Deep Analyses of Nulling in Arecibo Pulsars Reveal Further Periodic Behavior

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ABSTRACT

Sensitive Arecibo observations provide an unprecedented ability to detect nulls for an accurate pulse-modulation quelling (PMQ) analysis. We demonstrate that a number of conal pulsars show "periodic nulling" similar to the phenomenon found earlier in pulsar B1133+16.

Key words: miscellaneous – methods: — data analysis – pulsars: general

1 INTRODUCTION

The complex inner workings of the pulsar emission mechanism still remain something of a mystery four decades after their discovery. Pulsar emission is both difficult and fascinating, in part, because of its prominent modulation phenomena—in particular the “big three” effects of subpulse drifting, “mode” changing, and the pulse “nulling” that is the subject of this paper.

The nulling phenomenon has been very perplexing since first identified by Backer (1970), because the nulls affected all components, even interpulses, and were simultaneous at all frequencies. Nulls thus appeared to represent a temporary cessation of the pulsar emission process, but strangely “memory” was observed across nulls in some cases (Page 1973). Null fractions (NF) were computed for many of the known pulsars, and found to range from less than 1% up to 70% or so; but some half the stars appear not to null at all. The first systematic study of such null fractions was made by Ritchings (1976), who found a correlation between the NF and a pulsar’s spin-down age $\tau$. Ten years later, Rankin (1986) showed that while old pulsars null more than young ones, many old pulsars do not null at all.

Evidence has steadily accrued over the last few years that the nulls in many pulsars are not random turn-offs: the subpulse “memory” across nulls in B0809+74 closely associates them with the star’s drift (van Leeuwen et al. 2002, 2003); evidence of sputtering emission during nulls has been identified in both B0818–13 (Janssen & van Leeuwen 2004) and B1237+25 (Strotluk & Rankin 2005); almost all the nulls occur in one mode in B2303+30 (Redman et al. 2005); in B0834+06 the nulls tend to occur on the weak phase of the star’s alternate-pulse modulation cycle (Rankin & Wright 2007a); and finally the nulls in J1819+1305 exhibit a strong 57-stellar-rotation-period cyclicity (Rankin & Wright 2007b). These circumstances strongly suggest that nulls, in many cases, represent “empty” sightline traverses through a regularly rotating “carousel” subbeam system (e.g., Deshpande & Rankin 2001).

In a recent paper (Herfindal & Rankin 2007; hereafter Paper I), we identified evidence for periodic nulling in pulsar B1133+16, a pulsar which exhibits no regular subpulse modulation. The nulls could be distinguished with great certainty in this star, and we then applied a straightforward method of filling the non-null pulses with the appropriately scaled-down average profile. This pulse-modulation quelling (hereafter PMQ) technique then confirmed that star’s low frequency modulation feature was associated with its nulls. Here, the implication is that this star’s nulls are produced by a relatively stable, but irregular and sparsely filled carousel-beam system whose rotation gives a rough periodicity to “empty” sightline passes. Such an interpretation may also explain Bhat et al.’s (2007) result that B1133+16’s null pulses are not strictly simultaneous at all frequencies. They found about a 5% excess of nulls at meter wavelengths, and this may result from the star’s larger conal emission pattern here.

These various current results lend new importance to understanding pulsar nulling more fully. Carousel-related “pseudonulls” may occur widely and explain much, but in certain stars the evidence is very strong that their nulls represent a cessation of their emission (e.g., B1931+24), so at least two different types of nulls are implied. Nulling
is also closely associated with mode changing (e.g., Wang et al. 2007), and the recently discovered rotating-radio transients (RRATs) naturally raise questions about the nature of such pulsars’ long dormancies between their sporadic powerful bursts (McLaughlin et al. 2005).

Here we continue the analytical effort begun in Paper I—that is, applying the PMQ method to a small population of pulsars with conal profiles in order to test its efficacy and interpret its results in a larger context. Our Arecibo observations and analysis methods are briefly discussed in §2 and our results for each pulsar in §3. In §4 we summarize and discuss the results overall.

2 OBSERVATIONS & METHODS

All of the observations were carried out using the 305-meter Arecibo Telescope in Puerto Rico. Observations were conducted in the P band at 327 MHz. They used the same correction methods and instrumental techniques as in Paper I. Table 1 gives the resolution, length, and date of each observation.

