A LINEAR GaN UHF SSPA WITH RECORD HIGH EFFICIENCY

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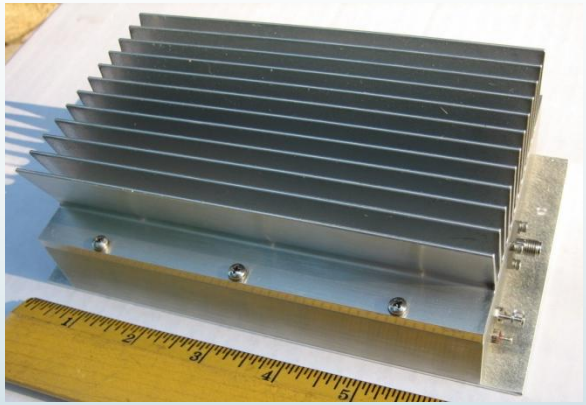
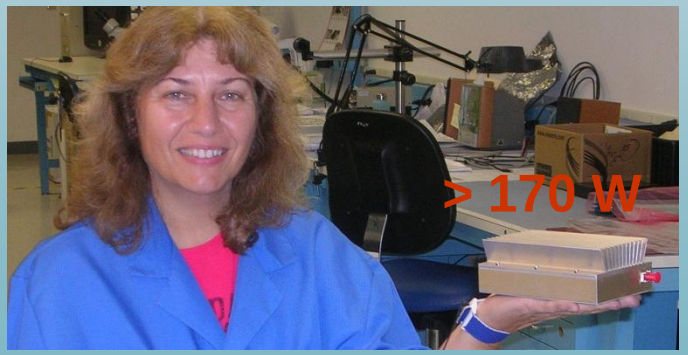




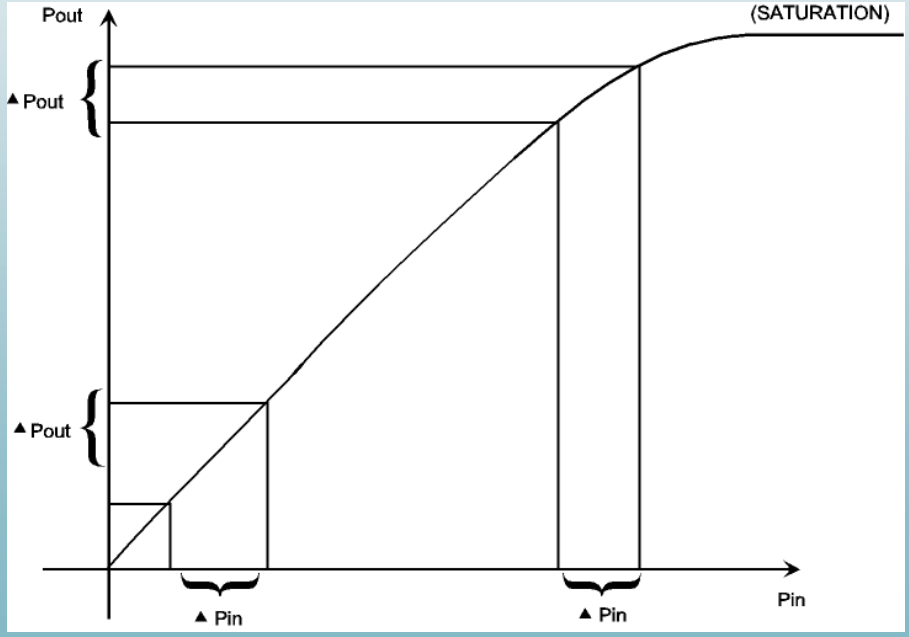
INTRODUCTION

OBJECTIVE: TO PRODUCE LINEAR UHF PA WITH THE HIGHEST POSSIBLE EFFICIENCY

TARGET: SPACE / AVIONICS APPLICATIONS

- PA EFFICIENCY IS CRITICAL FOR PORTABLE/MOBILE –
  MINIMIZE BATTERY
  SPACE – NEED HIGHEST EFF

- LINEAR AMPLIFIERS AT DISADVANTAGE
  NEED HIGH BACKOFF



GaN VS. GaAs AT UHF

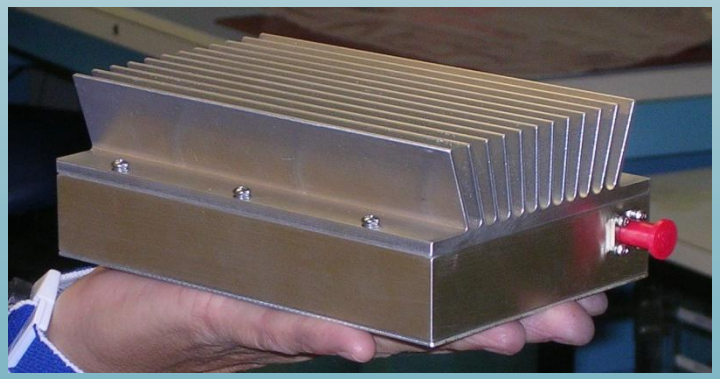
- **GaAs PAs**
  - LONG HISTORY OF USE IN SPACE AT MICROWAVE
  - RECENTLY USED AT UHF FOR HIGH EFFICIENCY
  - PRIMARILY FOR SPACE (PAE > 60%)
  - LINEARIZATION USED FOR OPERATION CLOSER TO SATURATION

- **GaN PAs**
  - SHOW GaN FETS PROVIDES EVEN BETTER EFFICIENCY (PAE > 85%)
  - LINEARITY NOT AS WELL BEHAVED: LINEARIZATION EVEN MORE IMPORTANT

SSPA DETAILS

DEVELOPED A DEMONSTRATION PA

- **OPERATING AT UHF (290 TO 320 MHz)**
- **EMPHASIS ON ACHIEVING PEAK EFFICIENCY**
  - **SELECTED EUDYNA EGN90MK GaN POWER FETS**
- **USED ADVANCED ANALOG LINEARIZATION**
- **COMPACT & LIGHT WEIGHT**
- **HIGH GAIN WITH EXCELLENT FLATNESS**

