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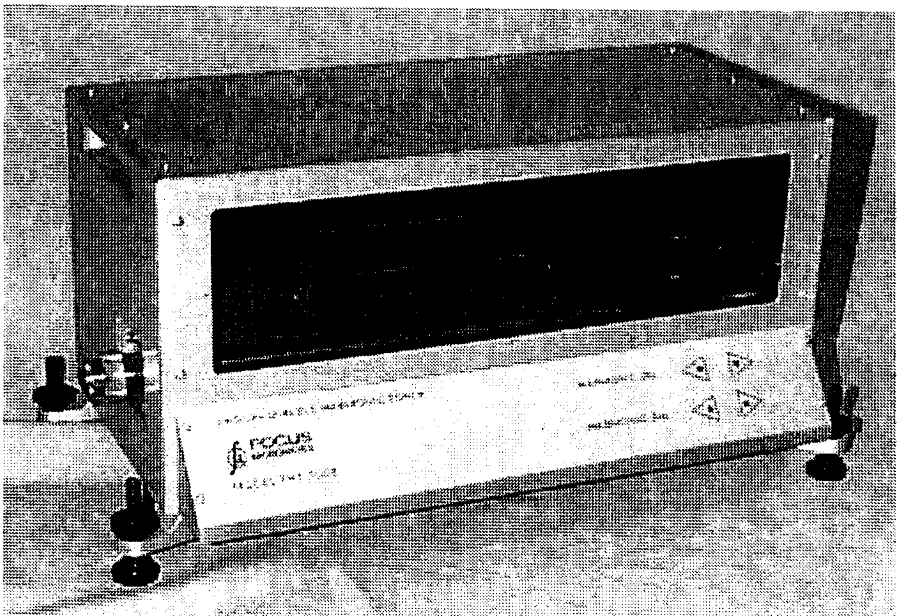
Focus microwaves

Product Note 44

Programmable Harmonic Tuner, PHT

Programmable Harmonic Tuners, model PHT, are precision electromechanical instruments able to selectively generate and independently control high reflection factors at predefined harmonic frequencies. PHT can be included in existing load pull setups and used to optimize the harmonic load conditions independently of fundamental frequency tuning. Standard PHT models control two harmonic frequencies. A source and a load PHT can be controlled by a separate tuner controller installed into the load pull system computer (IBM-PC).



Programmable Harmonic Tuner, for measurements up to 18 GHz

PHT at a glance:

Frequency Range (Fundamental)	800 MHz to 9.0 GHz
Frequency Range (Harmonics)	1.6 to 18 GHz
Instantaneous Bandwidth	200 MHz (adjustable)
Tuning Range (Amplitude)	0.85 to 0.98
Tuning Range (Phase)	0 to 360 degrees
Insertion Loss (@ Fundamental)	0.1 to 0.5 dB
Maximum CW Power	50 W (GPC-7), 100 W (N)

November 1997

Description of PHT

PHT includes both **hardware** and **software** components.

The hardware components include the **harmonic tuners and an IBM-PC insertable tuner controller**, to be used in parallel with the fundamental tuner (CCMT) controller.

The software components include a PHT **tuner calibration software**, compatible with all commercial network analyzers, and an **operation software**. The operation software loads PHT calibrations and can interpolate between calibrated points. It also has direct tuning capability to any phase on the Smith Chart entered in the keyboard or can be tuned using the arrow keys (cursors) of the control PC. Using the CCMT system's fine tuning capability, the PHT software compensates automatically for any changes in the fundamental impedance due to harmonic tuning. The software is therefore able to accurately measure the dependence of all measured quantities of the harmonic impedances alone.
The PHT tuners are inserted in the load pull setup in cascade between the test fixture and the fundamental tuners (figure 2):

