Metingen t.b.v. HF versterker ontwerp

Ir. Remi Tuijtelaars

RF Meetseminar, 14 dec 2013, Bos&Duin

Contents

1. Introduction, basic measurement setup
2. Intermezzo: RF PA desig
3. Tuners (variable matching network)
4. Measurement method
5. Load-pull ‘options’
6. Trends

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Power-amp characteristics

- output power
- efficiency
- distortion
- gain

- ! noise figure

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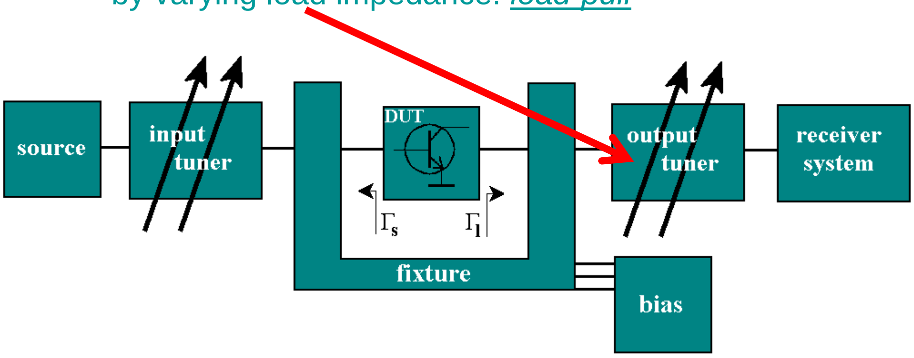
Basic measurement setup

- search for optimum of parameter(s) by varying load impedance: *load-pull*



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LP setup: example

Contents

Intermezzo: RF-PA amplifier design

Linear amplifier design (small signal)

- based on e.g. S-parameter characterization
- uses maximum power transfer theorem
  - complex conjugate match between device and source/load
  - typically becomes matched on input and output
- GAIN match; non-maximum output power

- linear amplifier
- EITHER voltage OR current clips at compression levels
- supply current is constant and independent of signal level

Class A RF amplifier

- based on maximum possible voltage AND current swing at the output of the device
- POWER match; non-maximum gain
- linear amplifier
- BOTH voltage AND current clip at compression levels
- constant average supply current

Gain match vs power match

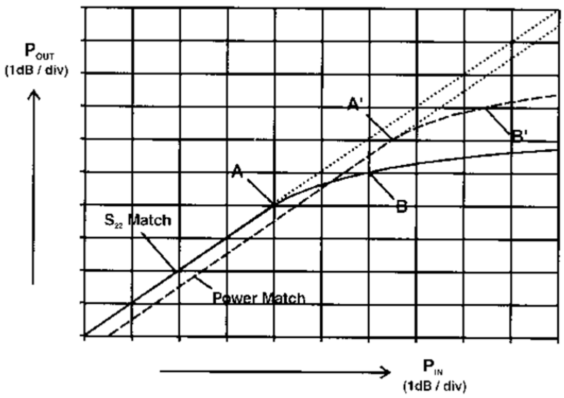

Figure 2.2 Compression characteristics for conjugate (S_{22}) match (solid curve) and power match (dotted curve). 1 dB gain compression points (B,B') and maximum linear power points (A,A') show similar improvements under power-matched conditions.

Class B, C, D, E, F, J, S RF amplifier

- based on maximum possible voltage or current swing
- no linear, small signal gain
- supply current grows with signal
- reduced DC average current compared to class A: increased efficiency!
- requires output filter for signal restoration

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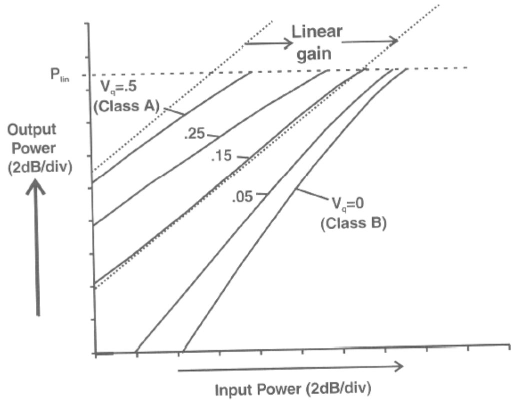
Class A, AB, B transducer gain

