"wright-on"

THE UBIQUITOUS OP-AMP

by MIKE WRIGHT

Among the mysterious little black boxes called integrated circuits (if they aren't mysterious, you can ignore this page) is a thing that, depending upon its package looks like a transistor that got involved in an affair with an octupus, or a modular spider. Some of these are op-amps, and some of these, in turn are sometimes useful in audio. At this point I expect the discrete purists will throw up their hands (I trust that will be all) and revert to Chivas Regal and other interesting pursuits.

Let us lay to rest some prejudices right now. Op-amps, depending on the type, can be either lousy with or quite free from TIM, latch-up, crossover notches, heavy expenses, and reliability. In other words, you have to pick them for the application. Some, we have found, can be made to do rather amazing things with a discrete transistor thrown in for good measure, things which no op-amp should, by all rights, do. (These things I am not going to talk about as we're using them in our pre-amps; this way you'll have to buy a pre-amp at least to find out).

Why the name? Well, back in the good-old-days of the first electric analogue computer, mathematical operations such as integration, differentiation, etc., etc., were done using a standard amplifier having a differential input, which could be operated (in theory) with 100% feedback for unity gain, and at all sorts of feedback-loop-component-determined gains, or gains that varied with feedback, etc., etc., to perform electrical analogues of the functions desired; these amplifiers became known as "Operational-Amplifiers" shortened to 'Op-Amps'. They were transformer case surmounted with a cluster of vacuum-tubes, with a bunch of binding posts on the front. These were racked up, several to a row, on a relay rack, and by the time you wired up a complicated problem (assuming you ever found enough banana plugged leads) it looked like fifteen Moog Synthesizers engaged in something too far advanced to appear in a public publication. That is, you usually wondered, when it didn't work, who was doing what and to whom; debugging was simple: you tore out all the patch cords and started again.

Well, as the ads say, we've come a long way, and what used to occupy several tens of cubic inches, as well as exerting itself in the improvement of the salty part of the engineer's vocabulary now takes up a very small space and can easily be handled by, I have it on reliable authority, less than two dozen cusswords. Progress in all things!

For instrumentation applications, op-amps have to do things that are not always needed in audio. It's great if they don't draw any power, or almost no power (Nano-watts that is!), don't have any voltage drift whatsoever (remember that they're often used as DC amplifiers), have gains that can be stabilized to .1% and work well up to 1kHz. Now these are not, you'll have to admit, very important specs for audio use. When you consider that the low stand-by power consumption is achieved by using a Class B output stage (that's B not AB) which does have a notch; that DC and Gain stability are achieved using bias networks that you wouldn't believe, and that even 45's go over 1kHz. O.K. so you've read the application notes and want to point out that some of the

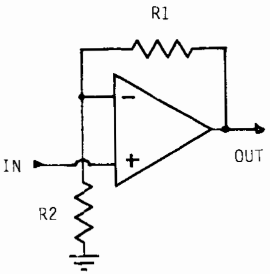


FIG. 1
Non-Inverting Amplifier

$$\text{Gain} = \frac{R1 + R2}{R2}$$

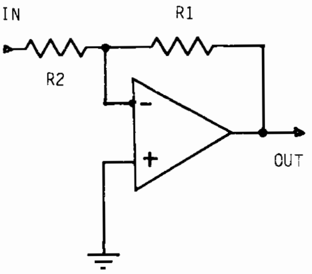


FIG. 2
Inverting Amplifier

$$\text{Gain} = \frac{R1}{R2}$$

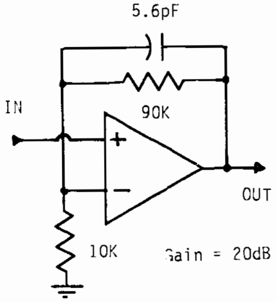


Fig. 3
Capacitive Load Stabilization

Remember, source has resistance
so:

$$\text{Gain} = \frac{R1}{R2 + R_{source}}$$

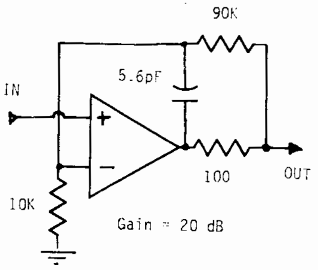
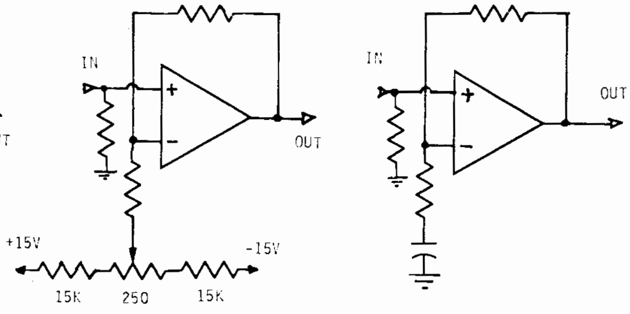


Fig. 4
Capacitive Load - Stabilization



Offset Adjustment

100 Feedback at D.C.

Fig. 5

Methods of Reducing D.C. Offset
Voltage at Op-Amp Output

little things have open loop bandwidths in excess of 10mHz! At what distortion? It isn't often that you find distortion specs for op-amps printed in with all the other things — unless it is for a 'consumer item'. It is interesting that the '749 for example has a sort of dubious standard, they don't seem to have decided if it is a legitimate op-amp or a consumer item I.C.

There are some op-amps in very general use, such as the '741, which are not all that good for audio. And here we come back to all that stuff about open loop gain, open loop bandwidth, feedback, and transient intermodulation distortion. You were planning to build an intercom? O.K. use a '741, it's ideal in that sort of usage.

To recap quickly: Op-amps generally have gains of about 105 to 110dB — from DC to 100Hz if they're internally compensated, or as high as 500kHz if they require external compensation. But the rub is that the time delay within the unit (remember Charley, there may be 40 transistors in that little thing) is such that if you want to run them at a 40dB gain block level, you may have to roll off the internal gain above 100Hz in order to get stability — otherwise you've got a great little oscillator. Therefore even if the open loop distortion should be, say, 1%, don't think that the effective feedback (let's set the open loop gain spec at 100dB, it makes things easier) of 100dB —40dB = *60dB* will get you a thousandfold reduction in distortion EXCEPT below 100Hz. At 1kHz you will have reduced the gain of the unit (by adding compensation) to 80dB. Thus the effective feedback will be only 80dB (not 100dB) —40dB = *40dB,* which would reduce the distortion a hundredfold. Now at 10kHz the distortion reduction would be only tenfold.

Aaaaaaa soooooo . . . you say, so we'll run 80dB feedback and thus get distortions of 1% divided by 100 at 10kHz, which is .01 which is still O.K. Well . . . yes, but there are other problems. The first of these is the Common Mode Rejection figure of the op-amp. What this means is, if the same signal is fed into both the non-inverting input (marked +) and the Inverting input (marked —) on the op-amp, just how good is the cancellation? If it is 40dB up to 10kHz, then you will get your hundredfold reduction in distortion; but usually the spec on CMRR will run say 70dB at 500Hz, 50dB at 5kHz, and perhaps 40dB at 10kHz. Result, you get .1% distortion at 10kHz, as it is then the Common Mode Rejection Ratio what determines the effectiveness of the feedback.

I have this gut level feeling that I lost some of you back there; perhaps I had better go back to real basics.

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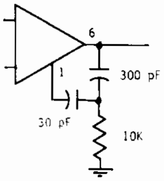

