AN-154

TA-103 HYBRID

TRANSISTOR ARRAY APPLICATION NOTES

Note to O.E.M. Users ... From Valley People, Inc.

As can be seen by a review of the material herewith the Valley People TA-103 array is capable of a variety of configurations requiring closely matched PNP transistors possessing extremely close thermal coupling.

The most popular use of the TA-103 is in low noise, low distortion microphone preamplifiers and high impedance differential input stages for line level and musical instrument use.

We, at Valley People, urge the O.E.M. user to discuss in detail his particular use and parameters he wishes to achieve with the product so that our engineering staff may offer specific recommendations for obtaining his goal.

Please do not hesitate to confer with our staff for assistance in developing circuits which use the TA-103 array.

For your convenience we can provide a TA-103 array mounted on a printed circuit board with pins configured so that the package may be mounted into a conventional .100 x .600 (24-position) D.I.P. I.C. socket for prototyping purposes. Additionally, opaque transfer patterns for drafting the TA-103 package onto circuit board layouts are available free-of-charge.

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APPLICATION NOTE AN154:

LOW NOISE AC AMPLIFIERS FOR LOW IMPEDANCE TRANSDUCERS

IMPORTANT INFORMATION ABOUT THE TA-103 TRANSISTOR ARRAY:

The Valley People TA-103 transistor array contains eight medium geometry annular PNP silicon transistors.

Proprietary matching techniques provide close tracking of base-to-emitter voltages (Vbe) of all eight devices. Typical Vbe matching is ± 200 µV in the current range of 10 µA to 1 mA, with tracking tested for worst-case values of ±1 mV.

By using specially developed fabrication techniques, all eight devices are very closely thermally bonded. Further thermal bonding exists between selected pairs of transistors, where a near metal-to-metal bond exists, providing junction temperature matching to 0.1°C.

Both the Vbe matching and close thermal coupling are desirable in configuring differential input stages.

The TA-103 transistor array pin-out is completely symmetrical, so that the array may be connected in its circuit in any orientation.

When using the TA-103 array, the designer should be aware that although the tight thermal coupling of the transistors compensates for changes in Vbe induced by ambient temperature changes, thermal gradients across the array should be avoided by locating components likely to generate heat (power resistors, power transistors, etc.) a sufficient distance away from the array so that differences in temperature across the array will not exist.

Although the TA-103 array is designed primarily for use in configuring, low noise differential AC amplifiers, its relatively high operating voltage and current capability make it suitable in other applications where ordinary monolithic arrays can not be used.

LOW NOISE AMPLIFIERS FOR LOW IMPEDANCE TRANSDUCERS:

When using low impedance transducers such as dynamic microphones, variable reluctance pick-ups and other electromagnetic sensors designed to deliver AC signals representing electrical analogs of dynamic processes, the noise contributed by the input gain block usually is much greater than the residual noise generated by the transducer. This is especially true of transducers having largely resistive intrinsic impedances of 50 to 600 ohm. Some particularly noise sensitive applications include hydrophones, instrumentation recorders, low level wideband amplifiers, studio sound equipment and sound level survey equipment.

TRANSDUCER NOISE MODEL:

In typifying transducer noise, one must view the transducer and connecting leads as a lumped noise source. Transducer noise can be divided into two major contributing sources, the thermal noise of the transducer, and induced noise.

Thermal noise is caused by thermal agitation of free electrons in a conductor. The result of this agitation is a randomly varying, minute voltage developed across the terminals of the conductor. This phenomenon was demonstrated by Johnson, and thus is sometimes referred to as Johnson Noise.

Nyquist showed, using a statistical thermodynamic model, that the mean-square thermal noise voltage generated in any impedance can be expressed as:

(Formula 1) $\overline{Vn^2} = 4kT\int_{f1}^{f2} R(f)df$

where $\overline{Vn^2}$ = mean-square of thermal noise voltage within the frequency band f_1 to f_2 in V

k = Boltzmann's constant (1.38×10^{-23} joule/Kelvin)

T = absolute temperature of R in Kelvins ($^\circ$ K)

R(f) = resistive component of impedance at frequency f in Ohms

f = frequency in Hertz

When the resistive component of the impedance is independent of frequency, the equation reduces to:

(Formula 2) $\overline{Vn^2} = 4kTf_{Bn}R$

Where f_{Bn} is the noise bandwidth $f_2 - f_1$ in Hertz. The term f_{Bn} is considered to be equal to the $-\infty$ dB points of the system under analysis, and in audio application is taken to be the band of frequencies from 20 Hz to 20 kHz.

