application note

# AB-0013: SPICE Models for the IAM- 81 and IAM-82 Active Mixers

Revised February, 1999

## Introduction

SPICE models provide the designer with insight into the non-linear behavior and bias dependence of semiconductor devices. This Bulletin presents the SPICE models for Hewlett-Packard's IAM-81 and IAM-82 active mixer product families.

## Simulation Accuracy

At the outset, a few words on the accuracy of SPICE predictions are in order. SPICE (Simulation Program with Integrated Circuit Emphasis) is the generic name for a number of time based non-linear simulators based on the original Berkeley SPICE of 1973. SPICE has become the accepted non-linear modeling tool of the analog IC design community, and in general SPICE simulations give good insight into how a circuit will perform.

SPICE is not, however, a perfect depiction of reality. Simplifications in design models and limitations in the simulator can lead to significant discrepancies between prediction and measured results. In particular, problems with accuracy have been encountered when saturated devices are simulated, for example in simulations with low values of Vcc or simulations at extreme temperatures. RF performance over temperature is not well modeled in SPICE. Self heating effects can be important, and simulation temperatures should be adjusted accordingly, especially for higher dissipation parts such as the IAM-82 mixers. A correct description of external parasitics, and in particular of the ground path, is essential if SPICE predictions are to correlate with reality. In summary, a SPICE simulation should be viewed as a way of predicting trends and directions, and in no way substitutes for actual measurements on physical parts.

## IAM-81 and IAM-82

The IAM-81 and IAM-82 are Gilbert multiplier active mixers manufactured using Hewlett-Packard's ISOSAT™ silicon MMIC process. Products based on these two designs can accept RF and LO signals up to 5 GHz, and provide gain with IF frequencies up to 1 GHz for the IAM- 81 and 2 GHz for the IAM-82. The [AM-81 mixers have a P1 dB of -6 d8m, while the IAM-82 mixers have a PI dB Of +8 dBm. More information on the IAM series products can be obtained in Applications Notes AN-SO10: A 5 GHz Bipolar Active Mixer and AN-SO13: MaglC™ Active Mixers.

The IAM81 and IAM82 mixers are offered in a number of packages. IAM-81000 and IAM-82000 are chip form; IAM-81008 and IAM-82008 are SO-8 plastic packaged versions, and IAM-81028 and IAM-82028 are glass-metal packaged devices. [Note: The IAM-82000 and IAM-82000 are obsolete products no longer offered for sale.]

## SPICE Models

The IAM-81 and IAM-82 active mixers were designed using PSPICE, a variant of the original Berkeley SPICE program. These design models are reproduced below. Figures 1 and 2 present the models for the IAM-81 and IAM-82 mixers respectively. The equivalent circuits shown contain a description of the MMIC chip, of the packaging around the chip,

and of external circuit elements such as signal sources and bias networks. The values for the circuit components are given in Tables 1 and 2.

The solid (black) nodes in the Figures correspond to the node numbers in the simulations. Node 0 is reserved for hard ground. Note that a correct description of the path between the die substrate (node 100) and system ground (node 0) is critical for proper simulation results.

## Chip Model

The MMIC chip description consists of an equivalent circuit that presented schematically, and transistor descriptions that appear as tables of parameter values. The boundaries of the chip are denoted in the Figures by hollow (white) circles. These circles correspond to the chip bond pads. Each bond pad is also labeled in square brackets (e.g. "[Vcc]") for easy identification.

The designed MIMIC consists of resistors and transistors. The resistors are all polysilicon, and have a temperature coefficient of TC1 =-8E-04. Process tolerances allows a ± 10% variation from lot to lot on resistor value, though tracking within a lot is typically ± 1%.

On-chip parasitic capacitances resulting from the metal interconnects on the die are not shown in the equivalent circuit, but are included in the tables of elements. Parasitic capacitors are given a name corresponding to the node number they are

associated with; i.e. C3 represents the capacitance between node 3 and the substrate (node 100).
The active transistors are described by sets of SPICE parameters. These descriptions are given in Table 3. This table presents a 'library' of devices used to make both the IAM-81 and the IAM-82 mixers. The transistor name gives pitch, number of emitter fingers, and emitter finger length. Four micron pitch transistors are used for the high frequency signal processing; eight micron pitch devices are used as biasing elements. Because of the number of transistors in the design, the 'spread base' description used in the catalog for discrete transistors is not used in the models of the active mixers - the resulting simulations would be excessively complex.