- output power vs input power; transducer gain



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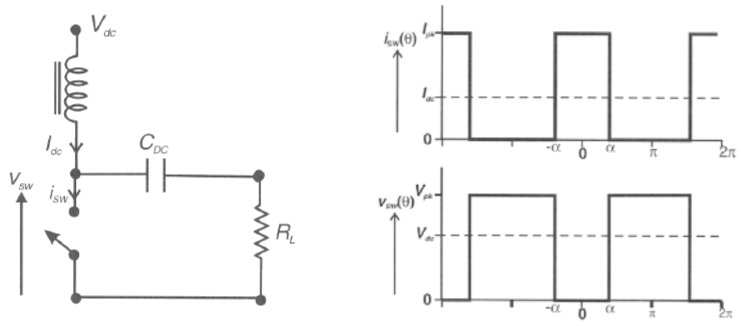
Switched mode amplifiers

- RF amplifier becomes a switch
- current and/or voltage become square wave shaped



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End intermezzo

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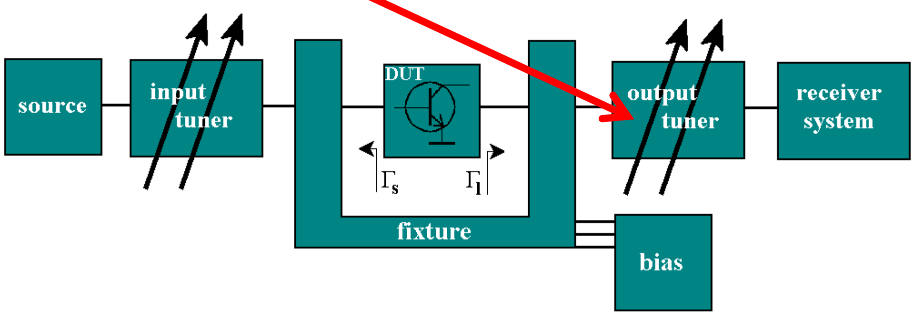
Basic measurement setup

- search for optimum of parameter(s) by varying load impedance: *load-pull*



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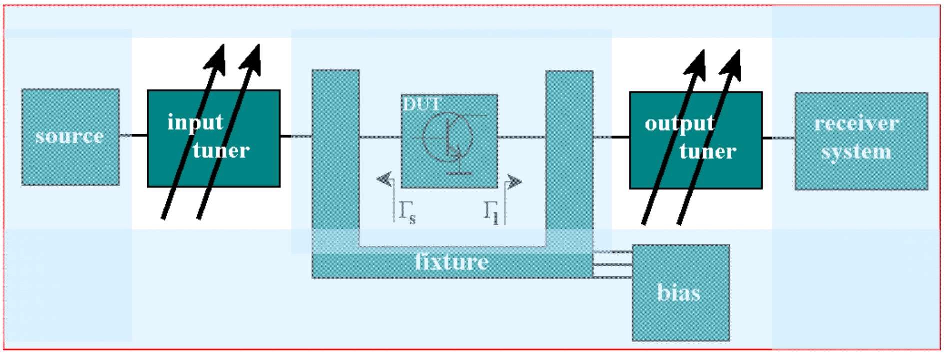
TestSystems&Consulting

Tuners



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Tuners

- 'variable matching network'
- stable and reproducible
- 'characterizable'
- low loss
- $d\Gamma/df$ sensitivity
- frequency characteristic
- weight; size

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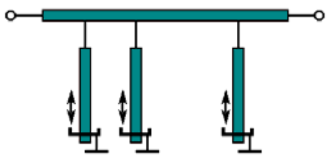
Tuners: stub tuner

- series of short circuited TL's, parallel to Z_0 line
- tunes G_s and B_s independently
- high VSWR
- difficult to set to $\Gamma=0$
- high pass frequency response



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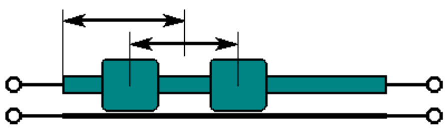
Tuners: slug tuner

- 2 (or 3) low Z_0 movable segments on coaxial-type Z_0 line
- tunes $|\Gamma|$ and $\angle\Gamma$ almost independently
- moderate VSWR
- easy to set high $|\Gamma|$; difficult to set to $\Gamma=0$
- low loss



