A Frequency Modulation Detector Using Operational Amplifiers

by Eugene T. Patronis, Jr., School of Physics, Georgia Institute of Technology

Integrated circuits are bringing about extraordinary changes in the electronics industry. These changes are manifested in many ways. The radical differences in the manufacturing processes of integrated circuits as compared with circuits assembled from discrete components are self-evident. In addition, however, there are notable differences in circuit capabilities and in design considerations as well. In general, integrated circuits have a higher circuit density, greater speed, and lower power dissipation when compared with conventional circuits. Integrated circuits lend themselves quite readily to those applications where a large number of circuits of a particular type are required, as in computer circuitry. They are finding increasing use in linear circuits where the applications can be tailored to a few standard configurations. Circuit designers will be called upon more and more in the future to design around a few standard integrated circuits or to evolve circuits which can be totally reduced to the integrated form. An example of a circuit design innovation which allows a frequency modulation detector to be produced completely as an integrated circuit will be given here.

Frequency modulation detectors usually take the form of a limiter-discriminator or ratio detector. Both of these circuits depend in part upon a tuned transformer for their operation. The other components in these circuits, such as transistors, resistors, diodes, and capacitors can all be readily produced in the integrated circuit form. The transformer can be integrated only with extreme difficulty (if at all). A circuit not requiring a transformer or other inductors would allow the detector to be produced completely in the integrated form. Clearly, the transformer must be eliminated. In order to see how this may be accomplished, consider the function that must be performed by the detector:

When the detector is presented with a signal whose frequency is f_o, the output of the detector is to be zero. When the detector is presented with a signal whose frequency is f, the output of the detector is to be a voltage whose value is proportional to Δf where $\Delta f = f - f_o$. In most applications Δf is no greater than one percent of f_o. The fact that the detector output is zero when the input is at a frequency f_o is suggestive of a null or balance technique. That is, if two signals, say A and B, can be derived from the input signal in such a way that their amplitudes are equal at the frequency f_o, then the difference of the magnitudes of these two signals will be zero at the frequency f_o. Furthermore, if the amplitude of A is an increasing function of f while the amplitude of B is a decreasing function of f, then the amplitude of the difference signal A-B contains information about Δf.

Let the input signal to the detector be a constant amplitude sine wave denoted by $e_i = E \sin(2\pi f t)$. From this signal must be derived the two signals A and B. The amplitude of signal A must be an increasing function of f. It is a well-known property of sinusoids that their time derivatives are proportional to f. The amplitude of signal B must be a decreasing function of f. This can be obtained through the time integral of a sinusoid which is inversely proportional to f. The signals A and B can thus be derived from the input signal e_i by the operations of differentiation and integration, respectively. These operations can be performed electronically with great accuracy by means of operational amplifiers, which can be constructed in the form of completely integrated circuits.

Figure 1 depicts a detector circuit arranged according to the considerations just discussed. The triangles represent inverting operational amplifiers having large open loop voltage gains for frequencies in the vicinity of f_o. The generator represents a frequency modulated signal source of the form:

$$e_i = E \sin(2\pi f t).$$

The operational differentiator produces an output signal e_A of the form:

$$e_A = -RC\,2\pi f E \cos(2\pi f t)$$

which, when rectified by the diode D_A and filtered by the network R_L and C_L, become E_A, where:

$$E_A = \eta RC\,2\pi f E,$$

η being the rectification efficiency. The operational integrator yields an output signal e_B of the form:

$$e_B = \frac{E}{RC\,2\pi f} \cos(2\pi f t)$$

which, when rectified by the diode D_B and filtered by the network R_L and C_L, becomes E_B, where:

$$E_B = \frac{-\eta E}{RC\,2\pi f},$$

assuming the same rectification efficiency. The output of the overall detector is then e_o, as given by:

$$e_o = \eta E\left[RC\,2\pi f - \frac{1}{RC\,2\pi f}\right].$$

If now the integration and differentiation time constant RC is chosen so that:

$$RC = \frac{1}{2\pi f_o}$$

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then e_o will become:

$$e_o = \eta E \left[\frac{f}{f_o} - \frac{f_o}{f}\right]$$

Remembering that $f = f_o + \Delta f$, we now have:

$$e_o = \eta E \left[\frac{f_o + \Delta f}{f_o} - \frac{f_o}{f_o + \Delta f}\right]$$

$$= \eta E \left[1 + \frac{\Delta f}{f_o} - 1 + \frac{\Delta f}{f_o} - \left(\frac{\Delta f}{f_o}\right)^2 + \dots\right]$$

Now $|\Delta f|$ is much less than f_o, so

$$\left[e_o = \eta E \frac{2\Delta f}{f_o}\right]$$

which is just the desired form.