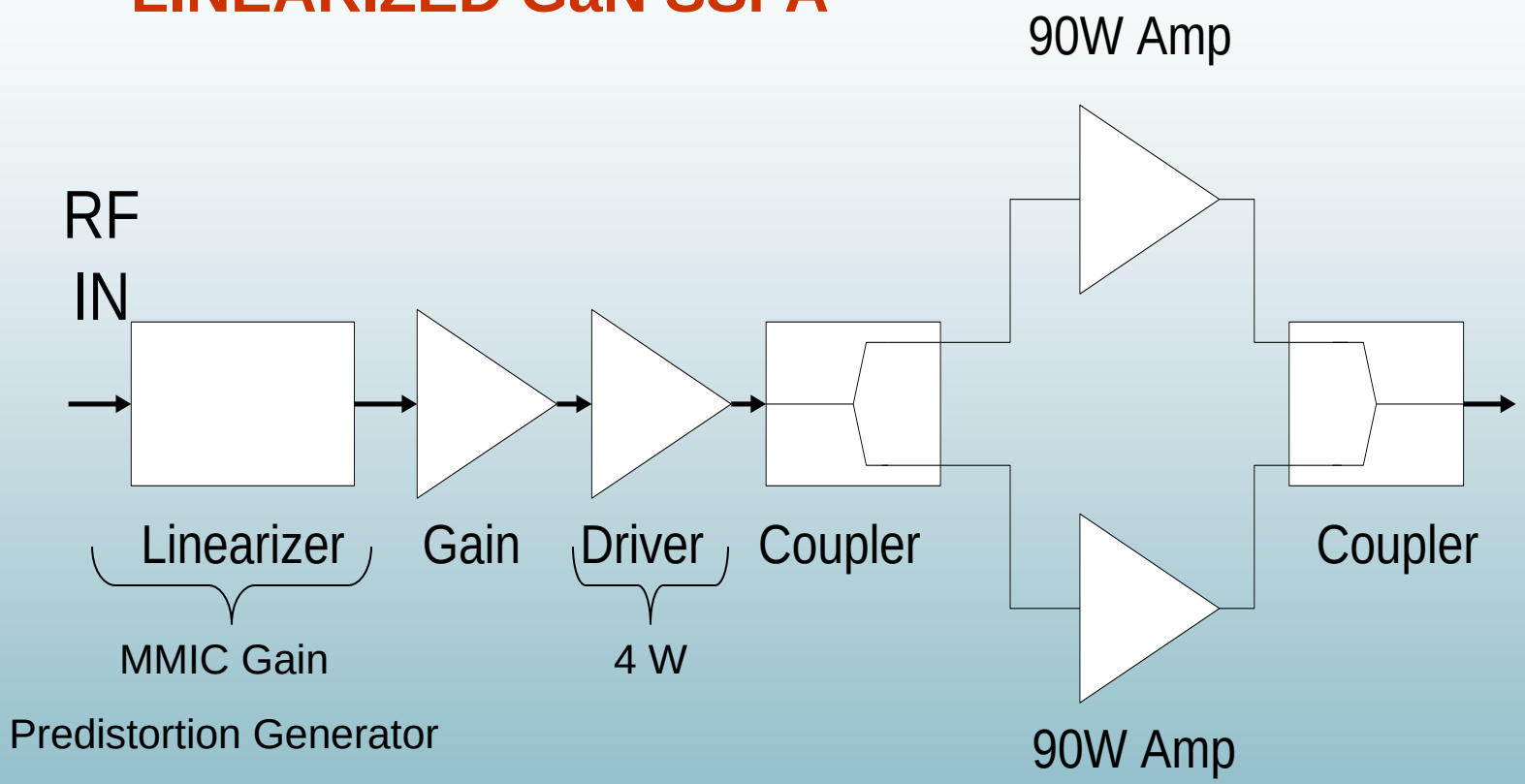


REQUIRED PA SPECS

Specification	Min	Max	Units	Conditions
Power out	100	-	Watts	At linear operating point
Efficiency	70	-	%	At linear operating point
Bandwidth	291	318.3	MHz	-
VSWR	-	1.5:1	-	Z_o = 50 Ohms
Gain	30	-	dB	-
Gain Flatness	-	+/- 0.5	dB	-
Spurious Signals	-	-60	dBc	-
Harmonic Signals	-	-30	dBc	-
Spectral Regrowth	-	-16	dBc	QPSK modulated carrier at +/- 1 symbol rate.
EVM	-	4	%	QPSK modulated.

