Application Note No.113
Title: The Cost of Loss
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Premise

Very few components in a high-power amplifier have a greater impact per dollar spent, than the final power combiner. It is within this component that small but critical material and design decisions, often impacting the overall amplifier system cost by less than one percent, can easily and often affect the final output power by 5% to 15%. For this reason, any improvement in combiner performance, made at nearly any cost relative to this single component, can typically reduce the overall amplifier dollars per watt cost.

Theory

When considering the true cost of a power combiner, you must not simply compare "dollars per dB" of insertion loss of the component alone, but rather it's impact on the "dollars per watt" of the overall amplifier system. Cost savings at the component level can surprisingly result in higher cost at the system level, if delivered with net losses greater than the amount saved as a fraction of the total system cost.

$$P_{out} = P_{in} \cdot 10^{-IL/10}$$

$$\text{Lost Power} = P_{in} - P_{out} = P_{in} \cdot (1 - 10^{-IL/10}) = P_{out} \cdot (10^{IL/10} - 1)$$

Combiner Insertion Loss is most dominant in this regard, but by no means alone in determining overall impact of the component. When operating against imperfect source (eg. amplifier module) and load (eg. antenna) impedances, the combiner Return Loss also affects apparent loss. Additional reflection losses result from the combination of phase and magnitude errors between combiner inputs, whether from variations in the amplifier modules and cabling, or from the manufacturing tolerances or design of the combiner itself.

For an accurate accounting of total combining losses due to insertion loss, return loss, and gain/phase balance errors, please see our Application Note "AN115 Accurate Calculation of Losses".

Example

Consider the simple case of a P_{out} = 500 watt broadband CW power amplifier with a build cost of $75,000, operating over multiple octaves in the L-band thru C-band space, in which the power combiner + output cabling represent $5k of the total cost. Our operating cost is $75k/500W = $150/watt. If the total (insertion + reflection + phase/mag. imbalance) output losses with cabling, directional coupler, and commercial off-the-shelf combiner total 1.0 to 1.5 dB, then we must produce P_{in} = 630 to 710 watts from the power modules to overcome this output loss.

Consider now the possibility of upgrading these output components for better performance, at a cost increase of 25%, but having a very achievable total loss of 0.5 to 0.8 dB. We can reap the benefit of this improved performance in one of two ways:

1. **Better power output:** *Keep remaining architecture unchanged, and leverage reduced losses into higher output power.* With same P_{in} = 630 to 710 watts, we can increase output power to 560 – 590 watts, at $76,250 build cost. Operating cost is reduced from $150/watt to approximately $130/watt, while exceeding the original performance specification.

2. **Reduced BOM cost:** *Keep target output power the same, but reduce remaining architecture to achieve a lower cost.* At a target P_{out} = 500 watts, we can reduce required input power to P_{in} = 560 to 600 watts, a reduction of 12% to 15% over the original requirement. In this case, extracting $5k for power combiner and $20k for chassis and front-end components note likely to change, we can assume primary power stages and associated hardware accounted for $50k of the original build cost. Reducing this $50k portion of the build cost by 12% to 15% would save us $5600 to $7800, meeting the original specification while reducing the operating cost from $150/watt to approximately $135/watt.