RFE and RFB effects

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There has been discussion of using two RF devices to probe the EDM of the proton and the deuteron in a storage ring such as COSY. One device will produce an RF field with a radial E-field, we will call this device RFE, while the other one produces an oscillating vertical B-field, we will call it RFB. I have used my particle-tracking program to study their effects in beam and spin dynamics. I have assumed a continuous ring with a radius of 40m, uniform magnetic field of ~0.125 T, tracking a deuteron with momentum of 1.5 GeV/c. The RFE device is oscillating with a frequency of $(1 + a * \text{gamma}) * f_c$, where a = -0.143, gamma ~1.28, the relativistic Lorentz factor, and f_c the cyclotron frequency. The amplitude of the RFE device is E_0 = 30MV/m and its azimuthal length is 10 cm. When the particle is in the RFE device it gets kicked in the radial direction changing its radial betatron oscillations. The particle starts off inside the RFE device.

Figure 1 shows the particle radial oscillations vs. time. The effect of the radial kick is substantial as expected.

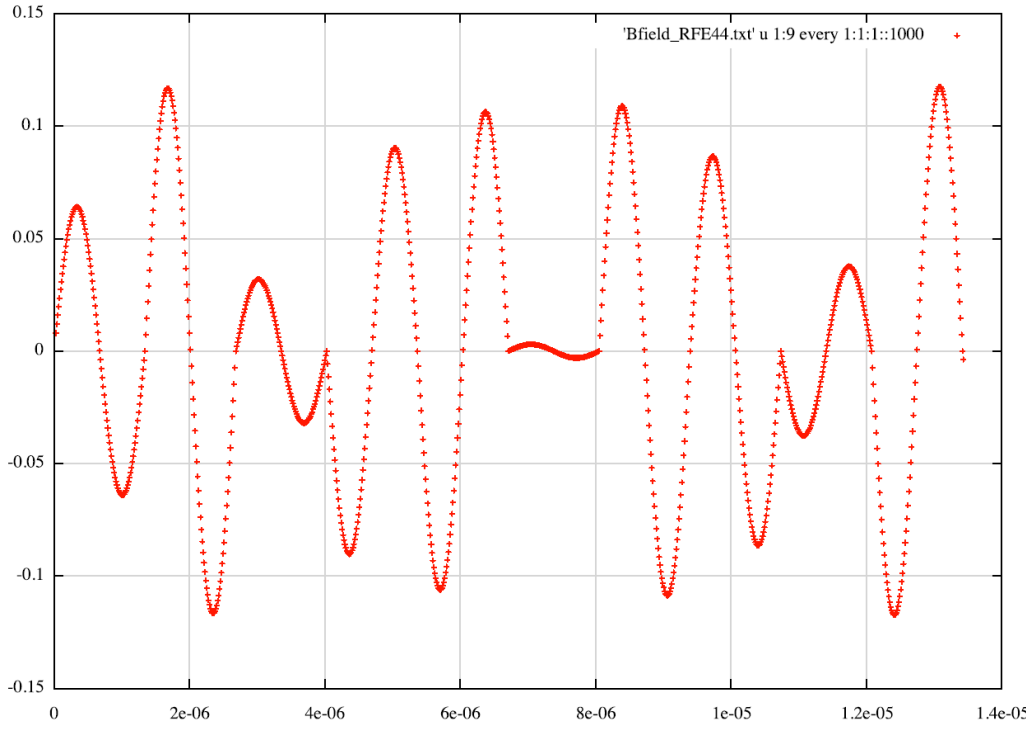

Figure 1. Radial oscillations [m] in the ring vs. time [s] of a deuteron particle. The particle gets kicked by the RFE device in the radial direction at every revolution.

Next I replaced the RFE device with a vertically oscillating dipole magnetic field as suggested by Bill. The strength of the B-field was estimated to match exactly the kick due to RFE. Hence, the amplitude of the RFB is E_0/(beta * C) ~ 1600 Gauss. Since I have estimated this amplitude exactly in the software, the kicks also match, as shown in Figures 2 and 3 below.

Figures 2 and 3 show three graphs: The red line (file 44) is the same as Figure 1 (it does not show well because it is overlapped by the green line). The green line is due to RFB alone (file 45) and indeed overlaps completely the RFE line. The line in blue (file 46) shows the radial kicks when I use simultaneously the RFE and RFB but this time the sign of RFB has been reversed to cancel the effect of RFE. All of these effects have been predicted and estimated in Bill's note.

