FTF 2016
TECHNOLOGY FORUM

PORTABLE RF HEATING APPLICATIONS

DESIGN CHALLENGES AND SOLUTIONS

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RF SYSTEMS & SOLUTIONS
SESSION FTF-HMB-N1995
17 MAY 2016

AGENDA

- Introduction to NXP’s RF Power Portfolio
- The Wayv Portable Cooking Appliance
  - What problem are we trying to solve?
- Principles of RF Heating
- Selection of Design Considerations
  - Design Challenge Overview
  - Electrical System Diagram
  - Heating Cavity
  - Power Amplifier Device Selection & Design
  - Heating Algorithm
- Cooking Results

RF POWER IN EVERYDAY LIFE

Cellular Infrastructure

- Cellular Standards to 5G
- 700 MHz to 5 GHz; 0.1 W to 500W
- Complimented by Network Processing, Baseband Processing

Solid State Heating

- RF Cooking, RF Heating, RF Drying, Plasma Generation
- 50 MHz to 4 GHz; 0.1 W to 1.5 kW

Industrial & Healthcare

- Magnetic Resonance Imaging, Plasma Etch, CO2 Lasers, Particle Accelerators
- 13 MHz to 2.9 GHz; 0.1 W to 1.8 kW

Other Communication

- Military/Defence, Radar/Avionics, Broadcast TV & Radio, Personal Mobile Radio
- 50 MHz to 5 GHz; 0.1 W to 1kW

RF Power Products for **EVERY APPLICATION**

- LDMOS
- GaN
- GaAs

→ DISCRETE DEVICES

→ HIGHLY INTEGRATED RFICS

THE WAYV PORTABLE HEATER

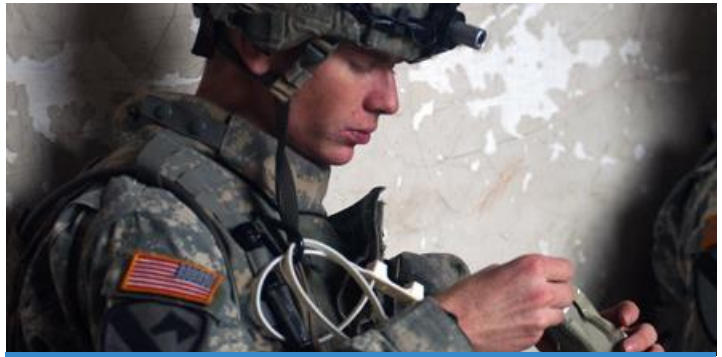
HEAT FOOD… ANYWHERE

- Solid state cooking appliance
- Heat food safely, cleanly & quickly
- Handheld and lightweight
- Rechargeable by mains or in car
- Easy to operate
- 30 minute operational time
- Safe for users and environmentally friendly:
  - No toxic carbon monoxide fumes
  - No fossil fuels
  - No risk of fire

WAYV PORTABLE HEATER USERS

Outdoor
Enthusiasts

- Heat foodstuffs, including ready to eat meals
- Warm coffee, tea or soup
- Alternative to camping stoves or open fires
- Safe from carbon monoxide fumes



Military
Personnel

- Heat MREs (food packets)
- Warm coffee, tea or soup
- Silent operation
- Significant reduction in logistical challenges to feed soldiers
- No ambient light on covert missions

People
On the Go

- Heat snacks and meals away from home
- Warm coffee, tea or soup
- Warm baby food
- Hot food and drinks in the office
- Charges from the car and mains

BRINGING IDEAS TO REALITY

wayv

THE CONCEPT

- Use Cases &Target Applications
- Performance Requirements
- **Realized Form and Fit**