Simplified further, thermal noise voltage may be calculated as:

(Formula 3) $(\sqrt{4kTR})V/\sqrt{Hz}$

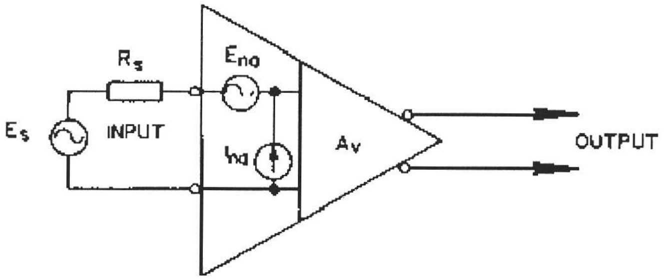
thus, a transducer having an intrinsic resistive impedance component equal to 150 ohm will produce a voltage of 1.58×10^{-9} Vrms/root hertz. (1.58 n $V/\sqrt{Hz}$). In audio application, this would equate to an absolute minimum noise level of -130.8 dB at 300°K referred to 0 dB at 0.775 Vrms in the 20 Hz to 20 kHz audio bandwidth.

In addition to the thermal noise generated by the transducer, the leads connecting the transducer to the system under consideration contribute induced noise caused by man-made sources, such as hum, RF, etc.

By correctly configuring a differential balanced amplifier, the user can both greatly attenuate the induced noise from the leads and maintain reasonable noise performance, or noise figures, in the input gain block of a system.

AMPLIFIER NOISE MODEL:

Let us examine a classic noise model for an amplifier fed by a source voltage generator, E_s , having a resistive impedance component, R_s , as Figure 1 shows.



NOISY AMPLIFIER

where E_S is the input signal voltage

R_S is the source impedance resistive component

E_{n_a} is a noise voltage generator having 0 ohm impedance

I_{n_a} is a noise current generator having infinite impedance

A_V is the voltage gain of an ideal noiseless amplifier

The noise generator E_{n_a}, by inspection, is seen to be the equivalent short-circuit input noise voltage. In practice, this noise voltage appears in series with the thermal noise source represented by R_S . The noise current generator, I_{na}, causes noise currents to flow through R_S, thus inducing an additional noise voltage to appear across R_S. Both E_{n_a} and $(I_{n_a} \times R_S)$ must be added in quadrature to the thermal noise generated by R_S. The thermal noise, E_{n_a}, and $(I_n \times R_S)$ may be ex- in (nano) Volts per root hertz, nV/ $\sqrt{Hz}$, at a given frequency or En (μ) volts over a given band of frequencies. The total noise voltage is calculated by the formula:

(Formula 4) $$E_{nt} = \sqrt{(E_{n_a})^2 + (E_n)^2 + (I_{na} \cdot R_s)^2}$$

where
E_{nt} = total noise voltage
E_{n_a} = short circuit input noise voltage
E_n = thermal noise of R (Formula 3)
I_{n_a} = amplifier noise current

Inspection of the formula indicates that for low values of R_S , noise voltage predominates, while at high values of R_S , noise current becomes predominate due to $(I_{n_a} \times R_S)$, thus, for low impedance transducers, bipolar transistors for input amplifiers have a distinct advantage, while FET's, having essentially no I_{n_a}, hold a distinct advantage when using high impedance transducers.

In configuring a low noise amplifier stage with bipolar transistors, one must be concerned with the emitter-base voltage noise. The theoretical value of this noise voltage is a function of absolute temperature and collector current alone.

(Formula 5) $$E_n = \sqrt{\frac{2}{qI_c}} \cdot kT$$

where
En = emitter-base voltage in V Hz
k = Boltzmann's constant (1.38×10^{-23} J/K)
T = junction temperature in Kelvins
q = charge on an electron (-1.60×10^{-19}C)
I_c = collector current in A

The formula indicates that the noise may be reduced to low levels by simply increasing the collector current. This is, in fact, what happens until the collector current reaches a level where parasitic transistor noise limits any further reduction. This noise is generally created by, and represented as, an equivalent resistor (rb') in series with the base. Low parasitic base resistance is then important in low noise applications.

