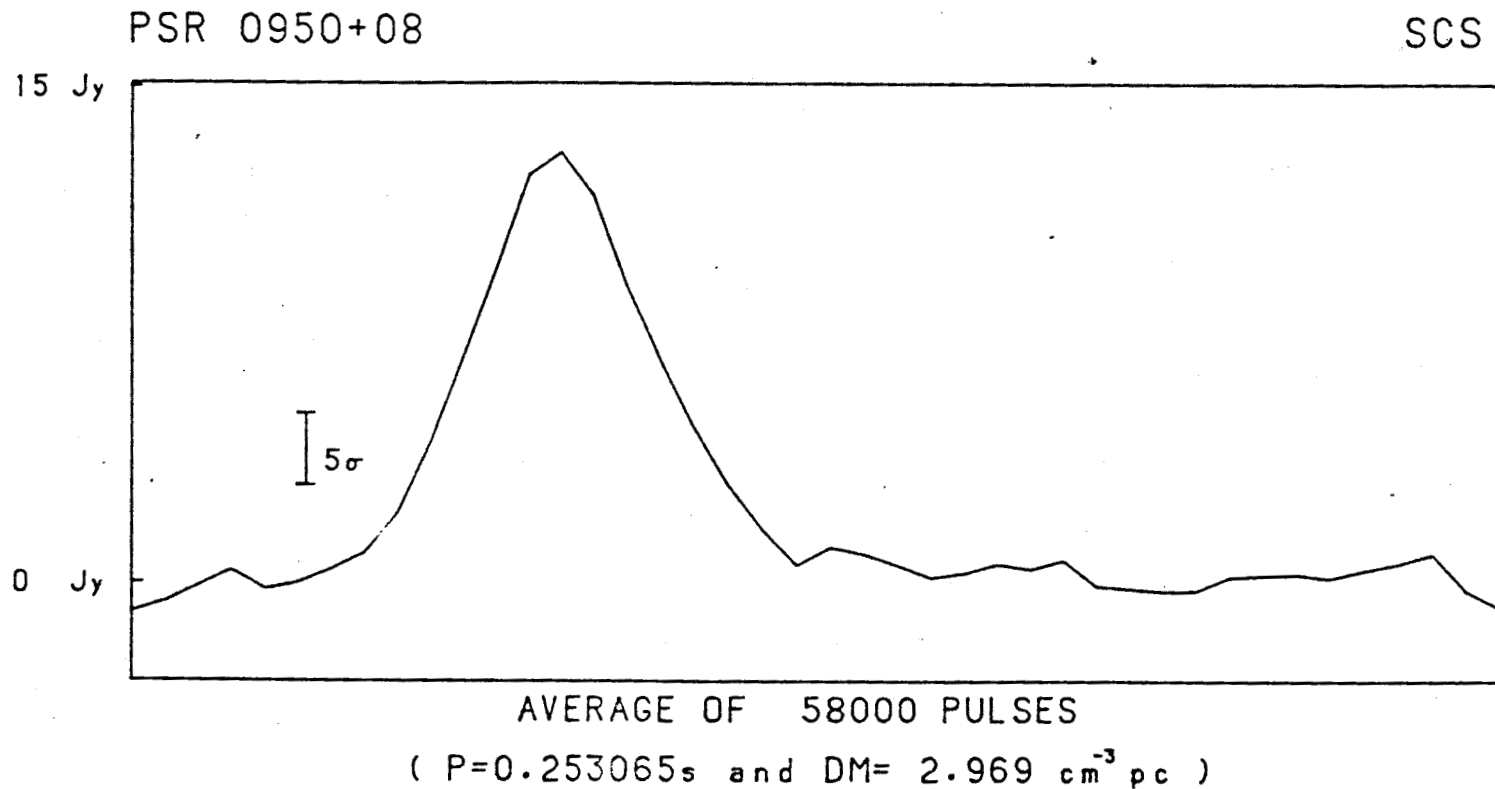


FIG-5-10 AVERAGE PROFILE OF PSR 0950+08 USING THE SINGLE FREQUENCY CHANNEL SCHEME

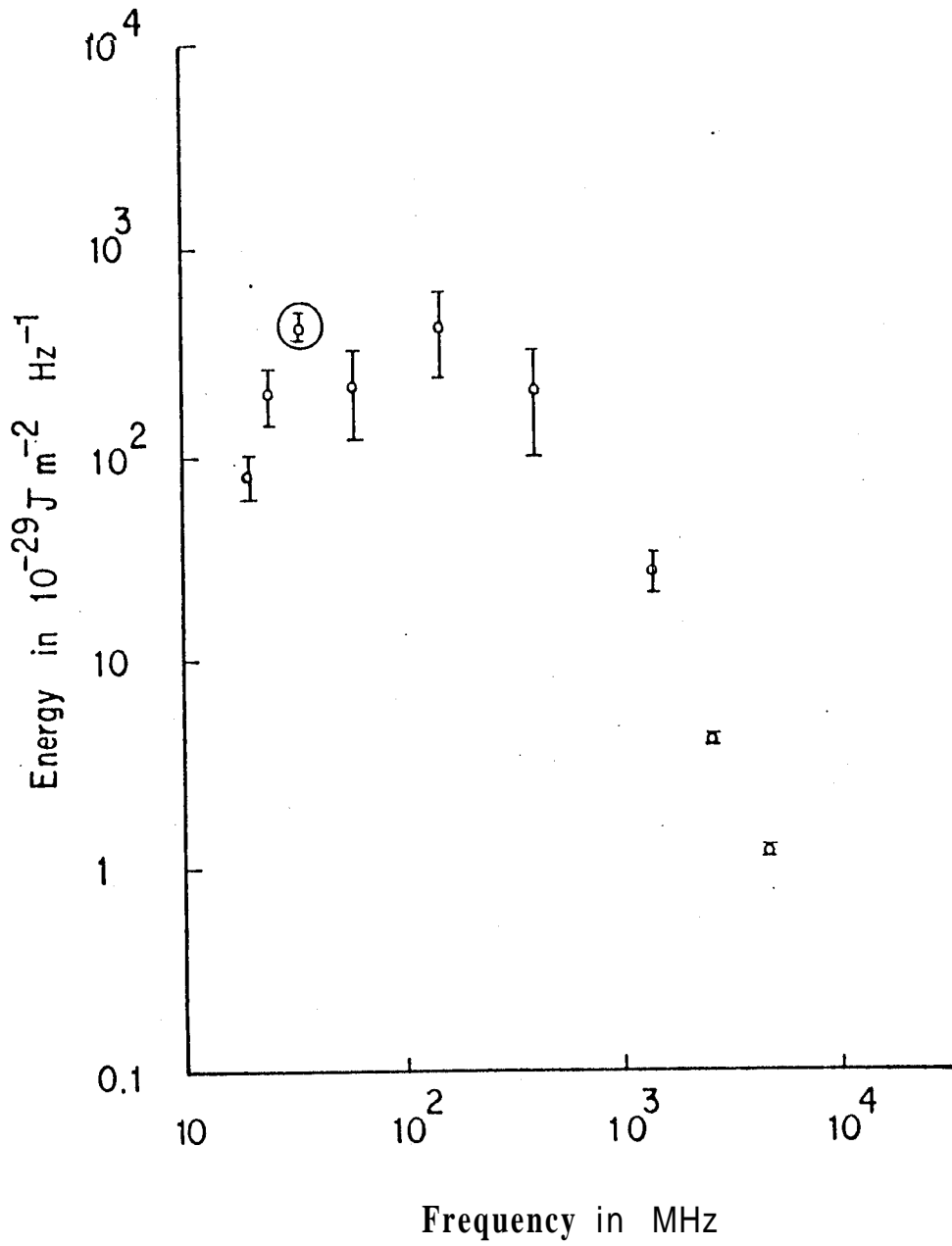


FIG. 5.11 Energy spectrum of PSR0950+08

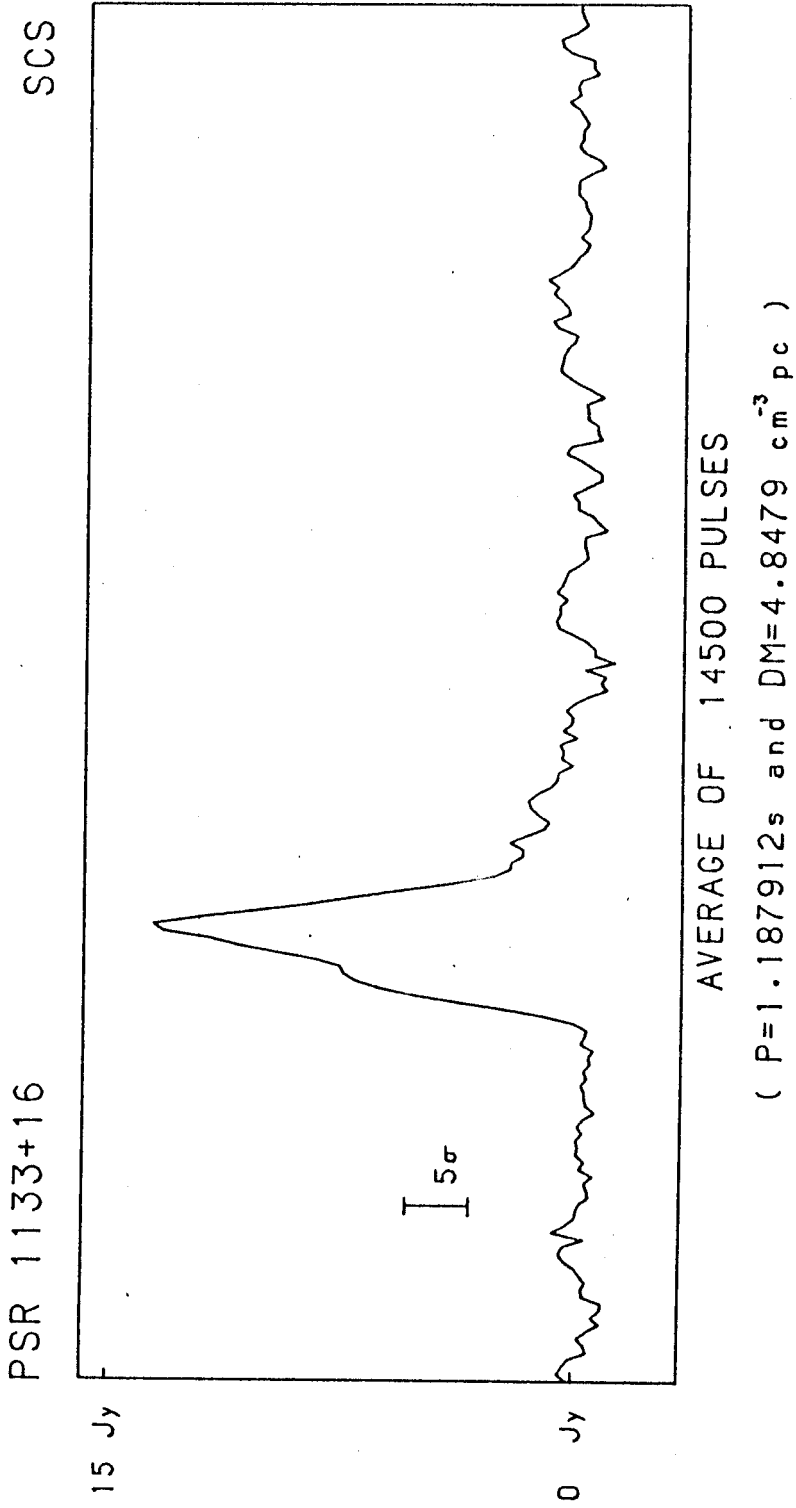


FIG.5.12 AVERAGE PROFILE OF PSR 1133+16 USING THE SINGLE FREQUENCY CHANNEL SCHEME

possible to obtain a very good fit to the observed profile, provided a component intensity ratio of **0.6:1** is used. It should be pointed out, that at 102 MHz [63] this intensity ratio is about unity, and is greater than unity at 400 MHz [28]. The energy spectrum is shown in Fig. 5.13.

### 5.9 PSR 1919+21

Observations of this pulsar were made using both the observing schemes. Fig. 5.14 shows an average profile obtained using the SFDS. This profile has the best longitude resolution obtained so far by us. The observed pulse width is about 30 msec. We do not find any significant interpulse emission in the profiles obtained on this pulsar. It should be noted, that significant interpulse emission has been reported at and below 25 MHz [76,77]. We estimate the average pulse energy to be  $(2560 \pm 400) \times 10^{-29}$  J/m<sup>2</sup>/Hz. This estimate is obtained using observations made using a 16 frequency channel analog receiver [103]. Fig. 5.15 shows our estimate with those at other frequencies [53] on an energy Vs. frequency plot.