NXP

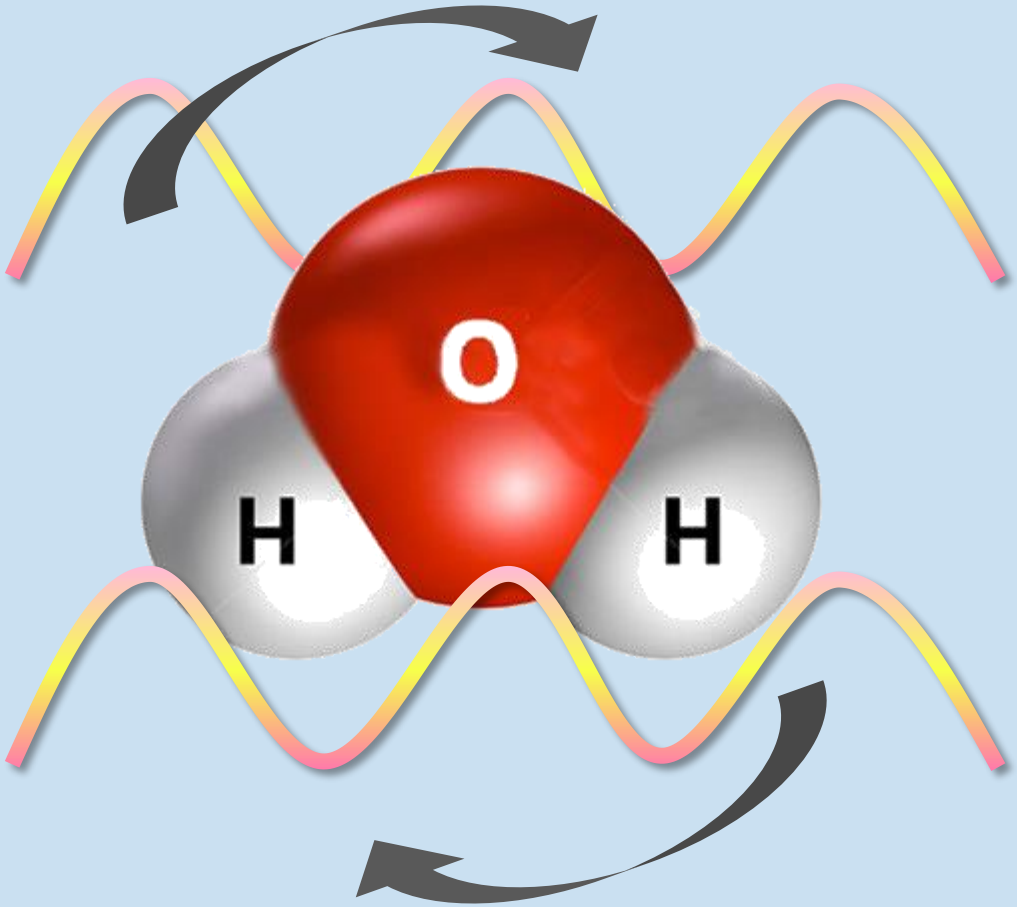
THE IMPLIMENTATION

- Semiconductor Solutions
- RF Design Expertise
- Software Enablement
- **Realized Function**

NXP

PRINCIPLE OF OPERATION

PRINCIPLE OF RF HEATING



Dipole Rotation Effect

MICROWAVE HEATING

- Electromagnetic waves absorption by load
- Molecule rotation and collisions create heat
- In contrast to radiant or contact heating, heats from inside out

TYPICAL CONSUMER MICROWAVE OVENS

- 2.45 GHz typical operating frequency
- 1000W RF power delivered
- Magnetrons have served as RF source for 50+ years
- Inexpensive, mature technologies
- Requires high voltage to operate

FAST, EFFECTIVE, AND EASY TO USE!

HOW MUCH ENERGY TO HEAT?

HEATING CALCULATION

- **Food Properties:** mass, water content, permittivity, and conductivity
- **RF Heating Source:** frequency of operation, power delivered to load, duration
- **Efficiency:** power conversion (AC or DC to DC, DC to RF), cavity efficiency
- **User Preference:** target temperature rise!

A FEW SMALL LOAD HEATING EXAMPLES

- 200 mL baby food, heated 30 deg. C
- 450 mL MRE, heated 30 deg. C

PRODUCT DESIGN & OPERATION

WAYV PORTABLE SOLID STATE MICROWAVE

USER INTERFACE & CONTROL

MINUTE & SECOND TIMER
START / STOP COOKING CYCLES
LCD BACKLIGHT TOGGLE
BATTERY CHARGE LEVEL
SAFETY MONITORING & ERROR REPORTING