DESIGN APPROACH

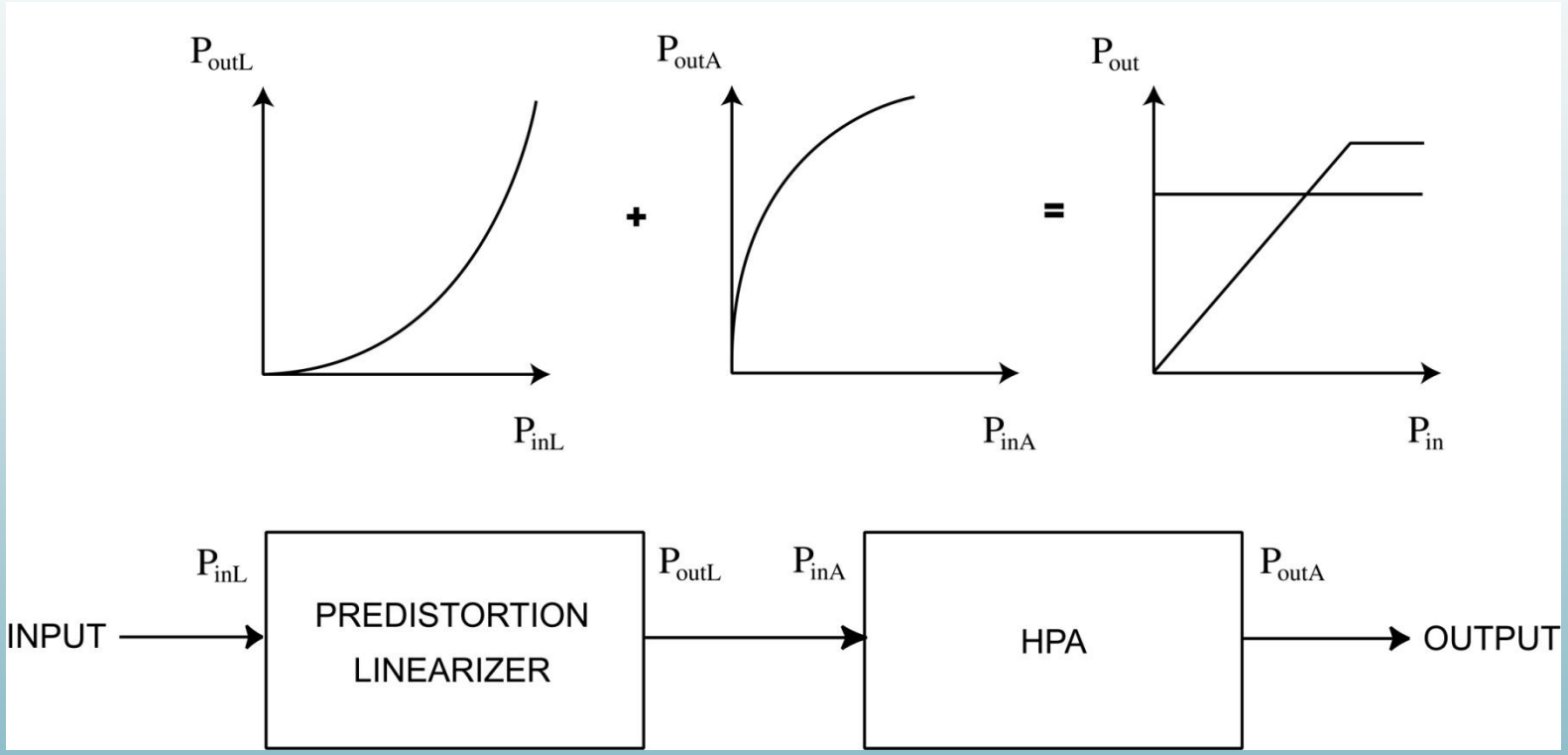
LINEARIZED GaN SSPA



- **USES 90 W GAN FET POWER STAGES BETWEEN COUPLERS**
- **OPTIMIZED FOR HIGH EFFICIENCY FROM 290 – 320 MHz**

THE LINEARIZER

PREDISTORTION LINEARIZER – GENERATES FUNCTION WITH INVERSE MAG AND PHASE TO TRANSFER FUNCTION OF PA

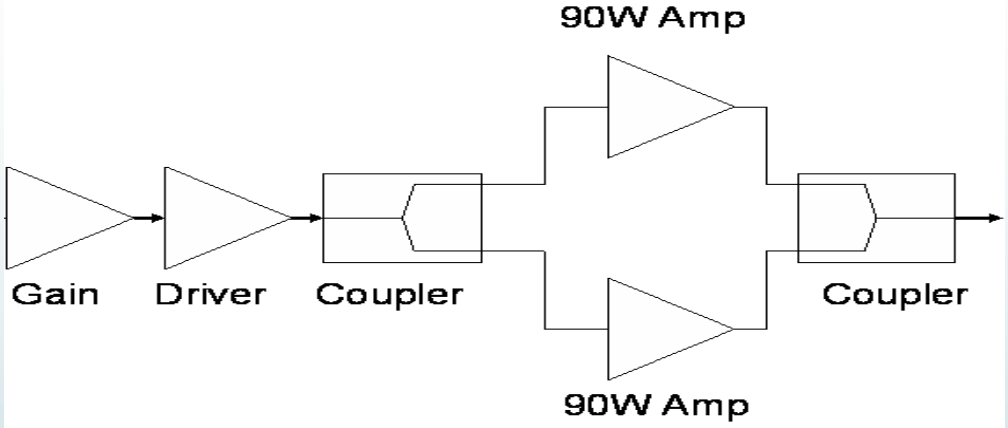


PREDISTORTS RF SIGNAL TO COMPENSATE FOR KNOWN NON-LINEARITIES IN PA FROM HIGHLY LINEAR OUTPUT

THE LINEARIZER

- **GOAL OF SSPA**: AMPLIFY AS EFFICIENTLY AND LINEARLY AS POSSIBLE – CONFLICTING
- INCREASE EFFICIENCY: DRIVE FET CLOSER TO SATURATION → SAME DISTORTION
- TWO CONTROLS
  - PHASE CONTROL: SETS PHASE CHANGE TO GAIN CHANGE RATIO FOR INCREASED INPUT
  - MAG CONTROL: SETS AMOUNT OF GAIN/PHASE INCREASE FOR GIVEN INPUT
- MOVED 1 dB COMPRESSION POINT OF SSPA 3 dB CLOSER TO SATURATION

POWER AMPLIFIER

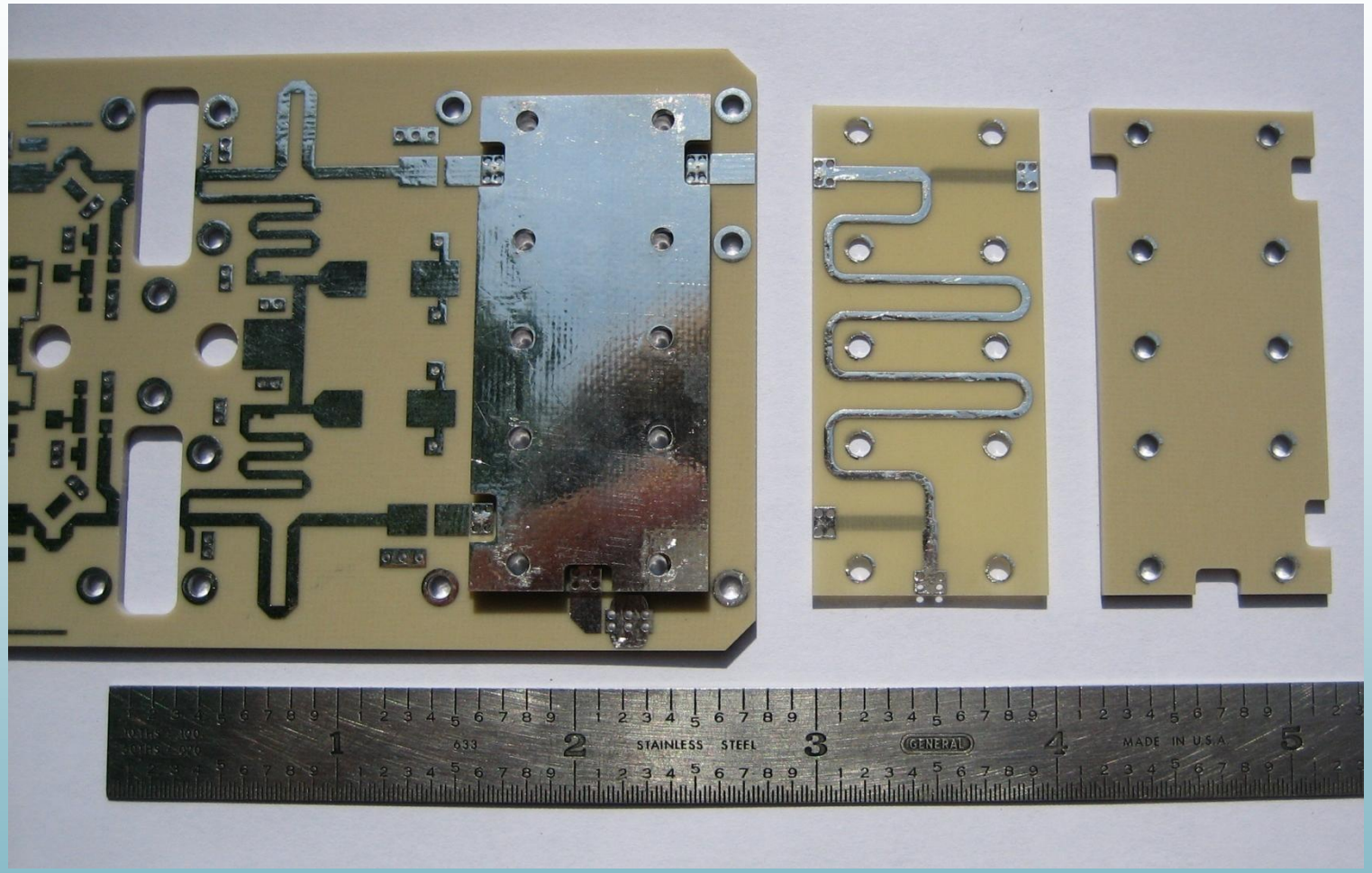


- GAIN AND DRIVER STAGES USED TO:
  1. OFFSET LOSSES FROM PREDISTORTER (10 dB)
  2. RAISE RF SIGNAL TO LEVEL REQUIRED TO DRIVE DUAL 90 W AMPLIFIERS
- CONSISTS OF:
  - ONE EUDYNA EGN004MK GaN FET (4 W)
  - TWO EUDYMA EGN090MK GaN FETS (90 W)
  - BROADSIDE COUPLERS (LOW INSERTION LOSS)

