NOTICE

IC CIRCUIT TECHNIQUES MTG

TIME: JULY 5 (WED) 8-9 AM

PLACE: BIG EXEC CAFETERIA

SUBJ: SUPER EMITTER FOLLOWER
AND
MULTI-TAN AMP

SPEAKER: BARRIE

GW

IC CIRCUIT TECHNIQUES

#2

'THE MULTITANH PRINCIPLE'

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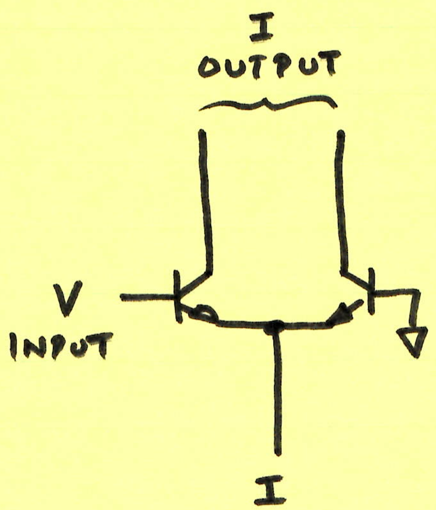
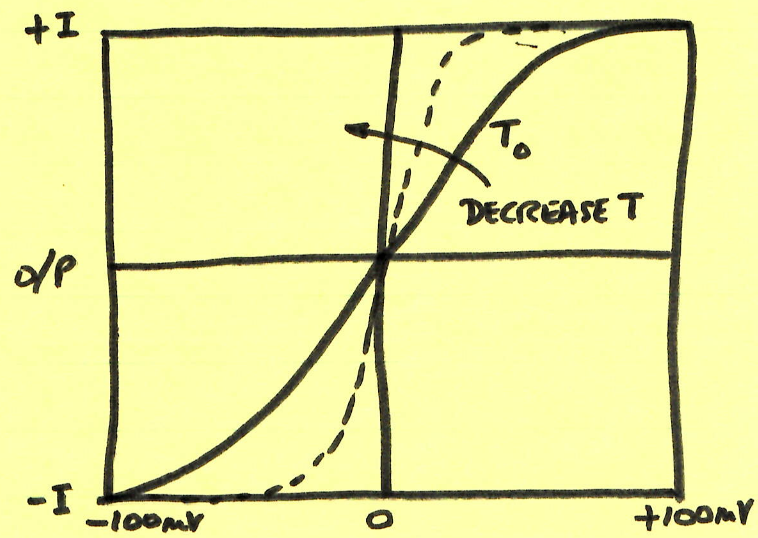
WEDNESDAY, JULY 5, 1978

MULTI-TANH

An awkward name (suggestions for alternatives welcome!) which ropes off a class of circuits in which the total static transfer response results from the summation, in-phase or with alternating summation phase, of a set of hyperbolic tangent functions.

Before getting too general, consider this:

