EVALUATING AUDIO OP AMPS PART TWO

Ben Duncan surveys developments from 1977 to date, as a prelude to performance tests performed on many of the models discussed

Part One of this series charted the initial development of op-amps and their fledgling application in pro-audio equipment. In 1977, Philips began making an op-amp called *TDA1034*. Probably intended for telephony/telecom equipment (Philips have a comic way of seeming to stumble on winning designs by accident), it wasn't long before *1034*s were being shipped out of Eindhoven to London, to upmarket console manufacturers. Packed in extruded aluminium tubes, the initial price was high (£5.00/$8.00) but then the *1034* combined a host of features that were desirable for audio and not available in any other op-amps. For the first time, you could build a compact, very simple and respectably quiet mic amp without resorting to discrete transistors. Harmonic distortion (THD) was commendably low, well below 0.01% and the *1034* ('ten thirty four' to its friends) could drive a 600 Ω load without driving a distortion meter off-scale. Moreover, you could use a ±22 V supply to achieve a high headroom of above +24 dBu.

In 1978, production was switched to an ailing stateside IC manufacturer that Philips had recently bought out, called Signetics. The Mullard/Philips *TDA1034* was then relabelled as the Signetics *NE5534*. The *5534*'s price fell swiftly between 1980 and '82, after Raytheon and later Texas and other makers began to second source their own 'klones'. By now, the *5534* was poised to become the *de facto* standard for pro- (and much later, domestic) audio, a position it still holds 13 years later. It's the only IC op-amp designed in Europe that's met with any continued success. The introduction by 1980 of a dual version (*NE5532*) in an 8-pin package did a lot for the *5534*'s future popularity and utility. Today, *5534* and *5532* klones are widely second-sourced and cost below 50p (80¢) in manufacturing quantities.

The *TL071* and *LF351* mentioned in part one had come into widespread use with audio manufacturers by the early '80s. The introduction of 8-pin dual (*TL072* or *LF353*) and 14-pin quad (*TL074* or *LF347*) versions helped immensely. Particularly if you were designing graphic equalisers or active crossovers. They were also a must for 'analogue computing', alias the sidechains of compressors and other processors as well as supervisory circuits, where the *NE5534* was unsuited as well as being too pricey. The first dual op-amps had 14 pins and not much standardisation. Having no room for null (DC trim) or comp (compensation) pins to confuse matters all subsequent 8-pin dual and 14-pin quad ICs have followed the leadout pattern established in the mid '70s by Texas' *TL* (and Nat Semiconductor's equivalent *LF*) series of op-amps.

Compared to discrete transistors where every conceivable leadout permutation occurs to frustrate manufacturers, an apparently accidental (or am I being too cynical?) act of standardisation has made it reasonably easy for different dual and quad op-amps to be tried out and/or substituted to facilitate production or upgrade the performance. Or retain existing performance while maintaining or reducing cost—all without changing the PCB pattern. The same is broadly true of all 8-pin single op-amps, except that the (normally unused) null pins on some devices are used for frequency compensation for others. In turn, it's not unheard of for adventurous, technically adept console owners to perform IC upgrades, particularly in the USA.

In the early '80s, National Semiconductor brought out an 'improvement' of the *LF351*. *LF411* had lower DC offset, achieved by alterations to the input and output bias circuitry. For the most part, the circuit is identical but some processes (the subtle bit of the 'circuit' they don't tell you about) would have been improved or tightened. The maker then apparently rationalised the *351*'s production by deriving them from batches of *441*s, which had less than 'A' grade DC offset specifications. The explicit data sheet specifications were maintained but the improved DC somehow altered the sonic performance. Along with Texas' competitive pricing, it may explain why Texas' Bi-FET op-amps have come to dominate budget (and not so budget) audio equipment where *5534*s and *5532*s are 'too good' or unsuited. The early '80s also saw the arrival of digital audio, opening up new but stringent applications for op-amps, as ADC and DAC interfaces. But devices that would routinely meet the special requirements were still being developed. An early example giving the rapid settling with impulse signals and high slew rate capability (>50 V/μs) needed for accurate A/D and D/A conversion was National Semiconductor's *LF400C*, introduced in 1982.

Advances in noise reduction

In 1981, Precision Monolithics (based in 'Silicon Valley') had introduced something comparable to the *NE5534*, in the shape of *OP37*. PMI had previously excelled in making op-amps featuring high DC precision and low noise for military, scientific and industrial instruments. They also published detailed data sheets that charted more facts than the competition. The *OP37* was the work of George Erdi, who had been designing ICs as long as Bob Widlar. It was 1 to 3 dB quieter than the *NE5534* (especially below 100 Hz) and unlike its rival, it could be used in high impedance and/or direct-coupled circuits. The *NE5534* can't because it 'pulls' a high bias current as a consequence of its low noise input transistors. The high current produces a correspondingly high voltage offset when the circuit resistance (through which the current is forced to flow) is high. Bias current compensation was pioneered by Bob Widlar to reduce offset in high impedance circuits in the late '60s. To allow DC precision to co-exist with large-geometry, low-noise input devices, Erdi devised a refined bias-current cancellation scheme that didn't defeat the object of the *OP37* by contributing excess noise. *OP37* also gave the wide bandwidth needed for quality audio and was later available in dual (*OP271*) and quad (*OP471*) versions. Sadly, it lacked the *NE5534*'s capability to drive 600 Ω at high levels (⩾+20 dBu), so it couldn't serve by itself as a pro-standard output stage.

In 1982, a new company was formed in California's Silicon Valley, to manufacture precision ICs. Linear Technology was founded with a new grouping of successful monolithic designers recruited from the giants of US IC manufacture. Linear's first step was to produce not klones but upgrades of other makers' op-amps and voltage regulators. George Erdi had joined and by 1983, LT had launched the *LT1037*, an upgrade of the *OP37*. The *LT1037* was slightly quieter, had tighter DC specifications and some irregularities with linearity at high frequencies had been fixed. In 1984, Derek Bowers (an expatriate keyboard player who graduated from the University of Sheffield with a BSc in Semiconductor Physics) devised an elegant compound IC, which combined two op-amps, large geometry transistors and a current source. Using a combination of current and voltage feedback, it squared a variety of engineering circles, combining a fuss-free, true balanced input[1] with exceptional bandwidth, even at the high gain settings needed for mic amps. The original circuit topology could employ low noise, bipolar input transistors without the usual setbacks. It made its debut as PMI's *AMP01*, a high gain differential or 'instrumentation' amplifier IC, which was as quiet as an *NE5534*. Later, the same topology was adopted by SSM, who were then a small Californian manufacturer of specialist analogue ICs for electronic music. With large geometry, low noise (1.3 nV $\sqrt{Hz}$) devices at the front end, the *SSM2015* was 10 dB quieter than the *NE5534* (4 to 5 nV $\sqrt{Hz}$) and offered a realistic transformerless balanced mic input for less money than esoteric devices like the late Deane Jensen's *JE990*, a high specification op-amp made from discrete components.

By 1986, it was Linear Technology's turn to break the noise barrier. George Erdi's *LT1028* was the first monolithic op-amp to compete with exotic discrete transistors (like *LM394* and *MAT01,2*) for ultimate microphone amplifiers. The *1028* yielded a noise floor, which at 0.85 nV $\sqrt{Hz}$, the same as a pure, 50 Ω resistor and less than the thermal noise produced by most dynamic mics' own coil resistance. The *1028* also had a very low LF noise corner: compared to other op-amps and most discrete transistors, its midband noise spec remains true down to subsonic frequencies, below 3 Hz. The *1028*'s main problem