Ultra-Wide Band Waveform Generation Using a Novel Nonlinear Oscillator

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Abstract. We report the experimental implementation of a novel device for producing ultra-wide bandwidth waveforms. The device is a chaotic electronic circuit consisting of a length of coaxial cable terminated on one end with a diode and on the other with a negative resistor. We observe the dynamics of the device as the negative resistance and line length are varied. The system produces ultra-wide band chaotic oscillations with a tuneable peak frequency in the range 7-53 MHz.

1. INTRODUCTION

Ultra-wide bandwidth waveforms are utilized in a diverse range of commercial and military applications including spread spectrum communication and ultra-wideband radar. In the military context, wide bandwidth technologies provide low probability of detection and interference and low susceptibility to jamming. We are investigating an unconventional source of wideband waveforms: the nonlinear phenomenon known as chaos (Corron et al., 2003; Corron et al., 2004). Chaos is random-like, non-repeating evolution in a deterministic nonlinear system. The random-like fluctuations of chaos produce waveforms with a broad continuous power spectrum while the determinism allows for novel phenomena such as small amplitude control (Ott et al., 1990) and self-synchronization (Pecora and Carroll, 1990). Surprisingly, despite the complexity of chaotic waveforms, very simple systems can produce chaos.

Exploiting chaos in ultra-wideband applications requires a reliable radio-frequency chaotic oscillator, the subject of this summary. Many different audio-frequency electronic circuits have been shown to be chaotic. Typically, these devices are constructed from just a handful of inexpensive, off-the-shelf components. However, such circuits have been difficult to implement for operation at radio frequencies where propagation delays and transmission line effects invalidate simple lumped element models. Other devices known to oscillate chaotically at radio or microwave frequencies utilize exotic components such as Josephson junctions. The lack of simple, well-understood RF oscillators is a barrier to exploiting chaotic dynamics for ultra-wideband applications.

To overcome this barrier, we have demonstrated radio-frequency chaotic oscillation in a novel oscillator that naturally incorporates the propagation delays and transmission line effects that are detrimental to other RF chaotic oscillators (Blakely and Corron, 2004). The oscillator, shown schematically in Fig. 1, consists of a transmission line terminated on one end with a diode and the other with a single op-amp active device that produces a negative resistance. Loosely speaking, chaos arises in the system when voltage waves are "stretched" upon reflection from the negative resistance and then "folded" by the nonlinearity of the diode. Despite its extremely simple structure, this device produces complex, ultra-wideband oscillations in the HF and VHF bands suitable for high-data rate communications and high range resolution radar.

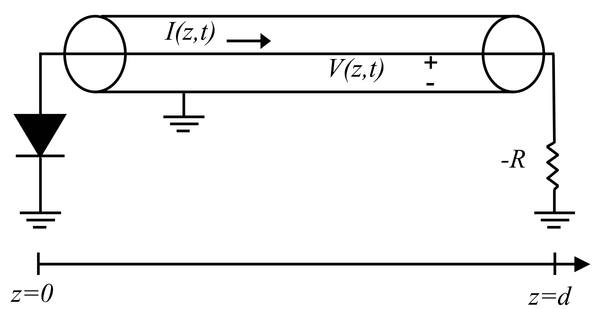

Fig. 1. Schematic of a novel wideband oscillator oscillator consisting of a transmission line of length d terminated on one end with a diode and on the other end with a "negative resistor".

2. EXPERIMENTAL IMPLEMENTATION

In our experimental implementation of the oscillator, the transmission line is a length of RG-58/U coaxial cable (Belden 9310) with characteristic impedance R_c = 50 ohms and a wave speed $v_0 = 1.97 \times 10^8$ m/s. The diode (1N34A, Radio Shack cat. no. 276-1123), chosen for its relatively low junction capacitance (typically 0.8 pF according to specifications) and low turn-on voltage (typically ~0.3 volts), is soldered directly to an SMA connector. The negative resistor is implemented with high-frequency surface mount components including a high-speed voltage-feedback op amp (OPA690, nominal large-signal bandwidth of 200 MHz) on a universal amplifier evaluation printed circuit board (Analog Devices EVAL-ADOPAMP-1R). A circuit diagram of the negative resistor is shown in Fig. 2. A variable resistor

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(BC Components SM4W101) is used to tune R, the magnitude of the negative resistance.

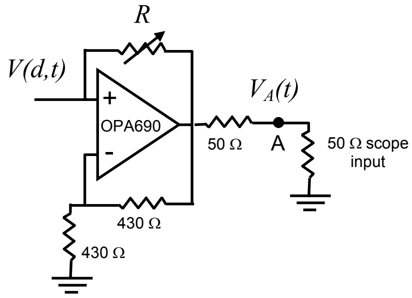

Fig. 2. Negative resistor circuit.

