第二届传感器学术讨论会

THE SECOND TRANSDUCER CONFERENCE

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論文集

上册

第二届传感器学术讨论会
论 文 集

上 册

前　言

《第二届传感器学术讨论会》是由中国仪器仪表学会、中国电子学会、全国高校三大领域所属的传感器、敏感技术、元件、材料等十个专业学会，首次联合召开的高层次专业学术会议，于4月24日至27日在武汉举行。

此次学术会议，是我国传感器及敏感技术学者、专家及专业技术工作者的一次盛会。参会论文作者628人，论文286篇，内容涉及物理量、化学量、生物量传感技术三个方面，反映了我国此项技术的前沿状况及当代水平，不少论文及其科研成果接近、达到或超过国际水平。

纵观全局，借助改革，加强横向联系，发挥优势，多学会联合举办学术会议，不仅有利于学术水平的提高，并将为召开大型国际传感器学术会议理顺关系，奠定基础。

我们深信，此届学术会后，在全国科技工作者共同努力下，定将开发出新一代的敏感元件及传感器新产品，定能把我国的传感技术推向一个新的水平。

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湖北省科学技术协会
武汉市科学技术协会
湖北省和武汉仪器仪表学会
全国高校传感技术研究会
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编辑执笔

一九八八年四月　武汉

编 辑 说 明

本《论文集》是由近300篇论文，经《第二届传感器学术讨论会论文评审委员会》评审后编辑的。

在评审时，考虑到每篇论文的学术价值、科学意义、经济效益三项标准及新内容、高水平两项原则。

《论文集》共编入论文286篇，分为论文题目、摘要、全文三种形式，其中全文154篇，摘要125篇，论文题目7个。

《论文集》中部份论文仅编入"论文摘要"的原因是：论文已在国内外期刊上发表；作者未在论文中发表实质性的内容；论文文字数超篇幅；图文不清；仅投寄摘要等原因。

在编辑过程中感受到，我国学术界应提倡良好的文风，论文作者要注重引论简洁，原理正确，论据充分，实验、分析合理，计算、结论无误，全文概念清楚，计量单位及符号应符合现行标准，重视语言结构及书写，以不断提高论文水平。

由于编辑水平所限，时间仓促，难免编校错误或遗漏，诚请论文作者、广大读者指正。

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FM DETECTION SYSTEM FOR USE WITH VARIABLE-FREQUENCY TRANSDUCERS

Clifford D. Ferris
Director, Bioengineering Program
Acting Head, Department of Electrical Engineering
College of Engineering
University of Wyoming
Laramie, WY 82071-3295 USA

ABSTRACT

An FM quadrature detection system for use with variable-frequency transducers is described. The signal from the transducer oscillator is mixed with the signal from a crystal-controlled reference oscillator to produce an intermediate frequency signal which is amplified and input to an FM quadrature detector chip. The result is a high-resolution (to 10 μm), high linearity (±0.5%), low-noise detection system for use with variable-capacitance or variable-inductance transducers. Applications include displacement, pressure, and vibration measurements.

INTRODUCTION

The *effective* excitation of a variable-capacitance or variable-inductance transducer is frequently a small mechanical displacement of a dielectric or ferromagnetic core relative to fixed capacitor plates or an inductance coil. Actual excitation need not be a mechanical displacement, but only a stimulus that can be converted to such a displacement. The transducer element so established (variable capacitor or inductor) is used in the frequency-determining circuit of an electronic oscillator, such that a change in frequency of oscillation occurs when the transducer is excited. The transducer-system output is thus a frequency-modulated signal, for which historically, many different detection schemes have been proposed. These include FM limiter-discriminator methods, marginal oscillators, and frequency-to-voltage convertors. The method described herein incorporates an available FM quadrature-detector microcircuit chip to produce a very linear, high-sensitivity, low-noise transducer signal-detection system. This system exhibits a better signal-to-noise ratio than can be obtained using marginal-oscillator methods, and has a considerably higher resolution than can be obtained by the use of conventional frequency-to-voltage convertor chips. It does not require a balanced-discriminator transformer associated with limiter-discriminator methods.

