The Voltage to Frequency Converter Using as Reference the Pull-In Voltage of a Reed Relay

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Abstract **-** The chief requirements of basic components of digital systems for industry are both the availability of preventive maintenance and high reliability. Integrated semiconductor components are highly lacking in both these requirements. To respond to the referred exigencies a voltage to frequency converter (VFC) by the use of a reed relay (RR) and a charge-discharge method with as reference the pull-in voltage of RR is illustrated. Test results prove a high linearity and that it is imperious to environmental temperature and proper for extreme environmental industrial conditions.

I. Introduction

Voltage to frequency converter (VFC) [1] is an oscillator whose frequency is linearly proportional to control voltage. There are two common VFC architectures: the current steering multivibrator and the charge-balance VFC. For higher linearity, the charge-balancing method is preferred. The charge balanced VFC may be made in asynchronous or synchronous (clocked) forms. The synchronous charge balanced SVFC or "sigma delta" (Σ-Δ) VFC is used when output pulses are synchronized to a clock. The charge balance VFC is more complex, more demanding in its supply voltage and current requirements, and more accurate. It is capable of 16 to 18-bit linearity. A new SVFC (NSVFC) [1] works similarly as conventional SVFC, but NSVFC it has a pure tone on output (for constant input voltage). Therefore, it is possible to measure the period of NSVFC output (this does not work for SVFC). The frequency is linearly proportional to a control voltage (input voltage must be offset in converter). In recent years, VFC have become quite popular due to their low cost and application versatility in variety of electronic control and measurement systems. With a good quality VFC, this circuit will match the performance of many commercial A/D converters. Its only disadvantage is relatively slow conversion time. Σ-Δ modulator [1] can be used for synchronous VFC (SVFC). In SVFC charge balance pulse length is now defined by two successive edges of the external clock. If this clock has low jitter the charge will be defined very accurately. The output pulse will also be synchronous with the clock. SVFC's of this type are capable of up to I8-bit linearity and they have excellent temperature stability, but are not pure tone for constant input voltage (output pulses are not equally spaced) [1]. The waveforms of Σ-Δ SVFC output periods are not the same. This disadvantage was taken away in NSVFC.

The widespread use of digital systems in industry responds to the trend of producers that aim to develop economical products with improved reliability. They also seek ways to trim cost and enhance quality, using advanced automation processes in manufacturing. The basic structure of a quality improvement program can delineate an optimization of preventive maintenance programs. As well the role of preventive maintenance in availability as the role of reliability of equipment in life cycle cost. Nevertheless [2] a method is necessary to cool the electronics contained in the readout boxes. The electronics to preamplify and digitize signals from the optical detectors will generate a large amount of heat that must be removed from the system.

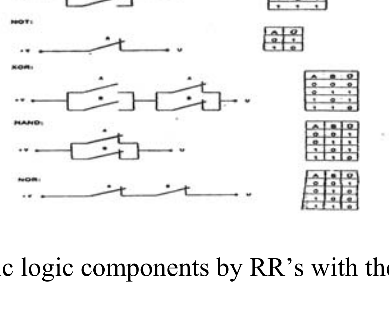

Fig. 1. The basic logic components by RR's with their truth table.

The chief requirements of basic components of digital systems for industry are both the availability of preventive maintenance and high reliability. Integrated semiconductor components are highly lacking in both these requirements. In fact their single parts can't easily be tested or replaced for preventive maintenance. And humidity, temperature, and wear greatly affect reliability of these components in spite of the progress in the area of electronic components in reliability that has occurred in the four decades ending in 1989 [3] even with the use of the exacting environmental stress screening. Frequent checks and calibrations are needed with; wear thermal shift, and humidity. In the case of industrial type laboratories these precautions and calibrations needed for analog signal are not compatible with production output or network tests. Moreover they are unavailable to check reliability as required in safety devices. The number of annual conferences through the world on this subject emphasizes the outlined lacks. Moreover the increased complexity required of electronic circuits and systems has significantly increased the difficulty of adequately testing analog and integrated circuits. One testing approach to the increased accessibility of internal nodes is to incorporate a built-in self-test circuit [3] in the unit under test. Nevertheless this inclusion further increases the required complexity. To respond to the referred exigencies are available the *hardwired components* (HWC), by the use of the reed relays (RR's). In the paper is illustrated a highly useful application to VFC. RR's have a high *electromagnetic compatibility* and e.g. the *European Standard* in EN60204-1: 1992 page 64 states that, "in all safety-related stopping functions, the use of hardwired electromechanical Components is preferred (i.e. the function should not depend on the operation of programmab1e electronic components). And when their use is admitted the safety precautions required make this use unfavorab1e". Now RR's are extensively used in: multip1exing, the primary side of te1ecommunication applications, in alarm and security technology, etc. Moreover they are used in some automated measurement systems [5], analog switches are used in A/D converters with capacitor match [6], latching relays have been used in matrix relay modu1es [7] and in many different cases [8-10]. In the applications of digital instrumentation we are going to treat name1y, in industrial plants or laboratories, in manufacturing automation, and in electric power plants, the illustrated new components have a high e1ectromagnetic compatabi1ity and, with respect to the integrated semiconductor ones, appear to be more reliable and to be able to overcome their main constraints. RR's may have reliable switching for over one billion of operations, namely, for about 12,000 days at 1 kHz of continuous operations. In the applications we are going to treat digital instrumentation never has a continuous use. E.G. in safety control systems the use may be once an hear, once a month, or once a day; ADC (also are intermittent used. In our applications the 1ife-time of RR's may then be considered nearly un1ited. In high-density applications such those for automatic test equipments or for packing density where very little board area is available we can find RR's of about 4xl0x1 mm dimensions. Maximum, operating, time about 250 μs to 1 ms.

