Resonance properties and Shapiro steps of annular system of parallel Josephson junctions

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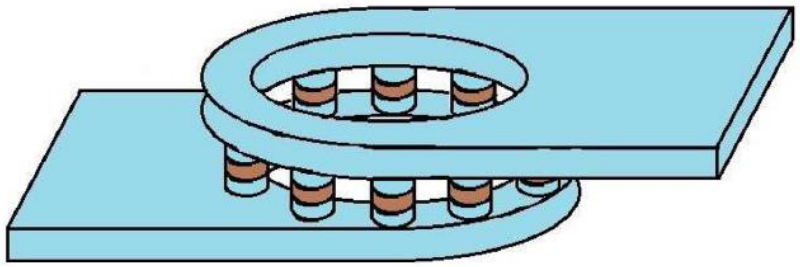
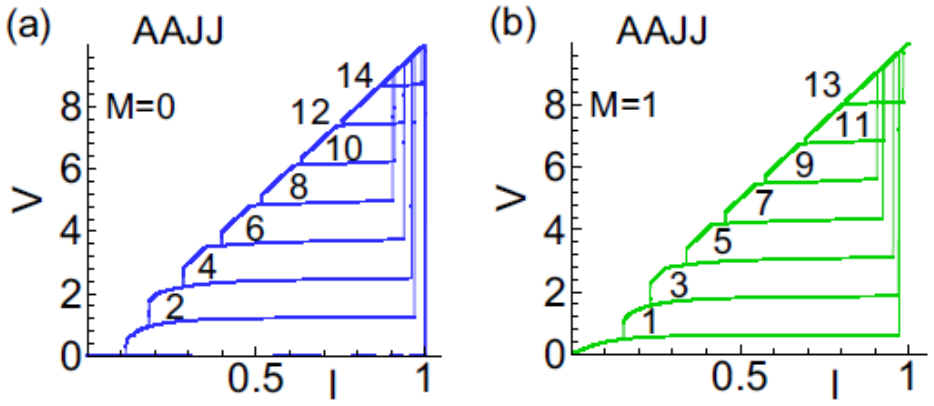
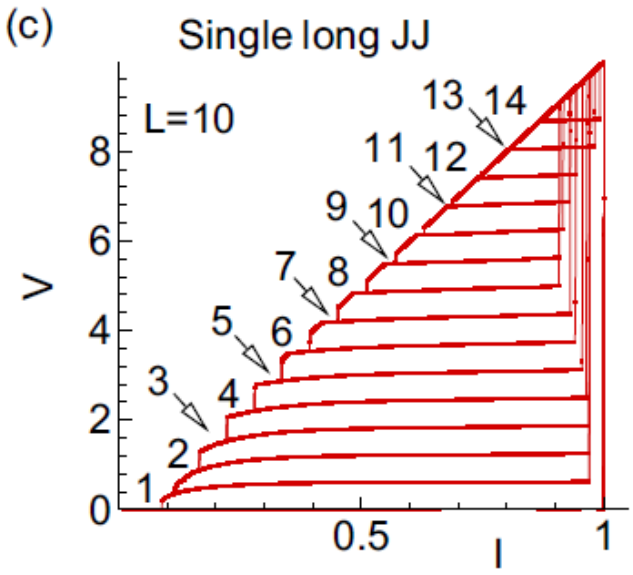
$$\frac{d^2\varphi_i}{dt^2} - \frac{\varphi_{i+1} - 2\varphi_i + \varphi_{i-1}}{a^2} + \sin\varphi_i + \alpha\frac{d\varphi_i}{dt} = I + A\sin(\omega t).$$