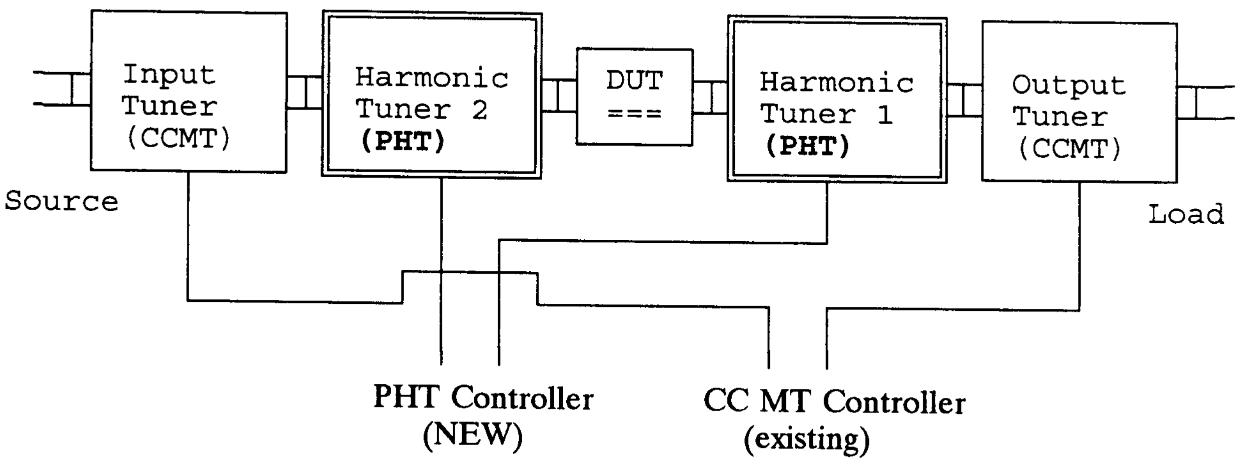


Figure 2: Implementation of PHT in an existing CCMT Load Pull setup.

The programmable harmonic tuners, PHT, employ resonant probes made using proprietary designs [(1)]. These resonant probes can be manufactured for any frequency up to 18 GHz and used in the PHT mainframe. Their positions are controlled by the precision stepping motors used also in the standard Computer Controlled Microwave Tuners (CCMT) of Focus Microwaves. These translation mechanisms have proven extremely accurate and reliable in over 350 CCMT tuners manufactured so far.
Due to very low loss materials used in the resonant probes, the harmonic tuners are able to generate very high reflection factors up to 0.98 at the tuner reference plane. These reflection factors can be adjusted in phase in order to optimize any measured quantity of the DUT, including Efficiency, Power, Gain, Intermod, ACPR etc... Because of the high

(1) *Patent Pending*

Q used, tuning the harmonics only slightly affects the impedances tuned at the fundamental frequency by the fundamental tuners in the setup (figure 2).
Figure 3 shows the hardware implementation of a load side PHT in a setup. The setup also includes one of Focus' Power Transistor Test Fixtures (model PTJ-0) and a 0.8 to 18 GHz programmable tuner, model CCMT-1808.