RUGGEDIZED EXTERIOR SHELL

HEATING CAVITY

900 mL TOTAL VOLUME
100 mL TO 500 mL LOAD SIZE
REMOVABLE, WASHABLE CAVITY LINER
INTEGRATED ANTENNA ELEMENT

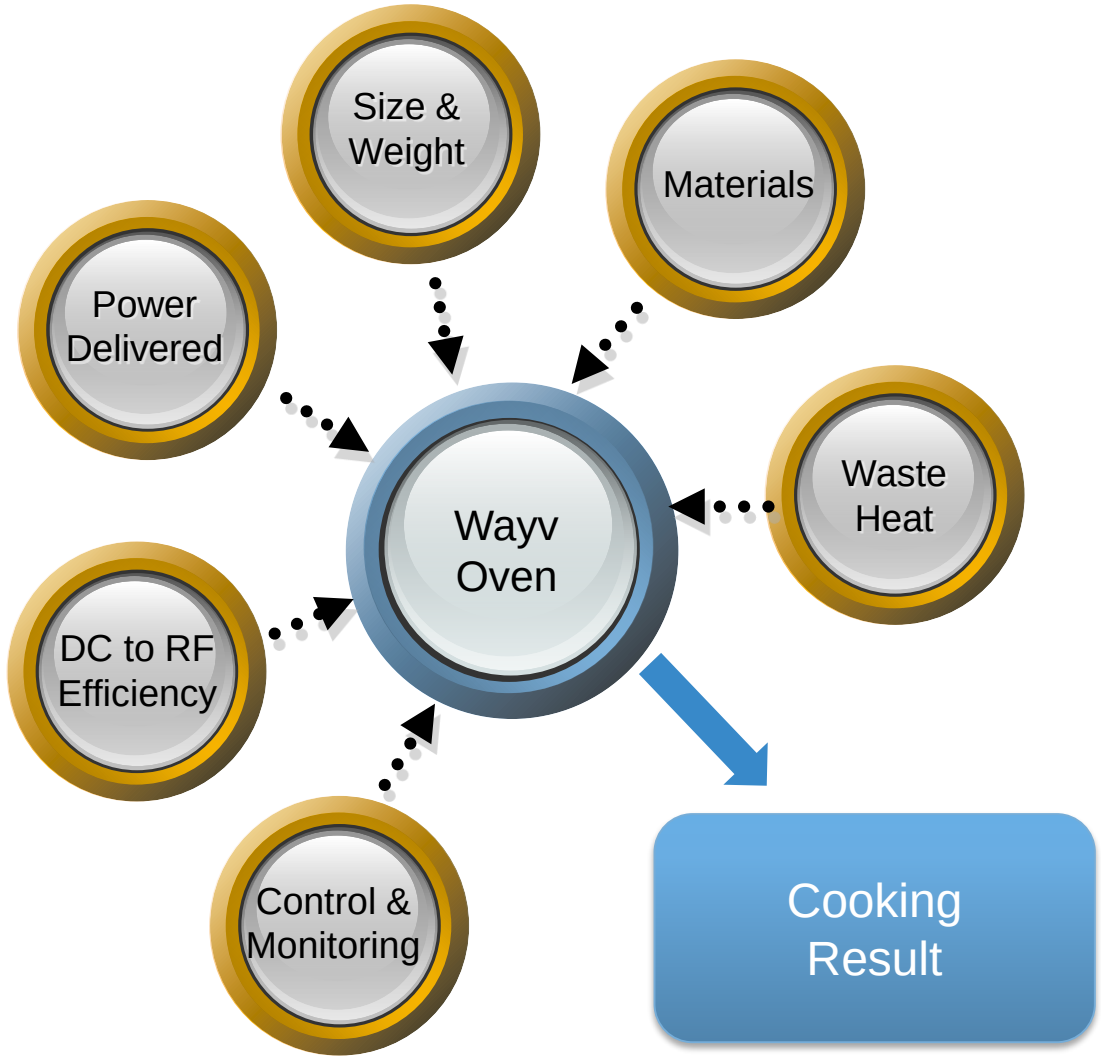
POWER SOURCE

8 CELL DETACHABLE BATTERY PACK
16 CELL DETACHABLE BATTERY PACK <OPTIONAL>
DIRECT WALL SUPPLY
USB CHARGER

RF POWER AMPLIFIER