SYSTEM IMPLEMENTATION

Figure 1 is a block diagram of the basic system. Figure 2 is the complete circuit schematic less power supplies. Both oscillators use the Colpitts configuration. The crystal-controlled reference oscillator is a common-emitter circuit with a small amount of emitter degeneration (negative feedback) to stabilize the circuit and improve output wave form. This is accomplished by the use of the unbypassed 330-Ω resistor in the emitter circuit. The transducer oscillator is a common-base configuration with the output taken from the emitter. This arrangement produces good frequency stability against output-load fluctuations. The trimmer capacitor (C_{T1}) fine-tunes the oscillator, such that when there is no transducer excitation, the output frequency is 10.7 MHz above the reference-oscillator frequency.

The base frequencies of the two oscillators are not critical. The only requirement is that they differ by 10.7 MHz. For this project, a 6.144 MHz crystal was used only because it was available, but this frequency has no theoretical significance. Normally one would attempt to select a transducer-oscillator frequency such that Δf is maximized with respect to ΔC or ΔL.

The prototype system described herein uses a variable-inductance element, simply for calibration convenience. Use of a dual-gate MOSFET as a mixer promotes good mixing action with conversion gain, and circuit simplicity. Gate 1 (transducer-oscillator input) is operated at 0 VDC via a 100k discharge resistor. Gate 2 is operated at 0.8 VDC, which optimizes mixing action (as determined experimentally for the 3N211). The mixer output transformer serves as both the 10.7 MHz output-tuning circuit for the mixer, and the impedance-matching network to the first IF amplifier. The two-stage IF amplifier is a modified version of a circuit recommended by the Radio Corporation of America (*Linear Integrated Circuits* manual) for use with the CA3189N quadrature detector.

With reference to Figure 2, note that all of the radio-frequency stages have been isolated from the 12-VDC bias supply by radio-frequency chokes and bypass capacitors. This is very important to ensure circuit stability. Conventional 10.7 MHz ceramic filters, which require no tuning, designed for use in FM receivers are used in the IF amplifier. The circuit configuration for the 3189 chip has been modified to some extent from the design recommended for FM receiver use by RCA. The 3189 chip provides several functions for FM receiver use (delayed AGC output, muting control, signal-strength-meter output, AFC output) which are not required in the present application. Deletion of these functions required several circuit-configuration changes. The double-tuned coil in the phase-shifting circuit of the quadrature detector provides lower harmonic distortion than can be obtained with a single-tuned coil. The purpose of this coil is to provide the 90° signal phase shift that is the basis for quadrature detection

CIRCUIT ADJUSTMENTS

The following adjustments are necessary after the circuit has been constructed: The unit is supplied with +12 VDC and an oscilloscope probe is connected to pin 1 of the 3189 chip. The two trimmer capacitors are adjusted until a maximum and stable 10.7 MHz signal is obtained. The actual frequency may differ slightly from 10.7 MHz depending upon the exact center frequency of the ceramic-filter combination. The output signal levels from the two oscillators should be in the range from 3 to 5 volts peak-to-peak. The signal level at pin 1 should be in the range from 2 to 3 volts peak-to-peak.

The oscilloscope probe is now shifted to pin 6 (output) of the 3189 for adjustment of the phase-shifting coil. At this point, the transducer should be driven sinusoidally (somewhere in the range from 0.1 to 1 kHz is preferred). The primary-coil tuning slug is adjusted until an undistorted sinusoidal wave form is obtained. The secondary-coil tuning slug is then adjusted for maximum output. If an audio distortion analyzer is available, it should also be connected to pin 6 and the two coil-adjusting slugs adjusted for minimum harmonic distortion in the output signal. This completes the alignment procedure.

SYSTEM CALIBRATION

Since the system described in this paper is a prototype, careful calibration was required. The "transducer" element is a single-layer close-wound solenoid composed of 22 turns of #24 AWG varnish-coated copper wire on a 0.280 inch diameter (outside diameter) nylon form (Bell Industries 4200 series) The coil tuning element is a cylindrical ferrite bead 0.070 inch in diameter by 0.20 inch long. The bead is cemented to the end of a glass capillary tube, the other end of which is attached to the shaft extension of an electromechanical driving transducer. The bead is located coaxially at the approximate center of the solenoid. The general calibation system is shown schematically in Figure 3.