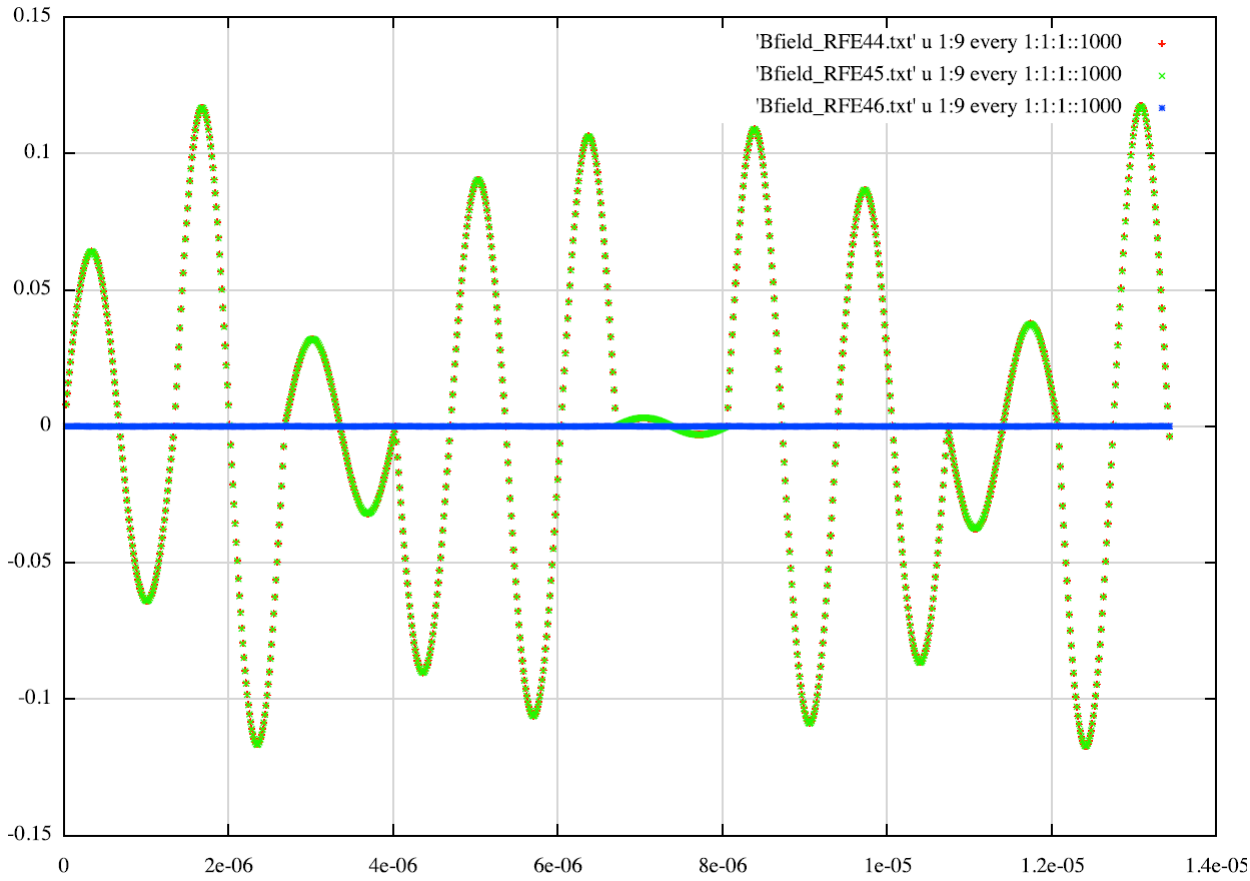

Figure 2. The radial positions [m] vs. time [s] for three cases. In red it is the RFE device alone, in green the RFB device alone and in blue both the RFE and RFB (opposite sign) are on simultaneously. The cancellation, when both devices are on, is excellent.

