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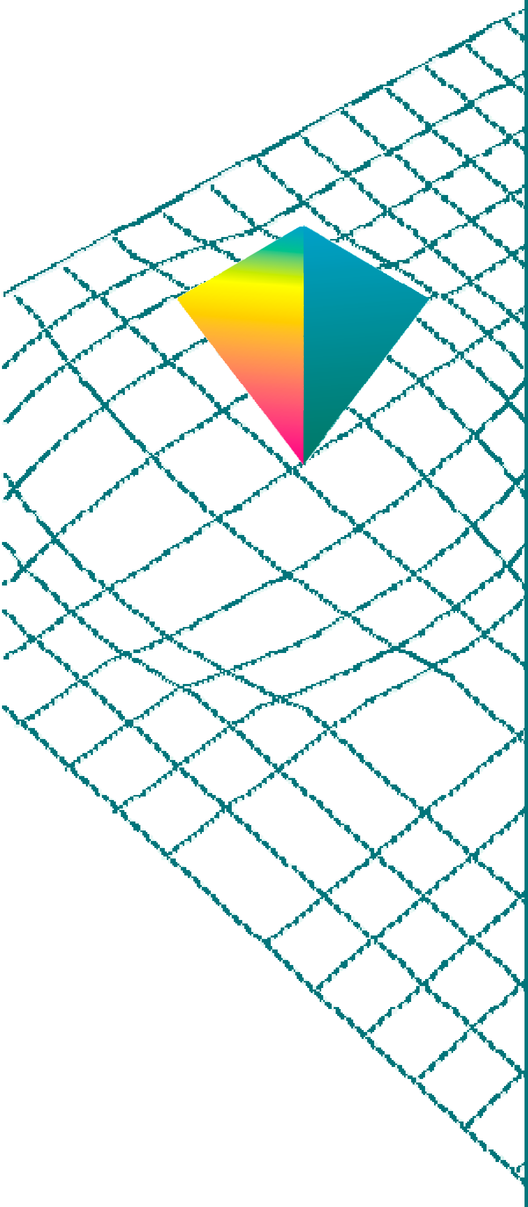

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50. Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
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Ch. Knoth / H. Toepfer

Electromechanical Issues of Powering Energy-Autonomous Electronic Control Units

ABSTRACT

Electronic sensors and control units which are self-supporting with respect to power supply are gaining more and more importance. Among the possibilities of converting environmental energy into electrical energy, the classical electromagnetic principle is a convenient option in cases when mechanical movement is involved. In the contribution, the general requirements for biasing a microcontroller circuit are considered. The analysis starts from basic considerations and provides for a proof of principle by means of circuit simulation.

INTRODUCTION

Today, the tendency of miniaturization continues to prevail in mechatronics. Besides the ever larger integration in electronics and the advances in micro-structuring, which both allow for to facilitate units of shrinking dimensions, the emergence of wireless networks has introduced a new quality in applying miniaturized modules as parts of a distributed system. Especially, technologies as e.g. ZigBee [1] enable the set-up of ad hoc networks with options for very low power consumption. Under these conditions, it appears as a logical consequence to get rid of the last of the traditional wires: the power supply cable. The common and trivial approach for this consists in using batteries. This, however, hampers the decentralization on a larger scale as the number of batteries would increase accordingly, leading to a prohibitive level of maintenance and costs. Alternatively, one can try to convert environmental energy into electrical energy in order to power electronic systems. Sources for such an energy conversion can comprise the movement of mechanical parts (via the electrodynamic principle [2]), temperature gradients (via the Peltier effect [3]), or even nuclear dynamos [4]. In our contribution, we assume the existence of a translatory movement and consider the conditions for generating the supply for a state-of-the-art networked electronic unit. For this, we perform an electromagnetic analysis of a representative structure. After this, suitable circuits for power supply conditioning are investigated. By means of circuit simulations, the suitability of the generated waveform as a power supply is investigated. Typical results are given and discussed.

ELECTROMAGNETIC ANALYSIS

The device under investigation is composed of a straight coil and a permanent magnet which is movable inside the coil. This movement, back and forth, induces a voltage in the coil via Faraday's law. The task is to determine the geometry of the set-up in such a way that the induced voltage is suitable to be processed towards a dc voltage biasing an electronic control unit. In Fig.1, the geometry is shown schematically.

