Pulse Generation using a Degenerate Band Edge Structure

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***Abstract*—We propose a pulse generation scheme based on a fourth-order degeneracy in the dispersion relation. We take advantage of the loaded quality factor enhancement and the ultra-sensitivity to external perturbations due to the high order degeneracy in such a structure. The proposed scheme is able to produce a train of nanosecond pulses with several watts of output power. Such a design offers a flexibility that allows to conceive either high output power pulses or high frequency train of pulses.**

Keywords—Pulse generation, Degenerate Band Edge, Dispersion Engineering

I. Introduction

Short duration pulse generation is an integral part of many applications in RF, microwave and optics such as their use in pulse radars, and for high resolution imaging at optical frequencies [1], [2]. In general, complicated schemes, involving high-power lasers, are required to produce nanosecond pulses that have very low peak power [1]. In this paper we present a relatively simple pulse generation circuit based on a microstrip technology by using a precisely engineered cavity that exhibits a degenerate band edge (DBE). The concept of this DBE pulse compression scheme was introduced in [3]. Such a structure is able to produce nanosecond pulses with power in the order of several watts.

A DBE represents a special point in the parameter space of a system at which four eigenmodes of the system coalesce, in both eigenvalues and eigenvectors [4]-[6]. Fig. 1(a) shows the engineered unit cell based on two coupled periodic transmission lines [7], along with its dimensions, that supports four propagating modes. The unit cell is constructed on a Rogers RO3003 substrate with thickness of 0.508 mm with dielectric relative permittivity of 3. Fig. 1(b) shows the modal dispersion relation of such periodic structure. It is seen that near 2.3 GHz a fourth-order degeneracy, the DBE, is observed, i.e., there are four coalescing modes (they have the same polarization, though this is not shown here [6], [7]). Near the DBE frequency ω_d, the dispersion relation is approximated as $(\omega_d - \omega) \propto (k - k_d)^4$ where k is the guided modal wavenumber, ω is the angular frequency, and $k_d = \pi / d$ is the wavenumber at the center of Brillouin zone where d is the unit cell length. Above ω_d, waves experience a very strong attenuation and thus a band-gap is formed. The complex dispersion relation of Fig. 1(b) was obtained using the method of moments (implemented in Keysight ADS).

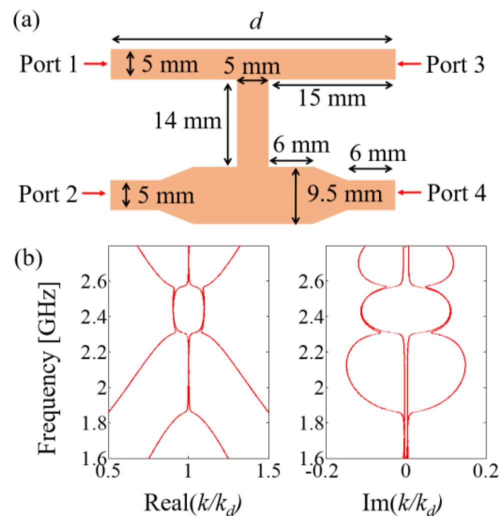

Fig. 1 (a) A unit cell of the proposed microstrip circuit on a grounded dielectric slab that exhibits a fourth-order degeneracy. (b) Dispersion diagram of periodic structure based of the unit cell in (a) showing the real and imaginary parts of the wavenumber.

II. Pulse Generaton Using the Periodic Unit Cell

The periodic structure used in the proposed pulse generation scheme is composed of 8 unit cells of Fig. 1(a) cascaded along the d direction. The DBE resonance in this finite structure exhibits some unique behavior such as giant-resonance and enhanced loaded Q-factor [8] which are the exact properties needed for a pulse generation structure. Due to the unique property of the DBE resonance, 60% of the energy inside the 8-cell structure is concentrated around the center [3]. To produce a narrow pulse, we need to extract the energy from the structure quickly, therefore, a fast and severe reduction of the loaded Q is needed to perturb the energy storage potential of the cavity with DBE resonance. Such a perturbation to the structure could be done, for example, by using a switch connecting the point with the highest energy to a load that dramatically changes the total quality factor.