A deficiency of SPICE is that R does not predict the variation in RC with VCE seen in actual devices; instead it uses a single value from the SPICE parameter tables. To mitigate this effect, two values of RC are listed in Table 3: one for 5V operation (IAM-81) and one for 10 V operation (IAM-82).

### Package Description

The equivalent circuits in Figures 1 and 2 include a number of elements labeled "pkg'. These elements represent the physical path between the semiconductor chip and the circuit. Included in this path are such elements as bond wire inductances, MOS capacitors used with the chip, and package parasitics. These elements vary with package style, and can radically effect simulation predictions.

A generic package model is given in Figure 4. Element values corresponding to the 08 plastic SO-8 package, the 28 ceramic package and the 00 chip version are listed in Table 4. In general the inductors next to the die represent bond wires, and the inductors away from the die represent package lead inductance (omitted from the chip description). C5, C7, and C9 represent MOS capacitors used with the chip that are internal to the 08 and 28 packages, and must be supplied by the user when working with the 00 die. C5 bypasses the DC line; C7 and C9 provide AC ground references to the low side of the RF and LO ports respectively. Hewlett-Packard uses 150 pF capacitors for each of these elements. The remaining capacitors represent package parasitics.

## External Circuitry

The equivalent circuits include such off-chip elements as AC signal sources and bias networks. These elements are required by the SPICE simulation, but will vary in value from simulation to simulation to fit device usage. The values listed are what was used in the design files, and represent ideal connections of signal sources to the packaged chip. This description should be augmented with a description of the physical environment the mixer will be used in. Particularly critical are accurate descriptions of the ground path (e.g. vias) and the decoupling of the bias line. Cglo, Cgrf represent external capacitors used to AC ground the FIF and LO ports. These elements are mandatory with chip (00 package) use, but are only used to extend frequency range for the packaged devices. For more on extended low frequency use see AN-S013. Cvcc represents external bypassing on the bias line.

VCC is the DC power supply; the values shown in Tables 1 and 2 represent the recommended bias levels for the mixer being modeled. The AC signal sources are simply listed as "AC*, their characteristics will vary from simulation to simulation as they define the frequency and power level of the input signals to the mixer. Vout is a "dummy' generator used to measure output characteristics.

A sample PSPICE file for the IAM-81028 mixer is given in Figure 5. This simulation results in a model of the packaged device only; no circuit effects are included. When describing the use of the packaged MMIC in a real circuit, appropriate values would be provided for Cglo, Cgrf and Lvia. Values for blocking capacitors Clo, Crf and Cout would be adjusted to those used in the circuit. Generator and load impedances would be adjusted to reflect the circuit environment- this might include moderately detailed descriptions of the applications circuit. Vlo and Vrf sources would be adjusted to describe applied signals.