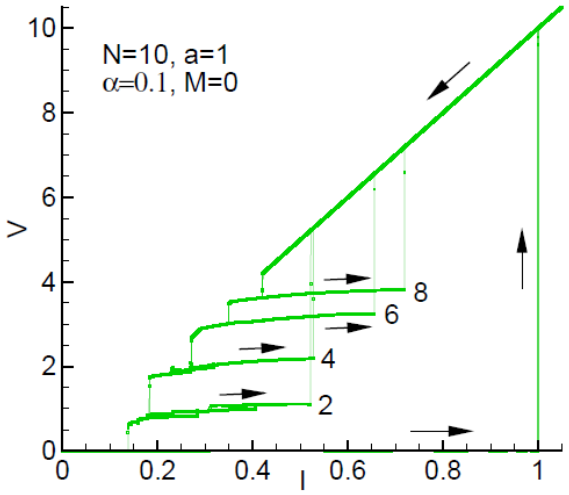
$$\varphi_{N+1} = \varphi_1 + 2\pi M, \qquad \varphi_0 = \varphi_N - 2\pi M,$$

$$\omega_m = \sqrt{1 + \frac{4}{a^2}\sin^2\left(\frac{\pi m a}{L}\right)}.$$









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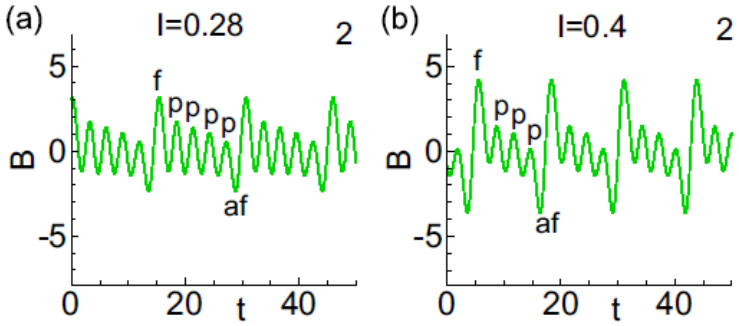
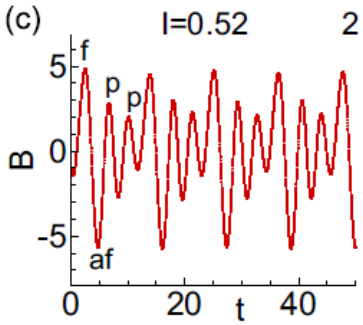
