FOCUS MiCROWAVES

APPLICATION NOTE 71

HYBRID HARMONIC LOAD PULL MADE REAL

Introduction

Harmonic Load or Source Pull is the systematic RF (and DC) characterization of a device under test (DUT, transistor) for a selected set of load (or source) impedances Z or reflection factors $\Gamma(f)=(Z(f)-Zo)/(Z(f)+Zo)$ at two or three harmonic frequencies f=fo, 2fo and 3fo. The device used to create and control Γ(f) is called a *harmonic tuner*. A harmonic tuner can be an instrument or a condition; both create harmonic signals that are returned to the DUT; if the returned signals are created by reflection on mechanical obstacles (tuning probes or slugs) we speak of a *passive harmonic tuner (Model MPT, see Focus Product Note 79)*; if they are created by injecting synchronized signals through feedback or by coherent external signal sources we speak of an *active harmonic tuner (Model DLP of Mesuro Inc.)*; if they are created by both active and passive method we speak of a *hybrid tuner*. Active or hybrid tuners are necessary if a passive (mechanical) tuner cannot reach, due to hardware limitations, the very small conjugate output DUT impedance Z_{DUT}*; this happens for very large (high-power) transistors with $|\Gamma_{DUT}(fo)|\approx 1$.

Summary

As already said, the main objective of load pull is to conjugate match the DUT at fo and optimize Γ(2fo) and Γ(3fo) to extract maximum power or maximize efficiency and linearity. This can be done by either mapping an area of or the entire Smith chart with selected impedances and extract the information graphically (Load Pull contours) or by using peak search routines with user-set objectives (maximum power, maximum efficiency, linearity etc.). In the case of passive or active load pull the search is straight forward: the quantity in question is measured and the impedance is changed using a gradient iterative method until the quantity is optimum.

In the case of wideband active harmonic load pull, though, the situation is complex (Fig. 1): the core device may be wideband, but the surrounding frequency sensitive components, like filters and triplexers are, by their nature, narrowband, and isolators in front of the amplifiers are not matched outside their nominal band.

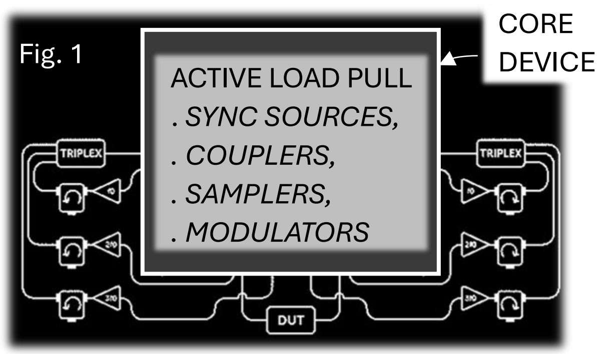


Fig. 1

Considering the overlapping passbands of the surrounding circuitry, it is obvious that such a project is not instantaneously wideband and, to switch frequency bands, new hardware must be procured and manually reconfigured.

A realistic solution

Pure active load pull requires high power 50Ω amplifiers to inject power into the low output impedance of the DUT; the ratio injected power to DUT power P_{inj}/P_{DUT}= $|\Gamma_{DUT}|^2/(1-|\Gamma_{DUT}|^2)$ (*), see Focus AN-70; This means a 10W/1Ω FET requires a 120W amplifier to be matched (Figs. 2, 3).

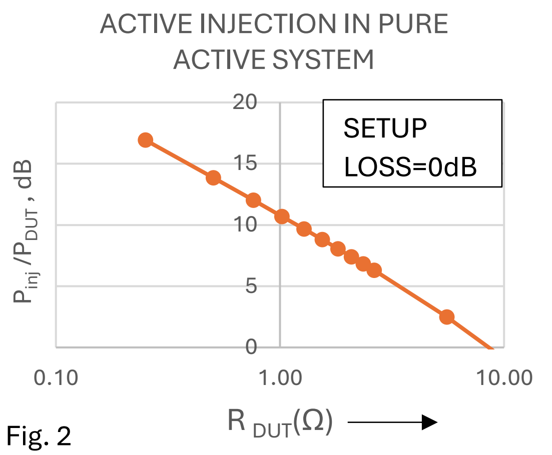


Fig. 2

This problem is solved by ~10dB using a passive tuner, in particular a Focus DELTA tuner in the, now hybrid, feedback loop:

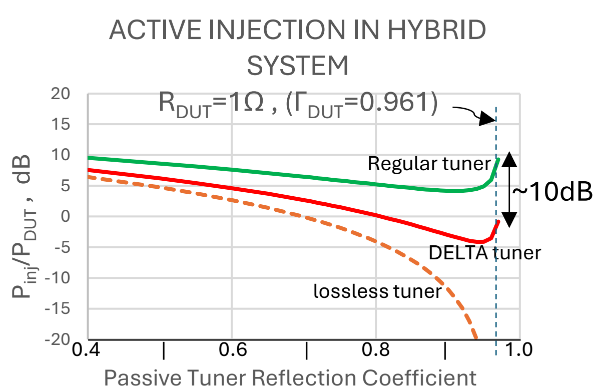


Fig. 3

All this is straight forward in the case of a CW fundamental (fo) signal. In the case of harmonic (2fo, 3fo) and modulated signal the situation is more complex and, as shown above, the practical solution should not be left with the unsuspecting user who, after purchasing the core device, he must procure also the associated circuitry (amplifiers, triplexers, circulators...) for each frequency range.

It is the purpose of this note to suggest realistic integrated wideband solutions versus hitherto proposed only project components:

The idea is to use a single coherent feedback source and a *wideband harmonic module* (basically a multi-harmonic tuner) in the feedback loop, serving as a power saving pre-matching and harmonic tuning device.

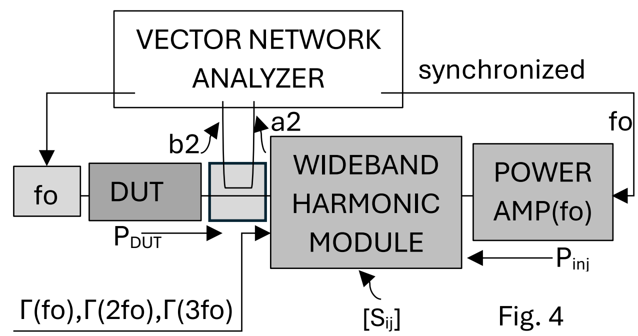


Fig. 4

This setup requires only a protecting circulator in front of the PA of which the out-of-band S_{11} is part of the harmonic tuning of the MPT in the harmonic module and nothing else. The harmonic frequencies 2fo and 3fo are generated by the DUT and reflected back by the HM with user-defined amplitude and phase Γ(2fo),Γ(3fo); their amplitude is reduced by the insertion loss btw DUT and HM; this is a tolerable compromise, since in terms of harmonics what matters is the phase of Γ(Nfo) knowing that the optimum is always close to |Γ(Nfo)|=1. On the other hand, active injection at the fundamental ensures up to |Γ(fo)|=1; in short this configuration allows effective hybrid harmonic tuning over a wide frequency range up to fo=40 GHz for fo,2fo,3fo and up to fo=60GHz for fo,2fo.

The case of modulated signal

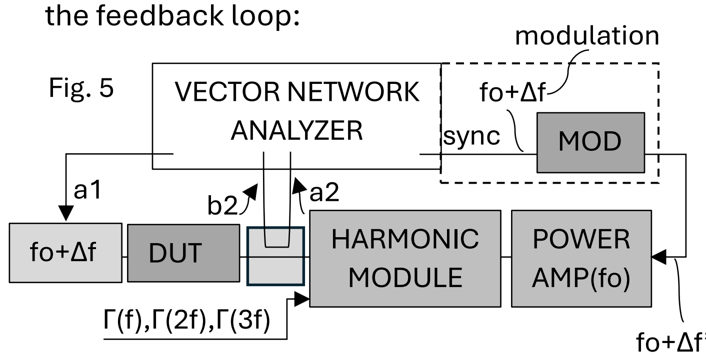
The term “wideband” is often mis-interpreted; In CW, *wideband* means several GHz octaves (ex. 0.4-18GHz, 6-40GHz, 36-110GHz). In modulation *wideband* means *Δf*~0.1-1GHz.

For reasons unknown, it became fashion to perform load pull testing at constant $\Gamma_{load}(\Delta f)$ on transistors, injected with signal modulated with patterns up to Δf=0.5 or 1GHz, whereas passive MIC or MMIC transistor embedding networks are naturally dispersive (Fig. 7). We dare to say that this is an unrealistic test environment, that, albeit led to developing sophisticated signal processing technology that creates active loads $\Gamma_{load}(\Delta f)$=constant, this possibly as a compromise, because nobody knows ahead of time what environment the DUT will be embedded afterwards, but still, it remains an unrealistic test environment.