### 5.10 SCATTERING IN THE INTERSTELLAR MEDIUM

The amplitude scintillation of pulsar signals and the temporal broadening of their pulse profiles are different manifestations of scattering by small-scale electron density

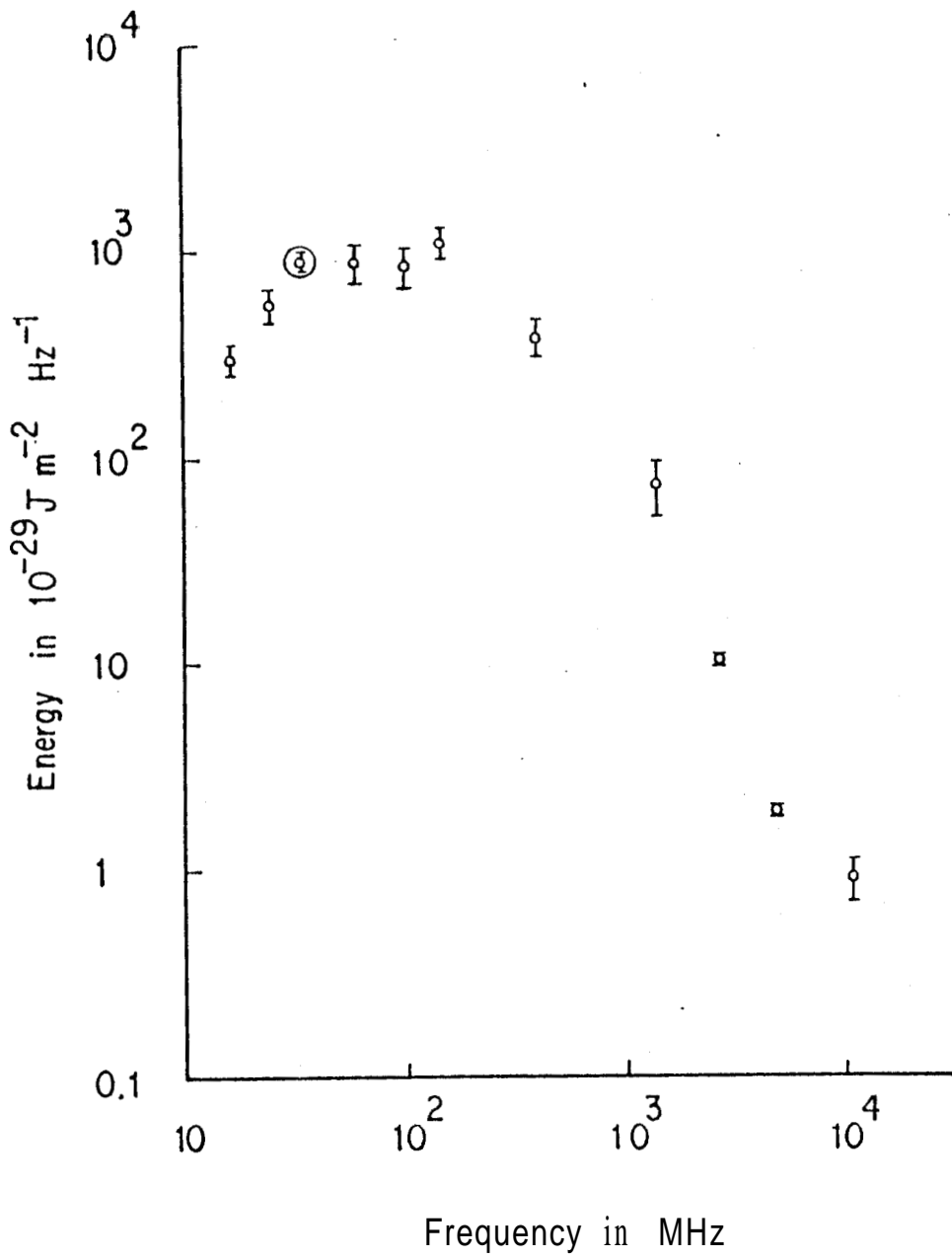
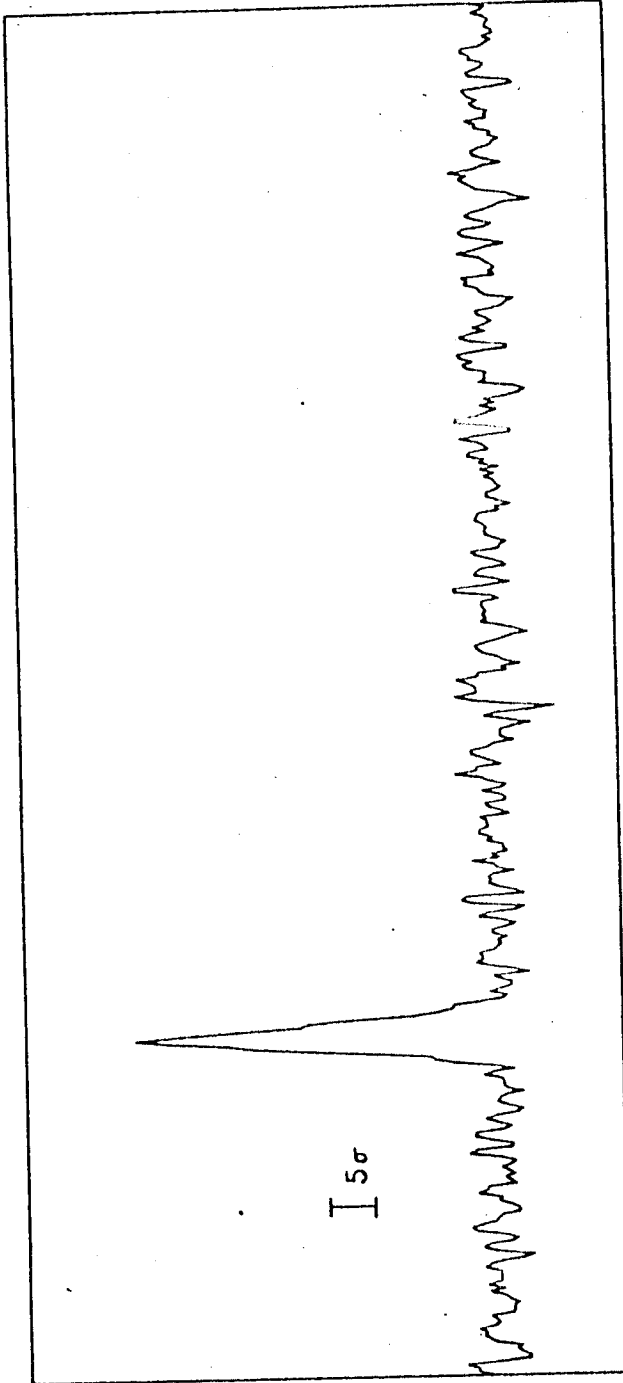