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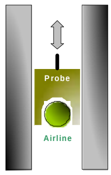
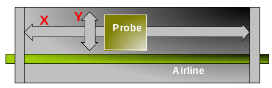
Tuners: slide-screw tuner I

- 1 (or 2) insertable, movable probe(s) on coaxial-type Z_0 line
- tunes $|\Gamma|$ and $\angle\Gamma$ almost independently
- high VSWR
- difficult to set high $|\Gamma|$; easy to set to $\Gamma=0$
- low loss





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Tuners: slide-screw tuner - automated

- Stepper motor driven
- end detectors on both ends
- tuners need initialization
  - purpose: find fixed, initial position ('0')
- Typically GPIB, USB or Ethernet control port

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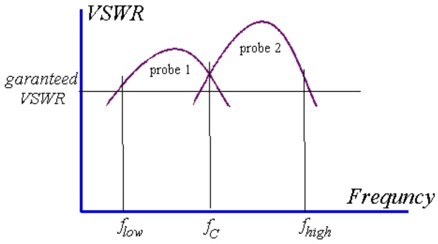
Tuners: slide-screw tuner II

- characterized by S-pars at various positions:
  - lower freq band: probe P1, carriage position L
  - upper freq band: probe P2, carriage position L
- typical behavior:



$$f_C \approx \sqrt{f_{low} f_{high}}$$

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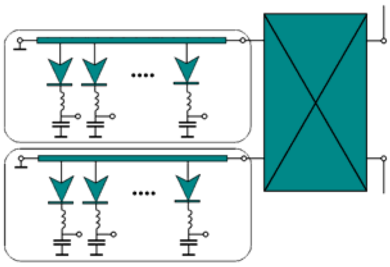
Tuners: electronic, passive tuner

- reactive terminations on hybrid arms
- set Γ to discreet values
- low VSWR
- highest loss
- small and light
- extremely fast
- extremely repeatable



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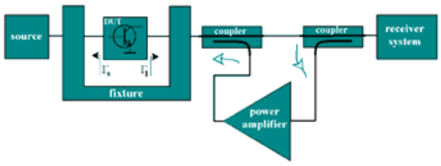
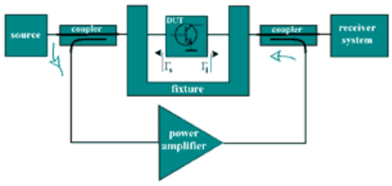
Tuners: electronic, active tuner

- 'create' reflected signal
- 1-port design



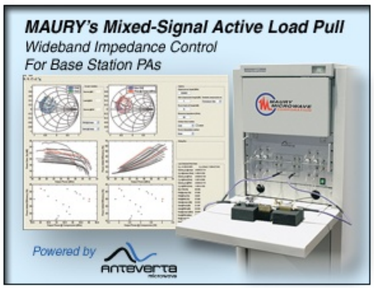
- 2-port design



- very high VSWR: $|\Gamma|>1.0$!
- very large $d\Gamma/df$: unusable for UMTS!

Commercial Active LP system

- TU-Delft spinn-off, Antaverta



- Agilent's PNA-X

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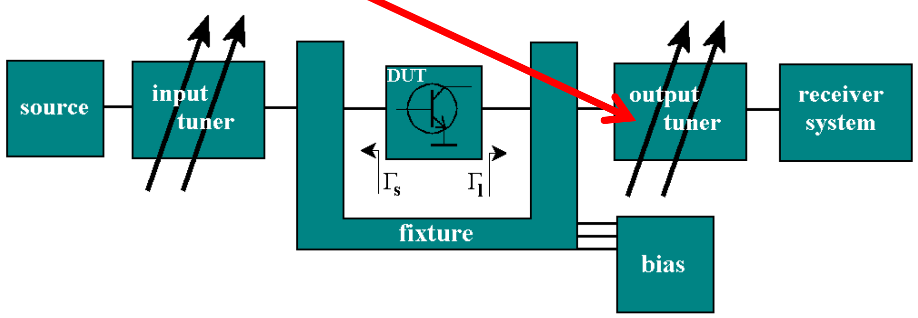
Basic measurement setup