A really useful information would be to select a specific matching network and emulate its frequency response by the tuner, passive, active or hybrid. In that sense purely active systems bear an advantage in that they can synthesize arbitrary impedance contours over Δf, whereas passive or uncorrected hybrid systems incorporate the natural negative phase slope of passive networks with uncontrollable skew.

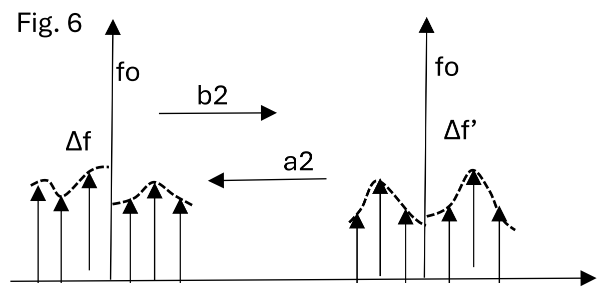
In order to take advantage of the considerable simplification of the hybrid harmonic load pull setup of fig. 4, which allows saving at least 10dB injection power (more when using DELTA tuners) together with 2fo and 3fo tuning also for modulated signals, one would have to re-program the modulation pattern of the second signal source to include the transfer function of the harmonic module and the power amplifier.
In order to control the modulated $\Gamma_{LOAD}(\Delta f)$ we need a modulating stage MOD(Δf) in the feedback loop:

Fig. 5



The modulation stage can be external or part of the control of the second source of the receiver (VNA). In any case its modulation pattern is driven by the difference between the measured and targeted Γ_{LOAD}=a2/b2 for each signal component of the modulation pattern.

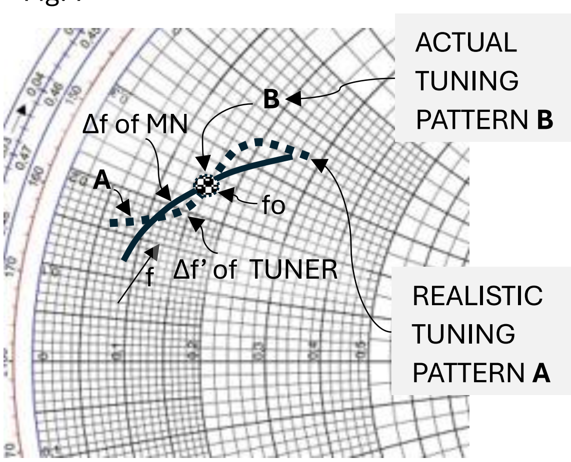
Fig. 6



Hereby the b2 signal delivered by the DUT is distorted relative to the original a1 signal entering into the DUT; It is therefore obvious, for the test to be realistic, that the return signal a2 must relate to the distorted b2 such that $\Gamma_{LOAD}(f)=a2/b2$ must emulate the contour of the anticipated matching network (MN). Because matching networks, especially in MMIC technology are very small, they do not include resonant loops, even at 1GHz modulation bandwidth. This means such embedding (matching) networks (MN) have a normal negative phase sloping behavior, normally spread on both sides of the optimum CW impedance Γopt, which must be emulated by the hybrid tuner, as shown in figure 7:

As an example: A 1mm long GaAs strip (ε_r~12.5) creates a Γ phase change of ca. 8° at Δf=1000MHz.

Fig. 7



Hitherto publications emphasize only the capacity of active tuning systems to create patterns of type B, i.e. regrouping all impedances Γ_{LOAD} in a small area around Γ(fo) for the entire modulation band Δf, whereas it would be more realistic and useful to emulate dispersive tuning patterns of type A.

So far, this approach remains unexploited.

(*) The exact relation linking the injected power P_{inj} with the DUT power P_{DUT} and the s-parameters of the passive tuner in a hybrid load-pull tuner in order to conjugate match a DUT with output reflection factor $\Gamma_{DUT}=(50\Omega-R_{DUT})/(50\Omega+R_{DUT})$ is

$$\frac{P_{inj}}{P_{DUT}} \approx \frac{|\Gamma_{DUT}^{*} - S_{11}|^2.(1-|S_{11}|^2)}{|S_{12}|^2.(1-|\Gamma_{DUT}|^2)}$$

or

if $S_{11} \approx \Gamma_{DUT}^{*}$ then $P_{inj}=0$, and

if $|\Gamma_{DUT}| \rightarrow 1$ then $P_{inj} \rightarrow \infty$

References

AN-70… "INJECTION POWER SAVINGS IN HYBRID LOAD PULL", Focus Microwaves.

PN-94… "Delta Tuners Inherently Offer Better Accuracy On-Wafer", Focus Microwaves.