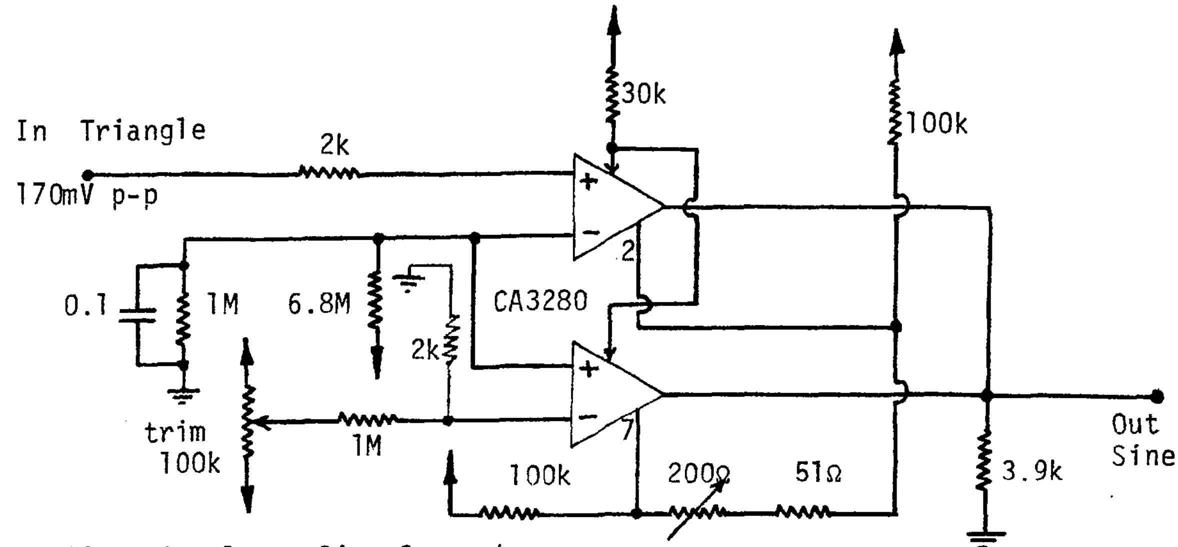

Fig. 12 Triangle-to-Sine Converter

IMPROVING SIGNAL-TO-NOISE RATIO:

As stated above, we found that the actual differential signal at the inputs of the OTA's was not as large as we would like to actually improve the signal-to-noise ratio. To understand how to improve the situation, it is necessary to understand the actual input conditions. For the diode linearization to work, the diodes must be biased on and be somewhere in their exponential region. Thus the standing currents through the diode must be greater than the signal currents. If we decrease the diode currents, we must also decrease the signal currents (and thus we are working over a different range of the exponential response). For the best linearization, we would need to choose the optimum region of the exponential response. Here however we may well prefer a slightly less optimum region if we can get some other imporvement.

In particular, if we decrease the diode currents, and at the same time decrease I_{ABC}, equation (5), assumed ideal, tells us that the gain remains the same. Thus, if we get the same output for a smaller I_{ABC}, we can conclude that the differential input voltage must have gone up. This is exactly what happens. For example, if the diode current of Fig. 6a or Fig. 7a is reduced to 0.3 ma, we still have a slight excess over the input current (±0.256 ma), and the differential input voltage goes up to nearly ±50 mV, a respectable level. Such a procedure is suggested, as it should give a 5:1 improvement over CA3080 signal-to-noise. The circuits suggested for the CA3280 in the RCA application notes seem to give acceptable levels of differential input for ±10 volt signals, but could be improved for ±5 volt signals. The circuits in the LM 13600 application notes should be improved for all levels by reducing the diode biasing current.

In a future issues, we hope to present more exact design information on these two devices.