II. Basic principle of Hardwired Logic Components by RR's

The basic HWC logic components by RR's may be obtained by implementing the Boolean algebra. The *pull-in voltage* on the coil that actuates RR is the *input signal*. The *logic states* 1 and 0 are the states of the contacts of RR respectively closed and opened with contact usually opened and vice versa with contact usually closed Their *noise margin*, namely, the range values in which may be contained the voltage levels of the two state values (0 and 1) or the difference between the minimum voltage level at state 1 and the maximum voltage level at state 0 may be of few hundreds (few volts per few tenths of millivolts). The *propagation delay time* is in about 1 ms.

III. Applications

This section is devoted to illustrate the available applications of HWC by RR's both as basic logic components and as VFW.

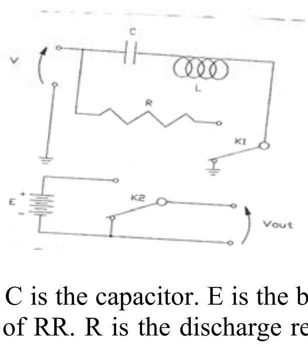

Fig. 2. Schematic diagram of VFC by a RR. C is the capacitor. E is the battery for the output voltage. K1, K2 and L are the, contacts and inductance of the coil of RR. R is the discharge resistor. V and V_{out} are the input and output voltages.

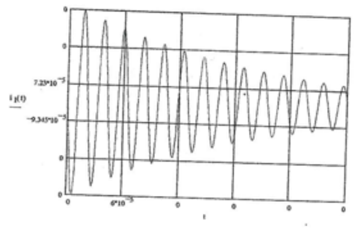

Fig. 3. Waveform of the evaluated discharge current.

A. Basic logic Components by RR's

The Boolean algebra summarizes in the self-explaining Fig. 1, the basic logic components by RR's with their truth table. The component STORE not illustrated in Fig. 1 is a held RR.

***B*. VFC by a RR**

Fig. 2 shows the schematic diagram of VFC by a RR. VFC is based on the method that we have denoted the "charge-discharge method". The used RR, for deviation or of C type (changeover), has two contacts, Kl, K2 The input voltage, V, is parallel connected with the capacitor C directly and through the coil L and the normally closed contact of the first, Kl, of the two contact of RR. As soon as V is connected with the input terminals of VFC, nearly on the instant, namely, in a time much shorter than the operating time of RR, C is charged at the voltage V. If V is not lower than the pull-in voltage of RR, RR is actuated. Nevertheless the pull-in voltage could be controlled from zero to any a value by a proper reference voltage battery system series connected with L. The illustrated configuration has been selected on account of its high reliability it only includes the, RR, C, and R. It has a pure tone on output (for constant input voltage). The period of VFC output may then be measured (this does not work forΣ-ΔVFC [1]). **-** *Output Frequency Evaluation* **-**When RR is actuated; C is discharged through the L-R circuit with the following exponential low,

$$I(t) = Ae^{\mu_1 \cdot t} + Be^{\mu_2 \cdot t} \quad (1).$$

Where, $\mu_{1,2} = \frac{1}{2}(-\frac{R}{L} \pm \left(\left(\frac{R}{L}\right)^2 - \sqrt{\frac{4}{LC}}\right)$, $A = \frac{\left(\frac{V}{L}\right)}{(\mu_2 - \mu_1)}$, and, B = -A.

The time constant, Td, is $\frac{1}{\mathrm{Re}^{\mu_{1,2}}}$ Td= $\frac{L}{Rt}$, where Rt=R+Rl and Rl is the resistance of the coil L. As soon as, the voltage at the coil reaches the dropout voltage value, Vd, RR is deactivated, the discharge is interrupted. The cycle newly starts. The discharge time, T, from V to Vd is,

$$T = Td \cdot \frac{(V - Vd)}{V} \quad (2).$$

And then frequency, f, is

$$f = \frac{V}{Td \cdot (Td - t)} \quad (3)$$

Table 1. Some measured values V and f and linearity of the realized experimental VFC by a RR.