Another factor affecting noise in bipolar transistor amplifiers is base current noise. Base current noise can be defined as:

(Formula 6) $$I_n = \sqrt{\frac{2qI_c}{h_{FE}}}$$

where I_n = base current noise in A/ $\sqrt{}$ Hz
q = the charge on an electron
I_c = collector current in A
h_{FE} = current gain of device at I_c

To find the collector current which yields the minimum input noise for a given source impedance, the total noise formula may be differentiated with respect to I_c to equal 0.

(Formula 7) $$\frac{d(Ent^2)}{d(Ic)} = \frac{-2k^2T^2}{qI_c^2} + \frac{2qR_s^2}{h_{FE}} = 0$$

Therefore, $$I_c\,(opt) \triangleq \left(\frac{kT}{q}\right)\left(\frac{\sqrt{h_{FE}}}{R_s}\right)$$ (Formula 8)

CALCULATING NOISE FIGURE, N.F.

The noise figure, N.F., of any amplifier may be calculated using Ent from Formula 4 and En from Formula 3.

(Formula 9) $$N.F. = 20 \log_{10} \frac{Ent}{En} \quad (in\ dB)$$

When rb' is known, or can be approximated, the noise figure of the amplifier may be predicted to within 1 dB.

100 uv = .1 mv = .0001 v

USING THE VALLEY PEOPLE TA-103

The Valley People TA-103 transistor array contains 8 medium geometry annular PNP silicon transistors. Proprietary matching and fabrication techniques provide Vbe values and junction temperatures which track within 100 µV and 0.1° C respectively throughtout the range of conditions encountered in even the most stringent and demanding applications.

The TA-103 is primarily intended for use in low noise, balanced differential AC amplifiers. The preferred configuration is illustrated in Figure 2.

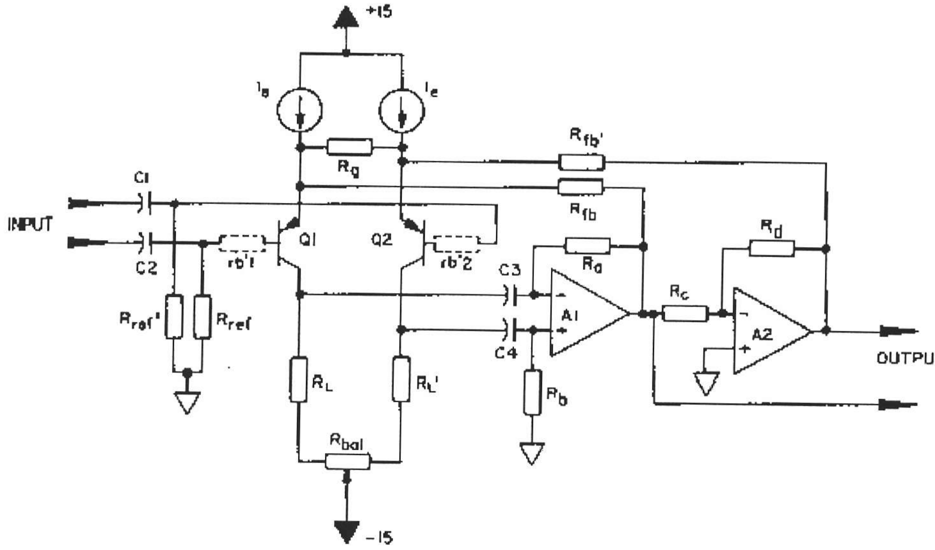


FIGURE 2

Figure 2 shows a commonly used low noise balanced differential amplifier stage. Transistors Q1 and Q2 may be single units. or two or more transistors in the array connected in parallel. Use with transducers having impedances less than 600 ohm usually requires that the input devices be paralled, thus reducing the value of the parasitic resistors rb'1 and rb'2. The emitter current sources are indicated as providing I_c, which in practice will be roughly equal to 0.99+X I_e . Amplifier A1 amplifies the differential voltage across load resistors R_L and R_L' as well as providing AC feedback through R_{fb} to Q1. Amplifier A2 is a unity gain inverter, and provides feedback through R_{fb}' to Q2. Resistors R_a and R_b provide DC stability for A1, while R_c and R_d set the gain of A2. Resistors R_{ref} and R_{ref}' fix the voltage of the bases of QI and Q2 at near 0 volts, in practice, about +1 V referenced to ground. Input capacitors C1 and C2 should be relatively large, low-leakage electrolytics, while C3 and C4 may be 0.5 uF tantalums. The gain set resistor, R_g , should be kept as low as possible and is calculated using the formula:

(Formula 10) $Av = \frac{R_{fb}}{R_g}$; $R_{fb} = R_{fb'}$

where Av = differential voltage gain

Amplifiers A1 and A2 may be BIFET types, such as TL071, TL072

The resistor, R_{bal} sets the common-mode rejection ratio. In applications requiring common-mode rejection better than 60 dB, additional resistors and trimmers may be added at the inputs between the input capacitors, CI and C2, and their respective bases. A typical configuration would use a 10 ohm resistor in one input, and a 50 ohm trimpot in the other input. The 50 ohm trimpot would then be used to set common-mode rejection at high gains.

An advantage of this particular configuration is that both the normal in-phase signal and the reversed phase (-180°) signal are accessible and either may be used as an output referenced to ground with a output level loss of 6 dB (referenced to the differential output level.)

OPTIMIZING THE AMPLIFIER

Let us now use the appropriate formulae to optimize the amplifier in Figure 2 for operation with a 150 ohm source impedance, and predict its noise performance.

STEP I

Calculate the optimum collector current I_c (opt) using Formula 8.

$$I_c \text{ (opt)} \triangleq \left(\frac{kT}{q}\right)\left(\frac{\sqrt{h_{FE}}}{R_s}\right)$$

Set R_s to equal the 150 ohm source impedance, T = 300° K and 150 for h_{FE} (typical for TA-103)

$$I_c \text{ (opt)} = \left(\frac{1.38\times10^{-23}\times 300}{-1.60\times10^{-19}}\right)\left(\frac{\sqrt{150}}{150}\right) = -2.11\times10^{-3}A$$

STEP 2

Calculate the short-circuit input noise of the input stage, E_{n_a}, using Formula 5.

$$E_{n_a} \doteq kT\sqrt{\frac{2}{qI_c}} \quad V/\sqrt{Hz}$$

$$= (1.38\times10^{-23})\,(300)\sqrt{\frac{2}{(-1.6\times10^{-19})\,(-2.11\times10^{-3})}}$$

$$= 3.18\times10^{-10}\,V/\sqrt{Hz}$$

Since in the differential configuration, both input devices contribute to E_{n_a} multiply the answer by $\sqrt{2}$, or $E_{n_a} = 4.5 \times 10^{-10}\ V/\sqrt{Hz}$

STEP 3

Calculate the base current noise, I_{n_a}, using Formula 6.

$$I_{n_a} = \sqrt{\frac{2qI_c}{h_{FE}}}$$

$$= \sqrt{\frac{(2)(1.6\times10^{-19})(-2.11\times10^{-3})}{150}}$$

$$= 2.12\times10^{-12}\ A/\sqrt{Hz}$$

For differential I_{n_a} using both sections multiply by $\sqrt{2}$ or $I_{n_a} = 2.99\times10^{-12}\ A/\sqrt{Hz}$

STEP 4

Calculate the additional noise voltage which will be induced across R_S by I_{n_a}.

$$(I_{n_a} \times R_S) = 4.50\times10^{-10}\ V/\sqrt{Hz}$$

STEP 5

To predict the approximate value of the noise figure of the amplifier in Figure 2, we must introduce two additional terms: rb', or the spurious base resistance, considered to be in series with R_S , and R_g , also considered to be in series with R_S . The resistors, R_{ref} and R_{ref}' may be ignored in this configuration.

For the TA-103, rb' may be estimated at 50 to 100 ohm per device. A good value to use is 80 ohm. Since we are configuring the input stage for a source impedance of 150 ohm, let us assume that both Q1 and Q2 are configured using two devices in parallel. The spurious base resistance term, rb', then can be estimated at 80 ohm, or 40 ohm per device. The spurious term rb' appears differentially in series with R_S , so that the total spurious base resistance noise Enrb' will be, from Formula 3.

$$Enrb' = \sqrt{4kT80}$$

$$Enrb' = 1.15\times10^{-9}\ V/\sqrt{Hz}$$

R_g for 60 dB of gain (A_v = 1000), assuming values of 10 kohm for R_{fb} and R_{fb}', will be 10 ohm. Calculate EnR_g using Formula 3.

$$EnR_g = \sqrt{4kT10}$$

$$EnR_g = 4.07\times10^{-10}\ V/\sqrt{Hz}$$

Since this particular amplifier's feedback configuration cancels most of the effects of I_{n_a} on the spurious terms rb' and R_g, they may be safely ignored.