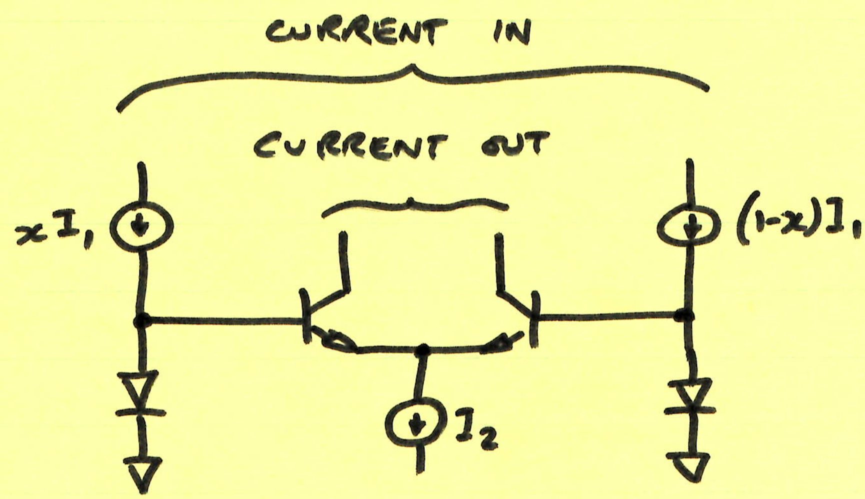




PROVIDES CURRENT-CONTROLLABLE TRANSCONDUCTANCE, DIFFERENTIAL-IN TO DIFFERENT-OUT FEATURES. BUT HOPELESSLY NONLINEAR (V-I — GREAT I-TO-I) AND HOPELESSLY TEMPERATURE-DEPENDENT TRANSCONDUCTANCE.

HOWEVER.......
THIS LIL' GUY IS WIDELY USED AS A 'VARIABLE-GAIN' ELEMENT IN HOKEY THINGS LIKE O-T-A s

Now steer your eyes to this:



THIS CLEANS UP THE LONG-TAILED-PAIR'S PROBLEMS NICELY, SO LONG AS THE INPUTS ARE CURRENTS, AND THE OUTPUTS ARE CURRENTS. I'VE CALLED I-IN, I-OUT CIRCUITS 'TRANSLINEAR' — NOT TO INVENT A BUZZ WORD, BUT BECAUSE OF GENUINE DIFFICULTIES IN COMMUNICATION. THE INTERNAL NODE VOLTAGES OF TRANSLINEAR CIRCUITS (ALL OF WHICH VARY LIKE CRAZY WITH TEMPERATURE) ARE INCONSEQUENTIAL. THE TRANSLINEAR MULTIPLIER SHOWN IS NICE BECAUSE: IT'S EXTREMELY LINEAR AND TEMPERATURE-INSENSITIVE ON FUNDAMENTAL CONSIDERATIONS, AND, IN THIS PARTICULAR CASE, THE 'STAGE GAIN' OF I_2/I_1 IS EVEN INSENSITIVE TO BETA, PROVIDED $\beta \geq I_2/I_1$. (OF COURSE, THERE IS AN ALPHA ERROR, BUT GAINS OF 80 CAN BE ACHIEVED WITH $\beta = 100$ WITH ONLY A 1% ERROR DUE TO ALPHA. I KNOW OF NO OTHER CIRCUIT THAT WORKS THAT WAY).

SO IF IT'S SO GOOD, WHY TURN THE PAGE?

Because, you suspect it's got problems, and of course you are right. This is not the place to talk about them (there are young students here who may lose heart).

But take just one of them.
HOW DO YOU DERIVE THOSE PRISTINE CURRENT SOURCES IF YOU HAVE A VOLTAGE SIGNAL TO BEGIN WITH?

(1) YOU ~~USE~~ SOMETHING LIKE AN EMITTER DEGERATED STAGE? OKAY, BUT NOT ALWAYS SUFFICIENTLY LINEAR, PARTICULARLY IF THE INPUT IS ONLY, SAY, ±100mV.

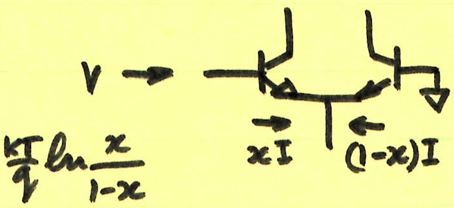
IN FACT, LET'S SKIP METHODS (2) ... (N), WHICH YOU ALL KNOW ANYWAY, AND THINK ABOUT THAT.