Longitude-resolved fluctuation spectra (hereafter LRF) of the total power component (Stokes I) were computed for all of the observations in Table 1 using Fourier transforms of length 256. Figure 1 shows the LRF spectra for pulsar B2034+19 with the aggregate intensity (middle panel of the right column) showing a clear 57±6 $P_1$ feature.

The null histogram for pulsar B2034+19 is shown in Figure 2. Notice the strong presence of pulses with zero (or near zero) aggregate intensity. However, note that the distribution is continuous between the pulses and nulls, frustrating any possibility of delineating the two populations positively. The dotted line represents the optimal boundary between nulls and pulses, corresponding to PSR B2034+19: 44% of the pulses fall below this threshold. Suitable pulse-intensity histograms were plotted for each observation to determine a plausible null threshold.

Pulse modulation quelling (hereafter PMQ) was performed on each observation by computing a binary series of nulls and pulses, particular to each observation. To get this, the null threshold from the pulse-intensity histograms was compared to each pulse, within the same window, in order to determine if it was a pulse or null. A new pulse sequence was created corresponding to the natural pulse sequence by substituting a scaled-down average profile for pulses and zero intensity for the “null” pulses. The lowest panel of the right column in Fig. 2 shows the LRF of the PMQ pulse sequence for pulsar B2034+19. Notice that the same low frequency feature persists!

3 INDIVIDUAL PULSAR PARAMETERS

B0301+19: This pulsar has been found to have straight drift bands in both components on the pulse–stack by

1 Pulsar B0525+21, observation dated 2003 October 4, used a FFT of length 128. Pulsars B2303+30 and J0540+32 both used a FFT of length 512.

2 $P_1$ is that particular pulsar’s period.

Table 1. Observational parameters.

| Pulsar    | Date          | Length (pulses) | Resolution (°/sample) |
|-----------|---------------|-----------------|-----------------------|
| B0045+33  | 01/07/2005    | 1085            | 0.30                  |
| B0301+19  | 01/08/2005    | 1729            | 0.19                  |
| B0525+21  | 10/04/2003    | 636             | 0.35                  |
| $\text{J}0540+32$ | 10/07/2006    | 961            | 0.35                  |
| B0751+32  | 10/04/2003    | 1248            | 0.35                  |
| B0823+26  | 10/04/2003    | 2080            | 0.35                  |
| B0834+06  | 10/05/2003    | 3392            | 0.35                  |
| B1237+25  | 07/12/2003    | 3789            | 0.35                  |
| B1649+2533 | 01/06/2005    | 2340            | 0.35                  |
| B1831-00  | 01/07/2005    | 5094            | 0.35                  |
| B1839+09  | 07/20/2003    | 4542            | 0.35                  |
| B1848+12  | 10/19/2003    | 5299            | 0.13                  |
| B1918+19  | 02/12/2006    | 2074            | 0.15                  |
| B2034+19  | 01/07/2005    | 1151            | 0.71                  |
| B2122+13  | 01/08/2005    | 1038            | 0.36                  |
| B2303+30  | 10/07/2003    | 1526            | 0.23                  |
| B2315+21  | 10/07/2003    | 622             | 0.35                  |
| $\text{J}0540+32$ | 01/07/2005    | 2491            | 0.26                  |

$\text{a}$ The last 121 pulses of this observation were ignored due to noticeable interference.

Schönhardt & Sieber (1973). Weltevrede et al. (2006, 2007; hereafter W0607), during their two-dimensional Fourier series (hereafter 2DFS) analysis, found the trailing component exhibits a broad drift feature with a much higher $P_3$ value than in the leading component. The LRF shows two prominent low frequency features which have a much higher value then any of the $P_3$ values reported. The highest feature is only prominent in the trailing component (this may be due to the sporadic nature of the trailing component) with the 51 ± 5 $P_1$ feature appearing in both components. After PMQ analysis only the 51 period feature remains. Rankin (1986) found a null fraction around 10%. The null histograms show a slightly larger null fraction, on order of 13%.

