ADMINISTRATIVE INFORMATION

Work was performed under program element 62712N subproject XF12143555 (NOSC 814-CM03), by the EHF Communications Systems Program Branch (Code 8143).

Released by
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SATCOM & HF Communications
Systems Division

Under authority of
H. D. Smith, Head
Communications Systems
and Technology Department
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11
K-BAND TECHNOLOGY DEVELOPMENT FOR EHF SATELLITE APPLICATION

M. I. T. - Lincoln Laboratory

C. Berglund
K-Band Technology Development For EHF Satellite Application

C. D. BERGLUND, R. J. LENDER, M. L. STEVENS

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY
K-Band Technology Development For EHF Satellite Application

C. D. BERGLUND, R. J. LENDER, M. L. STEVENS

INTRODUCTION

20 - 21 GHz RECEIVER FRONT END DESIGNS
SPECIFICATIONS
DEVICE CHARACTERIZATION
AMPLIFIER PERFORMANCE

20 - 21 GHz GALLIUM ARSENIDE MESFET AMPLIFIER DEVELOPMENT
DEVICE DEVELOPMENT
DEVICE CHARACTERIZATION
LOAD PULL TECHNIQUE/TUNEABLE SLABLINE CIRCUIT
LARGE SIGNAL "S-PARAMETER"/FIXED MICROSTRIP CIRCUITS
DEVICE PERFORMANCE
AMPLIFIER DESIGN AND PERFORMANCE

CONCLUSION
Q-BAND HPA CABINET

RF OUTPUT
ON SLANTED WALL

COOLANT I/O
RF INPUT
WAVE GUIDE, PRESSURIZATION

HINGED DOOR
HP CIRCULATOR
COLD PLATE
VERTICAL WAVEGUIDE
RUN PROTECTOR

CIRCUIT BREAKER COVER
VACUUM POWER SUPPLY
LOW VOLTAGE POWER SUPPLY

RF AMPLIFIER DRAWER
LOGIC ASSY BLOWERS
(SENTINEL(2))
LOGIC CARD BASKET

COLD PLATE
DOOR

CONVERTER Blower (PROP MAX 38)
POWER CONVERTER
GROWTH AREA 7.0
CHOKEs
CONTACTOR

24.0
48.0
50
19.0
Block Diagram - 20 -21 GHz Receiver Front-End

- Noise figure ≤ 6.5 dB
- Small size, volume = 6 in³
- Low cost
Performance of Low Noise Amplifier vs Bias

VARIAN VSF9320
I_{DSS} = 44 mA
DEVICE

FREQUENCY (GHz)

NF
I_{DS} = 22 mA
NF
I_{DS} = 10 mA
GAIN
I_{DS} = 22 mA
GAIN
I_{DS} = 10 mA

7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
20.5
21.0
20.0

NF AND GAIN (dB)
**K-Band FET Development Specification**

<table>
<thead>
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<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
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<tr>
<td><strong>PERFORMANCE AT 21 GHz</strong></td>
<td>GOAL</td>
<td>MINIMUM</td>
<td>GOAL</td>
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<tr>
<td>POWER OUTPUT</td>
<td>1.0 W, 0.5 W</td>
<td>--</td>
<td>1.0 W</td>
</tr>
<tr>
<td>POWER ADDED EFFICIENCY</td>
<td>20% 15%</td>
<td>20% 15%</td>
<td>20%</td>
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<tr>
<td>GAIN</td>
<td>5.0 dB 4.0 dB</td>
<td>5.0 dB 4.0 dB</td>
<td>10 dB</td>
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<td>CHANNEL TEMPERATURE RISE</td>
<td>&lt; 100°C</td>
<td>&lt; 100°C</td>
<td>&lt; 100°C</td>
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<tr>
<td>DELIVERABLES</td>
<td>50</td>
<td>60</td>
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<td>CONTRACTOR</td>
<td>MSC</td>
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<td>STATUS</td>
<td>COMPLETED</td>
<td>AUGUST 1980</td>
<td>SCHEDULED COMPLETION</td>
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Microstrip Amplifier Power-Bandwidth Response.
K-Band Low Noise Amplifier (with cover)
K-Band Low Noise Amplifier (without cover)
Block Diagram - Automatic Noise Figure Measurement System
Hot/Cold Waveguide Load
K-Band 0.5W. GaAs MESFET
Block Diagram of Load-Pull Measurement Set-Up.
Slabline Transistor Holder