The purpose of the external driving transducer is for calibration only. It simulates a mechanical input to the variable-inductance transducer, and facilitates driving the ferrite bead sinusoidally. The device selected was a Pye-Ling Type V47 vibration-generator manufactured by LTV Ling Altec, Ltd. in England. The drive-shaft of this unit is connected to the armature of a Hewlett Packard (Waltham Division) 7DCDT-050 DC-DC LVDT, which monitors the mechanical exictation (vibration) produced by the V47. This procedure provides verification that the V47 is producing linear sinusoidal motion of the drive shaft. The LVDT has a maximum stroke range of ±0.050 inches with linearity of ±0.5%. The glass capillary tube is attached to the armature of the LVDT. The LVDT requires a 6-volt DC bias supply and generates an internal AC carrier signal, which is internally rectified to produce (with some 10 kHz ripple) a DC ouput signal that is proportional to the position of the armature. The V47, which has an input impedance of 3 Ω, was driven by a custom-made low-distortion power amplifier (PA in Fig. 2). A Wavetek model 148A function generator provided the signal source for the power amplifier and V47. This portion of the experimental setup simply provided a monitored mechanical sinusoidal excitation for the ferrite bead to displace it vertically (and coaxially) within the solenoid. The result is a sinusoidally-driven linear change in inductance of the "transducer" coil as the ferrite bead is displaced mechanically.

To obtain data relating to mechanical-displacement versus drive-voltage-amplitude, the shaft displacement was measured using a dial gauge (Figure 4) while the V47 was excited with both DC and low-frequency AC (< 1 Hz) voltages. This step provided both static and dynamic calibration for the V47 and the LVDT, and verified calibration repeatability. The results are presented in Figure 5, which shows that the LVDT output is indeed linear with respect to displacement. The polarity shift (negative ouput voltage for positive displacement), relates only to the electrical excitation of the LVDT and has no significance. The slight offset at 0 is produced by the armature not being at the electrical center of the LVDT under conditions of zero excitation. This is not a problem associated with the LVDT, but rather a mechanical positioning problem associated with the extended shaft assembly. The displacement range was limited to ±0.040 inch which is less than the maximum operating range of the LVDT monitor (stroke range = ±0.050 inch). The slope-characteristic of the LVDT was determined as 46.15 volts/inch (static) and 47.0 volts/inch (dynamic). The response slope is a function of the external electrical load placed on this unit.

The next step was the frequency-shift (deviation) calibration for the system. The V47 was driven to produce known displacements based upon the previous calibration procedure. As is also shown in Figure 5, the frequency-deviation curve is smooth, but not linear with displacement. This is to be expected, since for a resonant circuit:

$$f = [2\pi(LC)^{1/2}]^{-1}$$

$$\partial f/\partial L = -[4\pi C^{1/2}]^{-1}L^{-3/2}$$

$$\partial f/\partial C = -[4\pi L^{1/2}]^{-1}C^{-3/2}$$

Based upon actual measurements, the frequency deviation of the transducer oscillator is linear (to three significant figures) for the displacement range: - 0.005 inch — + 0.010 inch, and this is a function of the electrical placement of the ferrite bead (in this case) within the solenoid. The $\partial f/\partial L$ (or $\partial f/\partial C$) nonlinearity presents no difficulty, since by its operation, the quadrature detector corrects for this situation.

SYSTEM PERFORMANCE

After calibration, to test the system, it was driven using sinusoidal excitations ranging from 0.01 Hz to approximately 1 kHz. The upper frequency limit was imposed by the V47 external drive generator and not by the detection system. The detector-system ouput was taken directly from pin 6 of the 3189. The ouput signals thus obtained from the system and the LVDT were overlaid on the screen of a Tektronix 2235 oscilloscope, and were found to track exactly over the displacement range of ±0.040 inch. The output voltage obtained from pin 6 of the 3189 is to some extent a function of the individual chip tested. With reference to Figure 5, the voltage scale (on the left side of the plot) represents the DC output or AC peak voltage ouput of the LVDT as a function of displacement. The 3189 output voltage was exactly 55% of the LVDT output voltage. The minimum usable output voltage from the 3189 was 20 mV peak-to-peak (10 mV peak; S/N ≈ 10.1), which corresponds to 18.18 mV peak (or DC) relative to the LVDT ouput. Using the dynamic slope-characteristic for the LVDT of 47.0 volts/inch, 18.18 mV translates to a displacement of 0.000388 inch = 0.00986 mm ≅ 10 μm. Thus the practical displacement detection limit for this system is 10 microns. The system linearity is at least as good as the HP LVDT which is rated at ±0.5%.