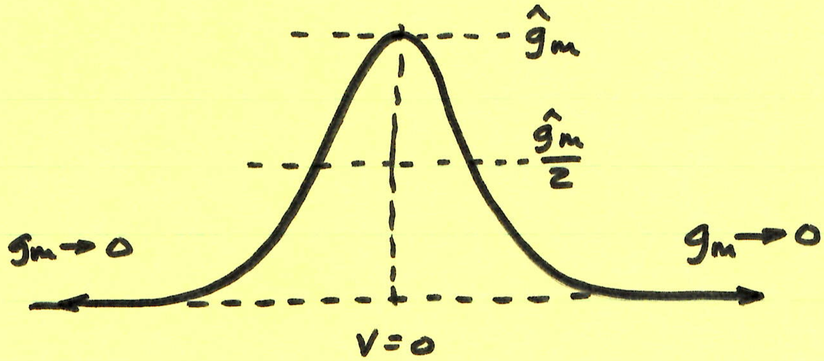
IF THE INPUT IS SMALL, A SIMPLE LONG-TAILED PAIR IS .... A L M O S T... GOOD ENOUGH. BESIDES, IF YOU MAKE AN EMITTER DEGENERATED (GOT IT THAT TIME) STAGE, THE OHMIC-R BIT GETS PRETTY SMALL ANYWAY.

HMM ...... LONG-TAILED-PAIR ALMOST HAS ENOUGH SIGNAL RANGE — LIKE, MAYBE, HALF ENOUGH RANGE?

NO RUDE COMMENTS ABOUT THE PERFESSER'S SPELLING, PLEASE.

Let's look at the LTP's incremental gain function. If my memory serves, it has a $\text{sech}^2(\,)$ form — you can work it out easily enough.





It takes less than 7E+06 lines of algebra to show that

$$g_m = \frac{Iq}{kT}\, x(1-x)$$

Quadratic! (That's irrelevant)

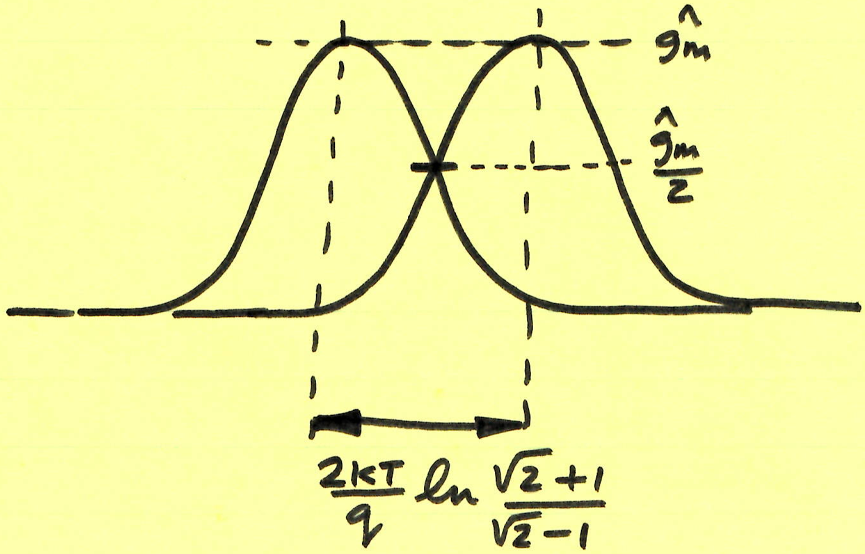
and at the half-gm point

$$V = \pm \frac{kT}{q} \ln \frac{\sqrt{2}+1}{\sqrt{2}-1}$$

which, on a hot July day, is about ±50mV.