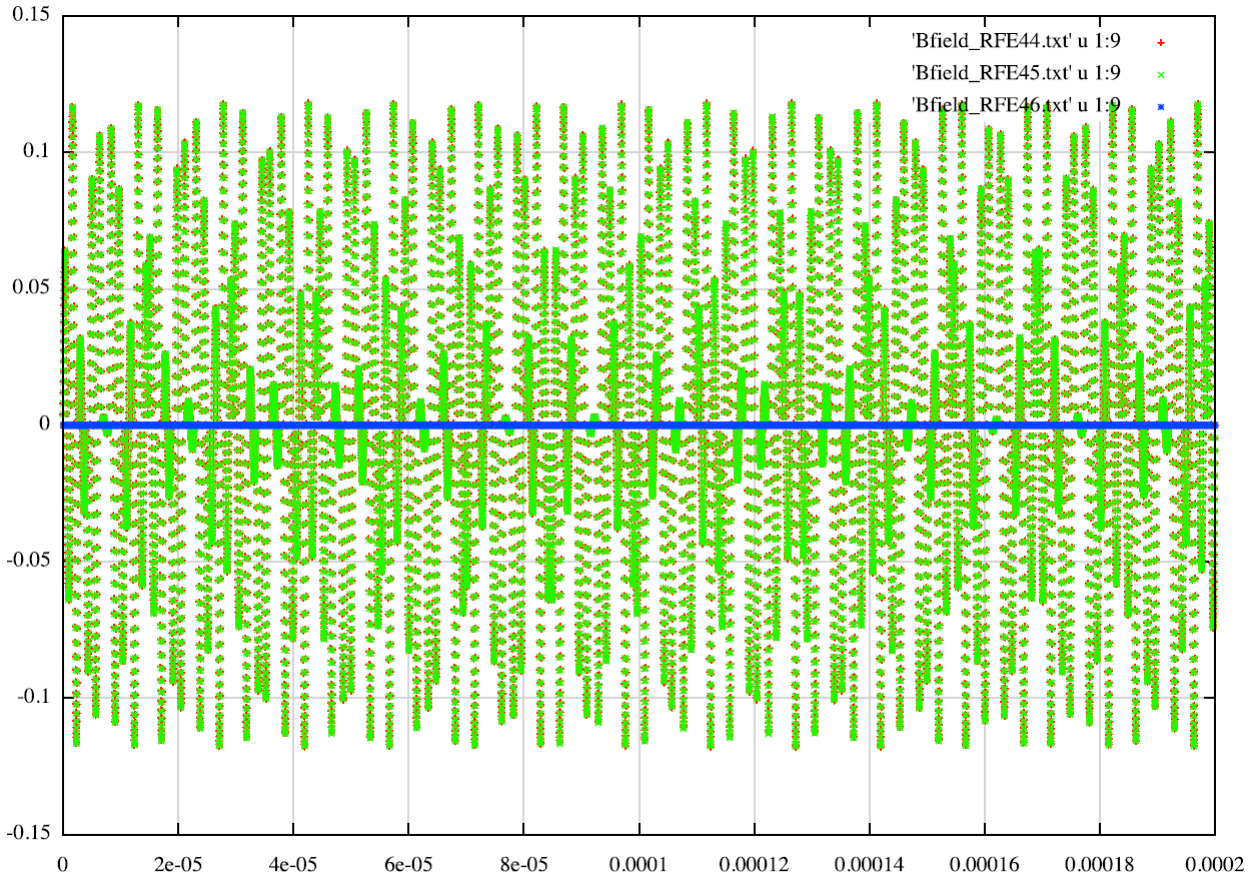

Figure 3. The radial positions [m] vs. time [s] for three cases. In red it is the RFE device alone, in green the RFB device alone and in blue both the RFE and RFB (opposite sign) are on simultaneously. The cancellation, when both are on, is excellent.

Now it is time to look at the EDM effect. Figure 4 shows the vertical spin component (the total spin is normalized to 1) vs. time. The oscillations are due to the vertical magnetic field and the fact that the deuteron anomalous magnetic moment is not zero. That effect oscillates and does not accumulate with time. However, the oscillating radial E-field (RFE), when in resonance, affects the EDM signal and produces the long-term tilt shown in Figure 4. However, when I replaced the RFE with RFB, the EDM signal accumulation disappeared. At first I thought I had a mistake (bug) somewhere. After I convinced myself that this was not the case I remembered we have fallen to this trap once more before. Yuri Orlov explained the effect in the previous case so I asked him about it. His answer: "*Whatever vertical B-field is there, no matter how it depends on time, the time can be redefined, t==>t', dt'=B(t)dt, so the spin eq. remains formally the same, but with t' instead of t. And since the eq. with the old t is not resonant, the eq. with the new t' is not resonant either. You need to oscillate either the radial or longitudinal B-fields, or an E-field.*" In plain English that means that the RFB influences both dipole moments (magnetic and electric) of the deuteron particle the same way so the angle between the corresponding angular frequency vectors never changes. Therefore the effect of RFB to EDM is zero.