The set-up for pulse generation is shown in Fig. 2(a). A Gunn diode or a cross-coupled transistor pair that offers a negative

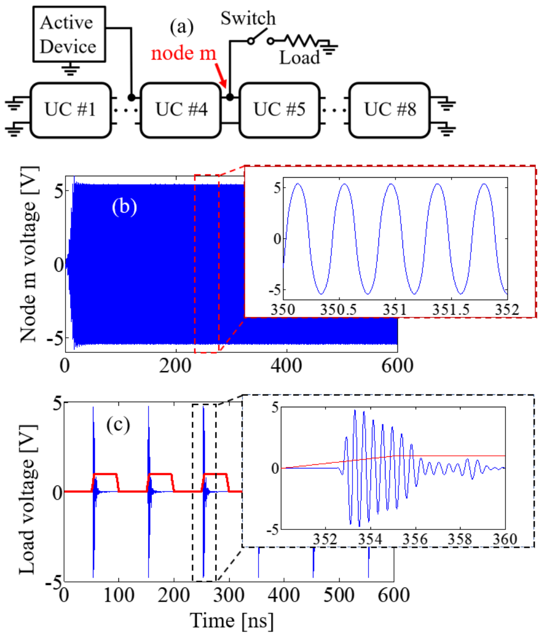

Fig. 2. (a) The 8 unit cell structure with an example of load and active device configuration. First the periodic structure with DBE is made to oscillate with most of the energy accumulated around the node m due to the structured DBE resonance. (b) Voltage at the center of the cavity, at node m, showing steady-state oscillations, assuming the DBE structures is not perturbed; (c) When a switch, whose controlling voltage is shown in red, is activated periodically and the Q of the DBE resonance is "destroyed", a pulse, shown in blue, is produced at the load located as shown in Fig. 2(a).

resistance is used as an active device to balance the cavity losses, and make the structure oscillate as shown in Fig. 2(b). Through a switch, the load resistor is connected to the point with highest peak energy, i.e., the node labeled with m as shown in Fig. 2(a), to perturb the DBE resonance, drastically lowering the Q_{tot} but is left disconnected when the structure is made to oscillate. With the switch closed, there will be a transient of energy moving towards the load. That is why after the energy is discharged to the load the switch is turned off restoring the high Q_{tot}, and allowing for the structure to reach steady-state oscillations again.

In summary, the pulse generation scheme presented here consists of a switch with a load that perturbs an oscillating cavity. First, with the switch open, the cavity is allowed to reach and oscillate at steady-state, after which the switch closes, Q_{tot} is drastically lowered, and the oscillating energy inside the cavity moves to the load for the duration of the switch being closed. Then, the switch is opened, and the structure reaches steady-state oscillation before the switch is closed again. The repetition of this scheme produces a train of pulses seen in Fig. 2(c) in blue, with the inset showing the profile of the generated pulse. The simulation is using an idealized switch, with its controlling voltage shown in red in Fig. 2(c). When the controlling voltage has amplitude of 0 V, the switch is open, and when the amplitude is 1 V the switch is closed. In this simplified simulation, the switch has fall and rise times of 5 ns, is kept closed for 40 ns, and the period is 100 ns. This produces a train of pulses with period of 100 ns and width of approximately 4 ns as shown in the inset of Fig. 2(c).

The amount of energy that travels to the load is proportional to the energy reduction in the cavity (minus the energy lost in the switch). The rise time of the generated pulse depends on the transient characteristics of the switch which makes it one of the limiting factors. The pulse duration mainly depends on the discharge characteristics of the reduced-Q cavity resonator when the switch is on. For sure the fact that most of the energy is concentrated in the middle of the cavity (before the switch is closed) is a convenient factor for this proposed scheme.

III. Conclusion

A pulse generation scheme based on a periodic structure with fourth-order modal degeneracy in the dispersion relation (i.e., the DBE) has been presented. They key features are the high-quality factor and the concentration of most of the cavity accumulated power around the center of the cavity. The relative simplicity of the structure along with flexibility in tradeoffs between generated pulse period and power, makes the proposed scheme a potentially cost-effective pulse generation to generate nanosecond pulses with power in the order of several watt desirable for radio frequency and microwave applications

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V. References

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