B0525+21: Backer (1973) found if emission occurs in component II then it can be predicted, reliably, that the next subpulses will be in component I. He also found that the most prominent feature is at 0.025 cycles/$P_1$ (40 $P_1$) and that it is present at all longitudes across the pulse. Taylor et al. (1975) found a very weak preference for negative subpulse drift in adjacent pulses, but it is almost equal to a positive subpulse drift. Recently W0607 found the trailing component shows a drift feature with opposite drift direction (at 21-cm), while there is evidence for a preferred negative drift direction in the leading component at 21-cm and 92-cm. They also confirmed

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Deep Analyses of Nulling in Arecibo Pulsars Reveal Further Periodic Behavior

Figure 1. Null histogram for the pulsar B2034+19. The integrated-intensity distribution of the pulses (solid line) and that of the off-pulse region (dashed line) are plotted. The vertical dotted line represents an integrated intensity limit of 0.50 \(<I>\) to distinguish the nulls. Notice the null distribution is contiguous with that of the pulses frustrating any attempts to decisively measure the null fraction. Forty one (41) pulses were ignored due to bad baselines.

J0540+32: This newly discover pulsar was found during the Arecibo Pulsar survey using the ALFA (Cordes et al. 2006). This pulsar has a clear separation between the null and pulse distributions with 54% percent of the pulses falling below our null threshold. There is a distinct very low frequency feature at 256±64 \(P_1\). The PMQ spectra shows the same feature with another harmonic feature at 85±15 \(P_1\).

B0751+32: At 430 MHz Backus (1981) identified a preference for negative drift in this pulsar; recently, W0607 found the leading and trailing components show a low frequency feature at 60±21 \(P_1\) and 70±10 \(P_1\), respectively (at 92-cm). Once the observations underwent Fourier transforms, the LRF’s revealed that the low frequency feature changes slightly between our observations. Nevertheless, after PMQ analysis the main features in the original LRF’s remain. Nulling in B0751+32 occurs around 34\% (Backus, 1981). The null fraction from the pulse-intensity distribution histograms changes slightly but is consistent with Backus’s results.

B0834+06: Taylor et al. (1969) found a strong response at 0.462 cycles/\(P_1\) (2.16 \(P_1\)), confirmed by Slee & Mulhall (1970), Sutton et al. (1970) identified it as a drifting feature, Backer (1973), Taylor (1975) found a preference for positive subpulse drift, and recently by Aseklar & Deshpande (2005) and W0607 confirmed the drifting feature’s measurement of 2.2\(P_1\). Rankin & Wright (2007a) showed the nulls are not randomly distributed, occurring in a periodic matter. The LRFs of these observations have a clear feature around 2.16 \(P_1\) which is conserved after PMQ. An unexpected feature was found after PMQ analysis of the longer observation at 16 \(P_1\). A null fraction of around 7.1\% was found by Ritchings (1976); Rankin & Wright (2007a) found that no more than 9\% of pulses are nulls. These observations have very distinct null–pulse distributions resulting in accurate null fractions which confirm these previous results.

J1649+2533: This pulsar was found to have a null fraction of 30\% by Lewandowski et al. (2004). The null fractions in these observations are slightly lower (on order of 21\%). Lewandowski et al. also measured a \(P_3 = 2.2 P_1\); both of the observations show this feature towards the outer edges of the profile, with a clear separation in the middle. After PMQ analysis, only the 27-odd \(P_1\) feature remains.

B1839+09: W0607 confirmed the result (at 21 and 92 cm) found by Backus (1981); stating that there is no preference in the drift direction for the subpulse modu-
Table 2. Observed low frequency feature(s), features after PMQ, and null fractions.