Transistor Holder (with side removed)
0.5 W Power MESFET Load-Pull Measurement.
<table>
<thead>
<tr>
<th>RING</th>
<th>P OUT (W)</th>
<th>GAIN (dB)</th>
<th>EFF</th>
<th>IDC (A)</th>
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<tr>
<td>△</td>
<td>0.284</td>
<td>3.56</td>
<td>0.304</td>
<td>0.095</td>
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<tr>
<td>○</td>
<td>0.281</td>
<td>3.52</td>
<td>0.304</td>
<td>0.093</td>
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<tr>
<td>□</td>
<td>0.274</td>
<td>3.41</td>
<td>0.300</td>
<td>0.091</td>
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De-Embedded Load-Pull Data.
Large Signal FET Characterization Procedure

I. CONVENTIONAL ONE-SIGNAL S-PARAMETER MEASUREMENT
   • MEASURE $s_{11}$ UNDER LARGE SIGNAL CONDITIONS
   • ITERATE TO ESTABLISH DESIRED INPUT LEVEL
   • DESIGN MATCHING NETWORK (IMN) FOR FET INPUT

II. TWO-SIGNAL S-PARAMETER MEASUREMENT
    • INSTALL IMN AND MEASURE $s_{11}$ TO DETERMINE INPUT MATCH
    • MEASURE $s_{22}$ UNDER LARGE SIGNAL CONDITIONS
    • DESIGN OUTPUT MATCHING NETWORK
Comparison of Load-Pull and S-Parameter Data.
0.5 W FET Performance Versus Frequency.
20 GHz Optimum Power Bias and Tuning.

20 GHz Optimum Efficiency Bias and Tuning.

21 GHz Optimum Power Bias and Tuning.

21 GHz Optimum Efficiency Bias and Tuning.

0.5 W Power MESFET Performance Summary.
Swept Response of Slabline Amplifier.
Performance of Slabline and Microstrip Amplifiers.
Two-Stage Microstrip Amplifier
Artist's Conception of a Beam-Hopped Downlink Transmitter.
Conclusion

K-Band Receiver Development

- Low-noise FET characterization techniques
- Ridge-transformer waveguide/microstrip transition
- Low noise amplifier:
  4.5 dB noise figure with 6 dB of gain

K-Band Transmitter Development

- GaAs power MESFETs
  0.5 W power output at 20% power-added efficiency
- Large signal FET characterization techniques
  Load-pull/two-signal S-parameters
- FET performance evaluated in slabline and microstrip circuitry
- Complete amplifier stage
  0.4 W power output/15% efficiency/3.0 dB gain

Continuing Development

- High-gain (8 dB) 0.1 W FETS
- High-power 1.0 W FETS
DESIGN AND OPTIMIZATION OF LOW NOISE AND POWER FETs FOR EHF APPLICATIONS

Hughes Aircraft

H. Yamasaki

(Document not available)
HIGH PERFORMANCE LOW COST MIXERS
FOR COMMUNICATION APPLICATIONS

HUGHES AIRCRAFT

H. Yamasaki

(Document not available)
IMPATT POWER BUILDING BLOCKS FOR 20 GHz
SPACEBORNE TRANSMIT AMPLIFIER

LNR Communications

H. C. Okean
IMPATT POWER BUILDING BLOCKS FOR 20 GHz

SPACEBORNE TRANSMIT AMPLIFIER

by

J. Asmus, Y. Cho, J. deGruyl, A. Giannakopoulos
and
H.C. Okean

presented at:

