XXV. CIRCUIT THEORY AND DESIGN*

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RESEARCH OBJECTIVES

Investigations of nonlinear, time-variant linear, and linear active circuits are aimed at a better understanding of the relations between theoretical models and physical devices. Current research includes:

(a) theoretical investigations, design, and experimental behavior of parametric amplifiers and frequency multipliers

(b) determination of the invariant properties of active network components under various kinds of embedding

(c) studies of transistor and tunnel-diode circuits.

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A. IDLER CIRCUITS IN VARACTOR FREQUENCY MULTIPLIERS

The application of the semiconductor capacitor diode (varactor) to frequency multiplication has received considerable attention in the past few years. Most of the analyses that have been presented are limited by restrictions to small-signals, lossless varactors, or the inconvenient parallel model for the varactor.

The recent studies made by R. P. Rafuse (1) and the author (2) consider the varactor as a series combination of a constant resistance and a charge- (or current-) controlled nonlinear elastance. There is good physical evidence for this choice. With this model and a Fourier-series approach, it has been possible to obtain closed-form, large-signal solutions for several abrupt-junction varactor frequency multipliers — doubler, tripler, quadrupler, and sextupler. (The abrupt-junction varactor is characterized by a nonlinear capacitance variation given by $C = K(v+\phi)^{-1/2}$, where K is a constant that is dependent upon diode geometry and doping, ϕ is the "contact" potential between the diode materials, and v is the magnitude of the reverse applied voltage.) In each case the solutions are quasi-optimum. The quasi-optimum solution has been found to be within 1 or 2 per cent of the true optimum solution which is determined by a much more difficult procedure.

It has been demonstrated (1, 2) that extra currents other than the fundamental and n^{th}-harmonic currents must be present in abrupt-junction varactor frequency multipliers (except the doubler, n = 2). These extra currents are called "idler" currents. For the best multiplier efficiency, the impedance of the external network seen by an idler current should be pure imaginary (lossless impedance) and of the proper

*This work was supported in part by Purchase Order DDL B-00306 with Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology with the joint support of the U. S. Army, Navy, and Air Force under Air Force Contract AF19(604)-5200.

magnitude and phase to tune the varactor elastance at the idler frequency.

Permissible idler frequencies can be established by considering the average power at the various harmonic frequencies for a particular order of multiplication. A negative average power at an idler frequency indicates that a passive termination is possible at that frequency. Positive idler power requires a source at the idler frequency. In particular, it is found that the first idler must always be at the second harmonic, $2\omega_o$, the second idler at $3\omega_o$ or $4\omega_o$, the third at $4\omega_o$, $5\omega_o$, $6\omega_o$, or $8\omega_o$, etc. For the general case, it is easily shown that a passive idler termination is possible if, and only if, the particular idler frequency is the sum of two lower-order idler frequencies, or at twice the frequency of some lower-order idler frequency (including the fundamental).

It is also possible to show that idler frequencies above the output frequency are undesirable. No such statement can be made at the present time about unnecessary idlers below the output frequency.

The choice of using the series model for the varactor (current-controlled elastance) means that the currents are the independent variables. Thus, in the theoretical (and experimental) work, only the necessary idler, input, and output currents are allowed to be present. All other currents are constrained to equal zero.

Synthesis procedures follow directly from the theory, as a consequence of allowing only certain currents to flow. The required multiplier is simply a varactor embedded in a lossless coupling network. The coupling network performs the operations of coupling the various currents to the varactor, separating the currents (that is, keeping the input out of the output, and so forth), and rejecting the undesired currents. In each multiplier the impedance level of the coupling network is set by the varactor that is used.

The experimental and theoretical results were found to be in good agreement in all respects: in efficiency, bias voltage, input and load resistances, and power-handling capability.

This summary gives a brief indication of the work that has been done at the Research Laboratory of Electronics in the field of varactor frequency multipliers. Most of the work that has been done is reported in considerable detail in the theses of Rafuse and the author (1, 2).

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References

1. R. P. Rafuse, Parametric Applications of the Semiconductor Capacitor Diode, Sc. D. Thesis, Department of Electrical Engineering, M. I. T., September 1960.

2. B. L. Diamond, Idler Circuits in Varactor Frequency Multipliers, S. M. Thesis, Department of Electrical Engineering, M. I. T., February 1961; Report No. 47G-0012, Lincoln Laboratory, M. I. T., Dec. 13, 1960.