- search for optimum of parameter(s) by varying load impedance: *load-pull*



Typical load-pull measurements

- As a function of Γ_l, <*@parameter*> measure:
  - gain
    - transducer, power, ...
  - power
    - *input*, output, compression, saturation, ...
  - bias
    - *quiescent*, supply currents/voltages
  - efficiency
    - collector/drain, power added, …
  - distortion
    - IMD, XMD, ACPR, harmonic content, …
  - impedance
    - *source* , input and load impedance at fund. and harmonics

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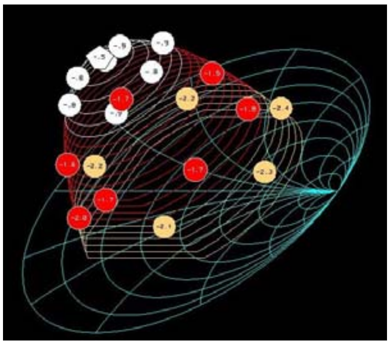
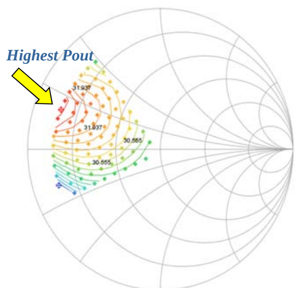
Basic measurement procedure

- define optimum goal!
- search for optimum in Γ_l -plane,
- *or* collect data at many Γ_l's and examine 3-D cones and 2-D contour plots.





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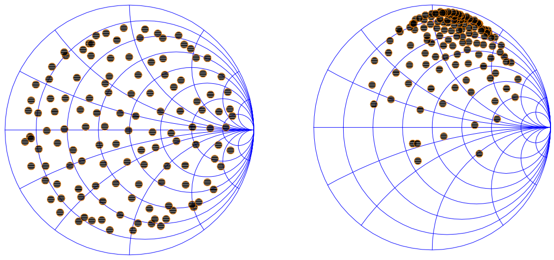
Contents

Load-pull 'options'

- pre-matching
- harmonic tuning
- VNA-based LP
- Modeling; X-parameters

Stepped tuning (pre-matching)

- Input/output tuning/pre-matching
  - improve system match
  - improve matching capabilities
  - ‘move’ active area on Smith-chart
  - ‘High Gamma Tuner’



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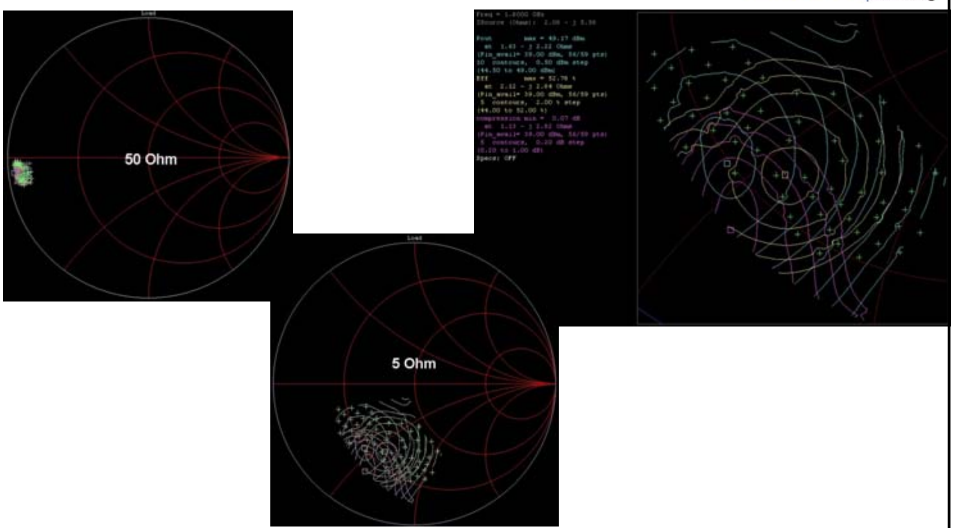
Stepped tuning (pre-matching)



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Fundamental vs harmonic tuning (I)

- consider $\Gamma_{s,l}$ at harmonic frequency:
  - neglected
  - known
  - adjustable
- examining 2nd order effects
  - increase efficiency, IMD, ACPR, …
  - improve ruggedness
  - waveform shaping

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Load-pull 'options'

- pre-matching
- harmonic tuning
- VNA-based LP
- Modeling; X-parameters

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Fundamental vs harmonic tuning (II)

