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A Sweeping Local Oscillator System for Pulsar Observations

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Abstract. We discuss here the design details of an inexpensive programmable Sweeping Local Oscillator System (SLOS) built for use in a 'swept frequency dedispersion scheme' for pulsar observations. A useful extension of the basic Divide-and-Add algorithm for frequency synthesis is developed for this purpose. An SLOS based on this design has been built and used for high time-resolution observations of pulsars at low radio-frequencies.

Key words: pulsars—interstellar scattering—dispersion

1. Introduction

The dispersion smearing due to the interstellar medium poses serious difficulties in high time-resolution studies of distant pulsars at low radio-frequencies. High time-resolution, however, can be obtained by using some suitable scheme for dedispersion of the received pulsar signals. Many variations of the pre-detection and the post-detection dispersion removal techniques have been used at high radio-frequencies (e.g. Taylor & Huguenin 1971; Hankins 1971). One of these is the swept-frequency dedispersion procedure as used by Sutton *et al.* (1970) and McCulloch, Taylor & Weisberg (1979). In this method, the periodicity and the dispersed nature of the pulsar signals are used to advantage. It can be shown, that due to the dispersion, the intensity variations due to pulsar signals in time get mapped into the frequency domain (Fig. 1). Therefore, a pulse profile over one full period can be obtained, if the intensity as a function of frequency can be measured at any instant in time over a finite bandwidth

$$\Delta f \sim kPf_0^3/\mathrm{DM} \tag{1}$$

where k = a constant, f_0 = centre frequency of observation, DM = Dispersion Measure, and P = Period of the pulsar.

Such a spectral pattern, however, sweeps across the band at an approximate rate of ($-\,\Delta f\,/P$). This pattern can be made to appear stationary by appropriately 'sweeping' the centre frequency of the receiver. Then the dispersed pulsar signal would result in a train of 'fixed' spectral features separated by Δf corresponding to the dedispersed pulse profiles. The pulse profiles can then be measured with high resolution using a suitable spectrometer. This requires that the centre frequency of observation is swept at a rate given by the dispersion relation, the sweep being reset at intervals of integral number of periods. The maximum time-resolution obtained in this way corresponds to the

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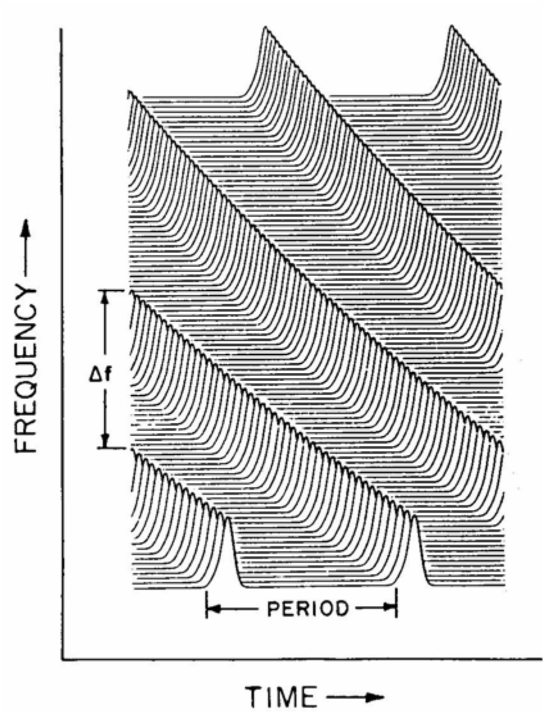

Figure 1. This figure shows typical intensity patterns in the time-frequency domain due to dispersed pulsar signals. The pulse profile over one period (P) can be equivalently obtained by measuring the intensity pattern in frequency over a finite bandwidth Δf at any instant. The spectral pattern drifts across the band with time at an approximate rate ($\Delta f/P$) and repeates after the period interval.

dispersion smearing over one spectral bin. The implementation of the above method requires a suitable sweeping local oscillator system.