EHF SATCOM Technology Workshop
San Diego, California
August, 1981
IMPATT POWER BUILDING BLOCKS FOR 20 GHz
SPACEBORNE TRANSMIT AMPLIFIER*

by

J. Asmus, Y. Cho, J. deGruyl, A. Giannakopoulos
and
H.C. Okean
LNR Communications, Inc.

---------------------------------------------------------------

Single-stage circulator coupled IMPATT "building block" constituents of a 20 GHz solid state power amplifier (SSPA) currently under development for spaceborne downlink transmitter usage has been demonstrated as providing ~1.25 to 1.5W RF power output at 3 to 5 dB operating gain over a 1 GHz bandwidth. Using either commercially available or recently developed in-house GaAs Schottky Read-profile IMPATT diodes, DC/RF power added efficiencies of 11 to 15 percent were achieved. A two stage IMPATT driver amplifier with similar RF output power capability exhibited 13 ± 0.5 dB operating gain over a 1 GHz bandwidth. A companion 20 GHz FET driver preamplifier is also under development. Extension of the above to the development of a "full-up" 20W IMPATT transmitter is currently in progress.

---------------------------------------------------------------

*This effort is sponsored in part by NASA Lewis Research Center and the Air Force Avionics Laboratory under Contracts No. NAS3-22491 and F33615-80C-1182, respectively.
20 GHz SOLID STATE TRANSMITTER DESIGN OBJECTIVES

PARAMETRIC

INPUT SIGNAL FORMAT
CENTER FREQUENCY
RF BANDWIDTH
SATURATED RF OUTPUT POWER
RF POWER OUTPUT VARIATION WITH FREQUENCY AND TEMPERATURE
RF GAIN @ SATURATION
IN BAND OVERDRIVE SURVIVABILITY
GAIN SLOPE
INPUT VSWR
OUTPUT VSWR
GROUP DELAY VARIATION
AM/PM CONVERSION
DEVIATION FROM PHASE LINEARITY
SPURIOUS RESPONSE (SUM OF HARMONIC COMPONENTS)
SPURIOUS RESPONSE (NON-HARMONIC COMPONENTS)
NOISE FIGURE
DC-RF EFFICIENCY
PRIME DC VOLTAGE INPUT
BASEPLATE TEMPERATURE

DESIGN OBJECTIVE (OVER PASSBAND)

ANGLE MODULATED, SINGLE CARRIER
20 GHz
1.0 GHz
20 WATTS (MIN)
0.6DB(P-P) @ NOMINAL DRIVE LEVEL
1.2DB(P-P) OVER NOMINAL+2DB DRIVE LEVEL RANGE
30 DB (MIN)
5 DB' ABOVE NOMINAL INPUT LEVEL
0.1 DB/MHz (MAX)
1.25:1 (MAX)
1.5:1 (MAX)
0.5 nS P-P (MAX) OVER 50 MHz SLOT
60°/DB (MAX)
10° (MAX)
17 DB BELOW CARRIER
60 DB BELOW CARRIER/20 MHz BAND
25 DB (MAX)
15 PERCENT (MIN)
28 V (NOM)
0 TO 50°C
PROJECTED PERFORMANCE

- FREQUENCY RANGE: 19.5-20.5 GHz
- RF OUTPUT LEVEL: 6.25W
- RF INPUT LEVEL: 0.02W
- OPERATING GAIN: 12.3dB
- DC POWER CONSUMPTION: 25W
- RF/DC POWER-ADDED EFFICIENCY: 23.5%
- GAIN COMPRESSION RATIO: 3.4 deg/dB
- AM/PM CONVERSION: 32.5 dB
- NOISE FIGURE: ±0.3dB
- GAIN FLATNESS: ±0.2dB
- PHASE LINEARITY: ±2 deg