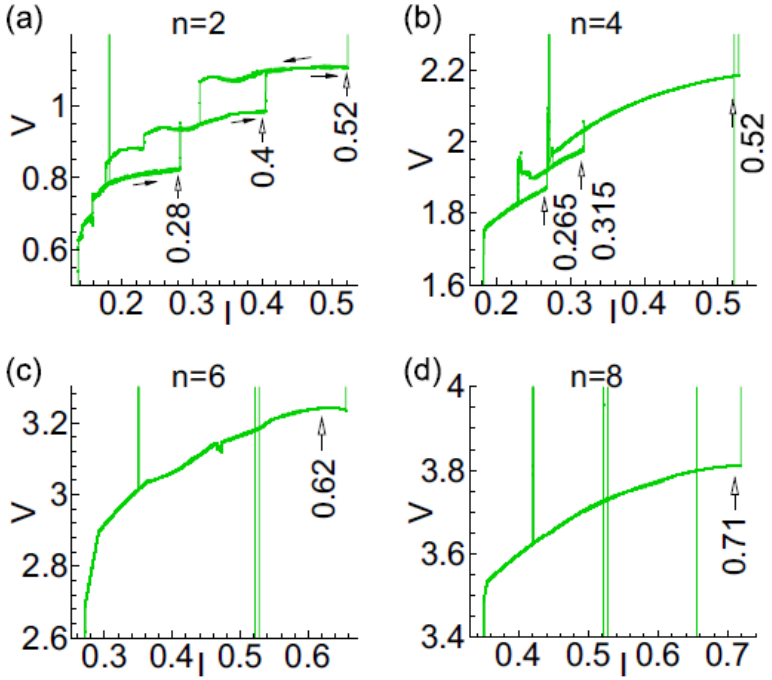
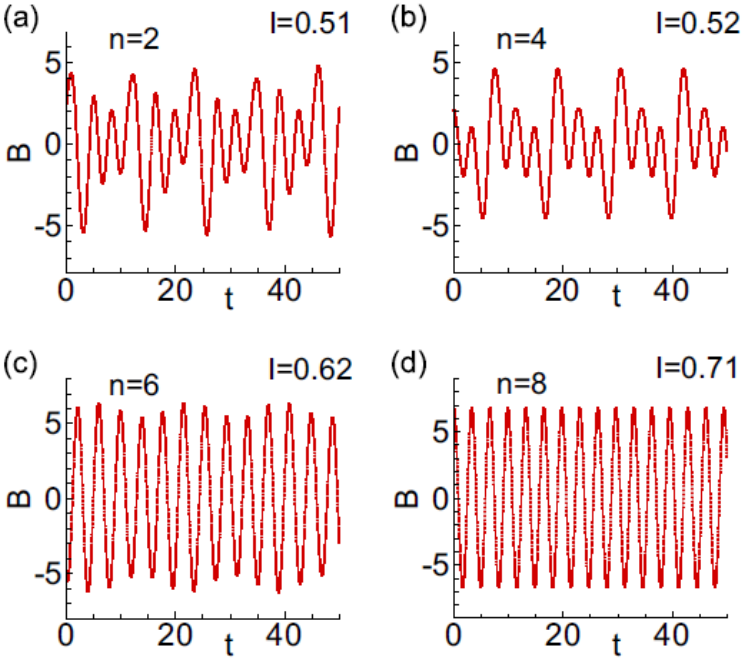
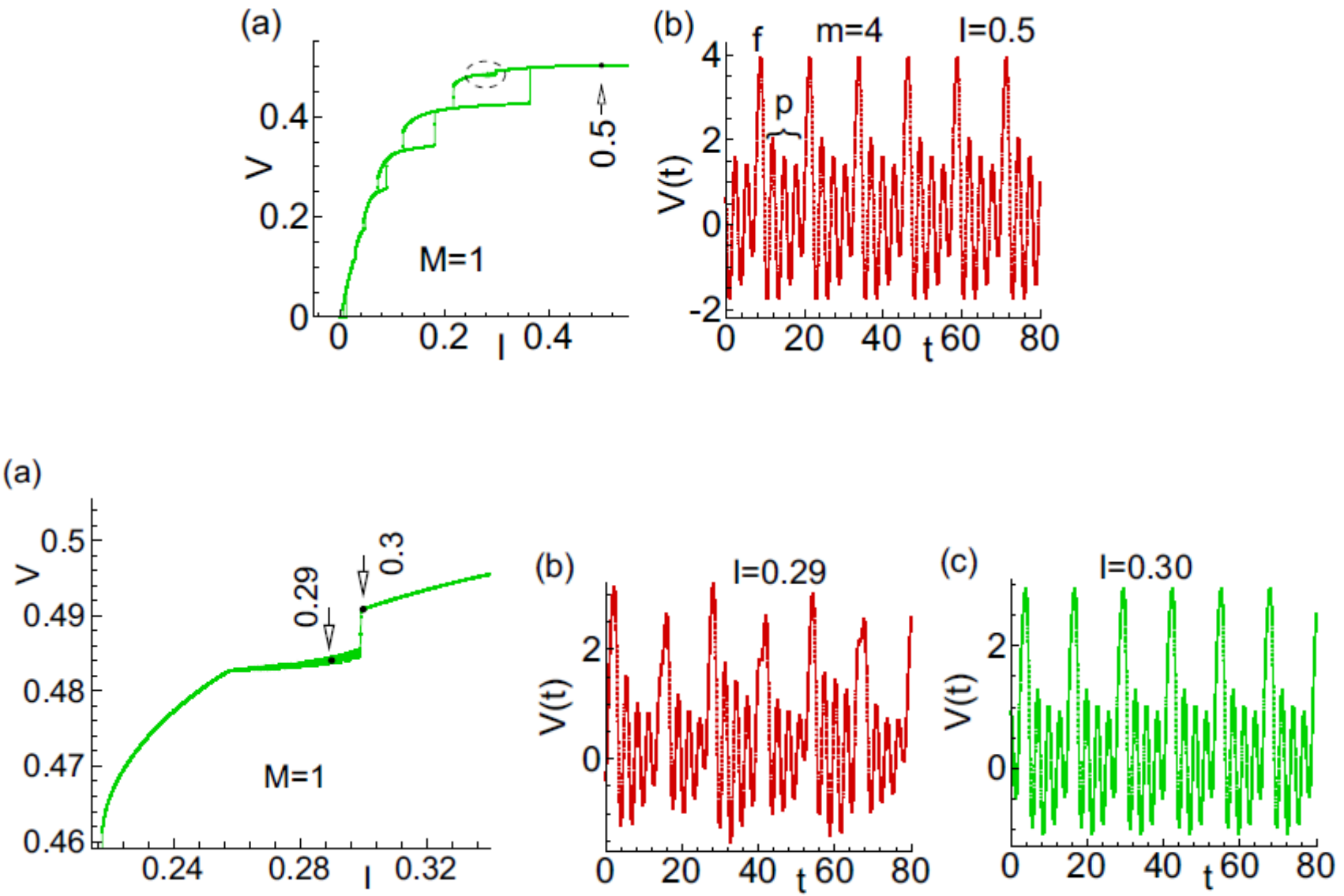
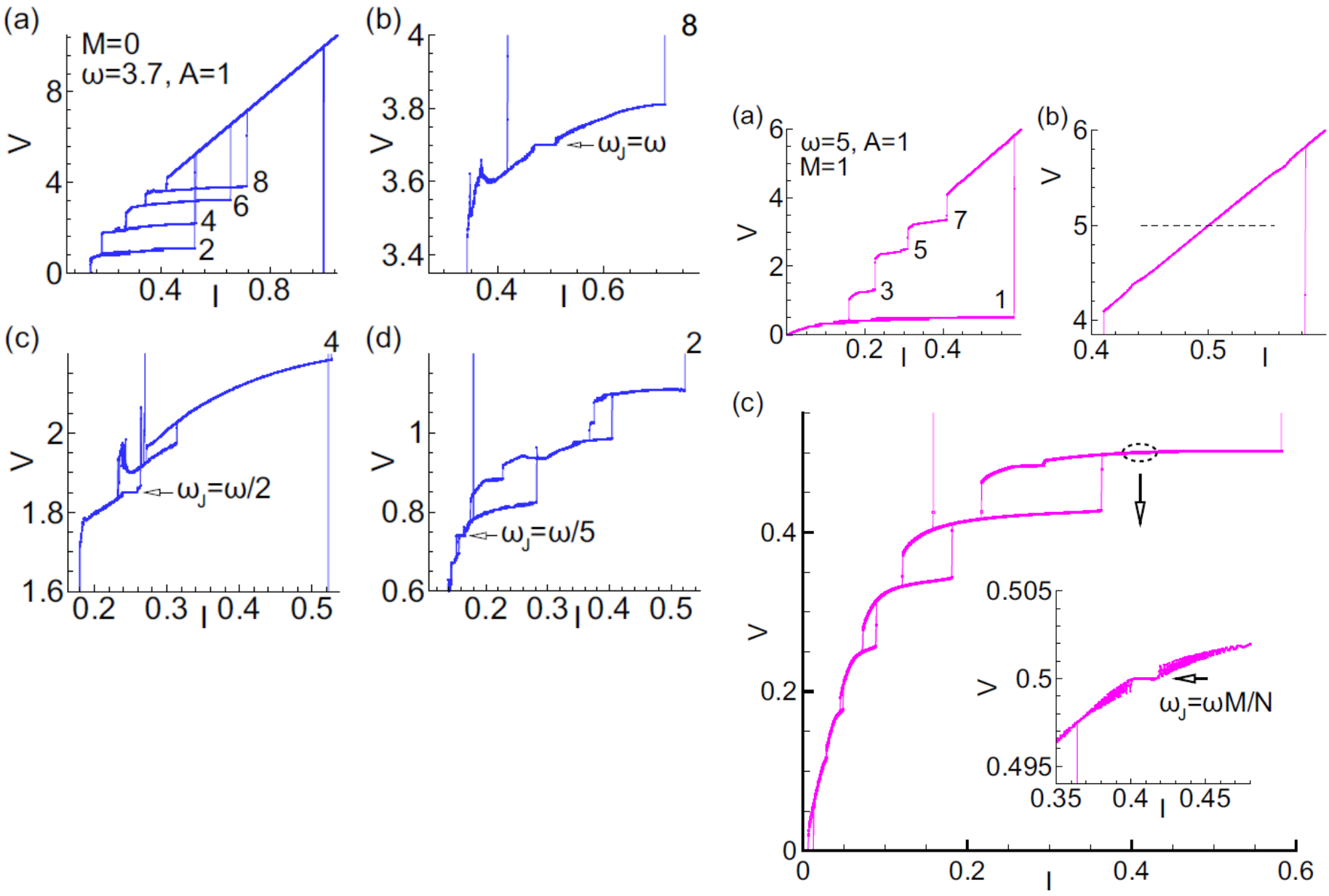