In this paper, we describe a design of a suitable sweeping local oscillator system. The specifications are based on the requirements for pulsar observations at 34.5 MHz (Deshpande 1987, Deshpande & Radhakrishnan 1990) with the Gauribidanur Radio Telescope (GEETEE) (Deshpande, Shevgaonkar & Sastry 1989). However, the basic design concepts have wider applicability.

2. The Sweeping Local Oscillator System (SLOS)

We note from equation (1) that the bandwidth (Δf) to be swept by SLOS is a function of the dispersion measure (DM) and the period (P) of the pulsar. We have considered most of the pulsars detected at 102 MHz (Izvekova *et al.,* 1979), as possible candidates for detection at 34.5 MHz, and have indicated them on the Period vs DM plot (Fig. 2). The curves corresponding to different values of maximum bandwidth that can be swept by SLOS are indicated. For a given value of the maximum sweep width, the system can observe all pulsars below the corresponding straight line. The dotted curve shows the limit set by scattering in the interstellar medium and is obtained by extrapolating from the scattering width measurements at 160 and 80 MHz (Slee, Dulk & Otrupcek, 1980)

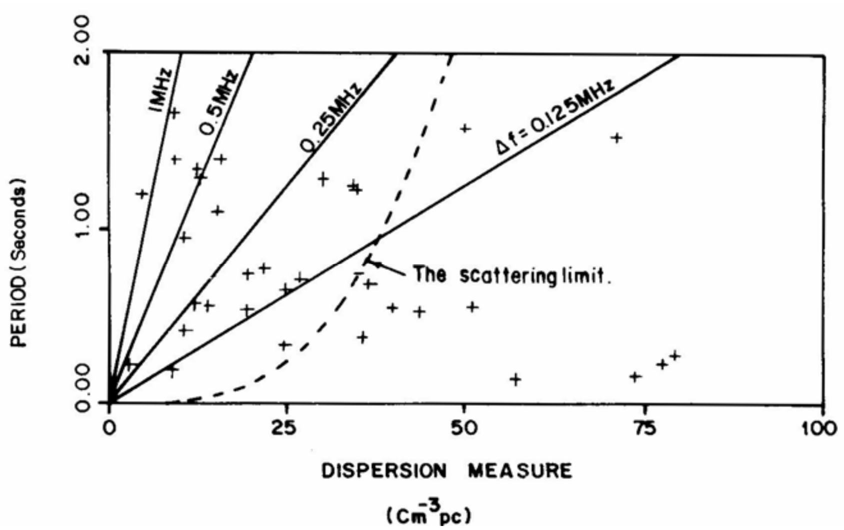

Figure 2. A plot of pulsar periods versus dispersion measures (see text for details).

assuming that $\tau_s \propto$ (wavelength)^4. For pulsars below this curve, the scatter broadening (τ_s) is expected to be larger than the pulsar period (P). A sweep bandwidth of 1 MHz (centred at 34.5 MHz) is sufficient for most of the pulsars indicated here. The pulsars, which need higher sweep bandwidths, have either very low DMs or longer periods and hence the effects of dispersion smearing are not so serious.

The next requirement is that the SLOS should produce the sweep as described by the dispersion relation with minimum possible error. The required frequency (f_r) in the range 34 to 35 MHZ can be computed as

$$f_r(t) = f_r(t') = f_{0s}\left[1 + \left(\frac{f_{0s}^2\, t'}{\mathrm{DM}.k'}\right)\right]^{-1/2} \tag{2}$$

where $t' = t - iP$; for $i = 0,1,2,...$; such that $0 < t' < P$, f_{0s} = the starting frequency of the sweep pattern, and k' = a constant.

The nonlinear sweep in frequency can be approximated by a "staircase" pattern with a uniform step width in time. In order to avoid any significant additional smearing of the pulse profile, the r.m.s. error in the sweep frequency should be less than the resolution of the spectrometer (assumed > 400 Hz in the present case). For example, an r.m.s. error of 400 Hz results in an additional smearing of about 8 milliseconds for pulsars with a DM of 100 cm^{-3} pc.