This detector offers a number of advantages other than the fact that it can be constructed completely in the integrated form. The operational amplifiers provide excellent isolation between the signal source and the detector load. The detector can readily be tuned by varying the time constant RC. In fact, this tuning could be accomplished remotely under voltage control by letting C be furnished by a silicon varactor diode. Finally, this detector can be used for a very wide range of frequencies, f_o.

Two models of the detector have been constructed. One circuit was built from discrete components while the other was built from commercially available operational amplifiers. The first of these has been employed at several frequencies ranging from low audio up to 10.7 megahertz. The latter has been used for frequencies as high as 4.5 megahertz. In the detector application, it is not necessary that the amplifiers have response down to DC; therefore drift problems can be readily corrected by employing suitable high pass filters in either the input or output circuits of the amplifiers. In fact, the circuit built from discrete components was AC coupled internally to avoid this problem. However, both models have been equally successful in the frequency ranges mentioned.

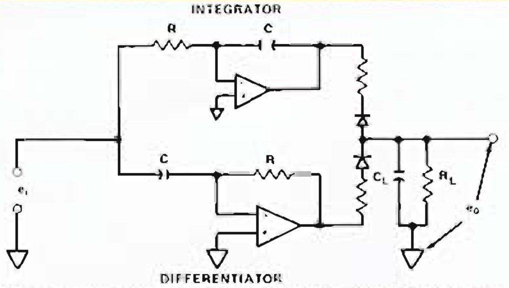

Figure 1. Idealized representation of the FM detector circuit. In practice, to avoid dc drift, the integrator would be ac-coupled through a capacitor much larger than C, and C would be shunted by a feedback resistor much larger than R; the differentiator would have a resistor much smaller than R in series with C, and R would be shunted by a capacitor much smaller than C, for noise reduction and dynamic stability.

Editor's Notes:

Paper Call. We have a gnawing hunger for articles illustrating new and better ways of using analog devices. Our only rule is that the applications be useful, i.e., that they "work", and that a large number of readers could benefit from reading and applying what they read. Other additional virtues, such as brevity, succinctness, and authority, are naturally desirable, but not essential. "Analog Briefs", little morsels with a single cogent idea, are especially welcome. We do not hesitate to award honororia when we print fresh unpublished articles submitted from outside the family.

Comment Call. We have plenty of ideas about what we think should turn you on, but we need your comments to keep us on the right track. Write, and tell us what you like or don't like about this publication, what you'd like us to emphasize or to abandon. Pat us on the back, or beat us on the head, but do let us hear from you. Your feedback helps maintain the *Dialogue*, in the most literal sense.

DAN SHEINGOLD

Readers' Notes:

I have read your excellent article on "Noise and Operational Amplifier Circuits" appearing in the March 1969 issue of *Analog Dialogue*.

I write in regard to the chart (Figure 14, page 14) showing voltage and current noise of your Model 230 Chopper-Stabilized Amplifier. In this data, voltage noise is shown extrapolated as a constant value ($2\mu V/\sqrt{Hz}$) down to 0.01Hz.

If this holds true, it implies that Chopper-Stabilized Amplifiers have the ability to eliminate pink (1/f) noise.

Would you please comment on this point.

C. L. Pomernacki
University of California
Livermore, California

The extrapolation is valid for the field of the chart, but not necessarily at lower frequencies.

The gain of the chopper amplifier reduces, but does not eliminate, 1/f noise. The chopper amplifier can be thought of as an integrator, i.e., its response increases with decreasing frequency, until the dc-open-loop gain of the chopper amplifier is reached; then it levels off. Below the frequency at which the gain becomes constant, if 1/f noise is still present in the amplifier, the overall noise will again start increasing, probably following the trend indicated between 1kHz and 10Hz, reduced by the open-loop chopper gain.

At such low frequencies, it is hard to get adequate measured data, because of the need for a large number of integrations over long periods. Furthermore, 1/f noise can be masked by long term drift, thermal offsets, etc.