- increased complexity in hardware and procedure; different implementations
- difficult to 'reproduce' harmonic termination in final circuit design!
- harmonic term. in fixture limits usefulness of harmonic tuning

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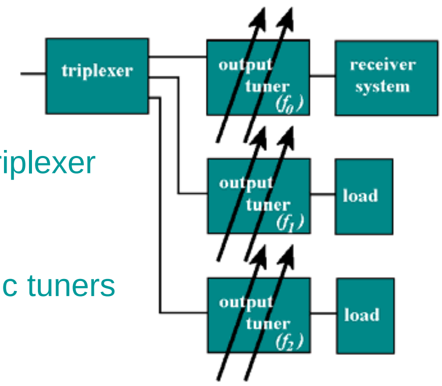
Tri-plexer harmonic tuning I

- adjust harmonic Γ's 'in parallel'



- need good di-/triplexer
  - separation
  - losses
- special harmonic tuners
  - sliding shorts

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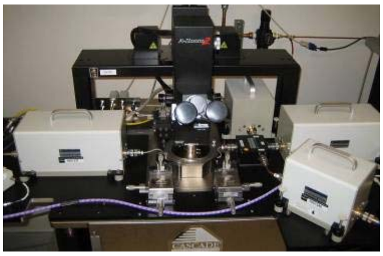
Tri-plexer harmonic tuning II



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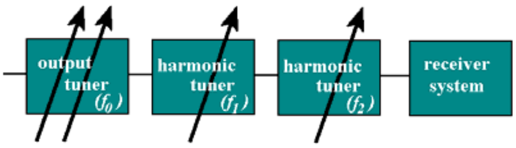
Cascaded tuners, harmonic tuning I

- adjust harmonic Γ's 'in series'



- special harmonic tuners
  - resonating stub(s)
  - need to be tuned
- cascaded standard tuners
  - different boxes
  - more cariages on one axis

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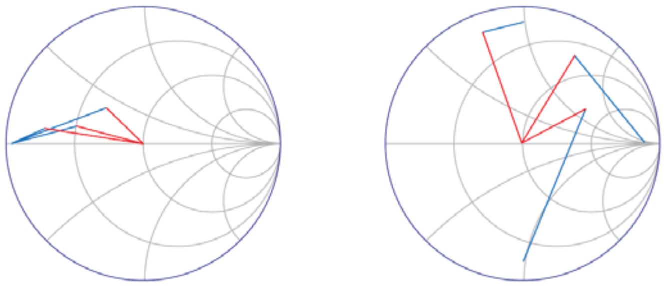
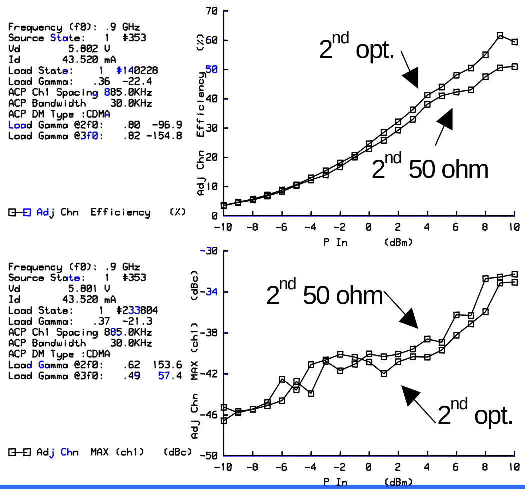
Cascaded tuners, harmonic tuning II

- Use over-determined system for fundamental to control harmonic impedances.
  - Manage tolerances and constraints
  - Intelligent search algorithm



Multiple paths to Γ_{Fo}=0.95∠180° Resulting Γ_{2Fo} positions (0.9∠0, 90, 270°)

2nd harmonic tuning: example



Efficiency improved by 8% from nominal at +6 dBm input

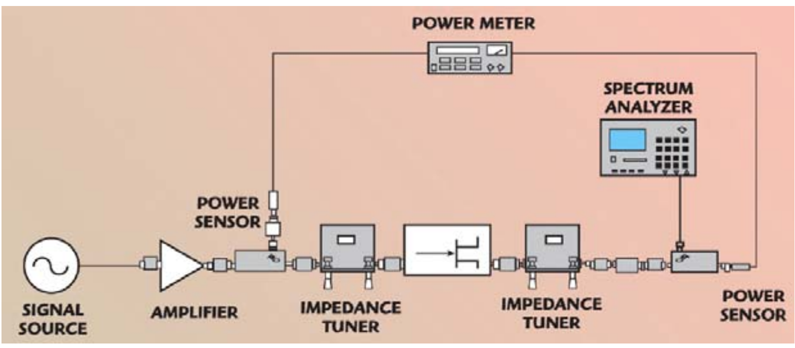
ACPR improved by 2dB from nominal at +6 dBm input