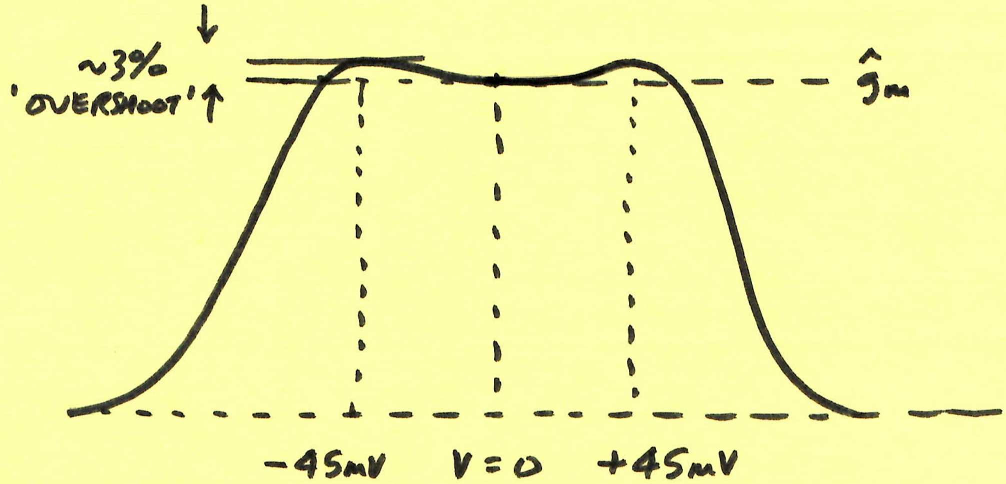
OF COURSE, THE GAIN ERROR OF 50% ISN'T VERY NICE. BUT 50mV ISN'T FAR FROM OUR DESIRED 100mV.

JUST SUPPOSE WE SUPERIMPOSED TWO OF THESE CURVES.... THE RESULTING PICTURE DESERVES A NEW PAGE:



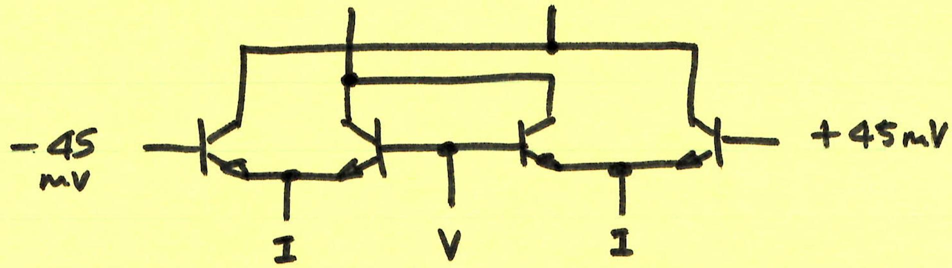
BY SOME ELEMENTARY OFFSET-BIAS SCHEME, THE TWO STAGES ARE OFFSET BY THAT FUNNY VOLTAGE. AT 300°K, THATS 45.567-AND-A-BIT mV X 2.

LET'S ADD THOSE TWO CURVES:



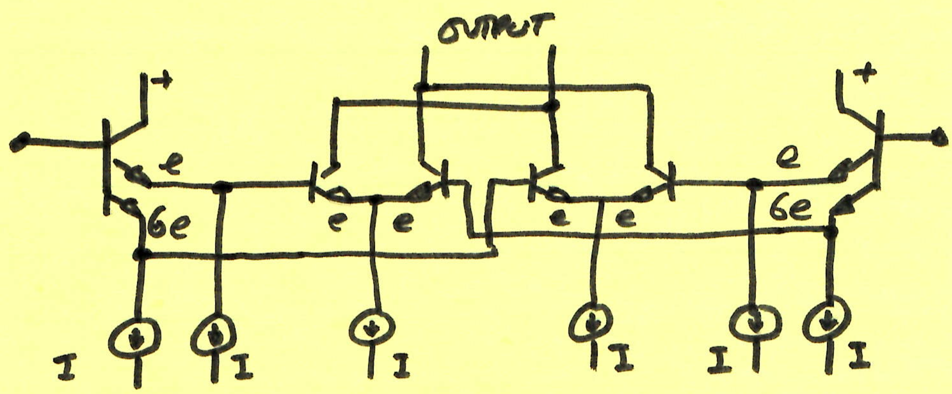
(EXERCISE: SHOW THAT $x = \frac{1}{2} \pm \frac{\sqrt{2}}{3}$ AT THE HUMPS — for the mostly-off stage — and that the g_m of this stage at the hump is $\frac{Iq}{kT} \cdot \frac{1}{36}$, exactly. Thus the 'hump' g_m is $1 + \frac{1}{36}$ or 1.0278)