POWER SOURCE
LOAD DETECTION
MONITORING AND SELF PROTECTION
2.4 – 2.5 GHZ UNLICENCED ISM BAND

THE DESIGN CHALLENGE



MECHANICAL OBJECTIVES

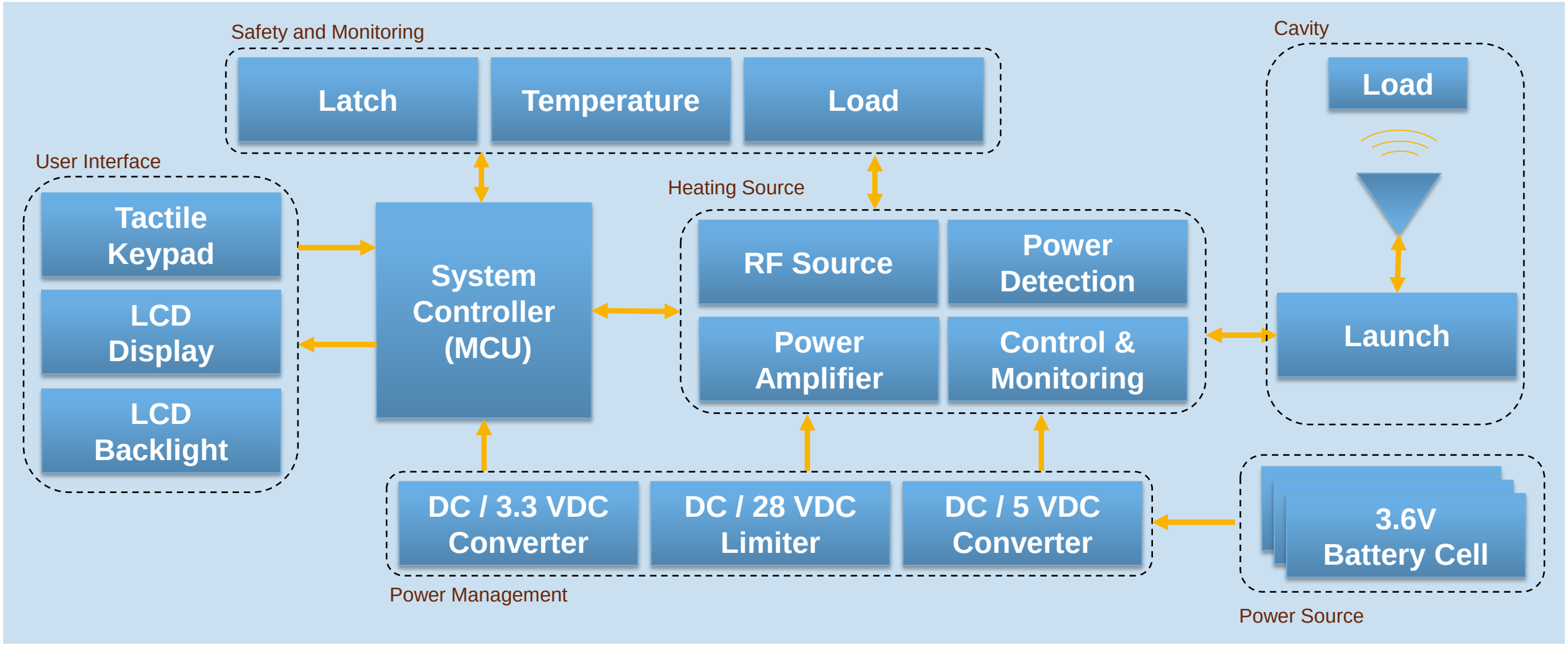
- Must be lightweight and easily carried
- Minimize temperature rise of cavity from waste heat
- Cool down quickly between cycles
- Manufacturing considerations