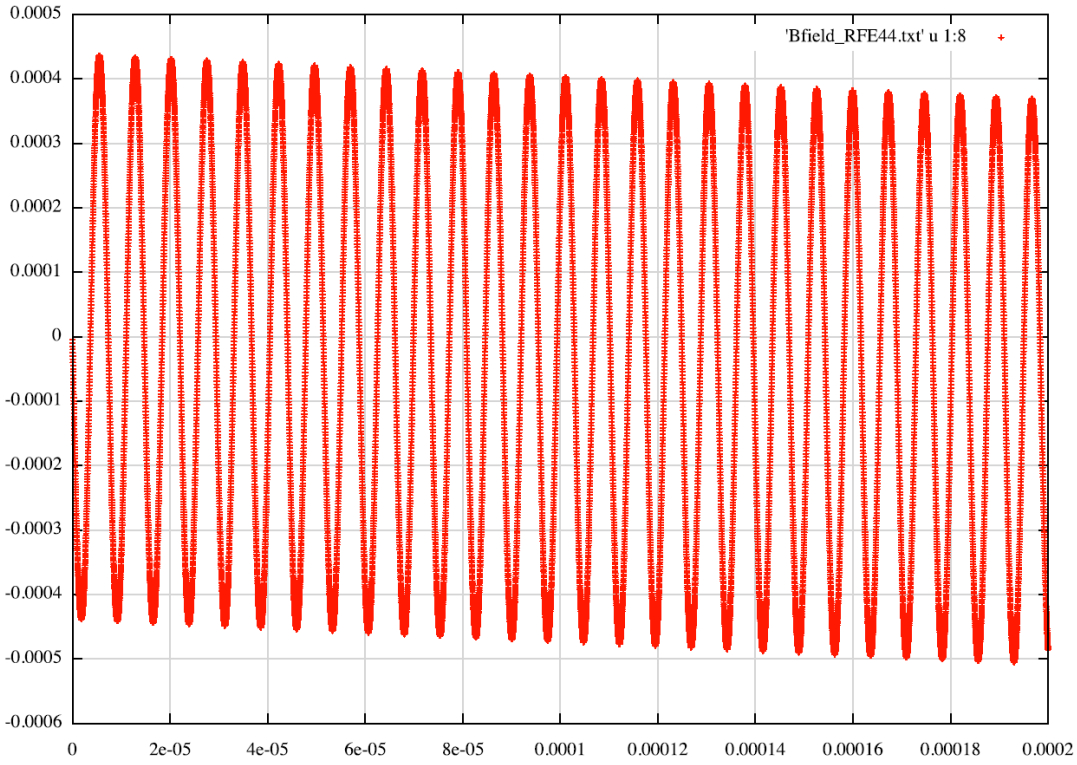

Figure 4. The vertical spin component as a function of time [s] for the RFE alone case.