PREFERRED 20 GHZ IMPATT POWER SECTION
"BUILDING BLOCK" AMPLIFIER DESIGN
A. SDR FLAT DOPING PROFILE

B. SDR HI-LO PROFILE (MODIFIED READ)

C. SDR LHL DOPING PROFILE (MODIFIED READ)

D. DDR FLAT PROFILE

ALTERNATIVE IMPATT DIODE DOPING PROFILES
Functional RF topology of 20GHz IMPATT transmitter
Modified Block Diagram of 31 dB Amplifier Module Including Bias Schedule

(Linear Amplifier)
IN-HOUSE K-BAND IMPATT DIODE DEVELOPMENT STATUS

1) TYPE:
   - GaAs MODIFIED READ-PROFILE (LHL)
   - SINGLE DRIFT

2) SUMMARY OF RESULTS TO DATE
   - FREQUENCY GHz 16-18 18-20
   - RF POWER OUTPUT-W 1.5-3.0 1.25-1.75 (TEST OSC.)
   - DC/RF EFFICIENCY-PERCENT 15-20 10-15
   - THERMAL RESISTANCE °C/W 20 20-22
MEASURED GAIN OF SINGLE-STAGE IMPATT AMPLIFIER UTILIZING LNR IMPATT DIODE
RF TRANSFER CHARACTERISTIC OF SINGLE-STAGE AMPLIFIER UTILIZING LNR IMPATT DIODE

NORMALIZED RF INPUT POWER-dB

FREQUENCY: 20 GHz

$V_{oc} = 33.1 \text{ V}$
$V_{dc} = 225 \text{ A}$
$P_{in} = 6.32 \text{ W}$
$P_{out} = 1.45 \text{ W}$
$P_{sat} = 0.17 \text{ W}$
$P_{dB} = 11\%$
TYPICAL EXTERNAL PORT ISOLATION OF BREADBOARD K-BAND 6-PORT CIRCULATOR

TYPICAL INTERJUNCTION ISOLATION OF BREADBOARD K-BAND 6-PORT CIRCULATOR
INPUT DRIVE LEVEL: +17 dBm
OPERATING GAIN COMPRESSION RATIO: 0.2 dB/dB
IMPATT DEVICE POWER ADDED EFFICIENCY: 18% (MAX)
DC POWER / STAGE: 6 W
(† COMM. AVAIL.)

MEASURED PERFORMANCE OF TWO-STAGE IMPATT PREAMPLIFIER
FUNCTIONAL BLOCK DIAGRAM OF S/Q BAND POWER UPCONVERTER
SIGNAL INPUT - 100 mw S-BAND

PUMP POWER LEVELS

MEASURED POWER OUTPUT - FREQUENCY RESPONSE OF S/Q-BAND USUC
FUNCTIONAL BLOCK DIAGRAM OF THE Q-BAND PHASE LOCKED SOURCE

LOCK STATUS DET/SEARCH WF GEN

Q-BAND GUNN OSC (VCO)

STABILIZED RF OUTPUT P0

LOOP AMP/LPF

5 MHz O-DET

DIVIDER ÷ 16

VHF IFA

HARMONIC MIXER

BUFFER AMPLIFIER

C-BAND PLO

ULTRA-STABLE REF INPUT (f_ref = 5 MHz)

LNR COMMUNICATIONS INC
MEASURED POWER UPCONVERTER CHARACTERISTICS

- Input frequency range 2-4 GHz
- Pump frequency 41 GHz
- Output frequency range 43-45 GHz
- Upper sideband output power 95mW (avg.)
- Passband output ripple 2 dB max. (P-P)
- Lower sideband rejection > 40 dB
- S-band input power 100mW
- Q-band pump power 400mW
- S-band input VSWR 1.3:1 (max)
- Q-band output VSWR 1.5:1 (max)
- Q-band PLO output power 105mW
- Projected ILO output power 450mW
\[ B_{\text{lock}} = \frac{2fp}{Q} \sqrt{\frac{P_0}{P_p}} > \Delta f_{o_p-p} \quad \text{(DRIFT)} \]

a) CIRCULATOR COUPLED IMPATT OSCILLATOR

b) HYBRID COUPLED GUNN DIODE OSCILLATORS

ALTERNATIVE INJECTION LOCKED OSCILLATOR CONFIGURATIONS
SCHEMATIC LAYOUT OF S/Q-BAND USUC
PERFORMANCE GOALS OF HIGH POWER S/Q-BAND UPCONVERTER