| J2000 name | B1950 name | Length (pulses) | NF (per cent) | LRF Feature(s) ($P_1$) | PMQ Feature ($P_1$) | Figure |
|------------|------------|----------------|---------------|------------------------|---------------------|--------|
| J0304+1932 | B0301+19    | 1729           | 15            | 128 ± 32               | —                   | Fig. A.77 |
| J0528+2200 | B0525+21   | 636            | 22            | 51 ± 5                 | 51 ± 5              | Fig. A.77 |
|            |            | 961            | 32            | 28 ± 2                 | 28 ± 2              |        |
|            |            |                |               | 22 ± 1                 | 23 ± 1              |        |
|            |            |                |               | 4.57 ± 0.04            | —                   |        |
| J0540+32   | —          | 1145           | 54            | 256 ± 64               | 256 ± 64            | Fig. A.77 |
| J0754+3231 | B0751+32   | 1248           | 36            | 51 ± 5                 | 51 ± 5              | Fig. A.77 |
|            |            | 2080           | 40            | 64 ± 8                 | 73 ± 10             |        |
| J0837+0610 | B0834+06   | 3789           | 9             | 2.17 ± 0.01            | 2.18 ± 0.01         | Fig. A.77 |
|            |            |                |               | 16 ± 1                 | —                   |        |
| J1649+2533 | —          | 1044           | 21            | 64 ± 8                 | 28 ± 2              | Fig. A.77 |
|            |            |                |               | 28 ± 2                 | 28 ± 2              |        |
|            |            |                |               | 2.5 ± 0.1              | —                   |        |
|            |            |                |               | 57 ± 6                 | 57 ± 6              |        |
|            |            |                |               | 26 ± 1                 | 26 ± 1              |        |
|            |            |                |               | 2.5 ± 0.1              | —                   |        |
| J1819+1305 | —          | 3394           | 46            | 57 ± 6                 | 64 ± 8              | Fig. A.77 |
| J1841+0912 | B1839+09   | 1573           | 3             | 37 ± 3                 | 37 ± 3              | Fig. A.77 |
|            |            |                |               | 28 ± 2                 | —                   |        |
| J1921+1948 | B1918+19   | 3946           | 9             | 85 ± 14                | 85 ± 14             | Fig. A.77 |
|            |            |                |               | —                     | 43 ± 4              |        |
| J2037+1942 | B2034+19   | 1676           | 44            | 57 ± 6                 | 57 ± 6              | Fig. A.77 |
| J2305+3100 | B2303+30   | 1526           | 11            | 102 ± 20               | 128 ± 32            | Fig. A.77 |
|            |            |                |               | —                     | 64 ± 8              |        |
|            |            |                |               | —                     | 37 ± 3              |        |

Table 3. Observed null fractions of “featureless” pulsars.

| J2000 name | B1950 name | Length (pulses) | NF (per cent) |
|------------|------------|----------------|---------------|
| J0048+3412 | B0045+33   | 1085           | 22            |
| J0826+2637 | B0823+26   | 3392           | 7             |
| J1239+2453 | B1237+25   | 2340           | 5             |
|            |            | 5094           | 6             |
|            |            | 4542           | 6             |
|            |            | 5209           | 5             |
| J1834-0010 | B1831-00   | 1151           | 3             |
| J1851+1259 | B1848+12   | 2074           | 54            |
| J2124+1407 | B2122+13   | 1038           | 27            |
| J2317+2149 | B2315+21   | 622            | 2             |
|            |            | 2491           | 2             |

4 DISCUSSION

Our surprise in Paper I was that the PMQ analysis associated B1133+16’s low frequency feature so clearly with its nulls! In this larger effort, we are no longer surprised to find abundant evidence for null-related periodicities in this population of conal dominated pulsars. We do, however, find pulsars whose nulls show no obvious periodicity.
Deep Analyses of Nulling in Arecibo Pulsars Reveal Further Periodic Behavior

5

as well as cases where PMQ reveals several, probably harmonically related, periodicities.

Specifically, the PMQ analysis did not always identify null periodicity. Table 3 lists seven pulsars which clearly have a null fraction but do not, except for B1237+25 & B1831–00, have a clear LRF feature. These seven pulsars tend to produce either very broad features or featureless (“random”) PMQ LRF spectra. These non-definitive results could come about because a pulsar: i) has several different drift modes; ii) an irregular carousel rotation rate; iii) an unfavorable sight-line traverse across the edge of the carousel; or iv) has nulls that are completely random.

In all cases the pulse-energy distributions were continuous with those of the null distributions. Strangely, we have yet to encounter any example of a pulsar whose pulses and nulls are fully disjoint.

The results of this paper amplify the evidence reviewed above to the effect that many pulsar nulls are neither random nor complete turn-offs. Other recent evidence (e.g., B1931+24), however, all but confirms absolutely that some pulsar nulls do represent a complete or almost complete cessation of the emission. The conclusion then can hardly be escaped that pulsar nulls are of at least two distinct types. And the recently discovered RRATs then reverse the traditional null question: “How can an electrodynamic system which is almost always in the null state then flash very occasionally into brilliance?”

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