Application of a linear transmission scheme to saturated TWT amplifiers*

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Abstract

It is desirable to operate traveling wave tubes (TWTs) well into the non-linear regime to maximize power efficiency. However, non-linear operation causes out-of-band emission, resulting in interference for other users, and in-band signal distortion resulting in reduced data transmission rates. A variety of linearization techniques have been proposed to reduce these distortions. In this poster we investigate application of the Linear-amplification-using-Non-linear-Components (LINC) method to TWTs. The LINC scheme has been studied in the context of solid-state power amplifiers, but does not appear to have been considered for use with TWTs.

The non-linear characteristics of traveling wave tube (TWT) amplifiers are often described by AM/AM and AM/PM transfer curves which relate the output amplitude and change in phase to the input amplitude. Under ideal conditions, LINC results in no non-linear distortion since it ensures that the amplifiers operate at a fixed point on the AM/AM and AM/PM curves. However, in practice, impairments result from non-idealities and mismatches in the components. We examine the effects of realistic non-idealities in order to determine the suitability of a TWT-based LINC scheme for common modulation methods.
Linearity: a critical issue

Non-linearities in the transfer curves cause:

- Inter-symbol interference
  whereas higher data rates are demanded

- Inter-channel interference
  whereas spectral availability is limited
Tolerance out-of-band emissions

– regulations require that spectral splatter be kept below -60 dBc

– without any correction technique, very large back-off (from saturation) is necessary
Efficiency of TWT amplifiers

The exceptional efficiency of TWTs at low back-off is a powerful motivation for improving the linearity of TWT transmitters operating near saturation

curve reproduced from Ref. [1]
Transfer curves for two TWT amplifiers

- Both curves are functions of the input magnitude
- Specific values of OBO are depicted
**Features of the transfer curves**

- Gain and phase change are not constant over the range of input magnitude
- Constant-envelope (CE) signals would not be affected by these non-idealities
- But CE modulations are spectrally inefficient

**Question:** is there a way to extract CE signals out of the input signal, while retaining a spectrally efficient scheme?
Introducing LINC

• Linear amplification using non-linear components (LINC) operates amplifiers at fixed points (for any nonzero-envelope modulation scheme). Ideally, this would result in no distortion.
• The source signal is split into two CE signals via a signal component separator (SCS)
• The two CE signals are separately up-converted and amplified using individual quadrature modulators (QMOD) and TWTs
• A rescaled replica of the original signal is finally reconstructed using a high-power combiner
LINC architecture

Generation of constant-envelope signals

Up-conversion

Amplification

Reconstruction

Possible QMOD errors:
- amplitude in two quadrature legs,
- phase in two quadrature legs,
- carrier leakage in \( s_m \)

Possible amplifier errors:
- different AM/AM, AM/PM transfer curves

Possible QMOD errors:
- amplitude in two quadrature legs,
- phase in two quadrature legs,
- carrier leakage in \( s_m \)
Non-idealities in LINC

• Reconstruction failure
  – the combiner does not accurately eliminate the quadrature signal (used to generate the accessory CE signals); the out-of-band emission is predominantly a residual of this signal
    • Cause: mismatch between the amplifiers

• Preservation of the constant envelopes
  – The envelopes fluctuate slightly: the amplifiers are not operated at a fixed point; this exhibits their non-linearities
    • Cause: QMOD misalignments
Generating the CE signals

- Source signal
- CE signals:
  \[ S_1(t) = s(t) + e(t) \]
  \[ S_2(t) = s(t) - e(t) \]
- Quadrature signal
  \[ e(t) = j \cdot s(t) \cdot \sqrt{ \frac{r_{\max}^2}{|s(t)|^2} - 1 } \]
QMOD misalignments: notations

- $g_I$: $I$-gain
- $g_Q$: $Q$-gain
- $\phi_I$: $I$-phase shift
- $\phi_Q$: $Q$-phase shift

- Common gain: $g_c = \frac{g_I + g_Q}{2}$
- Common phase shift: $\phi_c = \frac{\phi_I + \phi_Q}{2}$
- Normalized differential gain: $g_d = \frac{g_I - g_Q}{g_I + g_Q}$
- Differential phase shift: $\phi_d = \frac{\phi_I - \phi_Q}{2}$
- Carrier leakage $p$
**Differential misalignment effects**

- We consider the effects of differential gain ($g_d$), differential phase shift ($\phi_d$), and carrier leakage ($p$) on LINC effectiveness.

- Common QMOD misalignments ($g_c$ and $\phi_c$) are omitted in this analysis: they can be “incorporated” in the AM/AM and AM/PM relations of the amplifiers.
### QMOD misalignments: realistic estimates [4]

<table>
<thead>
<tr>
<th>Misalignments</th>
<th>Maximum values</th>
<th>Minimum values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g_d$</td>
<td>0.03</td>
<td>0.058</td>
</tr>
<tr>
<td>$\phi_d$</td>
<td>0.05</td>
<td>0.026</td>
</tr>
<tr>
<td>$p$ (% of input magnitude)</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>
Cases analyzed

<table>
<thead>
<tr>
<th>Case</th>
<th>Amplifiers’ characteristics</th>
<th>QMOD’s differential misalignments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>Identical</td>
<td>Maximum</td>
</tr>
<tr>
<td>Case 2</td>
<td>Identical</td>
<td>Minimum</td>
</tr>
<tr>
<td>Case 3</td>
<td>Mismatch</td>
<td>None</td>
</tr>
</tbody>
</table>

- The results are compared with the “no LINC” scheme (QMOD followed by a single TWT amplifier)
- The amplifiers are assumed memoryless
- Measured data have been fitted using polynomials
- The modulation is offset 4QAM
Results at saturation

Output back-off

OBO = 0.2 dB

Note: peak at f = 1 is due to carrier leakage and is unique to this offset 4QAM modulation scheme.
Results in the non-linear regime

OBO=2dB

Note: peak at f = 1 is due to carrier leakage and is unique to this offset 4QAM modulation scheme.
Results in the linear regime

OBO = 6 dB

Note: peak at f = 1 is due to carrier leakage and is unique to this offset 4QAM modulation scheme.
Observations

• Emissions due to amplifier mismatch and QMOD misalignments can be on the same order
• Emissions due to QMODs are negligible when the errors are reduced to a minimum
• Matching of amplifiers allows the transmitter to meet the -60dBc requirement

reflection: the results stimulate interest in matching amplifiers using predistortion-like techniques
Proposed configuration (I)

\[ s(t) \rightarrow \text{SCS} \rightarrow \text{QMOD} \rightarrow \text{QMOD} \rightarrow \text{Mismatched amplifiers} \rightarrow \text{LINC: } -40 \text{ dBc} \]

Feed forward linearization: 
\[ -30 \text{ dBc} \]

-70 dBc

Correction amplifier
Proposed configuration (II)

Minimum errors

SCS

QMOD

-60 dBc

Matched amplifiers

s(t)

s_{out}(t)
Summary and Conclusions

• Results suggest that -60 dBc out-of-band emission can be achieved with either:
  – LINC alone, provided minimum realizable QMOD misalignments and negligible TWT mismatch, or
  – LINC + feedforward, assuming maximum QMOD misalignments and significant TWT mismatch

• Similar results obtained with $\pi/4$-shifted differential QPSK modulation scheme.

• Method will not work for modulations with zero envelope events

• Suppression of spectral regrowth levels accompanied by increased bandwidth of spectral regrowth region
References