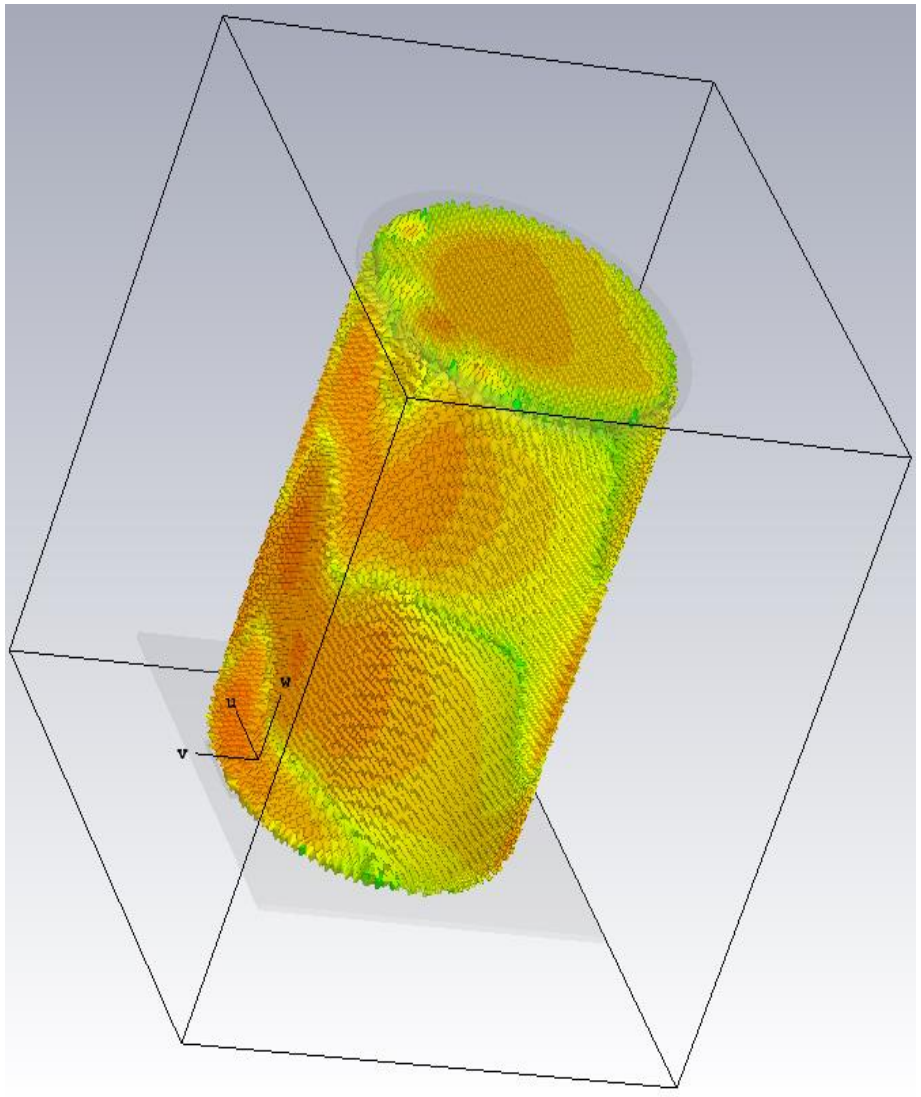
ELECTRICAL OBJECTIVES

- Minimize heating cycle times
- Minimize waste heat
- Protect PA from damage
- Manufacturing considerations

DESIGN ELEMENT DEPENDENCIES MUST BE CONSIDERED!

HIGH LEVEL ELECTRICAL BLOCK DIAGRAM





CAVITY HEATING

RF ENERGY DISTRIBUTION

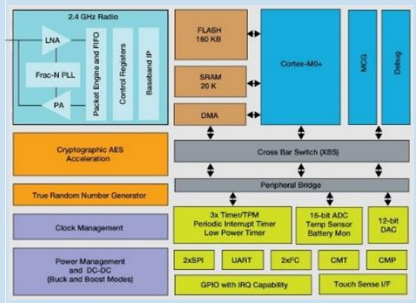
- RF Energy distribution is a function of cavity volume, operating frequency, radiator design, materials selection, and food load among other factors.
- Can be modeled in 3D EM tools such as CST or Comsol

DESIGN CONSIDERATIONS

- Goal is maximize RF energy delivered to load with minimum waste or loss.
  - Compromise between even and efficient heating
- Trade offs for amplifier protection, loss (wasted energy), size and complexity.