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A (Gulp!) Simple Balanced Four-Quadrant Multiplier With An OTA:

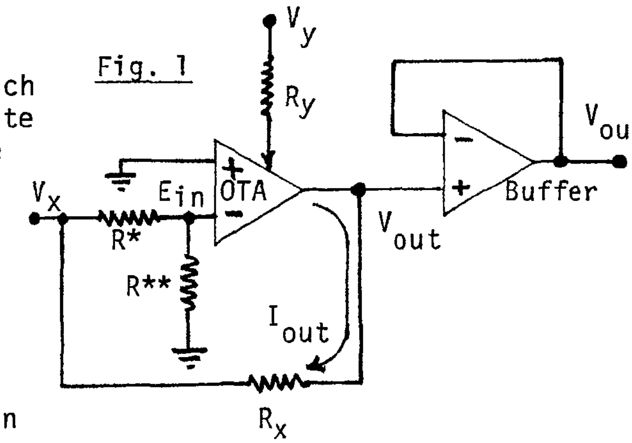
-by Bernie Hutchins

The "Gulp" above is for not discovering this before. The OTA is of course a well-known two-quadrant multiplier, and we have seen many such applications (typically, use of the CA3080 as a VCA). We have also used two CA3080's as a balanced modulator (four-quadrant multiplier) as can be seen in the ENS-76 series (EN#63, pg. 6). A standard technique for converting a one-quadrant multiplier to a four-quadrant multiplier has been around for years (see our supplement S-001, pg. 12-13), but is a little messy in that it requires several extra summers. The present technique is along the same lines, but takes advantage of the two-quadrant ability of the OTA, and follows with a very simple implementation of the remaining mathematical operations. Where did the idea come from? It can be found in the application notes on the new transconductor types LM13600 or XR13600 from National or Exar.

BASIC CALCULATIONS:

In Fig. 1, we show a transconductor which we can, but need not assume is a CA3080. Note that the load resistor R_x is fed back to the input voltage V_x. Two attenuating resistors R* and R** are placed on the actual IC (-) input to assume that the voltage there is small enough to justify the linear equation of operation:

Fig. 1



$$I_{out} = -19.2 \cdot I_{ABC} \cdot E_{in} \qquad (1)$$

We will assume that the current I_{ABC} is given by $(V_y+14.3)/R_y$, where the 14.3 comes from the fact that the control pin sits one diode drop above the negative supply rail, and this at -14.3, so the total voltage across R_y is $V_y+14.3$. This done, we get:

$$I_{out} = -19.2 \frac{V_y+14.3}{R_y} V_x \frac{R^{**}}{R^{*}+R^{**}} \qquad (2)$$

Now, since there is a buffer on the output, the only place the current I_{out} has to go is through R_x. Thus we can calculate V_{out}, which is the voltage at the output of the OTA, which is the same voltage buffered by the op-amp:

$$V_{out} = V_x + I_{out}R_x \qquad (3)$$

and substituting I_{out} from equation (2), we get:

$$V_{out} = V_x - \frac{19.2R^{**}R_xV_yV_x}{R_y(R^{*}+R^{**})} - \frac{19.2R^{**}R_x(14.3)V_x}{R_y(R^{*}+R^{**})} \qquad (4)$$

Note that the center term of the right side of equation (4) multiplies V_x and V_y while the first and third terms involve only V_x. We can get these V_x terms to cancel if we set:

$$\frac{19.2R^{**}R_x \cdot 14.3}{R_y(R^{*}+R^{**})} = 1 \qquad (5)$$

From which we obtain the required relationship between R_x and R_y as:

$$R_x/R_y = (R^{*}+R^{**})/(19.2 \cdot 14.3\, R^{**}) \qquad (6)$$

In many cases we can use the approximation R*>>R** in which case equation (6) becomes:

$$R_x/R_y = 0.0036\, R^{*} / R^{**} \qquad (7)$$

If we now substitute equation (5) into equation (4), we get:

$$V_{out} = -V_yV_x/14.3 \qquad (8)$$

Equation (8) tells us that the restriction on R_x and R_y that is needed to balance the multiplier will also dictate the gain of the multiplier as 1/14.3. Also notice that equation (8) has an overall minus sign. Both of these can be corrected and adjusted with additional op-amps if necessary. Note in particular that we can just make the buffer in Fig. 1 a non-inverting amplifier. A usual practice for a four quadrant multiplier (and for balanced modulators in electronic music) is that the amplitude of the output should be the same as that of the inputs. Thus if V_x and V_y are ±5 volt signals, their product would be a maximum of ±25, which is too high, so you would want to divide this by 5 to get back to ±5. Equation (8) shows a division of the product by 14.3, so it is already too low. Thus, we would make the buffer an amplifier with gain 14.3/5 = 2.86.