POWER AMPLIFIER

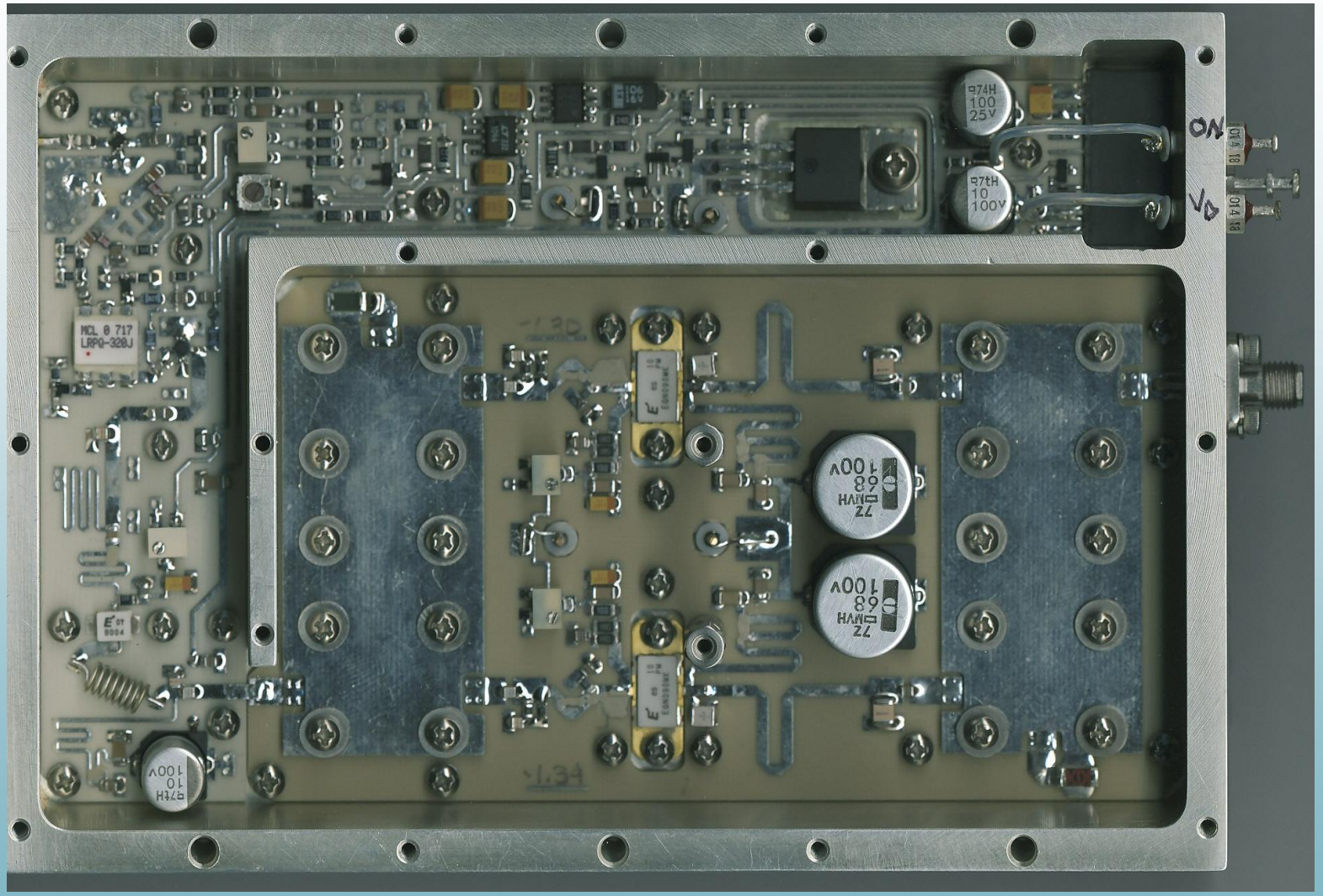
- USES MICROSTRIP INTERCONNECTIONS ON ROGERS 4003 LOW DIELECTRIC 32 MIL MATERIAL
- WITH MULTIPLE VIA HOLES FOR A GOOD GROUND RETURN
- PROPER DESIGN OF DRAIN AND GATE DECOUPLING IS IMPORTANT *(MEMORY EFFECTS*).
  - **GaAs DEVICES' LARGE CURRENTS CAUSE MEMORY EFFECTS**
  - **GaN'S RELATIVE LOWER CURRENTS MAKE LESS CRITICAL**
- THE IMPEDANCE OF THE MATCHING NETWORKS AND BIAS CIRCUITS AT THE SECOND HARMONIC FREQUENCY IS AN IMPORTANT CONTRIBUTOR TO PA EFFICIENCY