AMPLIFIER DEVICE SELECTION

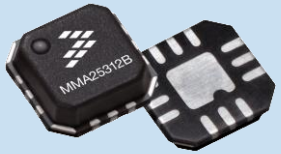
SIGNAL SOURCE Kinetis MK40Z MCU



Main Features

- Cortex-M0+ up to 48 MHz
- 160 KB Flash, 20KB RAM
- -20 to +5 dBm output power
- 13.5 mA Tx (0dBm) current target
- <2uA standby current
- Full featured, highly flexible peripherals

PREDRIVER STAGE MMA25231B



Performance @ 26V:

- P1 dB > 1W
- 30 dB Gain
- Low current draw

Low cost overmolded plastic packaging

DRIVER STAGE MHT1008N

Performance @ 26V:

- P1 dB > 12W
- 17 dB Gain
- Efficiency > 55%

Low cost overmolded plastic packaging

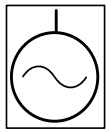
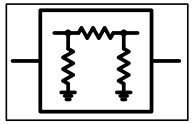
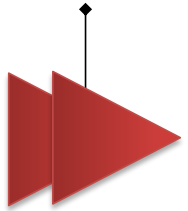
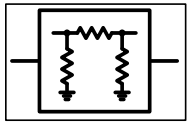
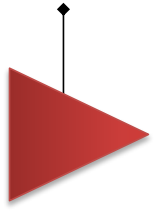
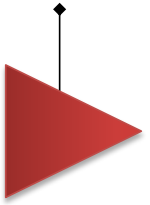
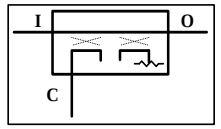
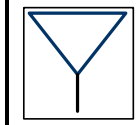
FINAL STAGE MHE1003N

Performance @ 26V:

- P1 dB > 200W
- 15 dB Gain
- Efficiency > 65%

Low cost overmolded plastic packaging

CALCULATED AMPLIFIER LINE UP BUDGET

Source	Pi Pad	Predriver AMP	Pi Pad	Driver AMP	Final Stage AMP	Coupler	Antenna
		5.0 		26.0 	26.0 		
	-6.0 dB	**+30.0 dB**	**-3.0 dB**	**+17.5 dB**	**+14.5 dB**	**-0.10 dB**	
OUT	**IN** / **OUT**	**IN** / **OUT**	**IN** / **OUT**	**IN** / **OUT**	**IN** / **OUT**	**IN** / **OUT**	**OUT**
0.1dBm	**0.1dBm** / **-5.9dBm**	**-5.9dBm** / **24.1dBm**	**24.1dBm** / **21.1dBm**	**21.1dBm** / **38.6dBm**	**38.6dBm** / **53.1dBm**	**53.1dBm** / **53.0dBm**	**53.0dBm**
0.00 W	0.0 W / 0.00 W	0.00 W / 0.26 W	0.3 W / 0.13 W	0.13 W / 7.26 W	7.26 W / 204.66 W	204.7 W / 200.0 W	200.0 W

Source Psat	+4.0 dB

Predriver Psat	42.0dBm
Average Power	24.1dBm
Current Draw	0.4 A
Est. n @ Pavg	**40%**
Pdc @ Pavg	**2 W**
Dissapated Power	**1 W**

Driver P3dB	41.0dBm
Pavg	38.6dBm
Current at Pavg	0.9 A
Est. n @ Pavg	**50%**
Pdc @ Pavg	**15 W**
Dissapated Power	**7 W**

Final Stage P3dB	53.5dBm
Pavg	53.1dBm
Current at Pavg	13.3 A
Est. n @ Pavg	**64%**
Pdc @ Pavg	**320 W**
Dissapated Power	**115 W**

At PA Output	
Total Line Up Gain	+52.9 dB
Total High Voltage Drain Current	14.2 A
Total PA Efficiency @ PA Output	**59.5%**
Total DC Power Consumption	**336 W**
Total Power Dissapation	**124 W**