A BALANCED "RING" MODULATOR

Fig. 2 shows a practical electronic music balanced modulator or "ring" modulator based on the CA3080 using the theory above. The simplicity is obvious, and the parts cost would seem to be under $2.

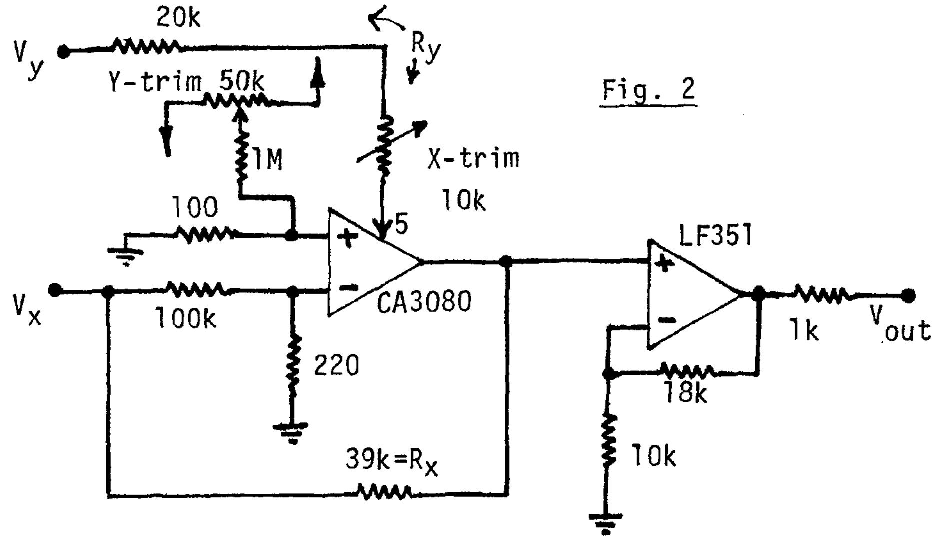


Fig. 2

As shown, the modulator gives the product $V_xV_y/25$, so is intended for ±5 volt levels. The entire circuit is based on the ideas above, and here we have just added some necessary trimmers. The main trimmer to worry about is the X-trim, which is used to adjust the value of R_y to the value required by equation (6). To trim this, ground V_y, apply a signal to V_x, and adjust the X-trim for minimum signal. In a similar manner, ground V_x, apply a signal to V_y, and adjust Y-trim for a minimum signal at the output. To check the final results, apply signals to both inputs and look for a balanced modulation pattern (equal lobes).

The results with this modulator are not quite as good as those made with the best four-quadrant multipliers, but you probably can't beat the performance of this one at the price. One thing to note however is that both V_y and V_x must be low impedance sources, and V_y cannot be AC coupled in. In practical terms, this may mean that you will get the best results if you balance the modulator in the actual system you are going to use it in. Thus you may be able to trim out the effects of 1k source resistance and DC levels in the outputs of VCO's, etc. Also, you can keep in mind that many times all you need is a ring-modulator sound, and a small amount of carrier feedthrough or other imperfection will not make all that much difference.

WHAT ABOUT DIVISION:

If you look back at equation (8), you might suppose that the circuit could be used as a multiplier/divider, since the 14.3 in this equation comes from the negative supply voltage to the CA3080, and since we can control this over some range with an op-amp, we might suppose that we could divide. Unfortunately this is not the case as you can see by looking back to the original equation (4). If we change only the 14.3, then the first and last terms in the right hand side will not cancel unless the ratio R_x to R_y is adjusted at the same time.

Note however that standard multiplier-to-division conversion methods could be used (see for example, the Motorola data sheets on the MC1495 multiplier or the Analog Devices data sheet on the AD533 multiplier). Another point that should be made is that even though a variation of the negative supply voltage of the CA3080 in this application does not give division, it could still result in a musically useful sound, and this could perhaps be investigated.

As we saw in the previous article on new OTA devices, it is convenient to use the diode bias current to achieve an analog division when this is necessary, so an actual division with the present circuit is probably not all that important. The reader should not suppose however that he can add external diodes to a CA3080 and achieve this function. Isolated diodes will likely be poor matches to the CA3080 transistors, will not track temperature well, and in fact, single silicon diodes will often show an exponential relationship with $E_{in}/\eta k_BT$ where η is more like 2 than 1.