BROADSIDE COUPLER



MULTI-LAYER STRIPLINE DESIGN

ASSEMBLED SSPA

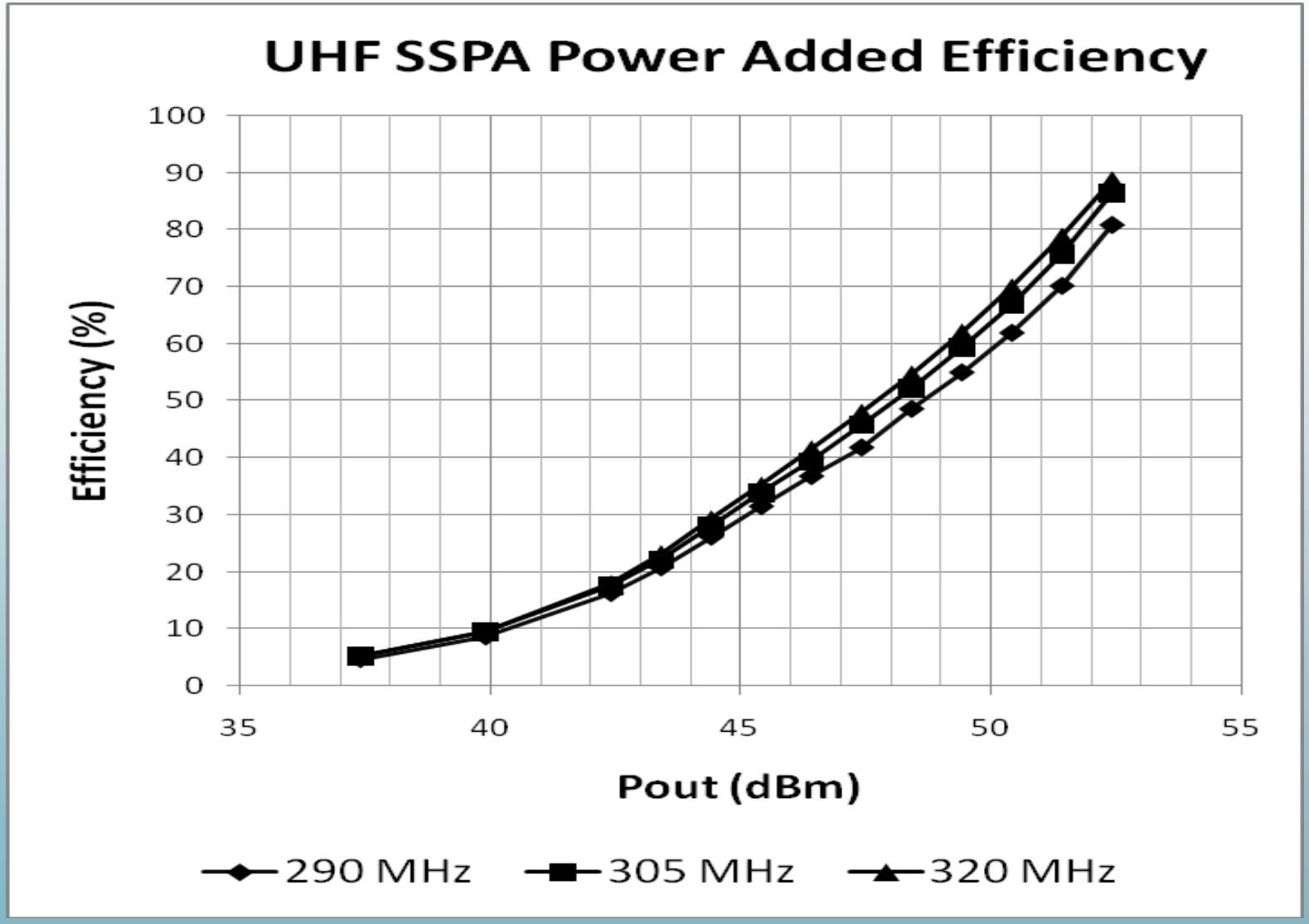


TEST RESULTS

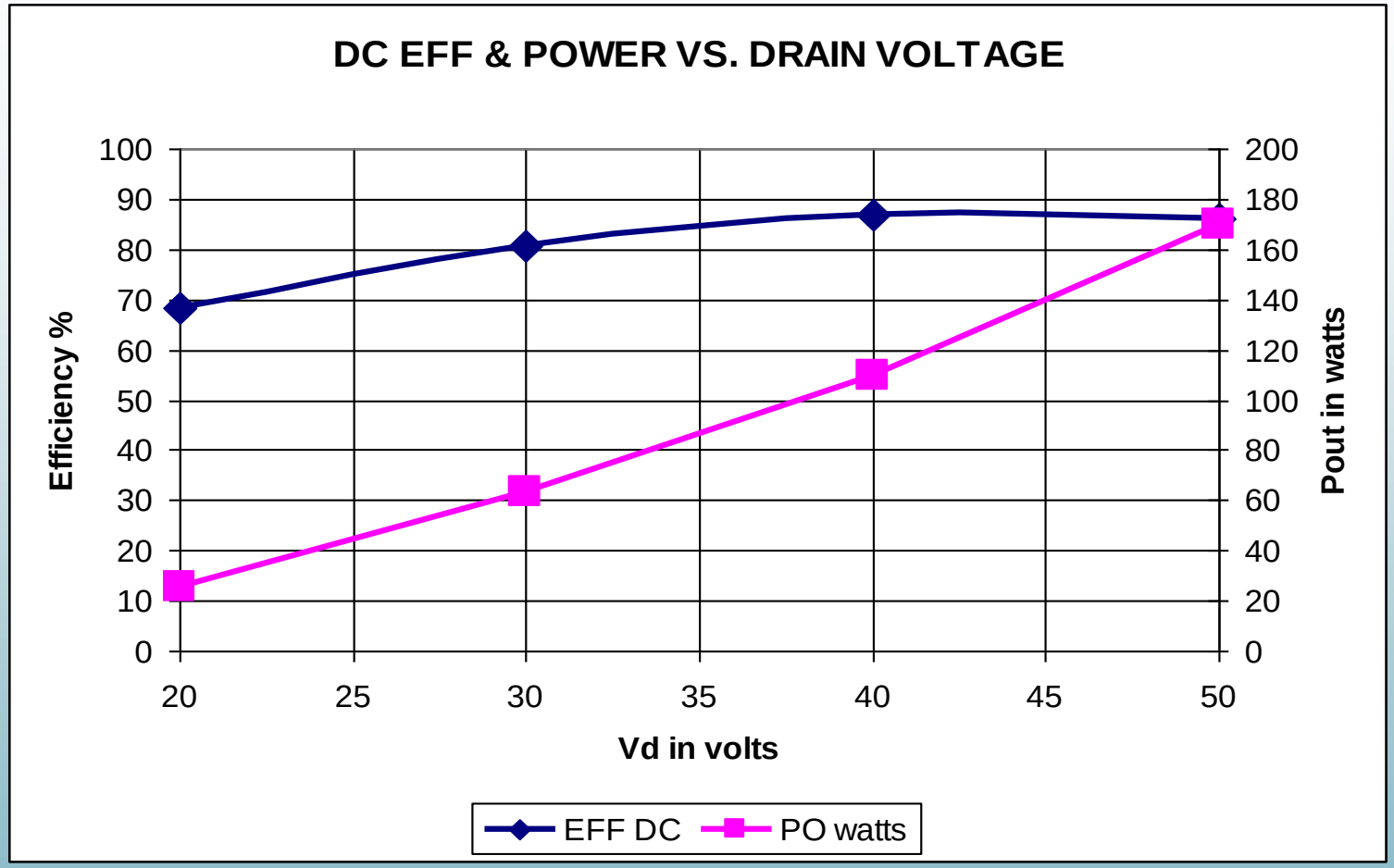
DATA AT CENTER BAND (305 MHz):

OPBO (dB)	Pin (dBm)	Pout (dBm)	VDC	IDC	Pout (W)	PAE (%)
At Saturation → **0**	**-27.3**	**52.3**	**49.9**	**3.94**	**169.8**	**86.36**
1	-32.0	51.3	49.96	3.57	134.9	75.63
2	-33.9	50.3	50.00	3.21	107.1	66.76
3	**-35.4**	**49.3**	**50.0**	**2.87**	**85.11**	**59.27**
4	-36.5	48.3	50.08	2.59	67.61	52.12
5	-37.4	47.3	50.11	2.34	53.70	45.80
6	-38.3	46.3	50.15	2.16	42.66	39.38
7	-39.1	45.3	50.15	1.99	33.88	33.95
8	-40.0	44.3	50.16	1.91	26.92	28.09
9	-41.0	43.3	50.16	1.92	21.38	22.20
10	-42.0	42.3	50.16	1.92	16.98	17.63
12.5	-44.6	39.8	50.15	2.00	9.55	9.52
15	-47.2	37.3	50.15	2.03	5.37	5.28