We see from equation (2) that the sweep pattern can be considered as a fixed function of (t'/DM). This allows us to use a fixed staircase pattern for the sweep frequency, provided the step width (Δt, say) in the pattern is made proportional to DM. In the present case, we have chosen Δt to be DM/20 msec so that the step height is approximately 250 Hz. The number of such steps required to span 1 MHz is about 4000. It should be noted that any error in the value of DM used causes an effective error in the SLOS output frequencies. To keep the frequency error to less than 250 Hz we need to know the DM to an accuracy of ± 0.005 c m^{-3} pc. Fortunately, the DM values for most of the relevant pulsars are available to this accuracy.

We have used these criteria to design the SLOS shown in Fig. 3. We have assumed f_{0s}

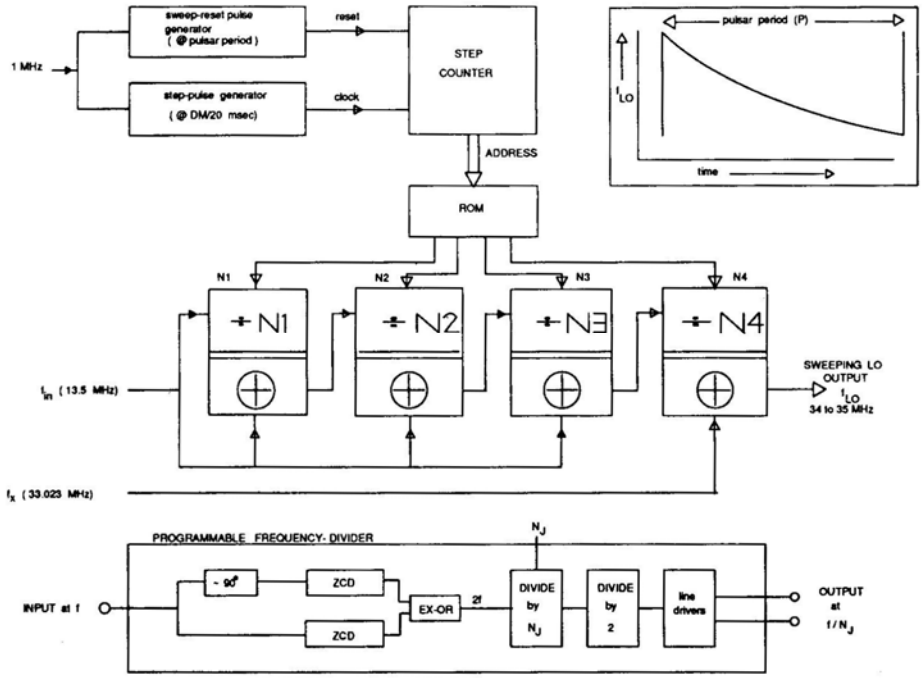

Figure 3. A simplified block diagram of the sweeping local oscillator system.

to be 35 MHz to determine a fixed staircase pattern for the sweep. A suitable section of this pattern can then be used to start the sweep from any desired starting frequency f_s such that $f_s < f_{0s}$ and the bandwidth to be swept is less than (f_s-34) MHz. The values of the starting frequency (f_s), dispersion measure (DM) and the period (P) of the pulsar are set on front panel switches. A 1 MHz reference frequency is used to derive the sweep-reset pulses at intervals of the pulsar period (P) and the sweep-step pulses at intervals of DM/20 msec. The step pulses increment a step-counter which is preset by the sweep-reset pulse to a starting step value ($\hat{n}_s$) depending on f_s. The step number $\hat{n}$ controls an oscillator to produce a predetermined frequency in the range 34 to 35 MHz.