- Input frequency range 2-4 GHz
- Pump frequency 41 GHz
- Output frequency range (USB) 43-45 GHz
- Upper sideband output power 100mW (Nom.)
- Passband output ripple ±1.5 dB (Max.)
- Lower sideband rejection 40 dB (Min.)
- S-band input power 100mW (Max.)
- Q-band pump self-contained phase @ 41 GHz
- Q-band pump power 300mW (Nom.)
- Pump source phase locked loop (PLL) bandwidth 20 KHz (Nom.)
- Reference input frequency 5 MHz
- Pump source FM noise within PLL BW of carrier (fΔ 20 KHz) $8.2 \times 10^3 \Delta f_{\text{ref.}}$ (rms Hz/√Hz)
HIGH POWER S/Q BAND SATCOM UPLINK TRANSMITTER UNCONVERTER

LNR Communications

H. C. Okean
HIGH POWER S/Q BAND SATCOM UPLINK
TRANSMITTER UPCONVERTER

BY

H. DeGruyl, H.C. Okean and L.J. Steffek

Presented At
EHF SATCOM TECHNOLOGY WORKSHOP
San Diego, California
August, 1981

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HIGH POWER S/Q BAND SATCOM UPLINK

TRANSMITTER UPCONVERTER*

by

H. deGruyl, H.C. Okean and L.J. Steffek
LNR Communications, Inc.

A 100mW output S-to-Q band varactor upper sideband up-converter (USUC), including associated phase locked solid state Q-band pump source, is being developed for use in the 44 GHz uplink transmitter sections of the 44/20 GHz Navy SATCOM ground terminals. Utilizing a balanced pair of in-house GaAs Schottky varactors embedded in a composite waveguide/TEM structure, said USUC translates a 2 GHz wide digitally modulated signal spectrum from the 2-4 GHz input to the 43-45 GHz upper sideband output bands. At 400 mW pump power at 41 GHz and 50 mW signal input level, the upper sideband output power ranges between 60 and 110 mW over 43-45 GHz, with better than 40 dB lower sideband rejection.

*This effort was sponsored by the Naval Ocean Systems Center under Contract No. N00123-79-C-1529.
DEVELOPMENT STATUS FOR A 20 GHz FET SPACECRAFT TRANSMITTER

Texas Instruments

V. Sokolov
DEVELOPMENT STATUS FOR A 20 GHZ FET SPACECRAFT TRANSMITTER

BY

V. Sokolov, R.C. Bennett, P. Saunier,
R.P. Lindsley, C.H. Moore, and R.E. Lehmann

Texas Instruments Incorporated
Central Research Laboratories
P.O. Box 225936
Mail Station 134
Dallas, Texas 75265

This work is supported by NASA (LERC) under Contract No. NAS3-22504
BASIC PERFORMANCE SPECIFICATIONS
(GOALS)
INTEGRATED POC MODEL POWER AMPLIFIER

- Center Frequency: 19 GHz ($f_0$)
- RF Gain at $f_0$: 30 dB
- Output Power at $f_0$: 7.5 W ($P_0$)
- 1 dB Bandwidth: 17.7-20.2 GHz
- Efficiency at $P_0$: 10%
- Third Order Intermodulation Products: At least 20 dBc at $P_0$
- RF Connectors: WR-51 Waveguide
- Operation of POC Model Over 0°-75°C Baseplate Temperature Range
Block Diagram of General Design Approach
20 GHz Amplifier Assembly Single Surface for Mounting and Heat Transfer
DEVELOPMENT STATUS FOR A 20 GHz FET SPACECRAFT TRANSMITTER