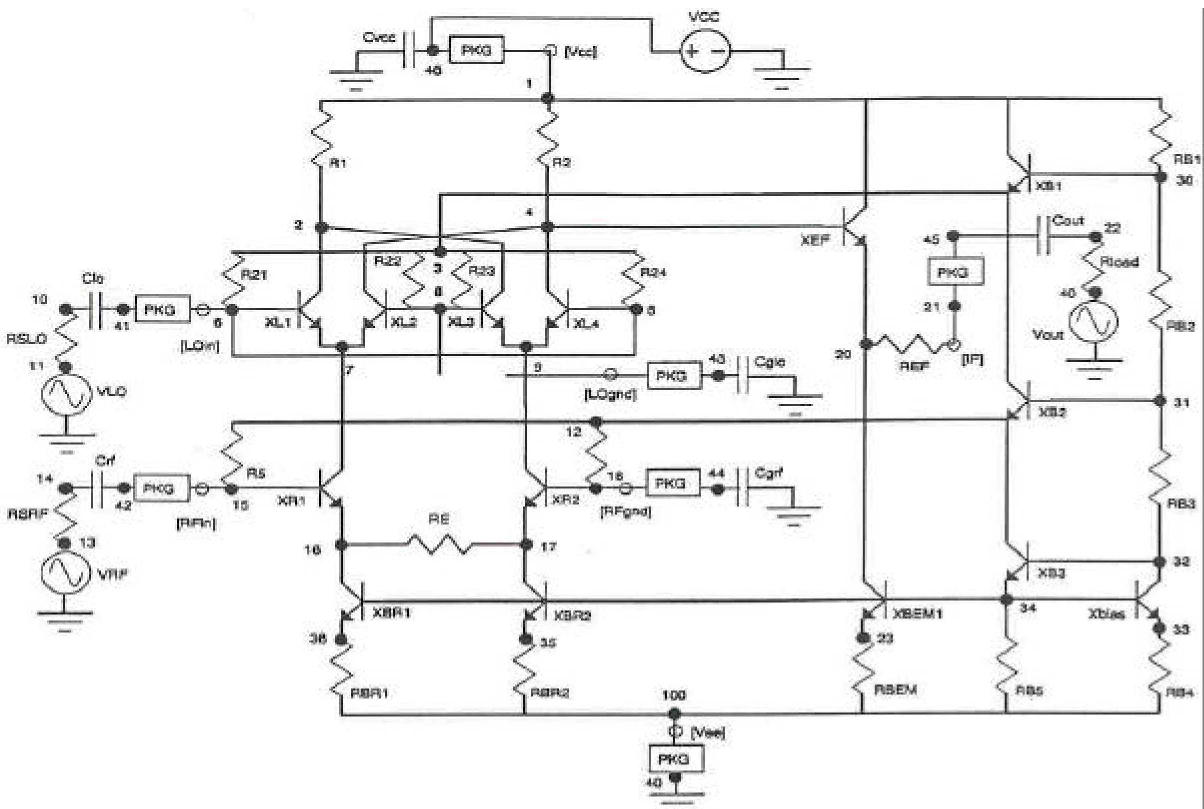


Figure 1. Equivalent Circuit for IAM-81 Active Mixer

Table 1. Equivalent Circuit Values for the IAM-81 Active Mixer

| Transistors | | Resistors | | Parasitic Capacitors | | External Components | |
|---|---|---|---|---|---|---|---|
| XR1 | I40420 | R1 | 400 | C2 | .05 pF | VLO | AC |
| XR2 | I40420 | R2 | 400 | C3 | .05 pF | RSLO | 50 |
| XL1 | I40220 | R3 | 50 | C4 | .08 pF | CLO | 6800 pF |
| XL2 | I40220 | R4 | 50 | C6 | .11 pF | VRF | AC |
| XL3 | I40220 | R21 | 100 | C7 | .02 pF | RSRF | 50 |
| XL4 | I40220 | R22 | 100 | C8 | .02 pF | CRF | 6800 pF |
| XEF | I40820 | R23 | 100 | C12 | .07 pF | Vout | AC |
| XB1 | I80220 | R24 | 100 | C15 | .09 pF | Rload | 50 |
| XB2 | I80220 | RE | 20 | C16 | .15 pF | Cout | 6800 pF |
| XB3 | I80220 | REF | 25 | C17 | .14 pF | Vcc | 5 V DC |
| Xbias | I80220 | RB1 | 800 | C20 | .05 pF | Cglo | user |
| XBR1 | I80220 | RB2 | 700 | C21 | .11 pF | Cgrf | user |
| XBR2 | I80220 | RB3 | 500 | C23 | .01 pF | Cvcc | user |
| XBEM1 | I80420 | RB4 | 200 | C30 | .05 pF | pkg | Table 4 |
| | | RB5 | 1000 | C31 | .03 pF | | |
| | | RBEM1 | 45 | C32 | .15 pF | | |
| | | RBR1 | 170 | C33 | .01 pF | | |
| | | RBR2 | 170 | C34 | .13 pF | | |