The most attractive possibility for the controlled oscillator is a commercial fast-switching frequency synthesiser, which can be controlled digitally. We describe an inexpensive design that is suitable for the present purpose and is based on the Divide-and-Add algorithm for frequency synthesis. In this method, one input frequency is divided by an integer divisor and the resulting frequency is added to another or same input frequency. Different output frequencies are generated by varying the divisor value. Apart from the programmability, one of the main advantages of this method is that its performance is not sensitive to variations in voltage and temperature. If we consider a single stage of Divide-and-Add to meet the present requirements, the input frequency to the divider turns out to be larger than 4 GHz which makes the hardware realization very difficult. However, if several such divide-and-add stages are cascaded a much lower frequency can be used. Fig. 3 shows a simplified block diagram of the scheme employed by us using a 4-stage divide-and-add algorithm. The output frequency, f_{out}, given by

$$f_{out} = f_{in}\left[\sum_{i=1}^{4} \frac{1}{\prod_{j=i}^{4} N_j}\right] + f_x \tag{3}$$

can be generated with suitable choices of fixed frequencies f_{in} and f_x and with appropriate N_j (j= 1 to 4) values in the range say N_j = N_{min} to N_{max}. The smallest frequency f_{min} and the largest frequency f_{max} that can be generated, correspond to N_j = N_{max} and N_{min} respectively. The range of the output frequencies, i.e. (f_{max} – f_{min}), is directly proportional to f_{in} . The choice of parameters in the above equation (3) is based on the following requirements.

i) The range (f_{max} –f_{min}) should be at least 1 MHz.
ii) Errors in the generated frequencies should be as small as possible.
iii) The frequency adder modules involve a mixer and a filter to pass the upper sideband, this filter should be easy to realize. Therefore, N_{max}, which determines the separation between the two side bands, should not be too large.
iv) The values of f_{in}, N_{max} and N_{min} are chosen so that the mixer outputs from the first 3 stages do not have any harmonic contributions in the range 34 to 35 MHz.

These constraints are satisfied if N_{max}= 15, N_{min} = 5, f_{in} = 13.5 MHz and f_x = 33.023 MHz.

The design of the programmable frequency-divider is also shown in Fig. 3. The input to the divider module is generally the analog output of the adder module. The input is converted to a digital signal using zero-cross detectors (ZCD) with differential inputs. In order to minimize harmonics in the output signal the divider circuits are arranged to provide a square-wave at the output frequency. For this purpose we generate a digital signal at twice the input frequency before the Divide-by-N counter. The frequency doubling is achieved by 'exclusive-or' ing the two ZCD outputs produced with about a quarter cycle phase difference. This signal is first divided by the programmable divide-by-N counter followed by a flipflop configured as divide-by-2 to produce a square wave at the required output frequency. The differential outputs of the line drivers isolate the analog and the digital grounds at the module level.

In the frequency-adder module, the two square wave inputs are AC coupled and low-pass filtered to obtain only the fundamentals. These signals are then mixed and the output is filtered to reject the lower side-band product. The output of the final adder module is passed through a ZCD and filtered to give + 10 dbm output level in the 34 to 35 MHz range.

Following the designs described above the SLOS was built successfully. Two readily available inexpensive synthesisers were used to provide the two inputs f_{in} and f_x. Spurious signals at the output were kept 30 dB below the main frequency output. Suitable values of N_j were made available as a function of the value of $\hat{n}$ (for $\hat{n}$ =0 to 4095) in a preprogrammed memory block. In order to obtain the 4096 'suitable' values of N_j, the frequencies corresponding to all the possible $((N_{max} - N_{min} + 1)^4)$ combinations were computed, sorted and scanned for suitability by comparing with a list of the desired frequencies. The distribution of the deviation of the final output frequency from the desired frequency is plotted in Fig. 4(A, B)· These deviations were measured by stepping through all values of $\hat{n}$ manually. The slight skew in the distribution of the deviations is real and results in a corresponding bias in the estimates