V	**2.5**	**5.0**	**7.5**	**10.0**	**V**
f	**8.300**	**25.300**	**42.340**	**59.400**	**kHz**
linearity	**0.003**	**0.0035**	**0.0023**	**0.003**	**%**

Fig. 3 shows the waveform of the discharge current evaluated with the data of experimental VFC by a RR. This evaluation has been performed to knowing the pick voltage and r.m.s. current supplying the coil, as data for coil designing). The output level square voltage Vout is obtained by K2 with a battery parallel connected at its output contacts. With RR not activated the output is at ground potential, with RR activated the output is at the level E of the output battery. The *reference voltage* of VFC is the highly reliable drop-out voltage, Vd, on the coil at which the RR is deactivated. The *output* of the VFC *is isolated* without the use of any external optoisolator. Moreover, to prevent the influence of the environment temperature, RR is enclosed (packaged) in a thermally insulating material. This thermal insulation increases the self-heating Nevertheless the self-heating in VFC by a RR is negligible, (see test results in the following Section), and allows for a thermal shield.

IV. Test Results

An experimental VFC by a RR has been developed. - A. *Prototype's Rated Data*- - *RR* - in the C form (changeover), with two contacts maximum, *operating, time* ≅ 0.5 ms and *rated voltage* 100 V, *contact resistance* ≅ 150 mΩ, operating *temperature range*, - 55÷ +70 °C, *shock resistance* 100 g - 11ms, *vibration resistance* (duration 6 h), 10 g, 10 ÷ 1500 Hz, maximum operating frequency 550 Hz, *expected life* for switching at 0.25A/40 V dc, over 510^8 operations (our prototype operates at ± 5 mA/5V), encapsulated *in a plastic package* (acting as a thermal shield) and features an internal mu-*metal screen*, overall dimensions, 3×5×15 mm. - *Battery* lithium-cadmium type, 6 V, capacity 1.9 Ah, temperature *range*, from – 55 °C to +85 °C, self decay < 1% enables *lasting* > 30 years to VFC, hermetically sealed is also highly corrosion-resistant, overall dimensions: 15×50×7 mm. The illustrated prototype of VFC has been used in carrying on a series of tests intended to detect the converter performances and its operating effectiveness.

A. Voltage to Frequency Test

The characteristic (see Table 1) has been detected in the input voltage (V) range from 2.5 V to 10 V. The frequency (f) has been in the range from 8 kHz to 60 kHz. The characteristic frequency to voltage can be approximated by a linear regression with, $1 - r \cong 3\cdot 10^{-7}$, *linearity* ≅ 0.0035%, and *conversion constant* ≅ 6.8 kHz/V. The conversion time has been resulted highly prompt, in practice zero. This will match the performance of many commercial A/D converters on the contrary of Σ-ΔVFC [1] that have a relatively slow conversion time.

B. Temperature Influence's Test

The test has been performed in the temperature's range from 20 °C to 110 °C with permanent input by a calibrated voltage of about 9 V. During this test none deviation on LSD in the period T has been detected. The LSD has been in about 50 ppm of the period T. Moreover, for the duration, of the whole test, namely, about 1 h it maintained a pure tone on the output allowing to measuring the period of output. These test results prove that VFC by a

V. Conclusions

The illustrated VFC by reed relay (RR) has shown, by test results, to respond to the trend of producers that aim to develop economical products with improved reliability and to the chief requirements of basic components of digital systems for industry, namely, both the availability of preventive maintenance and high reliability. They also seek ways to trim cost and enhance quality, using advanced automation processes in manufacturing. The experimental VFC by RR is imperious to environmental temperature and proper for extreme environmental industrial conditions and allowing to measuring the period (for constant input voltage).

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Biographies

FRANCO CASTELLI was born in Milan, Italy. He received the M.S. degree in electrical engineering from the "Politecnico di Milano", Milano, in 1958. He worked one year at C.G.E. (Compagnia Generale di Elettricità), Milan, in the servomechanism field. In 1961 he joined the Polytechnic of Milan as Assistant Professor of Electrical Measurements. He was awarded the "Angelo Barbagelata" premium in 1965 and the "Lorenzo Ferraris" premium in 1967 on the basis of the publications on electrical measurements. In 1971 he has been qualified for university teaching, on "Electrical Measurements". Since 1974 he has been an Associate Professor of "Advanced Electrical Measurements" at the Polytechnic of Milan. He has published various aspects of electrical measurements.

MARCO FAIFER was born in Bormio (Italy) on July 28, 1978. In 2003 he received his M.Sc. degree in Electronic Engineering at the Politecnico of Milan. Currently he is an assistant professor of Electrical and Electronic Measurements at the same University. His scientific activity is mainly concerned with the DSP techniques, the development of industrial sensors and the devices for High Voltage measurements.