OUTLINE

- AMPLIFIER PERFORMANCE GOALS
- AMPLIFIER BLOCK DIAGRAM
- 20 GHz FET DEVICES
- WAVEGUIDE DIVIDER/COMBINER DEVELOPMENT AND AMPLIFIER ASSEMBLY DRAWINGS
- AMPLIFIER MODULE DEVELOPMENT
- STATUS AND SUMMARY
WR-51 Flange and E-Bend

WR-51 Flange

WR-51 Magic Tee with Loaded Fourth Port

Block Diagram of Power Divider/Combiner
(a) Outline of the substrate inserted in the waveguide. (b) Position of the planar circuit in the waveguide.

A Low-Loss Transition from Waveguide to Microstrip
MODULE AMPLIFIER BLOCK DIAGRAM
(BREADBOARD VERSION)

TRANSITION LOSS
(dB)
-3 dBm
-0.3
5.5
5.5
5.3

STAGE GAIN

5.3
5.0
4.0
-0.3

27 dBm
Output

FET GATE WIDTH
(microns)

{150, 150, 150}
{300, 1350, 2x1350}

Nominal Drain Current (mA)

{30, 30, 30}
{60, 250, 500}

Nominal Drain Voltage ~7 V
20 GHz FETs

150 μm Gate Width Device

300 μm Gate Width Device
20 GHz FETs

600 μm Gate Width FET
Chip Dim: 0.76 x 0.3 mm

1350 μm Gate Width FET
Chip Dim: 1.5 x 0.3 mm
PERFORMANCES

- Tests are performed on 300 μm gatewidth devices at 15 GHz

- Small signal gain with 5 V on the drain (5 dBm input power)
  9 to 10.5 dB

- Input power versus output power with 8 V on the drain

![Graph showing input power versus output power with 6 dB and 4 dB lines, and a best device V_ds = 9.5 V marker.][1]
Gain Compression Curve for 1350 µm π-Gate FET
(In 5th Stage Amplifier Circuit)

F = 19.0 GHz
V_D = 8.0 V
V_G = -1.34 V
I_D ≈ 270 mA
Device: 1350 µm (80E13)

Small Signal Gain is 6.0 dB
1 dB Gain Compression Point is +26.6 dBm
DEVICES

STATUS

- About 150 μm gate 1350 μm devices are available

- A sufficient number of 150 μm and 300 μm devices have been fabricated for immediate need
16-WAY MANIFOLD REQUIREMENTS

PURPOSE: THE POWER DIVIDER/COMBINER WILL PROVIDE UNIFORM AMPLITUDE AND PHASE TO EACH OF 16 AMPLIFIER MODULES, AND WILL RECOMBINE THE OUTPUT POWER OF THE 16 MODULES FOR MAXIMUM EFFICIENCY

**ELECTRICAL**

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<th>PARAMETER</th>
<th>DESIGN GOAL</th>
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<td>FREQUENCY</td>
<td>17.7 TO 20.2 GHZ</td>
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<td>VSWR, INPUT</td>
<td>1.25:1 MAX</td>
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<tr>
<td>AMPLITUDE VARIATION</td>
<td>± 0.2 DB</td>
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<tr>
<td>PHASE VARIATION</td>
<td>± 5.0 DEGREES</td>
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<td>INSERTION LOSS</td>
<td>0.8 DB MAX</td>
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<td>ISOLATION (BETWEEN OUTPUTS)</td>
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**MECHANICAL**

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<td>WEIGHT</td>
<td>1.6 POUNDS MAX</td>
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<tr>
<td>SIZE</td>
<td>COMPATIBLE WITH OVERALL PACKAGING CONCEPT</td>
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<tr>
<td>INPUT PORT</td>
<td>1, WR-51 WAVEGUIDE</td>
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<tr>
<td>OUTPUT PORT</td>
<td>16, MODULE COMPATIBLE WR-51</td>
</tr>
</tbody>
</table>
20 GHz MANIFOLD DESIGN