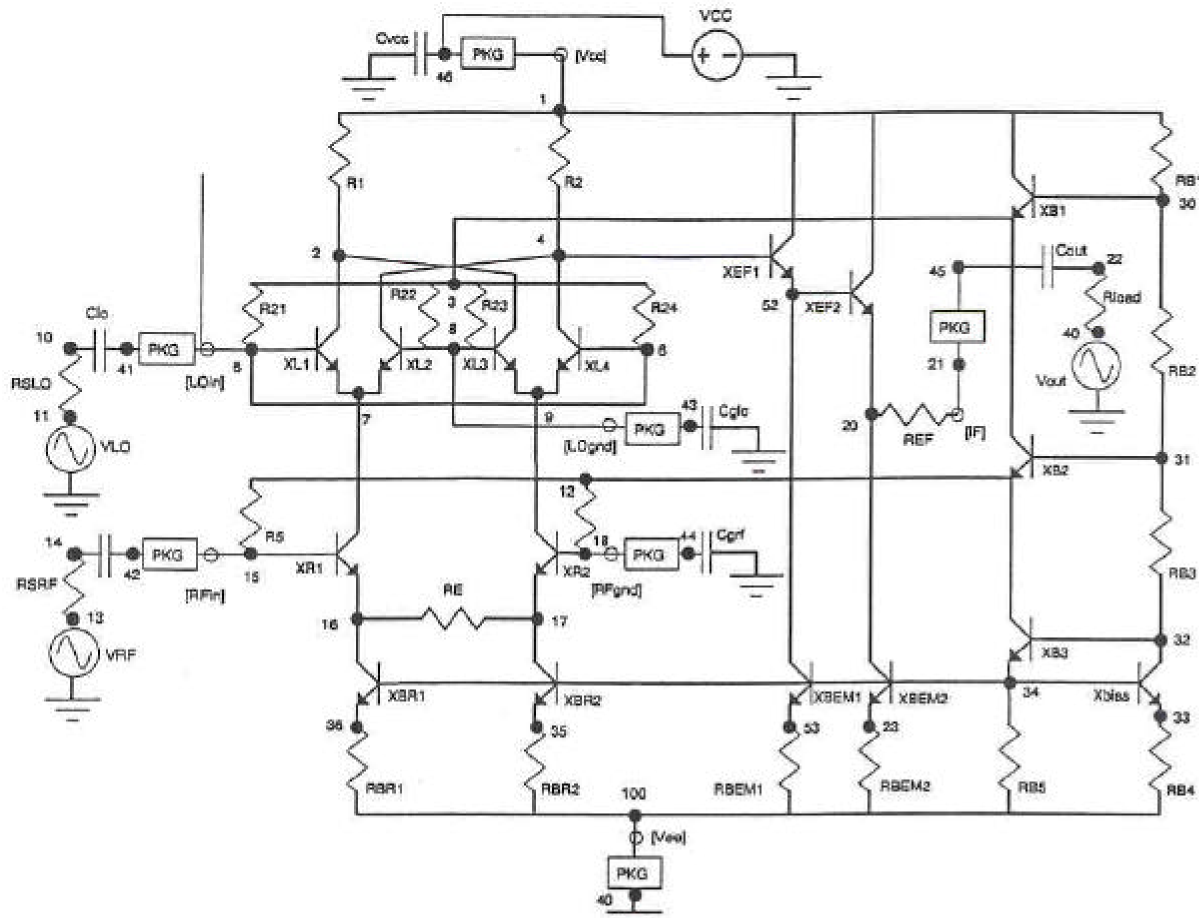


Figure 2. Equivalent Circuit for IAM-82 Active Mixer

Table 2. Equivalent Circuit Values for the IAM-82 Active Mixer

| Transistors | | Resistors | | Parasitic Capacitors | | External Components | |
|---|---|---|---|---|---|---|---|
| XR1 | I40820 | R1 | 700 | C2 | 05 pF | VLO | AC |
| XR2 | I40820 | R2 | 700 | C3 | .05 pF | RSLO | 50 |
| XL1 | I40420 | R3 | 50 | C4 | .08 pF | CLO | 6800 pF |
| XL2 | I40420 | R4 | 50 | C6 | .11 pF | VRF | AC |
| XL3 | I40420 | R21 | 100 | C7 | .02 pF | RSRF | 50 |
| XL4 | I40420 | R22 | 100 | C8 | .02 pF | CRF | 6800 pF |
| XEF1 | I40420 | R23 | 100 | C12 | .07 pF | Vout | AC |
| XEF2 | I41620 | R24 | 100 | C15 | .09 pF | Rload | 50 |
| XB1 | I80420 | RE | 40 | C16 | .15 pF | Cout | 6800 pF |
| XB2 | I80420 | REF | 25 | C17 | .14 pF | Vcc | 10 V DC |
| XB3 | I80420 | RB1 | 1260 | C20 | .05 pF | Cglo | user |
| Xbias | I80420 | RB2 | 465 | C21 | .11 pF | Cgrf | user |
| XBR1 | I80420 | RB3 | 275 | C23 | .01 pF | Cvcc | user |
| XBR2 | I80420 | RB4 | 200 | C30 | .05 pF | pkg | Table 4 |
| XBEM1 | I80420 | RB5 | 1000 | C31 | .03 pF | | |
| XBEM2 | I80820 | RBEM1 | 100 | C32 | .15 pF | | |
| | | RBEM2 | 25 | C33 | .01 pF | | |
| | | RBR1 | 170 | C34 | .13 pF | | |
| | | RBR2 | 170 | C52 | .06 pF | | |

Table 3. SPICE transistor models for IAM -81 and IAM-82 Active Mixers

| Parameter | I40220 | I40420 | I40820 | I41620 | I80220' | I80420 | I80820 |
|---|---|---|---|---|---|---|---|
| model | NPN | NPN | NPN | NPN | NPN | NPN | NPN |
| BF | 90 | 100 | 100 | 100 | 90 | 100 | 100 |
| IS | 7.9E-17 | 1.6E-16 | 3.2E-16 | 6.3E-16 | 9.6E-17 | 1.9E-16 | 3.8E-16 |