HOW TO DO THIS?
One way is to use simple offset voltages:



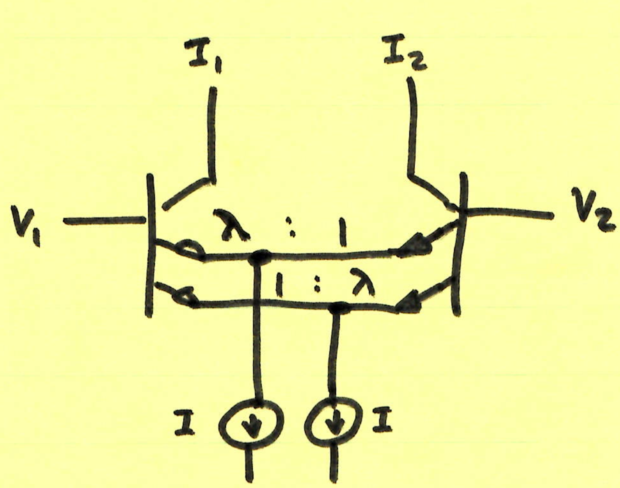
This is not so hot, because: (1) we've thrown away our differential-input capability (2) Those offsets need to be PTAT (A small fee will bring an explanation of the meaning of that term).

WELL, JUNCTIONS WITH UNEQUAL CURRENT DENSITIES MAKE PTAT VOLTAGES, SO THAT'S A NATURAL NEXT STEP — MAYBE THIS?



($\frac{kT}{q} \ln 6 \approx 45mV$). DID YOU REALLY THINK OF THAT MONSTROUS SCHEME? OR, DID YOU JUMP DIRECTLY TO 'GO' — THIS SUPER SIMPLE WAY

TA-DAH!



THIS, FFOLKS, IS THE FIRST MULTITANH CIRCUIT OF IMPORTANCE. CALL IT 'THE DOUBLET'. (YOU THEN WILL KNOW WHAT I'M TALKING ABOUT — BUT YOU CAN CALL IT WHATEVER YOU WANT.....).

HAVING WORKED SO HARD TO GET HERE, NOT TO MENTION RAISING IBM-XEROX SHARES A NOTCH, LET US SIT ON A ROCK AND GLOAT A LITTLE BIT.

THIS CIRCUIT HAS

1) A SUBSTANTIALLY <u>LINEAR REGION</u> OF OPERATION — GAIN ERROR ABOUT −3% AT ±50mV, NOT BAD FOR STARTERS.

2) DIFFERENTIAL-IN/DIFFERENTIAL-OUT

3) <u>TRUE</u> TRANSCONDUCTANCE, WHICH IS

4) <u>CURRENT-CONTROLLABLE</u> OVER A VERY WIDE RANGE — IN PRINCIPLE, OVER THE TRANSISTORS' ENTIRE CHARACTERIZABLE RANGE.

SOME HALF WAY QUESTIONS That must have occurred to U.

Q1. WHAT IS THE EFFECTIVE g_m?

Q2. HOW CAN I INCREASE THE INPUT RANGE?

Q3. IS IT POSSIBLE TO ACHIEVE 0.1% ERRORS?

Q4. FOR WHAT VALUE OF λ IS THE CIRCUIT OPTIMIZED?

Q5. IF YOU INCREASE THE NUMBER OF EMITTER PAIRS, CAN YOU COMBINE WIDE DYNAMIC RANGE WITH LOW ERROR?