FIG. 5.13 Energy spectrum of PSR 1133+16

SFDS

PSR 1919+21



EFFECTIVE INTEGRATION : 73 minutes.

( P=1.337301s and DM=12.431 cm<sup>-3</sup> pc )

FIG.5.14 AVERAGE PROFILE OF PSR 1919+21 USING THE SWEPT-FREQUENCY DEDISPERSION SCHEME

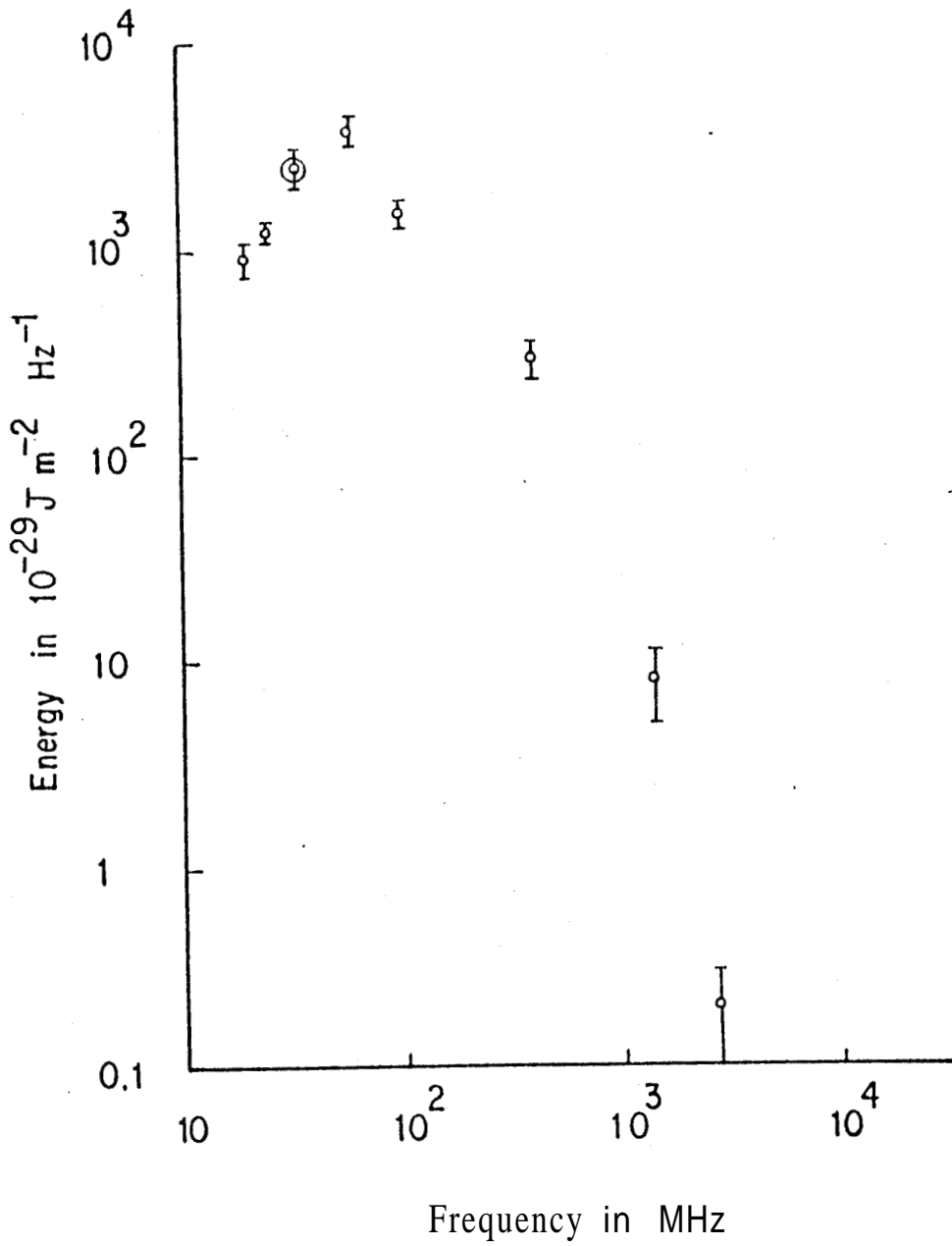


FIG. 5.15 Energy spectrum of PSR1919+21



fluctuations in the interstellar medium. The observable quantities  $\tau_s$  and  $\Delta\nu$ , which are respectively the  $\exp(-1)$  width of the impulse scattering function and the decorrelation bandwidth of the amplitude scintillation, are generally used to measure the strength of scattering along a line of sight to the pulsar.

At higher radio frequencies it is convenient to measure  $\Delta\nu$  instead of  $\tau_s$  for most of the pulsars. However, at low radio frequencies, as  $\Delta\nu$  is too small to be measured conveniently, the obvious choice is to attempt measurements of  $\tau_s$ . However,  $\tau_s$  cannot be measured directly from an observed pulse profile, but needs to be estimated after accounting for the intrinsic profile shape and the instrumental effects [see section 3.2.5]. The intrinsic profile at the observing frequency is usually assumed to be the same as that at a high frequency (where smearing due to scattering can be ignored) after suitable scaling of the width of the profile. However, many observations [e.g. 823 including the present work, clearly show that profiles for a pulsar at different frequencies differ in many ways. Therefore, the profiles at different frequencies cannot always be assumed to be related to each other by just one scaling law. Hence, any estimate of  $\tau_s$  assuming the extrapolated intrinsic profiles can have large errors. The  $\Delta\nu$  measurements, on the other hand, are practically independent of the pulse profiles.

Here we discuss three cases where high resolution profiles have been obtained using the SFDS.

**i) PSR 0628-28:** From the decorrelation bandwidth measurements at high frequencies, we would expect the  $\tau_s$  at 34.5 MHz to be about 8 msec, assuming that  $\tau_s \propto (\text{frequency})^{-4}$ . Using the pulse width at 102 MHz [63] (after (frequency)<sup>-0.25</sup> scaling and accounting for instrumental effects), we find the predicted pulse width to be larger than the observed width, even if  $\tau_s = 0$ . This clearly indicates that our assumption about the behaviour of the intrinsic pulse width with frequency does not hold good.