Load-pull 'options'

- pre-matching
- harmonic tuning
- VNA-based LP
- Modeling; X-parameters

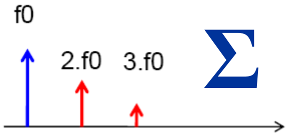
Classic LP measurement setup

- using traditional power meters
- measure scalar power reflection coefficient

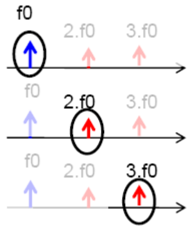


What power is measured ?

- power meter: thermal power, integrated spectrum



- VNA receivers: tuned to fundamental and harmonics



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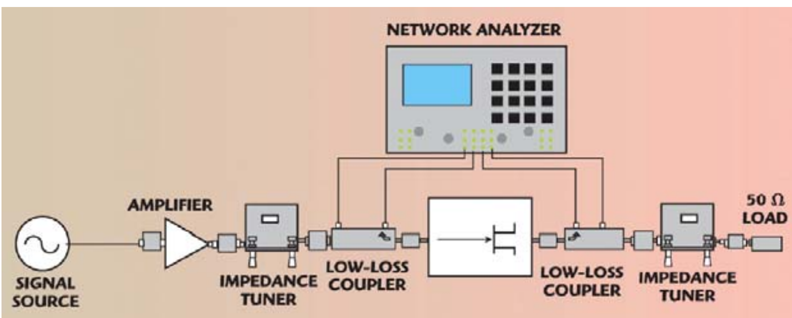
VNA-based LP (I)

- vector corrected measurement of a_1, b_1, b_2 and a_2 at fundamental and harmonics, in amplitude and relative phase



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VNA-based LP (II)

- use VNA source
- couplers between tuners and DUT:
  - real-time measurement system
  - in-situ measurement of the load termination at fundamental and harmonics
  - no (real) need to pre-characterize tuners
- couplers outside of tuners:
  - approach similar to traditional load-pull
  - need to pre-characterize tuners

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Compare classic – VNA Load-Pull

Measurement available	Power Meter based Load Pull	VNA based Load Pull
Input Reflexion Coefficient	✗	✓
Source Power	✓	✓
Input Power	✗	✓
Output Power	✓	✓
Power Gain	✗	✓
Transducer Power Gain	✓	✓
PAEfficiency	✗	✓
Transducer Efficiency	✓	✓
AM/PM	✗	✓
True Harmonic calibrated power measurements	Using external spectrum analyser	✓ ✓
2 tones Load Pull measurements	Using external spectrum analyser	✓
Wimax (Modulated signals)	Using external spectrum analyser	✗

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Load-pull 'options'

- pre-matching
- harmonic tuning
- VNA-based LP
- Modeling; X-parameters

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NVNA and X-parameters

- add Harmonic Phase Reference
- vector corrected measurement of all a's and b's at fundamental and harmonics, in amplitude and ***absolute*** phase
- construct voltage/current waveforms (NVNA)
  - to make sense, this requires de-embedding down to device's intrinsic input and output current source
- add extraction tone to measure **X**-parameters
  - behavior device model, accurate within domain from power down to small signal (→**S**-parameters)

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Contents

Trends

- new devices
- complex signal to amplify
- higher power densities

- new amplifier principles require harmonic tuning
- re-vitalization of IV waveforms in µw/RF PA design

- from lab to test-floor
- active load-pull
  - Commercially available
  - Less academic

- Measurement based behavior models (e.g. X-parameters)

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- world citizen since March 1962
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  - hts (Breda, NL; 1981-1985)
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- employment:
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  - Philips Semiconductors (Nijmegen, NL; 1987-1999)
  - BSW TestSys.&Consltng AG (~Munich, DE; 1999-2000)
  - BSW TestSys.&Consltng bv (Boxmeer, NL; 2000)