To calculate the predicted noise figure, N.F., of the circuit shown in Figure 2, use Formula 9.

$$N.F. = 20\log_{10}\frac{Ent}{En}$$

The total noise for the amplifier, Ent, will be the sum of all the noise voltages added in quadrature, or

$$Ent = \sqrt{En^{2} + End^{2} + (InaRs)^{2} + Enrb^{2} + Enra}$$

$$= \sqrt{(1.58x10^{-9})^{2} + (4.50x10^{-10})^{2} + (4.50x10^{-9})^{2} + (1.15x10^{-9})^{2} + (4.07x10^{-10})^{2}}$$

$$Ent = 2.09x10^{-9}\ v\sqrt{Hz}$$

thus, the predicted noise figure is

$$N.F. = 20\log_{10}\frac{2.09x10^{-9}\ v\sqrt{Hz}}{1.58x10^{-9}\ v\sqrt{Hz}} = 2.43\ db$$

The actual measured differential noise figure of the amplifier stage in rms volts a 20 kHz bandwidth when Av = 1000 and Rs = 150 ohm is 2.3 to 2.8 db.

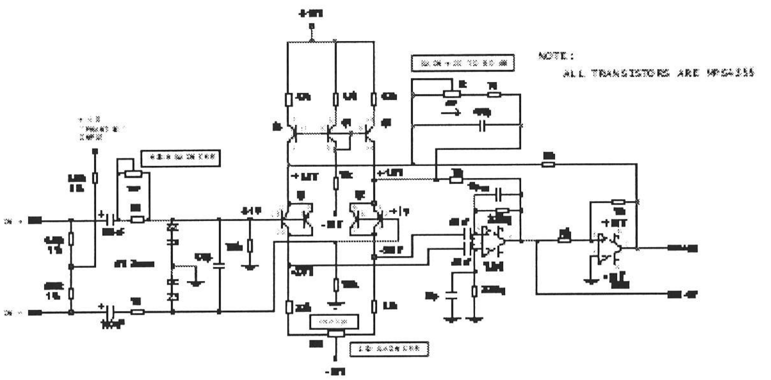


FIGURE 3 SCHEMATIC OF TA-103 IN LOW NOISE MICROPHONE PREAMPLIFIER

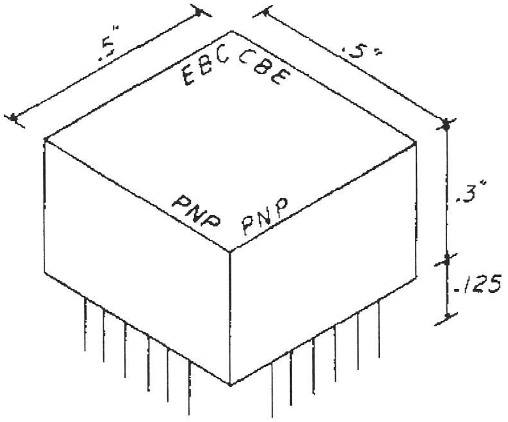
Figure 3 illustrates a low noise microphone preamplifier using the TA-103 as the input section. The operational amplifiers may be NE 5532 or NE 5534 ibn lieu of the TL072 shown, thus allowing the circuit to drive 600 ohm balanced lines.

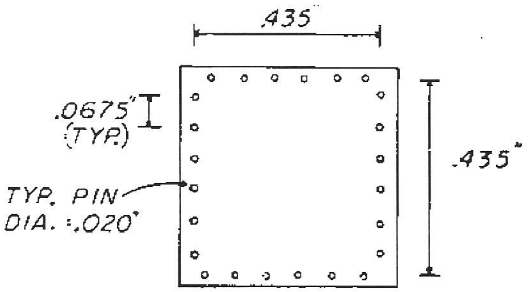
A "phantom power" distribution network consisting of three 6.81 kohm resistors is included at the microphone input terminals to provide polarizing voltaqge for those microphones requiring external power. The input capacitors are low leakage electrolytics, although tantalum capacitors may be used in the presence of the polarizing voltage.