Q6. WHAT DOES ALL THAT EXTRA CAPACITANCE DO TO TRANSIENT RESPONSE?

Q7. CAN WE EXPECT NOISE PERFORMANCE TO IMPROVE?

Q8. SUPPOSE I DON'T LIKE ALL THOSE CURRENT SOURCES FOR MULTI-TANH CIRCUITS. IS THERE A SIMPLER WAY USING JUST ONE CURRENT SOURCE?

Q9. HOW ABOUT DIFFERENT CIRCUITS BASED ON THE SAME PRINCIPLE?

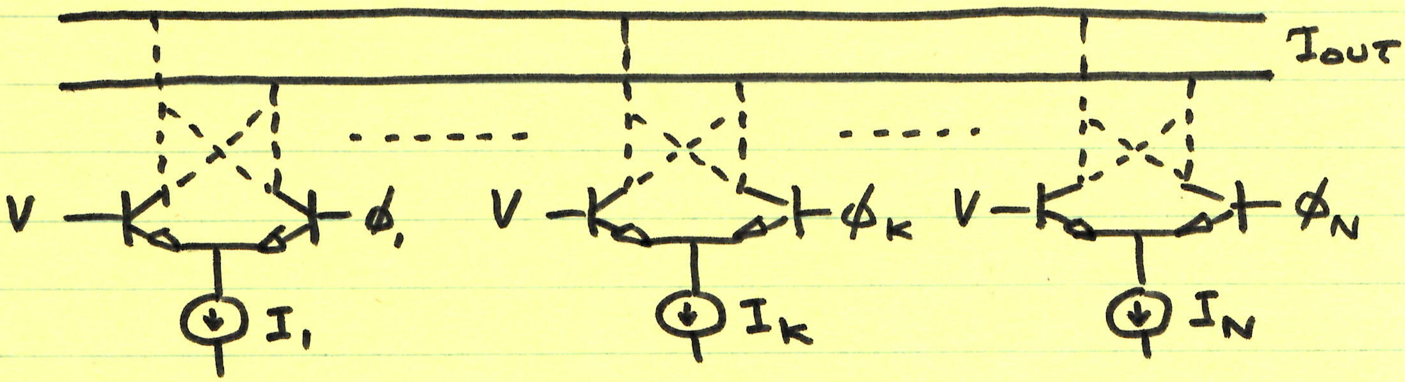
These questions will be answered "live" on Wednesday. Interim answers are (1) $4\lambda/(1+\lambda)^2$ times the g_m you'd get if all the current went to one stage (2) Quite easily (3) Yes (4) That all depends (5) Yes (6) Umm..... it can be bad (7) Yes (8) Yes (9) How about them?

HERE'S WHAT WE'LL DISCUSS :

A. Use of doublet as
   (1) Linear multiplier
   (2) Op-amp input stage
B. Triplet Optimization
C. Elimination of multiple current sources
D. General Multitanh Circuit
E. Application to sine-function synthesis
   (1) Heavy Theory
   (2) A Dead-simple Implementation
F. Other ways to use the principle.

MULTITANH is relatively new. There's lot's of room for innovation and discovery. You are encouraged to bring along your own ideas to the meeting — Vu-graphs if you want to share.

FOR THE RECORD — The Almost-Completely General Multitanh Circuit is



NOTE: COLLECTORS MAY BE IN- OR OUT-OF-PHASE
OFFSETS ϕ MAY BE REAL OR BUILT-IN (λ)
OFFSETS MAY OR MAY NOT BE EQUISPACED
CURRENTS I_K MAY OR MAY NOT BE EQUAL

THE GENERAL TRANSFER FUNCTION IS

$$I_{OUT} = \sum_{k=1}^{N} s(k)\, I_k \tanh\left(\frac{V - \phi_K}{kT/q}\right)$$

where $s(k)$ is the sign of the collector phase