| VA | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| BR | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| ME | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| NF | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| PTF | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| TF | 1.2E-11 | 1.2E-11 | 1.2E-11 | 1.2E-11 | 1.2E-11 | 1.2E-11 | 1.2E-11 |
| CJE | 1.2E-13 | 2.3E-13 | 4.6E-13 | 9.2E-13 | 1.4E-13 | 2.8E-13 | 5.6E-13 |
| XTF | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| IK | 6.4E-03 | 1.3E-02 | 2.6E-02 | 5.1E-02 | 7.7E-03 | 1.5E-02 | 3.1E-02 |
| PE | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 |
| ISE | 2.4E-13 | 4.8E-13 | 9.6E-13 | 1.9E-12 | 2.9E-13 | 5.8E-13 | 1.2E-12 |
| NE | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| VTF | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| XTB | 1.818 | 1.818 | 1.818 | 1.818 | 1.818 | 1.818 | 1.818 |
| ITF | 1.4E-02 | 2.9E-02 | 5.8E-02 | 1.2E-01 | 1.7E-02 | 3.5E-02 | 7.0E-02 |
| RB | 58.47 | 29.42 | 14.78 | 7.59 | 90.24 | 44.69 | 22.40 |
| RE | 2.08 | 1.04 | 0.52 | 0.26 | 1.60 | 0.80 | 0.40 |
| RC (5V) | 81.45 | 59.90 | 31.62 |  | 95.27 | 27.63 |  |
| RC (10V) |  | 20.83 | 29.73 | 13.64 |  | 13.64 | 14.61 |
| CJC | 6.1E-14 | 1.0E-13 | 1.9E-13 | 3.6E-13 | 1.0E-13 | 1.9E-13 | 3.6E-13 |
| CJS | 1.0E-13 | 1.3E-13 | 1.8E-13 | 2.8E-13 | 1.3E-13 | 1.8E-13 | 1.8E-13 |
| XCJC | 0.16 | 0.19 | 0.20 | 0.21 | 0.12 | 0.13 | 0.14 |
| PS | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 |
| MS | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| PC | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 | 0.76 |
| MC | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 |