The S/N (signal-to-noise) figures were measured at 100 Hz excitation frequency using a Keithley true-rms-reading digital voltmeter. For a 1 V peak-to-peak output signal level at pin 6 of the 3189, S/N = 173.0:1 = 44.76 dB ≈ 45 dB.

According to the RCA specifications for the CA3189, the minimum AM rejection limit is 45 dB. The typical total harmoninc distortion (THD) for this chip when a double-tuned quadrature coil is used is 0.1% for $\Delta f = \pm 75$ kHz. Typical system output wave forms are shown in Fig. 6. The experimental setup and circuit board are shown respectively in Figures 7 and 8. It was necessary to use high-density-foam supports beneath the V47 assembly and the circuit board during system evaluation to eliminate normal laboratory vibrations. This detection system is sufficiently sensitive in the prototype design described herein that it detects changes in air currents from the building air-handling system.

The detector circuit is contained on a double-ground-plane printed-circuit board which measures 8.5 cm x 14 cm. Double-ground-plane construction (both top and bottom of board) is preferable in radio-frequency design to ensure stable circuit operation. Extra space was provided on the board for an emitter-follower output stage following the

3189 chip, but its use was not necessary.

TYPICAL APPLICATION — *Pressure Measurement*

Figure 9 illustrates a typical pressure-measurement application for the system described. The pressure transducers are small cylinders with a pressure diaphragm located at one end, and they are vented to ambient pressure at the opposite end so that changes in barometric pressure do not influence measurement. The end to which the diaphragm is attached can be threaded, or equipped with some other coupling mechanism, so that it can be introduced into the pressure system. A light-weight, rigid, non-metallic rod is attached to the center of the back of the diaphragm. The opposite end of this rod is attached either to a ferrite bead which moves coaxially within a coil (as in the calibration system described above), or to a dielectric element that moves between two capacitor plates. In this manner, either a variable inductance pressure transducer or a variable capacitance pressure transducer is created. These transducers are then used as the tuning elements for transducer oscillators of the type described above.

SUMMARY

As documented in the "System Performance" section above, the unit described in this paper provides a stable high-sensitivity (10 μm lower limit), high-linearity (±0.5%), low-distortion (≈ 0.1% for Δf limited to ±75 kHz), low-noise (S/N = 45 dB) detection system for variable-capacitance or variable-inductance transducers in which effective excitation is a mechanical displacement. The basis of operation is the hetrodyne principle using a variable-frequency transducer oscillator and a crystal reference oscillator. A MOSFET mixer, ceramic-filter-based IF amplifier and quadrature detector IC complete the design.

The individual frequencies of the two oscillators are not critical; the only requirement is that they differ by 10.7 MHz in this design. Other quadrature detector chips can be used, such as the MC1357 (10.7 MHz), CA3089 (10.7 MHz) or the MC1358 (4.5 or 5.5 MHz with appropriate ceramic filters). The circuit shown in Fig. 2 has a component cost (including the 2-pole filter, but excluding the 12 VDC power supply) of approximately $35.00 (US). Applications of this design are limited only by the imagination of the researcher. Typical applications are: vibration sensing; pressure transducers in which the motion of a pressure diaphragm translates to a displacement; linear displacement transducers. Actual overall system performance (linearity, sensitivity, etc.) will depend upon the transducer configuration used

When a variable capacitance element is used as the transducer, the coil L is fixed (although it may be slug-tuned for fine tuning of the oscillator). In this case C_{T1} becomes the transducer element; otherwise the system remains unchanged.

REFERENCES

RCA Solid State. 1982. *Linear Integrated Circuits and MOS/FET's.*
Motorola Inc. 1983. *Small-Signal Transistor Data.*