POWER ADDED EFFICIENCY

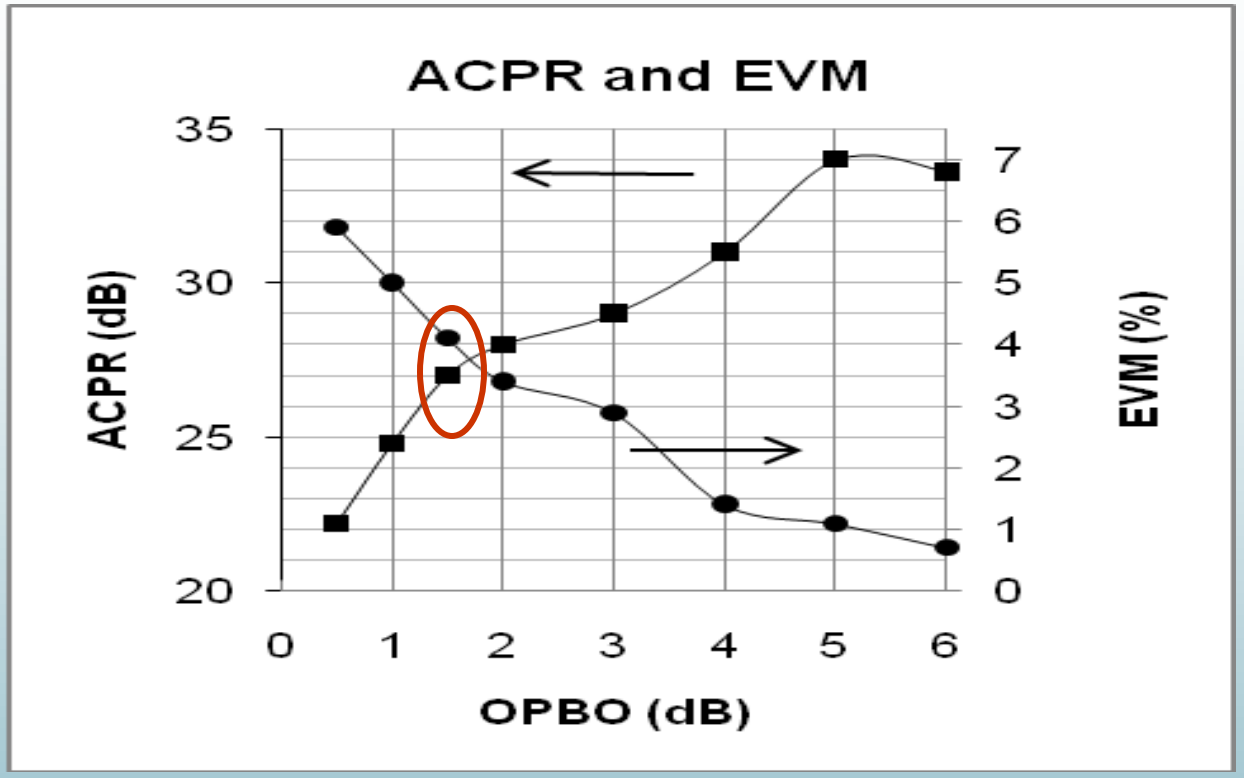


EFFICIENCY AND POWER VS. V DRAIN



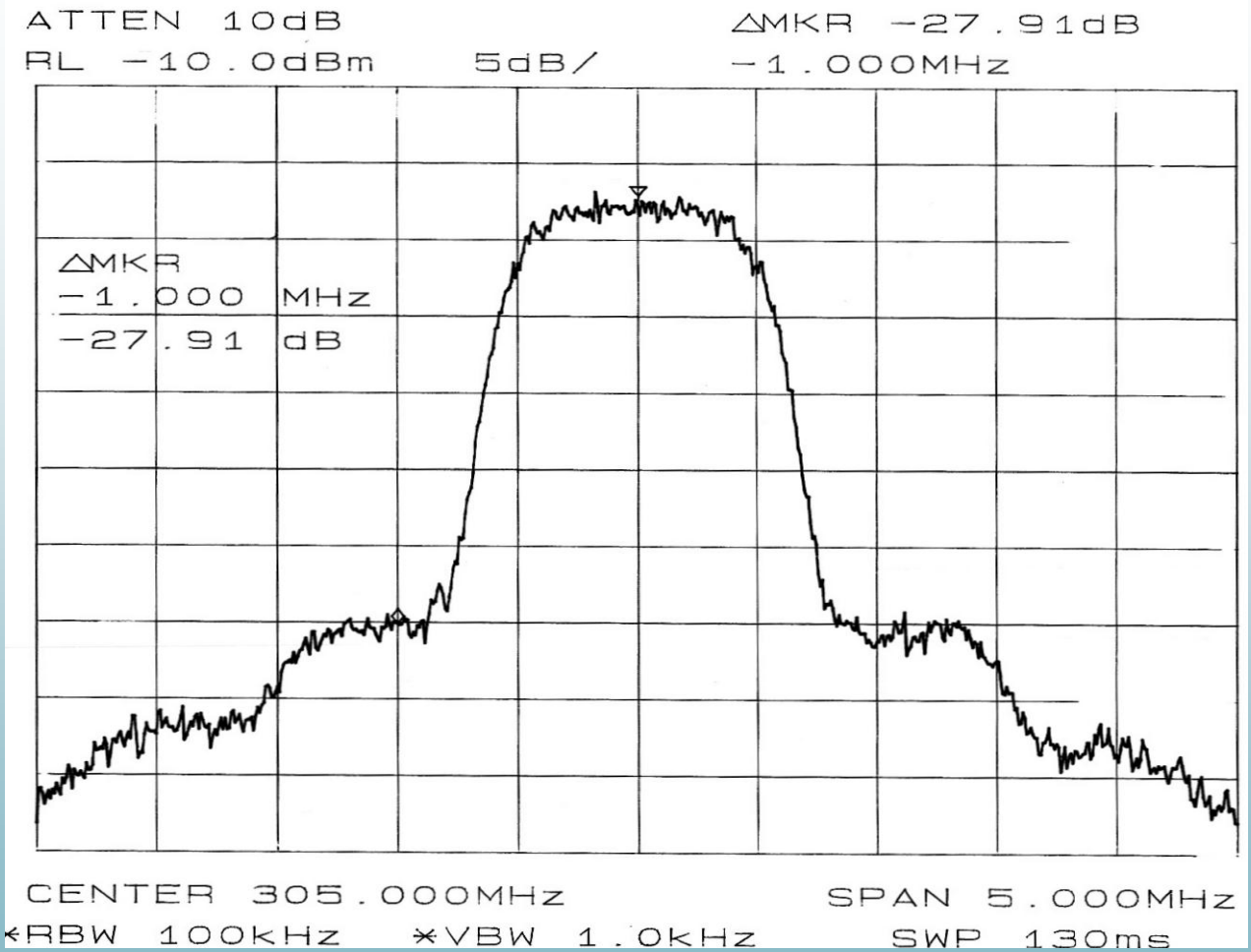
EFFICIENCY > ~70% FROM 20 TO 50 V

ACPR AND EVM VS. Pout



- WORST CASE LINEARITY ACROSS BAND
- Vd ADJUSTED FOR > 100 W AT SPEC'D LINEARITY
- PA BIASED AT 40 V WITH I_Q OF 2.5 A
- PAE OF 70% (1.6 dB OPBO)