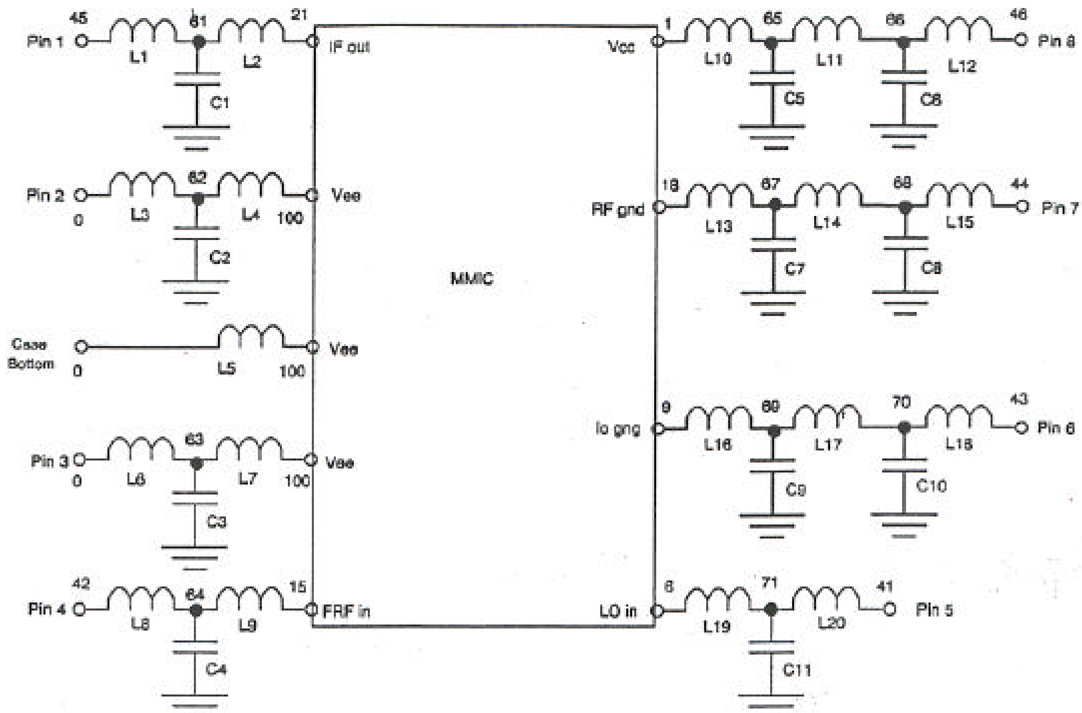


Figure 3. Package Equivalent Circuit

Table 4. Component Values for 00, 08 and 28 Package Models

| Elements | Units | Chip (00) | SO-8 (08) | Ceramic (28) |
|---|---|---|---|---|
| L1 | nH | - | 1.8 | 1.5 |
| L2 | nH | 0.8 | 0.8 | 0.8 |
| C1 | pF | - | 0.2 | 0.2 |
| L3 | nH | - | 1.8 | 1.5 |
| L4 | nH | - | 0.6 | 0.6 |
| C2 | pF | - | 0.2 | 0.2 |
| L5 | nH | 0.15 | - | 0.25 |
| L6 | nH | - | 1.8 | 1.5 |
| L7 | nH | - | 0.6 | 0.6 |
| C3 | pF | - | 0.2 | 0.2 |
| L8 | nH | - | 1.8 | 1.5 |
| L9 | nH | 0.8 | 0.8 | 0.8 |
| C4 | pF | - | 0.2 | 0.2 |
| L10 | nH | 0.4 | 0.4 | 0.4 |
| L11 | nH | - | 0.4 | 0.4 |
| L12 | nH | - | 1.8 | 1.5 |
| C5 | pF | - | 150 | 150 |
| C6 | pF | - | 0.2 | 0.2 |
| L13 | nH | 0.4 | 0.4 | 0.4 |
| L14 | nH | - | 0.4 | 0.4 |
| L15 | nH | - | 1.8 | 1.5 |
| C7 | pF | - | 150 | 150 |
| C8 | pF | - | 0.2 | 0.2 |
| L16 | nH | 0.4 | 0.4 | 0.4 |
| L17 | nH | - | 0.4 | 0.4 |
| L18 | nH | - | 1.8 | 1.5 |
| C9 | pF | - | 150 | 150 |
| C10 | pF | - | 0.2 | 0.2 |
| L19 | nH | 1.0 | 1.0 | 1.0 |
| L20 | nH | - | 1.8 | 1.5 |
| C11 | pF | - | 0.2 | 0.2 |