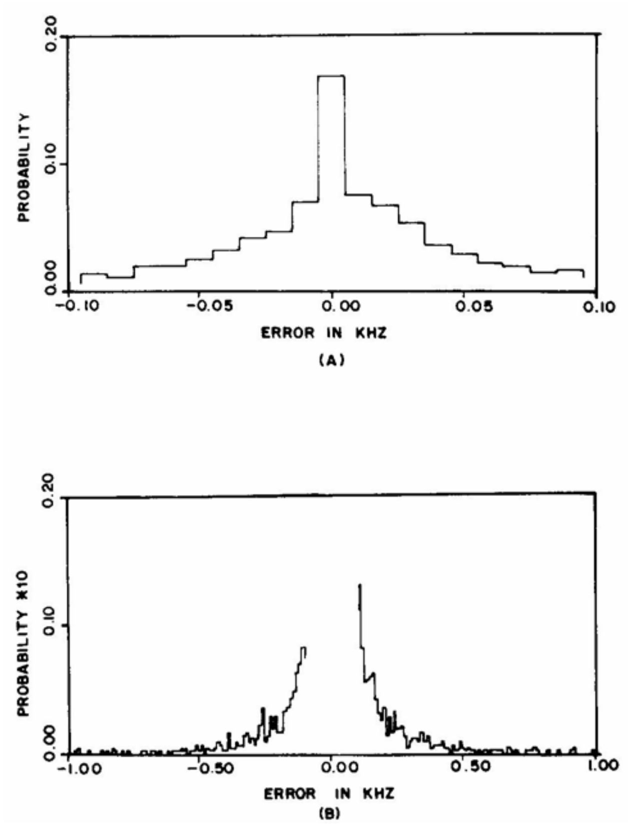

Figure 4. The distribution (probability density distribution with 10 Hz resolution bin) of the errors in the final output frequency of the SLOS.

of the time of arrival of pulsar signals. We expect this skew to depend on the starting sweep frequency and the band width swept.

3. Conclusion

In this paper, we have described a design of a programmable sweeping local oscillator system which was developed for pulsar observations at 34.5 MHz employing a swept-frequency dedispersion method. This design exploits the advantages of both analog and digital devices making the system inexpensive and reliable. Although the basic divide-and-add algorithm for frequency synthesis is well known, we have shown how the use of several such stages in cascade can reduce the frequency step-size without the need of a very high input frequency. This system together with a 128-channel digital autocorrelation receiver (Udaya Shankar & Ravishankar 1990) has been used successfully to study highly dispersed pulsar signals with high time resolution (Deshpande 1987, Deshpande & Radhakrishnan 1990). Fig. 5 shows a sample pulse-profile obtained for PSR 1919 + 21. The details of these observations will be discussed elsewhere (Deshpande & Radhakrishnan 1991).

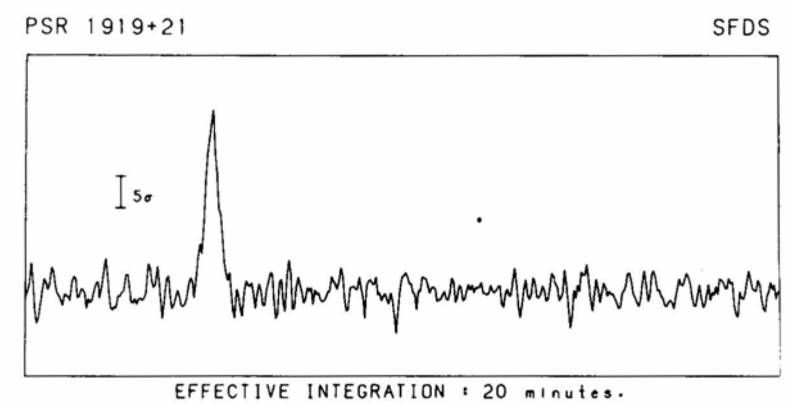

Figure 5. An average pulse profile for PSR 1919 + 21 at 34.5 MHz obtained from observations made using the sweeping local oscillator system.

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