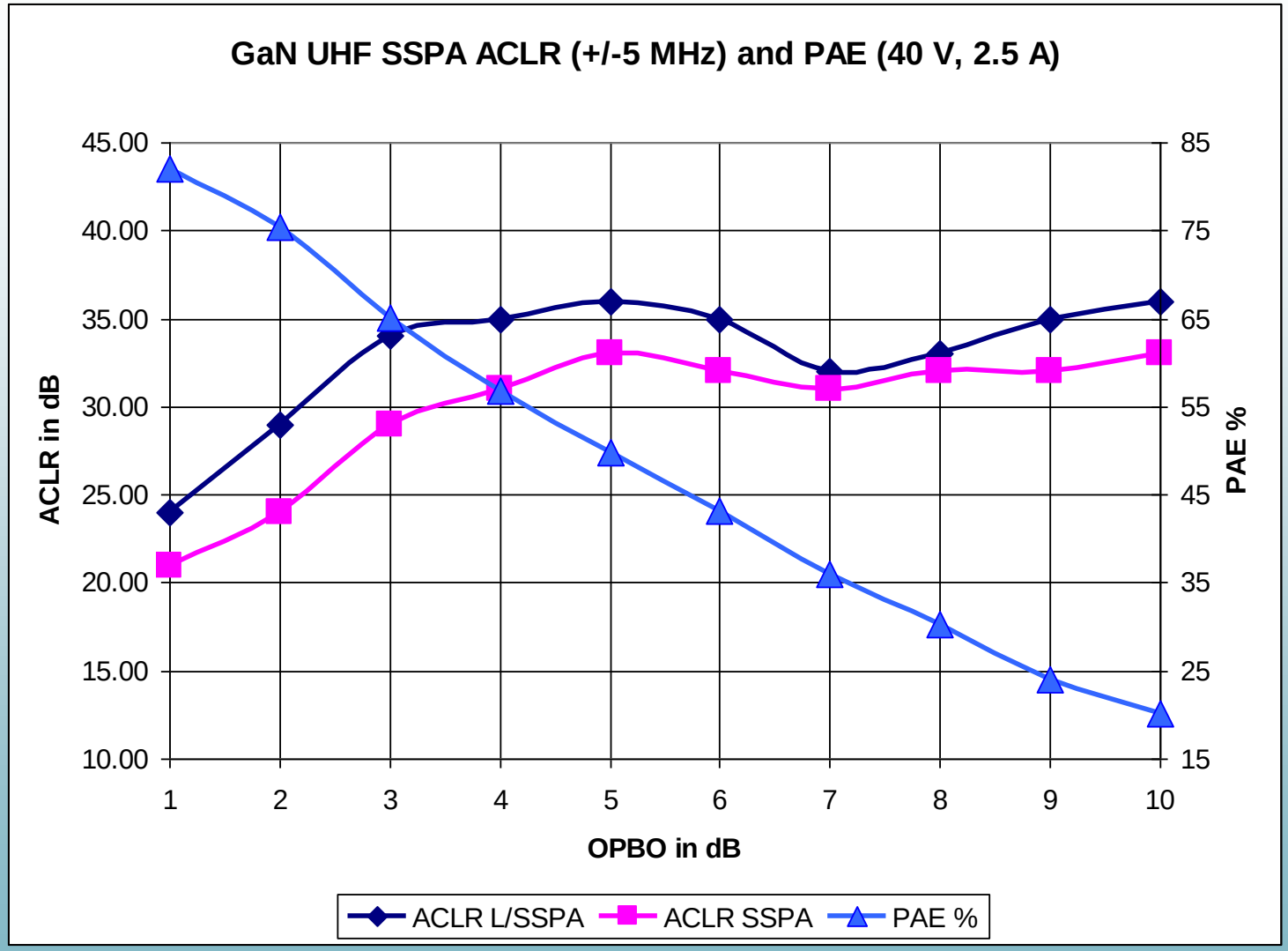
QPSK ACLR @ 1.6 dB OPBO



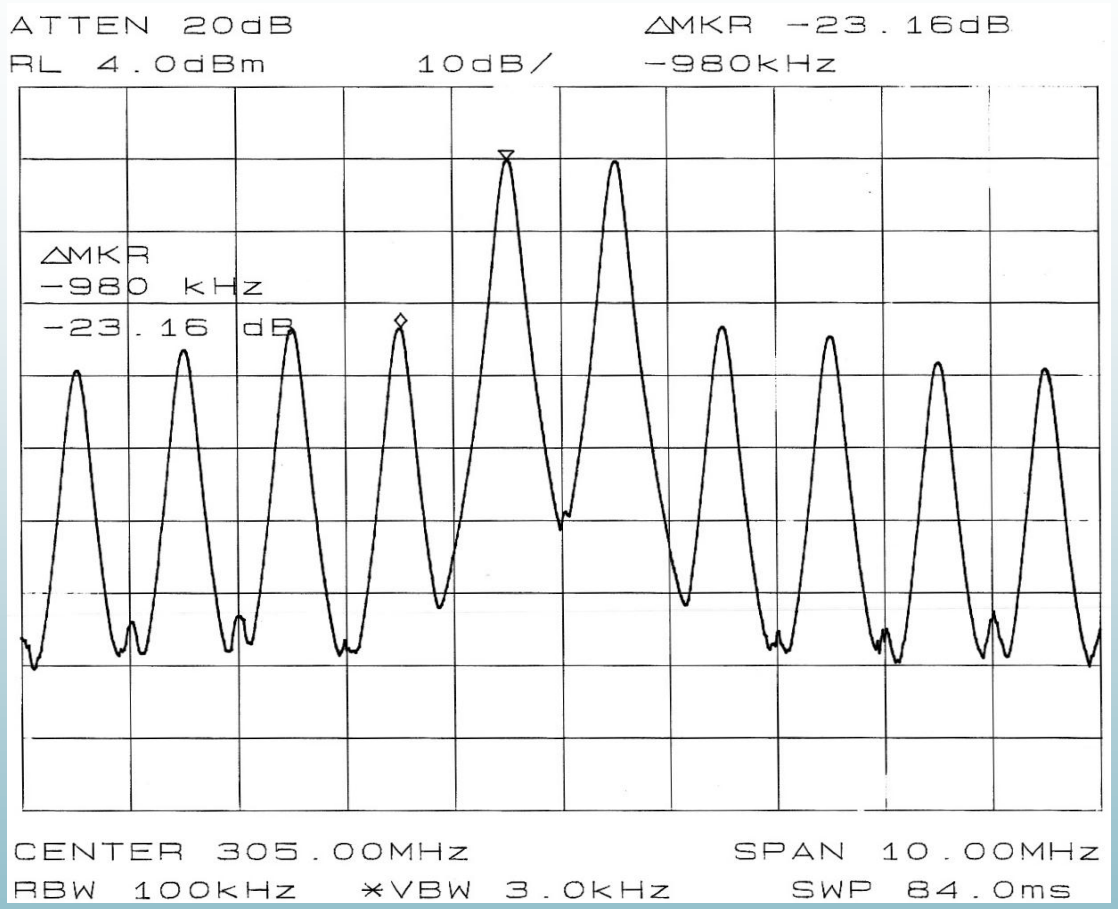
→ ACLR BETTER THAN 27 dB ←

WCDMA ACLR & PAE

ACLR -25 dB
OPBO 1.2 dB
PAE ~80%,

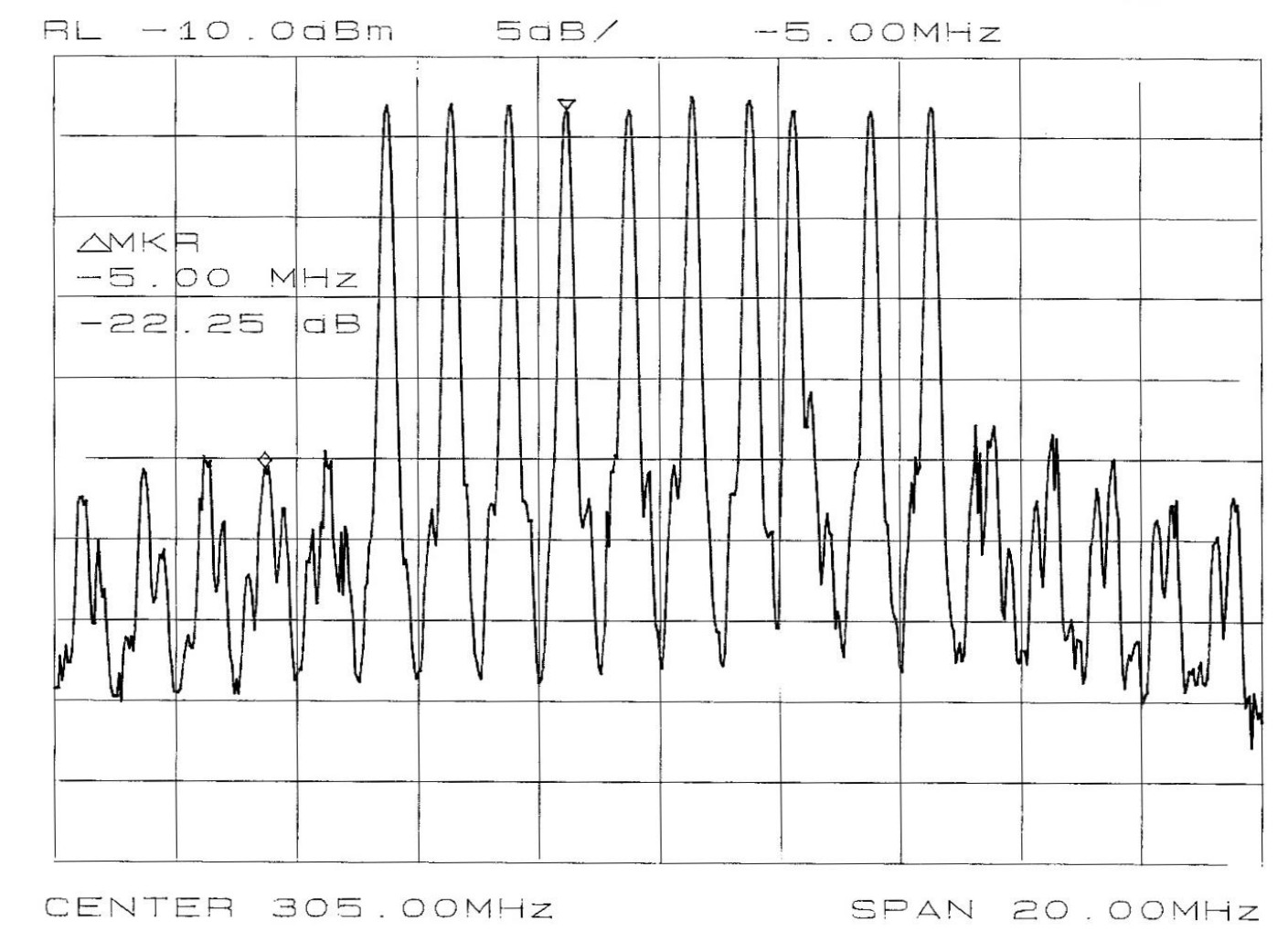


MULTI-TONE C/I PERFORMANCE



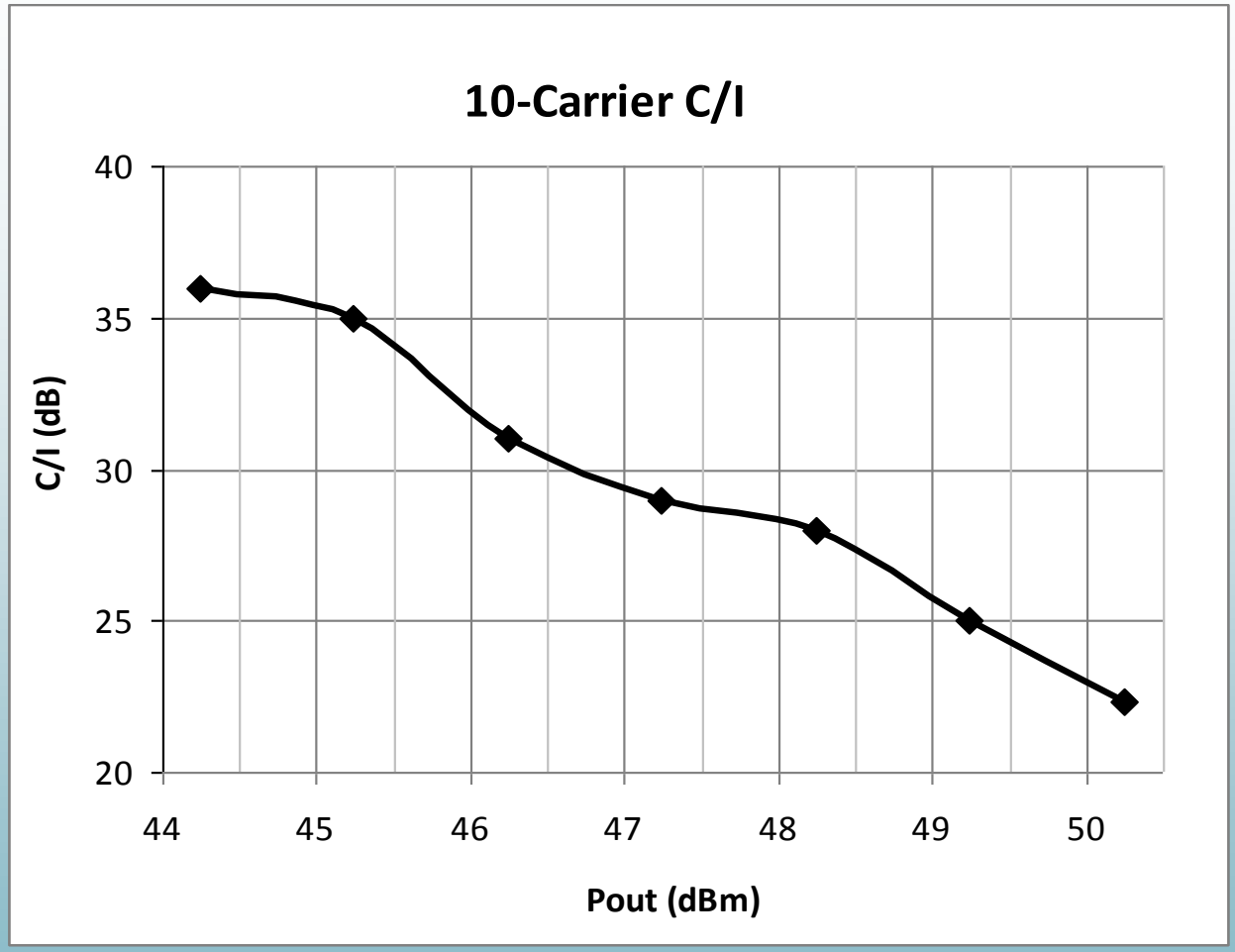
ACHIEVED C/I OF 25 dB AT SLIGHTLY > 2 dB OPBO WITH LINEARIZATION

TEN CARRIER C/I AT 2 dB OPBO



10-CARRIER C/I PERFORMANCE

- BIASED 50 V AND Iq 2.5 A
- OPBOs 2 TO 8 dB
- CENTERED 305 MHz



10-TONE C/I > 25 dB ACHIEVED AT 3 dB OPBO

ACHIEVED

- EMPHASIS ON EFFICIENCY
  - PEAK EFFICIENCY APPROACHES 90%
  - > 84% EFFICIENCY ACROSS 290 TO 320 MHZ BAND
  - MAINTAINS EFFICIENCY OVER WIDE POWER RANGE (~30 TO > 170 W)
- ADVANCED ANALOG LINEARIZATION