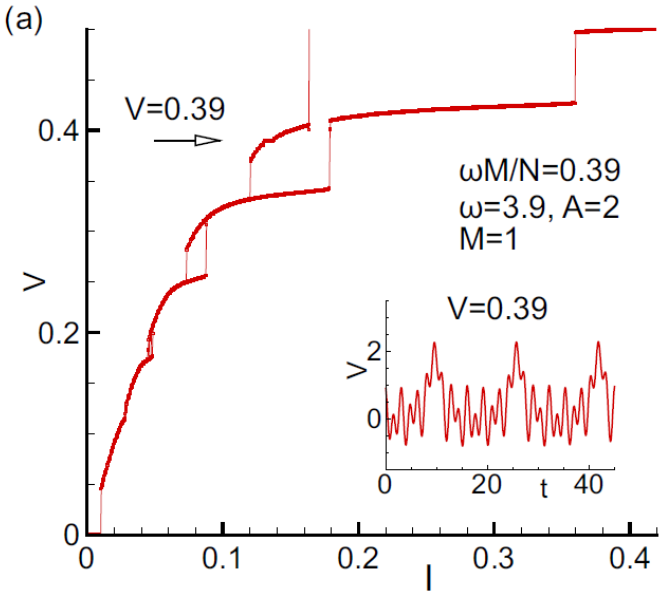


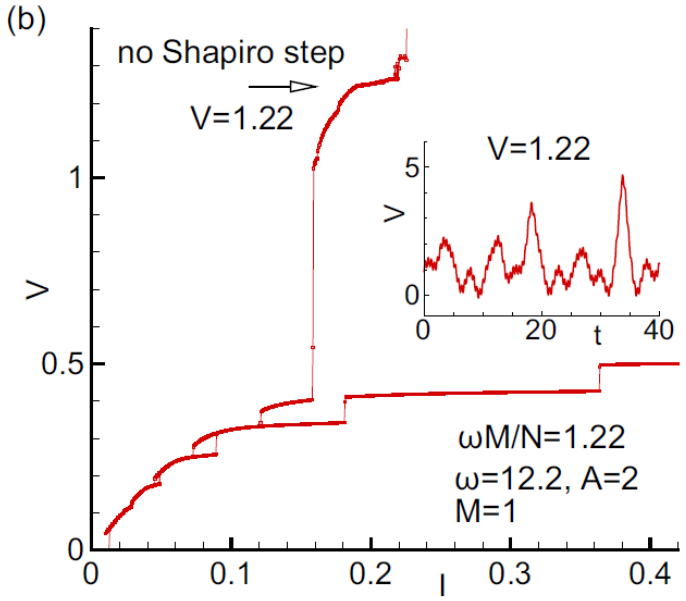


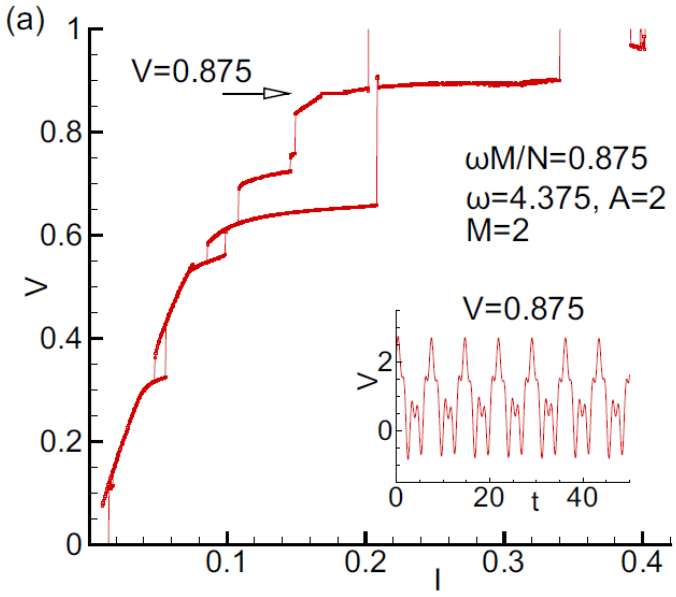


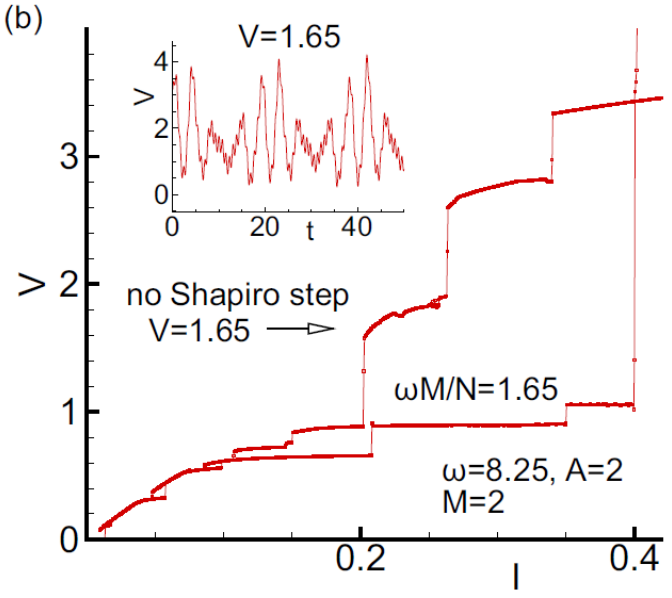

(a)
V
0.4
0.2
0
M=1
0.5
0
0.2
I
0.4
(b)
f
m=4
I=0.5
p
4
2
0
-2
V(t)
0
20
40
t
60
80
(a)
V
0.5
0.49
0.48
0.47
0.46
0.29
0.3
M=1
0.24
0.28
I
0.32
(b)
I=0.29
2
0
V(t)
0
20
40
t
60
80
(c)
I=0.30
2
0
V(t)
0
20
40
t
60
80


(a)
M=0
ω=3.7, A=1
V
I
2
4
6
8
(b)
ω_J=ω
(c)
ω_J=ω/2
(d)
ω_J=ω/5
(a)
ω=5, A=1
M=1
1
3
5
7
(b)
(c)
ω_J=ωM/N


(a)
V=0.39
ωM/N=0.39
ω=3.9, A=2
M=1
V=0.39
V
t
I


(b)
no Shapiro step
V=1.22
V=1.22
ωM/N=1.22
ω=12.2, A=2
M=1
V
t
I


(a)
V=0.875
ωM/N=0.875
ω=4.375, A=2
M=2
V=0.875
V
t
I


(b)
V=1.65
no Shapiro step
V=1.65
ωM/N=1.65
ω=8.25, A=2
M=2
V
t
I