- A SINGLE MANIFOLD CONSISTS OF A 16-WAY MATCHED WAVEGUIDE POWER DIVIDER.
- LIGHT WEIGHT, DIP-BRAZED ALUMINUM CONSTRUCTION OFFERS LOW LOSS PERFORMANCE.
- FOUR "QUADS" PER MANIFOLD ASSEMBLY OFFERS MODULAR CONSTRUCTION.
- THE MODULAR HEAT SINK DESIGN PROVIDES EASY INTERFACE WITH A COLD PLATE.
- A PAIR OF MANIFOLDS FOR EACH PROOF-OF-CONCEPT TRANSMITTER Allows POWER DIVISION AT THE INPUT AND LOW LOSS POWER COMBINING AT THE OUTPUT.
- STANDARD TEST EQUIPMENT FLANGES (HEWLETT PACKARD STYLE) ARE PROVIDED ON THE INPUT/OUTPUT PORTS.
MECHANICAL DATA

RF INPUT INTERFACE
WR-51 WAVEGUIDE FLANGE
(HEWLETT PACKARD VERSION)

RF OUTPUT INTERFACE
WR-51 WAVEGUIDE FLANGE
(HEWLETT PACKARD VERSION)

D.C. POWER INPUT
MS TYPE CONNECTOR
MS3101R-20-16P

MOUNTING
INTERFACE SURFACE ACTS
AS MOUNTING SURFACE AS
WELL AS THERMAL CONDUCTOR

WEIGHT
13.8 LBS.

SIZE (CLEARANCE)
8.60 IN. X 8.50 IN. X 7.60 IN.

VOLUME (MAX)
556 IN.³
THERMAL DESIGN

REQUIREMENTS (Worst Case)

A. Maximum Device Temperature - 100°C
B. Maximum Temperature Variation Between Modules - 10°C
C. Operate in a 75°C Environment

ANALYSIS DATA

AMPLIFIER CARRIER TEMPERATURE

<table>
<thead>
<tr>
<th>Assembly</th>
<th>Power (W)</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Amplifier Assembly</td>
<td>0.72</td>
<td>90°C</td>
</tr>
<tr>
<td>Second Amplifier Assembly</td>
<td>0.48</td>
<td>90°C</td>
</tr>
<tr>
<td>Third Amplifier Assembly</td>
<td>2.0</td>
<td>94°C</td>
</tr>
<tr>
<td>Fourth Amplifier Assembly</td>
<td>4.0</td>
<td>99°C</td>
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</tbody>
</table>

Heat Sink/Mounting Plate 75°C
TWO QUAD ASSEMBLIES TERMINATION BLOCK, AND FLANGE ADAPTORS

Insertion Loss (Top Trace): 0.5 dB/div
Center Line Ref. = 0 dB

Return Loss: 10 dB/div
Center Line Ref. = 0 dB

Frequency Range: 17.7-20.2 GHz

RF PERFORMANCE OF A PAIR OF BACK TO BACK QUAD ASSEMBLIES (FIRST ASSEMBLY, PRELIMINARY RESULTS ONLY)
Waveguide-to-Microstrip Transition
Test Fixture and Test Circuit
FREQUENCY RESPONSE
OF
TWO WAVEGUIDE-TO-MICROSTRIP TRANSITIONS
(BACK-TO-BACK)
Etched Circuit Pattern

Alumina or Quartz Substrate

FET

Bias Choke

Copper Block

Typical Carrier Block with Microstrip Impedance Matching Circuit

<table>
<thead>
<tr>
<th>First Three Stages</th>
<th>Fourth Stage</th>
<th>Fifth Stage</th>
<th>Sixth Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>[3 x 150 μm]</td>
<td>[300 μm]</td>
<td>[1.35 mm]</td>
<td>[2 x 1.35 mm]</td>
</tr>
</tbody>
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Length of Four Blocks - 2.25"

Transition Length - ~ 1.50" each

Total Module Length - ~ 5.25"

FET Carrier Blocks Used in Breadboard Amplifier