  - SPECTRAL REGROWTH > 20 dB AT 0.5 dB OPBO (> 76% EFF)
  - WCDMA ACLR 25 dB AT 1.2 dB OPBO (~80% EFF)
  - 2-TONE C/I > 25 dB AT 2.5 dB OPBO (> 60% EFF)
- COMPACT & LIGHT WEIGHT
  - 6” X 4” X 1” (WITHOUT HEAT SINK)
  - 2.5 LBS WITH HEAT SINK
- HIGH GAIN WITH EXCELLENT FLATNESS
  - > 50 dB SMALL SIGNAL GAIN WITH ±0.5 dB FLATNESS

CONCLUSION

- PROVIDED > 100 W OF LINEAR OUTPUT POWER FROM 290 – 320 MHz.
- QPSK EVM <4%, ACLR >16 dB (27 dB), PAE > 70%
- SHOWS THAT PREDISTORTION LINEARIZATION COMBINED WITH GaN DEVICES CAN PROVIDE HIGH LINEARITY AND EFFICIENCY.
- BELIEVED HIGHEST EFF REPORTED FOR CLASS AB AMPLIFIER TO DATE.

OUR THANKS TO ONR NSWC DAHLGREN FOR SUPPORTING THIS WORK UNDER CONTRACT NUMBER N00178-08-C-3010.