Fig. 6

Two Pole Compensation

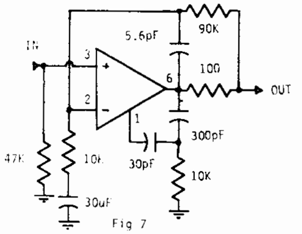

Fig 7

Non-Inverting 2-Pole
Compensated Amplifier, Gain=20dB

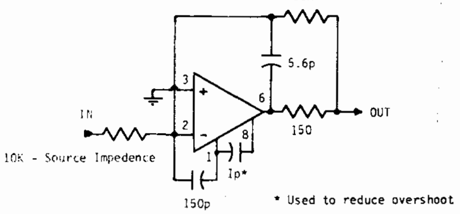

Fig. 8

Feedforward Inverting Amplifier
with fast risetime Gain = 20dB

82k, 150k, & 47k Resistors are metal film low noise types

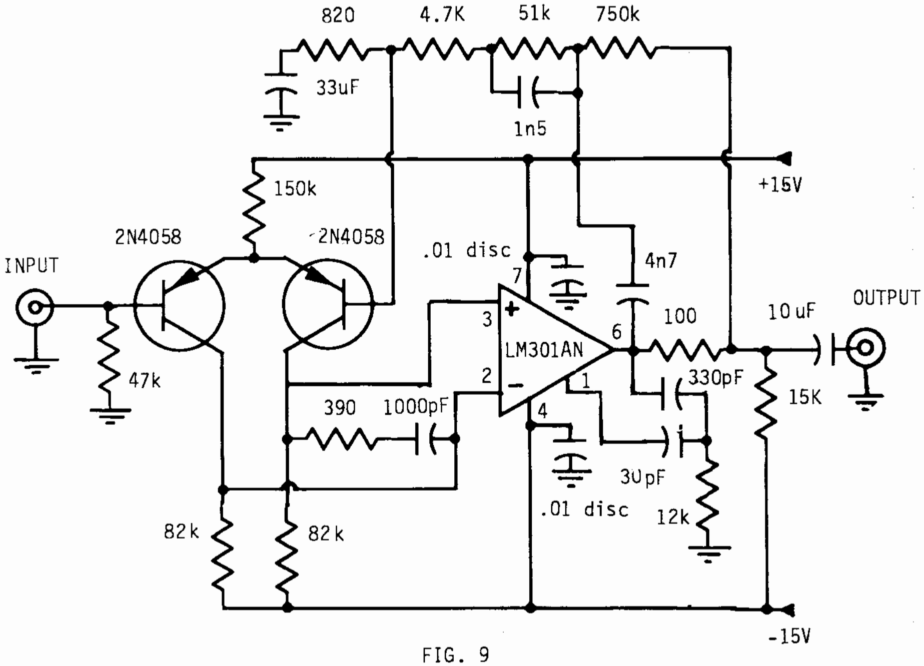

FIG. 9

LOW NOISE PHONO PREAMPLIFIER

82K, 150K, & 100K Resistors are metal film low noise types

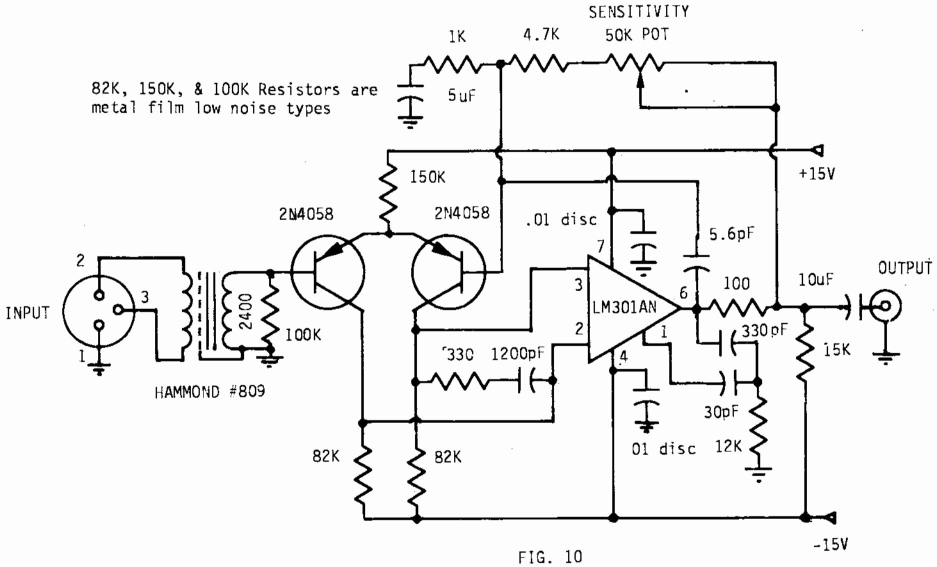

FIG. 10

LOW NOISE MICROPHONE PREAMP.