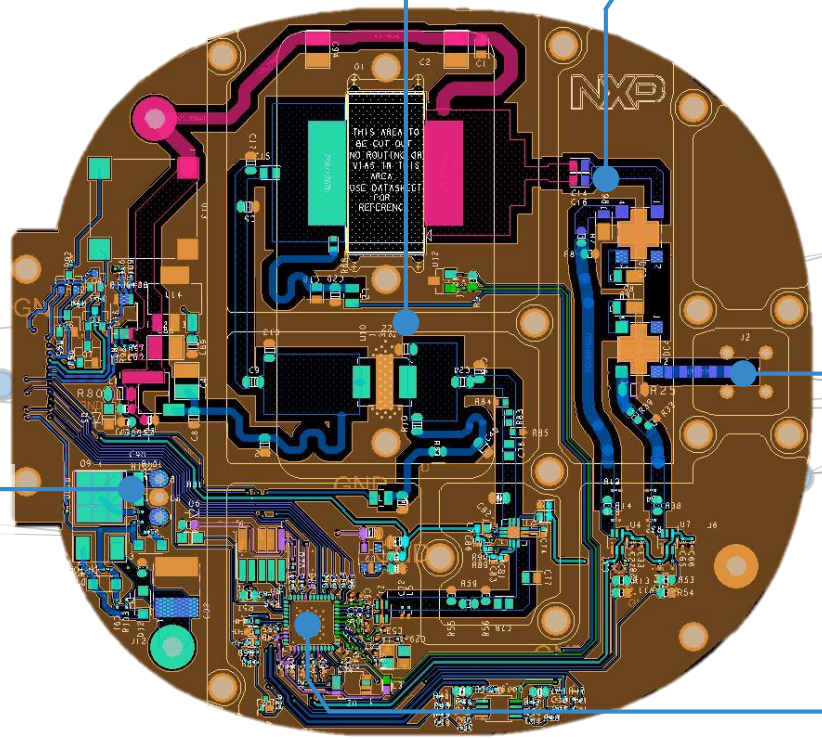
POWER AMPLIFIER DESIGN

POWER AMPLIFIER

POWER TRANSISTORS
RF MATCHING CIRCUITS
POWER TRANSISTOR BIAS NETWORKS
HIGH PERFORMANCE RF PCB MATERIAL
CAVITY ISOLATION

POWER DETECTOR

FORWARD POWER MONITORING
REFLECTED POWER MONITORING
LCD BACKLIGHT TOGGLE
BATTERY CHARGE LEVEL
SAFETY MONITORING & ERROR REPORTING



RF LAUNCH

200W POWER DELIVERED
LOAD DETECTION
2.4 – 2.5 GHZ UNLICENCED ISM BAND

POWER MANAGEMENT

MINUTE & SECOND TIMER
START / STOP COOKING CYCLES
LCD BACKLIGHT TOGGLE
BATTERY CHARGE LEVEL
SAFETY MONITORING & ERROR REPORTING

RF SIGNAL SOURCE

200W POWER DELIVERED
LOAD DETECTION
2.4 – 2.5 GHZ UNLICENCED ISM BAND

HEATING ALGORITHM

System Ready Check
PA Operational, Communication OK

↓

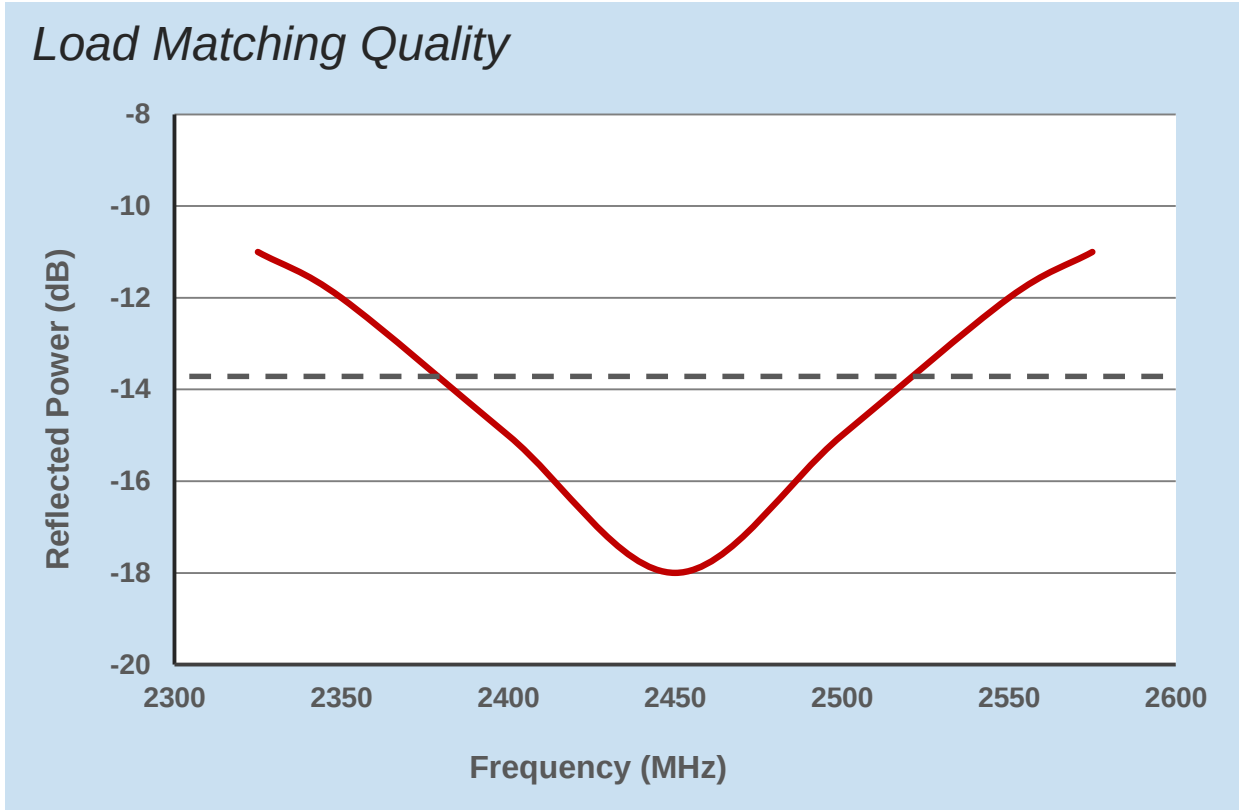
Load Detection
Load Present, No Foreign Object