We use a fast digital oscilloscope (Agilent 54641A) with 50 ohm input impedance to record $V_A(t)$, the voltage following the 50 ohm resistor at the output of the operational amplifier (node A in Fig. 1(b)). The 50 ohm resistor serves to isolate the amplifier from the capacitive load of the oscilloscope input. Assuming ideal amplifier operation, the voltage $V_A(t)$ is equal to $V(d,t)$.

We observe the dynamics of the experimental system as we vary R, the magnitude of the negative resistance. As R approaches R_c from above, reflected waves are amplified with increasing gain. With a large value of R, the system resides in a steady state. As R decreases towards R_c, a supercritical Hopf bifurcation gives rise to a periodic oscillation.

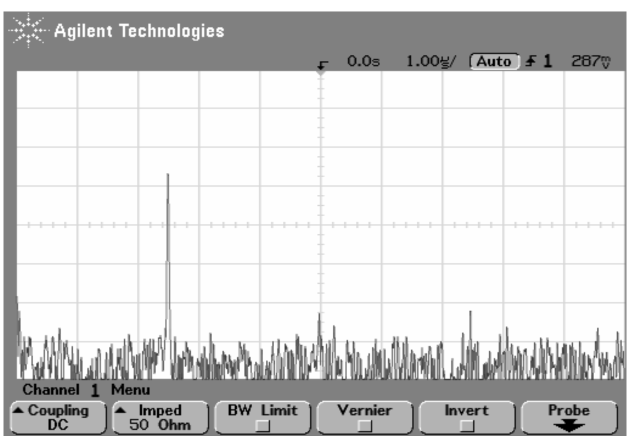

Fig. 3. Power spectrum of negative resistor output showing a periodic oscillation just beyond the Hopf bifurcation. The cable length is 14.6 cm and the negative resistance is 99.5 ohms.

By changing the length of the coaxial cable from 5 m to 37 cm, we observe oscillations with frequencies in the range 7 to 53 MHz. A power spectrum of a typical periodic oscillation just beyond the Hopf bifurcation is shown in Fig. 3. We note that by using a faster op amp and a shorter transmission line the results obtained here should scale directly to technologically relevant VHF and UHF frequencies.

Beyond the Hopf bifurcation, we observe a period doubling route to chaos. Figure 4 shows a power spectrum of a typical chaotic oscillation. The spectrum consists of peaks near the Hopf frequency and its harmonics along with an extremely wide, continuous background. This broad frequency content makes the system suitable for ultra-wideband applications.

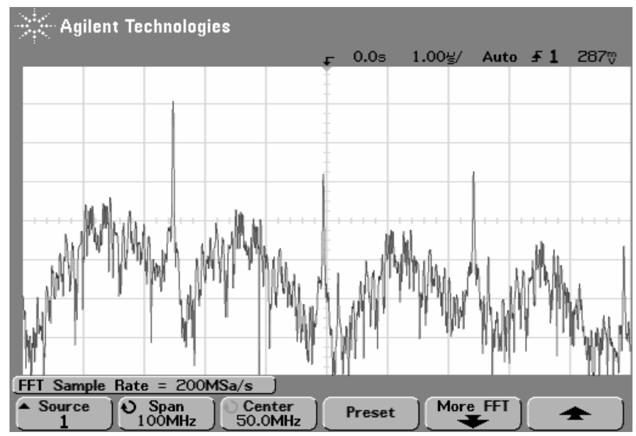

Fig. 4. Fast Fourier Transform of negative resistor output showing an ultra-wideband chaotic oscillation. The cable length is 14.6 cm and the negative resistance is 81 ohms.

4. CONCLUSIONS

We presented an experimental implementation of a chaotic RF circuit. Ultra-wide bandwidth oscillations with a tuneable peak frequency between 7 and 53 MHz were observed. Future implementations utilizing a microstrip transmission line should allow for chaotic oscillations up to a few gigahertz. This oscillator may be a key enabling technology in a novel low-cost, high-performance, ultra-wide bandwidth radar.

REFERENCES

Blakely, J. N., and Corron, N. J., 2004: Experimental Observation of Delay-Induced RF Chaos in a Transmission Line Oscillator, *Chaos*, to appear.

Corron, N. J., Pethel, S. D., and Holder, J. D., 2003: Shifterless Beam Steering in Wide-Bandwidth, Nonlinear Arrays, *1st Annual Waveform Diversity Workshop*, Naval Research Laboratory, Washington, DC.

Corron, N. J., Blakely, J. N., and Pethel, S. D., 2004: Beam Steering by Lag Synchronization in Wide-Bandwidth, Chaotic Arrays, *Proc. 8th Experimental Chaos Conference*, to appear.

Ott, E., Grebogi, C., and Yorke, J. A., 1990: Controlling Chaos, *Phys. Rev. Lett.* **64**, 1196-1199.

Pecora, L. M., and Carroll, T. L., 1990: Synchronization in Chaotic Systems, *Phys. Rev. Lett.* **64**, 821-824.