**ii) PSR 0834+06:** In this case the observed profile is consistent with the value of  $\tau_s$  expected by extrapolation from high frequencies.

**iii) PSR 1919+21:** The observed pulse width of 30 msec. is smaller than the intrinsic pulse width itself that is expected by extrapolation from high frequencies. However, as the expected  $\tau_s$  is 35 msec., we can definitely conclude that the broadening due to scattering is much less in this case than that expected.

Cases i) and iii) are extreme examples of a situation where  $\tau_s$  estimation is affected by the assumptions regarding the intrinsic pulse shape. The scaling of  $\tau_s$  with frequency and DM depends on the nature of the spectrum for the density

irregularity sizes. The Gaussian spectrum predicts  $\tau_s \propto (DM/f^2)^4$ , while the power-law models predict  $\tau_s \propto (DM/f^2)^{\alpha/\alpha-2}$ . For example, for the Kolmogorov spectrum  $\alpha=11/3$  and thus  $\tau_s \propto (DM/f^2)^{2.2}$ . The frequency scaling corresponding to a Kolmogorov spectrum predicts even higher values of  $\tau_s$  than can possibly be attributed to scattering in all the three cases.

**ON THE DEPENDENCE OF  $\tau_s$  ON DM:** The observed dependence of  $\tau_s$  on DM from high frequency observations has been discussed by many authors (e.g. [70, 71, 72]). The dependence is studied by combining the estimates of  $\tau_s$  and  $\Delta\nu$ . The  $\tau_s$  measurements generally correspond to high DM pulsars, while the  $\Delta\nu$  measurements are available for pulsars with lower values of DM. It has been seen that  $\tau_s$  increases with DM more steeply than the increase predicted even by the Kolmogorov spectrum [70]. Appreciating the fact that  $\tau_s$  estimates (mainly for high DMs) can be affected by the assumptions about the intrinsic pulse profiles, it is possible that the observed dependence on DM may be an overestimation. If so, it is appropriate that only  $\Delta\nu$  measurements should be used to obtain the dependence on DM.

Further, we observe that the scattering has a less rigid connection with DM than has been generally assumed. Support for this can be found from the large scatter in the observed  $\Delta\nu$  in any narrow DM range. The apparent dependence on DM is

probably only due to the common parameter, the distance. The turbulence level, which is the main parameter associated with the scattering, is not in general a function of DM. In fact, it would be appropriate to define a more relevant quantity, say "scattering measure", which represents the right combination of both; the turbulence level and the distance to the pulsar.

## 5.11 SUMMARY

The results discussed in the earlier sections indicate that we have been able to obtain good quality observations on many pulsars at a low frequency by employing the methods presented in this thesis.

The profiles obtained using the SCS are affected by dispersion smearing over the 30 KHz band and fail to show the pulse structure in detail.

However, the use of the SFDS has enabled us to detect finer details in the pulse profiles. The dispersion smearing in the worst case (i.e.  $DM = 34.36 \text{ cm}^{-3} \text{ pc}$ ) is only about 9 milliseconds. Such smearing can be further reduced by observing with bands narrower than that (333 KHz) used for the present observations. The subsequent loss in the signal-to-noise ratio, however, should be recovered by observing over longer lengths of time.

The estimates of the pulse energies in 5 cases confirm the low frequency turnovers already known from other observations. Out of the 3 new detections by us at 34.5 MHz, only in one case does the spectrum not appear to have a turnover down to 34.5 MHz. Such a spectrum can be of great interest if found to have similar a character at even lower frequencies.

Lastly, regarding the interpulse emission, we notice no significant emission beyond the main pulse window in those cases where significant interpulse has been detected at 25 MHz. However, it may be possible to detect such emission by improving the signal-to-noise ratio to values better than that attained in the present work.

## CHAPTER 6

### CONCLUSIONS

The behaviour of pulsars at **decametric** wavelengths is still very poorly known. This is so, because only a very **few** pulsars out of the more than 400 known have **been** detected at **such** wavelengths. It is, however, extremely difficult to observe pulsars **with** a good **signal-to-noise** ratio and high time-resolution at these wavelengths. The **difficulties** arise mainly due to the propagation effects in the intervening interstellar medium. Further, the bright sky background at frequencies below 100 MHz, and the often reduced strength of pulsar signals at the **lowest** frequencies observed demand extremely high system sensitivity for such observations.