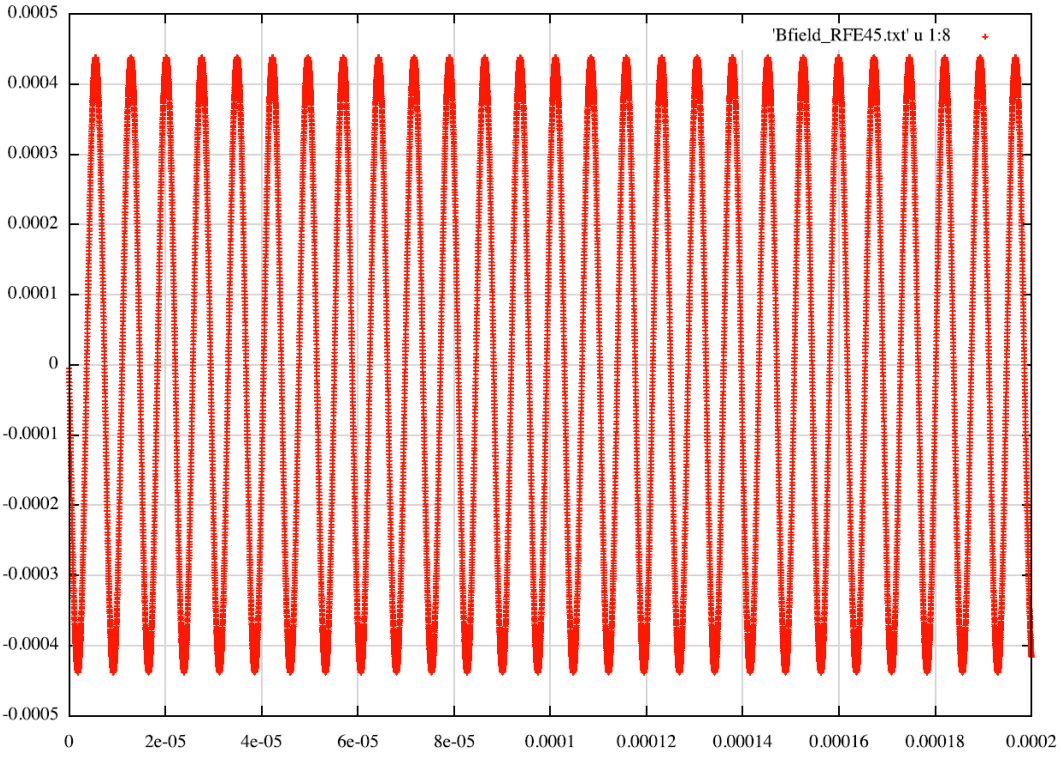

Figure 5. The vertical spin component as a function of time [s] for the RFB alone case.

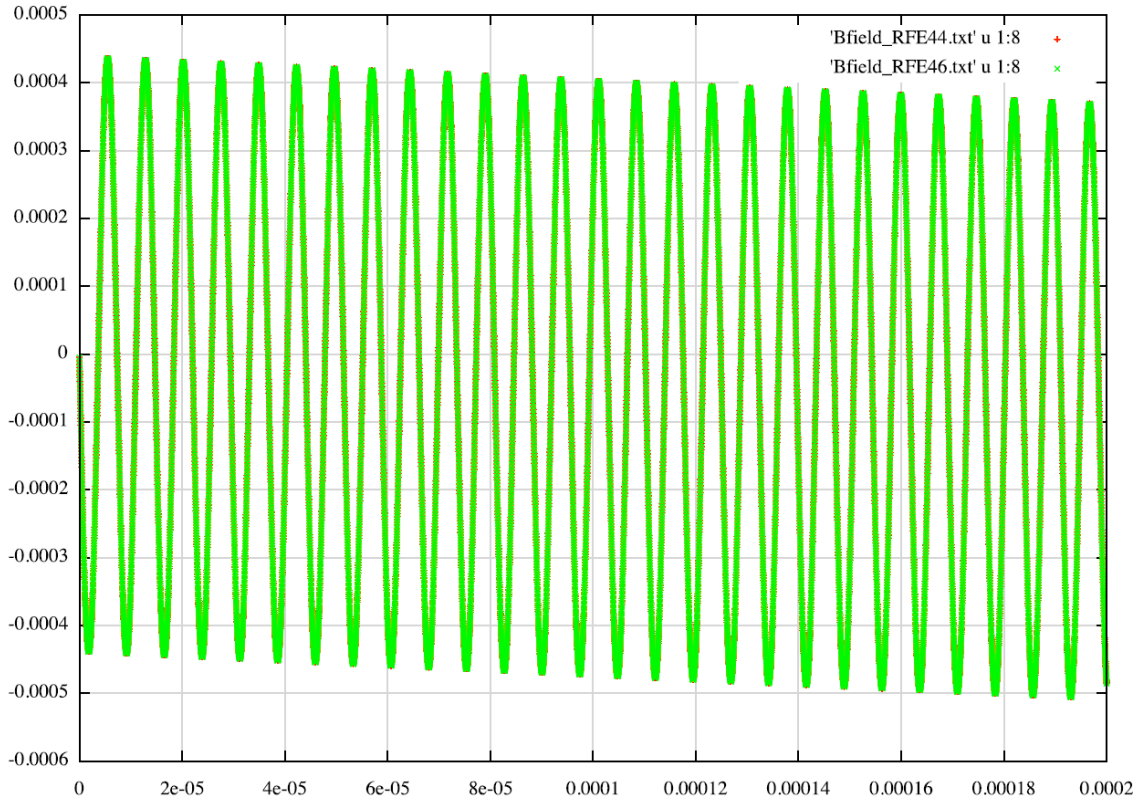

Figure 6. The vertical spin component as a function of time [s] for two different cases. In red (file 44) only the RFE is on. In green (file 46) both the RFE and RFB devices are simultaneously on.

Figure 6 shows two graphs: The red graph (file 44) shows the EDM effect with the RFE device alone and the green (file 46) when both the RFE and RFB (opposite sign) are simultaneously on. The overlap is complete indicating the effect of RFB to the EDM is zero.

Conclusion

The effect of the vertical oscillating B-field (referred here as RFB) to the EDM is zero, while the radial kicks replicate the RFE radial kicks exactly as expected.