### Figure 5. PSPICE simulation of IAM-81028

```
*IAM81.CIR **5 volt ISOSAT active mixer**
LIB IAM81.LIB
.OPTIONS LIMPTS 20001 ITL1=100 ITL2=100 ITL5=O RELTOL=0.01 NOMOD
.Op
*EXTERNAL COMPONENTS SOURCES AND LOADS
VLO         11        0          0
VRF         13        0          0
VOUT        40        0          0
VCV         1         0          5
CLO         10        6          680OPF
CRF         14        15         680OPF
COUT        21        22         680OPF
CVCC        46        0          100OPF
RSLO        10        11         50
RSRF        14        13         50
RLOAD       40        22         50
*EXTERNAL ELEMENTS NOT USED FOR SIMULATION OF PKGD MMIC ONLY
CGLO        43        0          0.01PF
CGRF        44        0          0.01 PF
LVIA        48        0          0.01NH
* MMIC DESCRIPTION
RE       16      17      RPOLY   20
XRI      7       15      16      100      I40420
XR2      9       18      17      100      I40420
XL1      2       6       7       100      I40220
XL-2     4       8       7       100      I40220
XL-3     2       8       9       100      I40220
XL-4     4       6       9       100      I40220
XEF      1       4       20      100      I40820
XB1      1       30      3       100      I80220
XB2      3       31      12      100      I80220
XB3      12      32      34      100      I80220
XBIAS    32      34      33      100      I80220
XBR2     17      34      35      100      I80220
XBR1     16      34      36      100      I80220
XBEM     20      34      23      100      I80420
RB1         1         30      RPOLY      800
RB2         30        31      RPOLY      700
RB3         31        32      RPOLY      500
RB4         33        100     RPOLY      200
RBS         34        100     RPOLY      1000
RBR1        36        100     RPOLY      170
RBR2        35        100     RPOLY      100
RBEM        23        100     RPOLY      45
Rl          1         2       RPOLY      400
R2          1         4       RPOLY      400
R21         3         6       RPOLY      100
R22         3         8       RPOLY      100
R23         3         8       RPOLY      100
R24         3         6       RPOLY      100
REF         20        21      RPOLY      25
*CN=METAL OR POLY TO SUBSTRATE C ASSOCIATED WITH NODE N
C2          2         100     .05PF
C3          3         100     .05PF
C4          4         100     .08PF
06          6         100     .1lPF
07          7         100     .02PF
C8          8         100     .02PF
C12         12        100     .07PF
C15         15        100     .09PF
C16         16        100     .15PF
C17         17        100     .14PF
C20         20        100     .05PF
C21         21        100     .1lPF
C23         23        100     .01PF
C30         30        100     .05PF
C31         31        100     .03PF
C32         32        100     .15PF
C33         33        100     .01PF
C34         34        100     .13PF
*PACKAGE DESCRIPTION
Ll          45        61      1.5NH
L2          61        21      0.8NH
CPl         61        0       0.2PF
L3          48        62      1.5NH
L4          62        100     0.6NH
CP2         62        0       0.2PF
L5          48        100     0.15NH
L6          48        63      1.5NH
L7          63        100     0.6NH
CP3         63        0       0.2PF
L8          42        64      1.5NH
L9          64        15      0.8NH
CP4         64        0       0.2PF
L10         1         65      O.4NH
Ll1         65        66      O.4NH
L12         66        46      1.5NH
CP5         65        0       15OPF
CP6         66        0       0.2PF
L13         18        67      O.4NH
L14         67        68      O.4NH
L15         68        44      1.5NH
CP7         67        0       15OPF
CP8         68        0       0.2PF
L16         9         69      0.4NH
L17         69        70      O.4NH
L18         70        43      1.5NH
CP9         69        0       15OPF
CP10        70        0       0.2NH
L19         6         71      1.ONH
L20         71        41      1.5NH
CPl1        71        0       0.2PF
.END
```

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