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ScienceDirect
Nonlinear Analysis: Real World Applications 10 (2009) 691–701
Nonlinear Analysis Real World Applications
www.elsevier.com/locate/nonrwa

The nonlinear current behaviour of a driven R–L-Varactor in the low frequency range

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Received 19 September 2007; accepted 25 October 2007

Abstract

The nonlinear behaviour of an R–L-Varactor circuit, simulated by *Multisim 7.0* at a driving frequency that is below the circuit resonance frequency, is reported and evaluated. A new high amplitude oscillation is observed and attributed to the emergence of a large diode junction capacitance. Increasing the driving signal amplitude, the circuit is led to a non-periodic mode of operation, producing trajectories of increasing chaotic content in a four-dimensional phase space. At specific amplitudes a two-dimensional tori was monitored, where trajectories are periodic, like in a two oscillator system with commensurate frequencies. Poincaré cross-sections, FFT spectra and correlation dimension calculations, suggest the quasi-periodicity route to chaos.

Keywords: Chaos; Chaotic circuits; Nonlinear circuits; R-L-Varactor circuit

1. Introduction

Recently, resonant circuits including active components such as diodes, varactors or transistors have been studied for their nonlinear behaviour [1–4]. One of the best known simple circuits that produces a wealth of chaotic phenomena is the oscillator formed by a resistor, an inductor and a varactor diode connected in series, as the one in Fig. 1. It is a non-autonomous passive circuit that displays bifurcations and chaos with the sinusoidal driving frequency and amplitude, being the circuit control parameters. Various bifurcation diagrams can be obtained by changing the inductance or the type of the varactor or by varying the value of the damping resistor.

Many publications report on the circuit chaotic behaviour in the high frequency range [3–9]. The role of the nonlinear capacitance of the varactor diode [6,7] and the contribution of a finite reverse recovery time to nonlinearity, are discussed in the related literature [5,10,11]. It is well-established that chaotic dynamics are readily observed for driving frequencies in the vicinity of the resonance frequency $f_0 = 2\pi(LC_0)^{-1/2}$ and above (C_0 is the zero bias

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1468-1218/$ - see front matter
doi:10.1016/j.nonrwa.2007.10.023

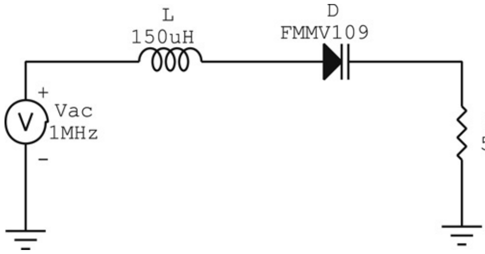

Fig. 1. The R–L-Varactor in series circuit.

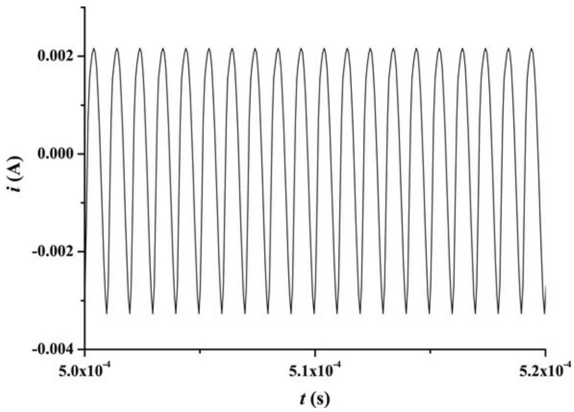

Fig. 2. The circuit current for very low amplitude driving signal $V_{in} = 1.5$ V ($f_{in} = 1$ MHz).

capacitance of the varactor), while in the sub-resonance region and with driving signals of very low amplitude the varactor diode do not exhibit complex dynamics.

However, to fully characterize an electronic element such as a varactor diode, its behaviour at high amplitude driving is necessary. The present article focuses on the varactor nonlinear response when high amplitude driving signals are applied. These signals, though in the sub-resonance frequency region, cause the circuit to exhibit complex dynamics.

2. Results in the sub-resonance region

In this study, the circuit operation was simulated using *Multisim 7.0*, while *National Instrument's LabVIEW 8* was used as a tool for digital processing, in order to further explore nonlinear behaviour in the R–L-Varactor circuit. The components used in the present simulation were an FMMV109 Si diode varactor, a 50 Ohms resistor and an inductor of 150 μH (Fig. 1), therefore the resonance frequency was set to $f_0 = 1.6$ MHz. It should be mentioned that this circuit was experimentally studied by Klinger et al. [8], at frequencies above 1 MHz and for low driving amplitudes; their results were also reproduced by the simulation method used in this study.

In the present simulation, the amplitude of the external voltage signal served as the control parameter. The circuit current was monitored indirectly by the voltage across resistor R, which was regarded as the output signal.

For low driving amplitudes in the range 1 V $< V_{in} <$ 1.8 V, the circuit current was of low amplitude and periodic with a frequency equal to the driving signal frequency (1 MHz), as shown in Fig. 2. For $V_{in} = 1.8$ V a period doubling occurred (Fig. 3), followed by a second period doubling at $V_{in} = 9.7$ V (Fig. 4). This behaviour is presented in the bifurcation diagram of Fig. 5. It must be noted that this bifurcation sequence at low amplitude values was also predicted by the phase diagram of Klinger et al. [8].

However, at a critical driving amplitude $V_{in} = 10.8$ V the system exhibits a new high amplitude oscillation, as shown in Fig. 6. This new oscillation for $V_{in} = 10.8$ V was periodic with a frequency ∼9.35 kHz, as calculated from the related FFT, which is much lower than the driving frequency of 1 MHz. The amplitude of this new oscillation exceeded the amplitude of the periodic signal of Fig. 4, which in Fig. 6 also exists forming the low amplitude background.

By further increasing the driving amplitude, an interesting nonlinear behaviour appeared. Non-periodic waveforms are observed and become denser in chaotic content as the driving amplitude increases. A typical evolution of this