↓

Cavity Scan
Best Match Identified, Match Quality Check

↓

Load Heating
Ramp Power and Complete Cycle



HEATING RESULTS

HEATING RESULTS

397 mg MRE
Southwestern Chicken

Cooking Performance

- Start Temp: 24.5 deg C
- End Temp: 48.2 deg C
- Temp Rise: 23.7 deg C
- **Total Time: 240 sec**

Electrical Performance

- Frequency: 2430 MHz
- PA Output Power: 197 W
- Power Delivered: 168 W
- PA Efficiency: 57%
- Cavity Efficiency: 85.5%

255 mg MRE
Three Cheese Alfredo

Cooking Performance

- Start Temp: 24.0 deg C
- End Temp: 40.0 deg C
- Temp Rise: 16.0 deg C
- **Total Time: 120 sec**

Electrical Performance

- Frequency: 2480 MHz
- PA Output Power: 193 W
- Power Delivered: 169 W
- PA Efficiency: 58%
- Cavity Efficiency: 82.3%

SUMMARY

- A concept for a portable RF heating appliance has been created
- A solid state power amplifier has been developed using NXP RF power transistors
- The design has been optimized to heat small food loads quickly, safely and effectively

HEAT FOOD… ANYWHERE IS NOW A REALITY

RF HEATING @ FTF

NXP SOLUTIONS FOR SOLID STATE RF COOKING

Digital, Security, Connectivity

- Discrete devices
- NFC
- MCU
- BLE
- LCD drivers
- Sensors
- Power Management
- SMPS controllers

Broad digital and mixed-signal portfolio

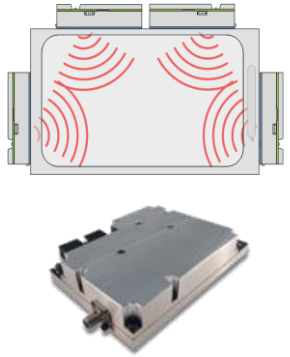
RF Components

Highest performing portfolio 27MHz – 2.4GHz

Development Tools

Simplifying appliance development

Solid State Modules



Ease of use modules for cooking appliance

Reference Design

Innovative appliance design for Smart Kitchens

Highest performing solutions with lowest consumer cost and highest ease of use

RF COOKING @ FTF

Visit our other sessions:

- FTF-HMB-N1994 *Determine Optimum Cooking Cavity Configuration in Solid State RF Cooking Appliances*
- FTF-HMB-N1995 *Lunch and Learn: Design Challenges of Portable RF Heating Applications*
- FTF-HMB-N1996 *Design Considerations for High-Performance Solid State RF Cooking*

Visit our demonstrations in the Tech Lab

- Located between Smart Life and Smart Cities

Visit us on the web at WWW.NXP.COM/RFCooking

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