Docket #: S19-234

High Efficiency, High Power, Variable Output of Multiple Power Amplifiers

Researchers at Stanford have developed a method to tune power amplifier circuits to directly connect their output power (and adjust the combined output power) without any additional power combiner network. This method allows any number of amplifiers to be combined while isolating their influence on each other. It eliminates efficiency losses; decreases system size, weight, and cost associated with a combiner network; and outperforms state of the art. (See Table 1 for comparison.) In addition, Stanford researchers can modulate the combined power output via phase control and power combining using a system with multiple power amplifiers connected in parallel. Output power is adjusted by selecting a number of amplifiers, and fine-tuned by running some power amplifiers 'backward.' This method significantly outperforms state of the art both at full load and light load (Table 2), making it ideal for radiofrequency (RF) plasma generating systems, and footprint /weight limited applications such as RF communication for mobile phones and micro-satellite propulsion.

Reference	Frey, IMS 1999	Jurkov, TPEL 2013	Choi, ECCE 2018	**Ours**
Topology	1x class-E	4x class-E	4x class-Φ2	**6x class-E**
Power [W]	490	100	1150	**1500**
Frequency [MHz]	27.12	27.12	40.68	**40.68**
Efficiency	83%	79% (85% pre-cmb)	83% (89% pre-cmb)	89%
Combiner	n/a	Lossless multiway	none	none
Device	Si	GaN	GaN	**GaN**

Power Amplifier Combined Outputs Comparison Table courtesy SUPER Lab

Reference	Godoy, TMTT 2009	Jurkov, TPEL 2013	Ours	
Topology	2x class-E	4x class-E	**6x class-E**	**6x class-E**
Max Power [W]	20	100	**1500**	**2200**
Frequency [MHz]	48	27.12	**13.56**	**40.68**
Efficiency @ full/-10dB	83/23%	79/39%	93/83%	87/66%
Combiner	Energy recovery	Lossless multiway	none	
Power control	Outphasing	Outphasing	**Modular on/off & phase-shifting**	

Power Amplifiers with Variable Power Output Comparison Table courtesy SUPER Lab

Stage of Development – Proof of Concept

The **S**tanford **U**niversity **P**ower **E**lectronics **R**esearch Lab demonstrated three power amplifier systems, each with six sub-circuits, with combined output of 1500W @40.68 MHz; 1500W@13.56 MHz; and 2200 W@40.68 MHz. The SUPER lab power amplifiers significantly outperformed state of the art. Research is ongoing.

Applications

- RF plasma generation systems for semiconductor manufacturing.
- RF power amplifiers for satellite communication and radio broadcasting.

Advantages

- Smaller footprint, simpler design, and lower manufacturing cost.
- Versatile - any number of power amplifiers can be combined.
- High efficiency, lower operating/electricity costs.
- High power, high control speed, and very fast (sub-microsecond) transient response.

Publications

- Surakitbovorn, Kawin, and Juan M. Rivas-Davila. "Modular ON/OFF and Phase-Shifting for High-Speed Radio Frequency Power Modulation." *IEEE Open Journal of Power Electronics 1* (2020): 393-406. DOI: 10.1109/OJPEL.2020.3024030

- Surakitbovorn, Kawin, and Juan M. Rivas-Davila. "A simple method to combine the output power from multiple class-E power amplifiers." *IEEE Journal of Emerging and Selected Topics in Power Electronics* (2020). DOI: 10.1109/JESTPE.2020.3011658

Patents

- Published Application: 20210021236
- Issued: 11,411,536 (USA)

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