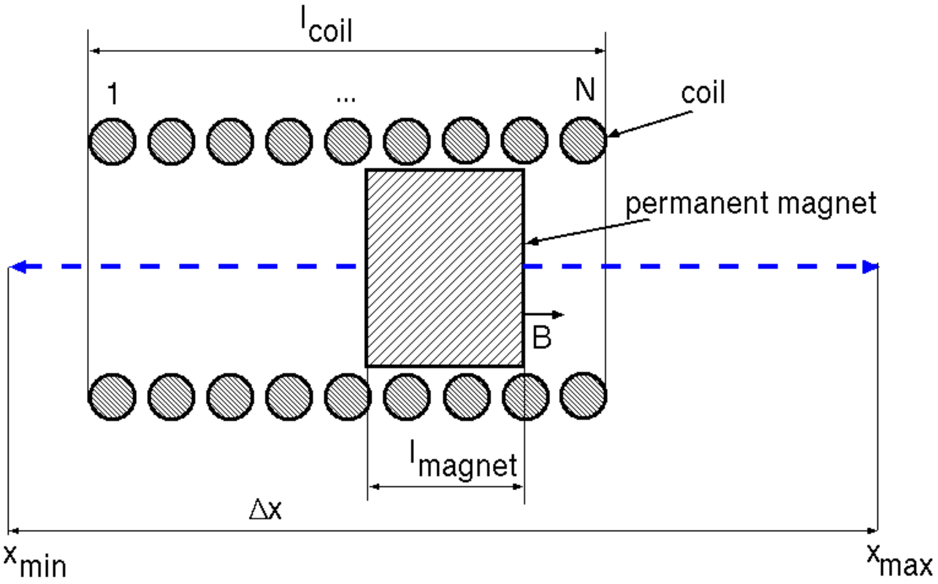

Fig.1: Set-up of the device under investigation. The permanent magnet with a length l_{magnet} is moving along the dashed line within the limits (x_{min},x_{max}). The coil is comprised of N turns. Its length is given by l_{coil}.

Under this assumption, in the steady state the movement of the magnet results in a periodic change of magnetic flux Ψ across each of the N windings. Following Faraday's law, this induces a periodic electromotive force and leads to a voltage V. Because the magnetic flux density B is a function of the position x, so is Ψ, and the voltage induced in the i-th turn results as

$$V_i(t) = -d\Psi_i(t)/dt \qquad (1)$$

where $\Psi_i(t)$ denotes the flux at the position of the i-th turn which is time-dependent due to the periodically moving magnet. The particular dependence $B(x)$ has been measured on pellet-shaped NdFeB magnets. A representative decay of the flux density is shown in Fig. 2.

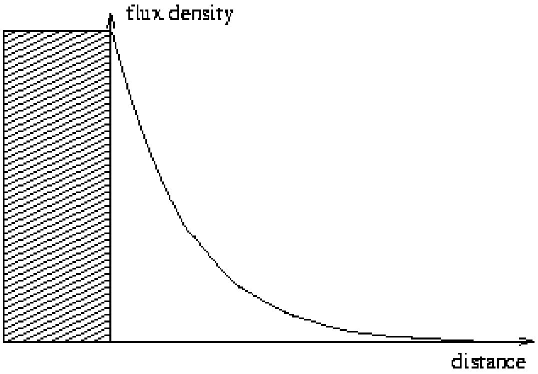

Fig.2: Qualitative behaviour of *B(x)* as measured for the magnets used

Instead of considering the equation of motion and solving it for the position-dependent voltage, we made use of the steady-state assumption and considered the contributions of each of the turns to the entire voltage across the coil. For this, the particular *B(x)* has been approximated by a polynomial fit and taken into account. The variation in time is introduced via the angular frequency ω of the magnet's movement. Finally these contributions are summed-up. All calculations have been made using the MAPLE software package [5]. Due to the consideration of the experimental *B(x)*, the resulting voltage has a non-trivial shape. A typical waveform of *V(t)* over one period is shown in Fig. 3.

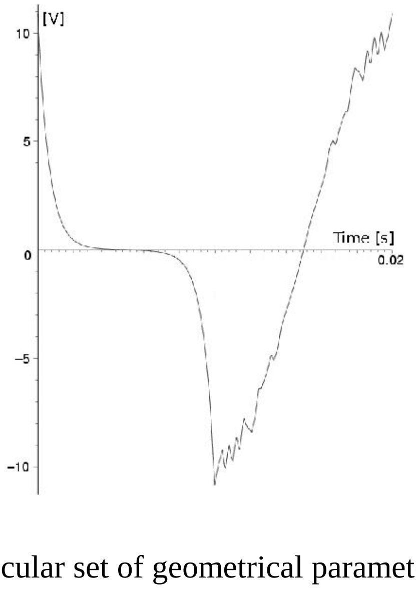

Fig.3: Calculated *V(t)* for a particular set of geometrical parameters. The resulting curve exhibits asymmetry due to the consideration of the magnet's stray field in the direction of movement.

The output voltage as calculated from this model can by used to enter the further investigation in subsequent circuit simulation.

POWER SUPPLY CONDITIONING

As there is a vast variety of integrated circuits being in use in embedded systems, the aim of the investigation can consist only in a feasibility study for particular cases. One of the microcontrollers with very modest requirements is the TI MSP430 [6] working from a voltage of 1.6V on and requiring only about 250µA per MIPS. For greater versatility, the induction coil will be supplemented by a conditioning circuit which is comprised of a voltage doubler with a capacitor for energy storage The voltage doubler as shown in Fig. 4 is a simple standard version taken from a textbook [7].