The 3.3 kohm load resistors are selected to place the collectors of the input pairs, Q1, Q2 at about 1/2 Vcc with the collector current uses, approximately 2 mA.

Current sources Q3 and Q5, providing I_e , are biased by transdiode Q4. Use of active current sources allows the circuit to operate with extremely low distortion products.

PHYSICAL DESCRIPTION



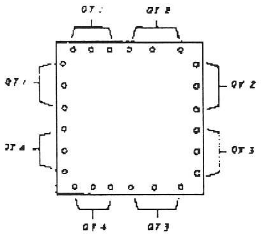


(BOTTOM VIEW)

APPLICATION NOTE AN-149

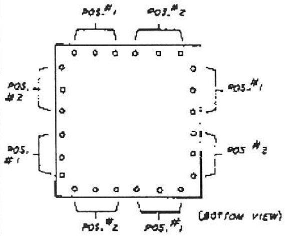
TA SERIES - 8 TRANSISTOR ARRAYS

THERMAL PAIR I.D.



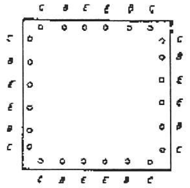
(BOTTOM VIEW)

POLARITY



TA101 (GREEN)	TA102 (ORANGE)	TA103 (BROWN)
POS.#1 = PNP POS.#2 = NPN	ALL POS. NPN	ALL POS. PNP

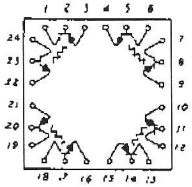
PIN INFORMATION



TA 10x

NOTE: ANY TA SERIES DEVICE MAY BE INSERTED IN ANY POSITION SINCE THEY ARE ALL TOTALLY SYMMETRICAL.

SCHEMATIC DIAGRAM



BOTTOM VIEW

(TA 101 SHOWN)

∿∿ = CLOSE THERMAL COUPLING

Figure 4 shows one half of a stereo input configured using one TA-103. This input stage may be fed by microphones, musical instruments, or line level devices by selecting the appropriate position of switch S1, thus changing the gain and collector current through the input pair. Transistors Q1 throught Q4, as well as their counterparts (Q5) through (Q8) in the other half of the stereo input are contained in a single TA-103. Transdiodes Q9 and (Q10) may be any PNP silicon type. Operational amplifiers U1a, U1b, U1(c) and U1(d) may be a single quad package such as the TL074. Be sure that the symmetrical pairs, i.e. Q1/Q2, Q3/Q4, etc. consist of thermal pairs as identified in AN 149 "Thermal Pair I.D." for best thermal stability.

The circuit of Figure 4 will perform within the following specifications:

Input Impedance	200 kohm balanced 100 kohm unbalanced
Equivalent Input Noise Voltage	200 ohm source impedance, @ 40 dB gain, "mic." selected ≈-126 dB (N.F.≈3.5 dB) 50 kohm source impedance, @ 20 dB gain, "inst." selected≈-104 dB (N.F.≈ 1.5 dB)
Output Noise and Hum Voltage	0 to 10 kohm source impedance, unity gain, "line" selected ≈-90 dB
THD or SMPTE IMD	Less than 0.05% at any gain with any source
Maximum Output Voltage Level	+26 dB into 2 kohm or greater
Gain Range	"mic." selected, from +26 to +40 dB "inst." selected, fixed @ +20 dB "line" selected, fixed @ 0 dB

This input circuit may be sourced by balanced or unbalanced devices, and the output may be taken unbalanced from either opamp output with a resulting level drop of 6 dB referred to the differential output level.

NOTES: Unless otherwise specified measurements made differentially.
Noise voltage measurements made in 20 Hz to 20 kHz bandwidth.
0 dB refers to 0.775 Vrms.

CONCLUSION AND SYNOPSIS

The Valley People, Inc. TA-103 transistor array offers the designer an excellent cost effective device for the configuration of low noise AC amplifiers. Some of the benefits are the close matching of Vbe and extremely tight thermal coupling, as well as a cost-to-performance advantage over most monolithic pairs and arrays having less impressive performance parameters.

By using the relatively simple procedures outlined in the text, the designer may easily configure and closely approximate the noise performance of balanced differential low noise AC amplifiers without the necessity of prototyping.

The O.E.M. user is urged to contact the engineering staff at Valley People, Inc. for assistance in specific applications of the TA-103.