The limited data from low frequency observations have suggested that more such observations are of great importance for a better understanding of the physical processes that cause the observed radiation from pulsars. Therefore, at low radio frequencies, further observations on as many pulsars as possible are desirable.

Our aim, in the course of the present work, was to obtain observations of as many pulsars as possible with high sensitivity and high time-resolution at a low radio frequency. The Decameter-wave Radio Telescope at Gauribidanur, India, operating at 34.5 MHz was used for this purpose.

The main limitation of the telescope system, as it existed, was its poor sensitivity for pulsar observations. The required sensitivity improvement was achieved by increasing the observing time per day on any source by a factor of  $\sim 25$ . For this purpose, a tracking system was designed, fabricated and installed. This system enables observation of a source for  $42 \sec (\delta)$  min. in a day, where  $\delta$  is the declination of the source. This increase in the observation time led to an improvement in the sensitivity by a factor of  $\sim 5$ .

Using the telescope with its improved sensitivity, observations of strong but not highly dispersed pulsar signals were attempted first. The already existing

single-frequency-channel receiver with a 30 KHz bandwidth was used. Suitable procedures were developed for observation, data acquisition, data processing, detection and calibration. A dedicated data acquisition system was built for this purpose and suitable Fortran algorithms were developed for the data processing. Following these developments, observations were made on 20 candidates. A stringent detection criterion was used for increasing the reliability of detection. For this purpose, the raw data were folded over two-period stretches and were tested for significant detection of two pulses separated exactly by one period. With this **reliable** criterion, 8 pulsars were detected successfully. Average pulse profiles, estimates for the average pulse energy etc. were obtained for the 8 pulsars. Possibilities to study fluctuation spectra. **and** low frequency variability of pulsar signals was considered and a few attempts made in that direction are reported.

A scheme was devised to enable high **time-resolution** observations of highly dispersed pulsar signals. This scheme involves a basic swept-frequency dedispersion procedure. The sweeping intensity **patterns** mapped in the frequency domain **as** a result of dispersion in the ISM are made to appear stationary by appropriately sweeping the centre frequency of the receiver. A reliable programmable sweeping local oscillator system required for this scheme was designed and



built. This system was used with the existing 128-channel autocorrelation receiver to obtain intensity patterns with high resolution in the frequency domain. The tracking facility was also used to enable higher time integration. A new method was used to avoid the need for gain calibration of individual frequency channels, as well as the need for absolute synchronisation of the sweep. It is shown, that with this method, higher resolution can be obtained for strong pulsar signals. Suitable observational procedures, along with the software algorithms, were developed for this purpose. Use of this scheme has successfully demonstrated its ability to observe pulsars having dispersion measures as high as  $35 \text{ cm}^{-3} \text{ pc}$ , with high sensitivity and high time-resolution.

Both the schemes have yielded useful results. The highlights of these results include

i) Detection of 3 more pulsars at a decametric wavelength which includes the detection of a pulsar with a DM of about  $35 \text{ cm}^{-3} \text{ pc}$ .

ii) Measurements of average profiles for 8 pulsars with good time-resolution and sensitivity.

iii) Reliable estimation of average pulse energies in all the 8 cases.

iv) Extension of the spectra towards lower frequencies for 3 pulsars where one odd case shows no turnover even down to 34.5 MHz.

v) A marginal detection of interpulse emission in the case of PSR 0628-28.

vi) Absence of significant interpulse or off-pulse emission in those cases where significant interpulse emission has been reported at 25 MHz.

vii) The scaling law for intrinsic pulse width as a function of frequency is seen to break down. In one case (PSR 0628-28), the intrinsic width at 34.5 MHz appears to be, in fact, smaller than that at higher frequencies.

viii) Clear demonstration that measurements of  $\tau_s$  at low frequencies could be unreliable and misleading.

Further pulsar observations can be made, using the two schemes with the present telescope system, to obtain more data with higher signal-to-noise ratio and higher time-resolution. The observations can be made more time efficient, if the number of available spectral channels is increased. These schemes can be fruitfully employed in future to detect superdispersion delays in more cases, if simultaneous data also at a suitable different frequency can be made available.

The study of low frequency variability for pulsars can be pursued further by making frequent enough routine observations over spans of many months.