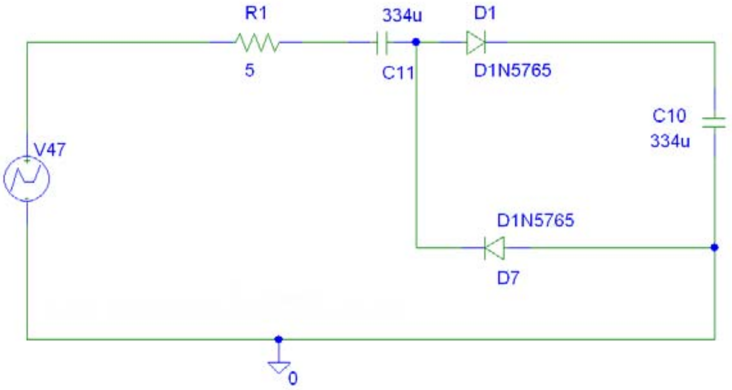

Fig.4: Voltage doubler circuit after [7], equipped with contemporary components

Its operation has been verified by means of PSPICE simulations. Fig. 5 shows the resulting voltage across the capacitor as a function of the applied frequency. For this initial consideration, a sinusoidal excitation has been applied. From the simulation results, it can be inferred that for excitation above about 10Hz the capacitor is charged quickly to a sufficient voltage level.

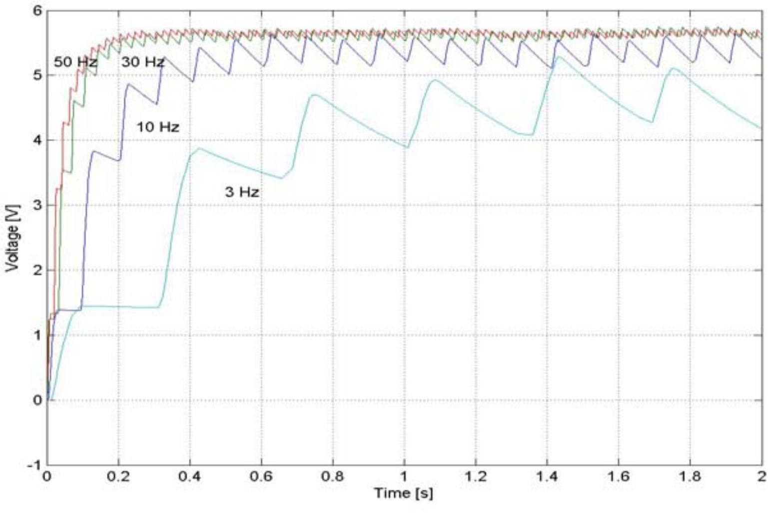

Fig.5: Operation of the power supply conditioning stage for a set of applied frequencies.

PARAMETER STUDY

As the next step of the analysis, the calculated voltage waveform similar to the one shown in Fig. 2 is applied to the abovementioned circuit. For this, the applied voltage is approximated as a piecewise-linear function. Fig. 6 shows the results of a simulation.

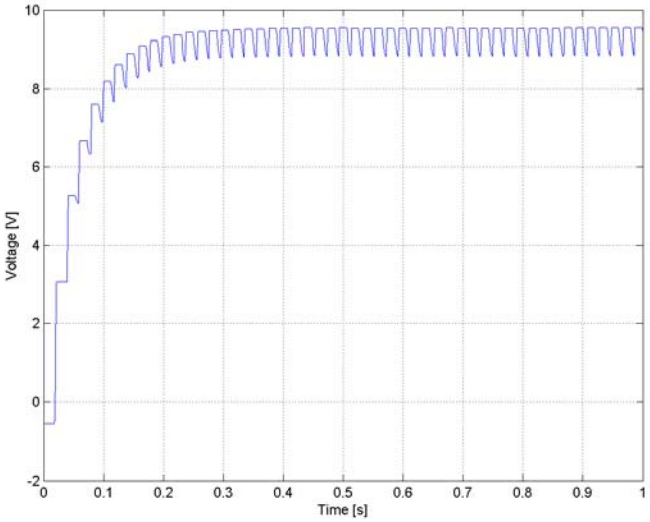

Fig.6: Simulated operation of the entire power supply module.

The frequency of the mechanical movement is taken as 50Hz.

RESULTS

A simple model for the conversion of mechanic energy into electric one, studied under consideration of practical constraints for the size of the magnet, its maximum range of movement, and the number of turns, points out that within a fraction of a second, energy for biasing low-power microcontrollers can be accumulated.

CONCLUSION

The results show the feasibility of the approach and provide reason to carry on with the study on a more detailed level. The inclusion of a load equivalent for an actual microcontroller as well as an experimental verification are subject to further investigation and will be reported elsewhere.

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