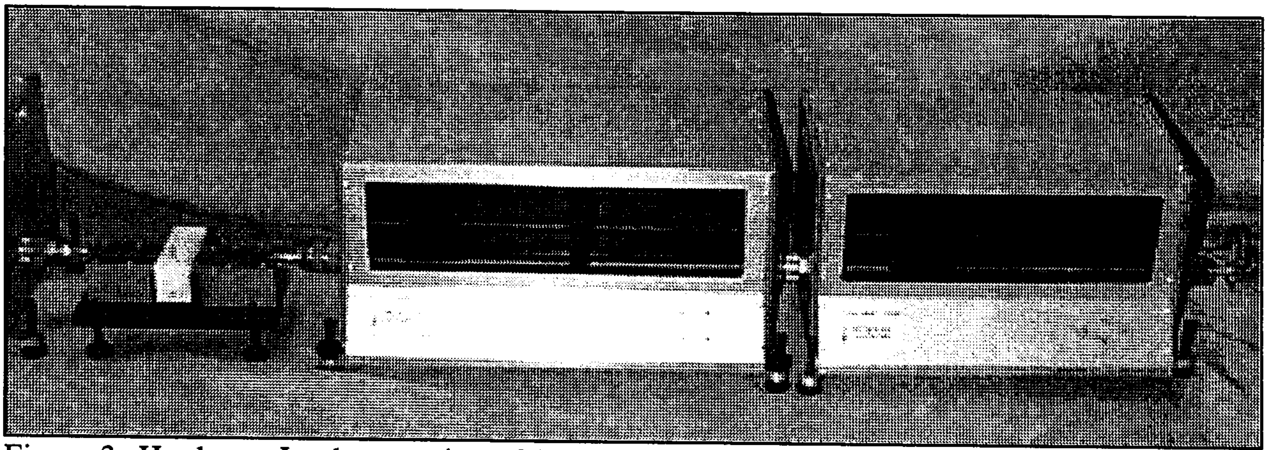


Figure 3: Hardware Implementation of Programmable Harmonic Tuner in a load pull setup.

PHT Calibration

PHT is calibrated using any of the commercially available network analyzers. Supported analyzers include all HP-8510, HP-8720 and HP-8753 (including 8753-D) as well as Wiltron 360 and 37000. Calibration is fully automatic and the calibration data is saved in calibration files on the hard disk, one file per frequency.

The user can select between 100, 225 and 400 calibration points per frequency. The positions of the tuner are such as to perfectly cover 360 degrees at each calibration frequency. The number of calibrated points is fully sufficient for use in interpolation routines to generate the impedance at any combination of motor positions. This provides an extremely high tuning resolution of the order of 0.1 to 0.2 degrees per step.

The calibration procedure takes between 5 and 15 minutes per frequency point, depending on the calibration density and frequency selected. All tuner calibration points are situated within an area between 0.9 to 1.0 on the Smith Chart (figures 4, 5).

Using a low loss test fixture allows to synthesize very high reflection factors at the harmonic frequencies required to optimize transistor Efficiency, Linearity and any other parameter of interest.

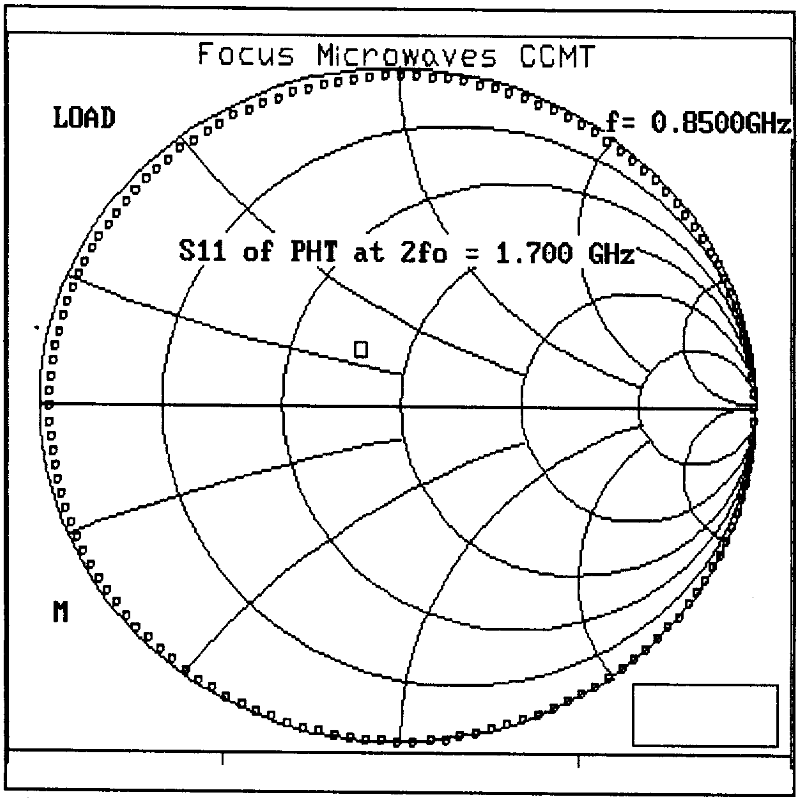


Figure 4: PHT tuner calibration at $2f_0$ (1.7 GHz)

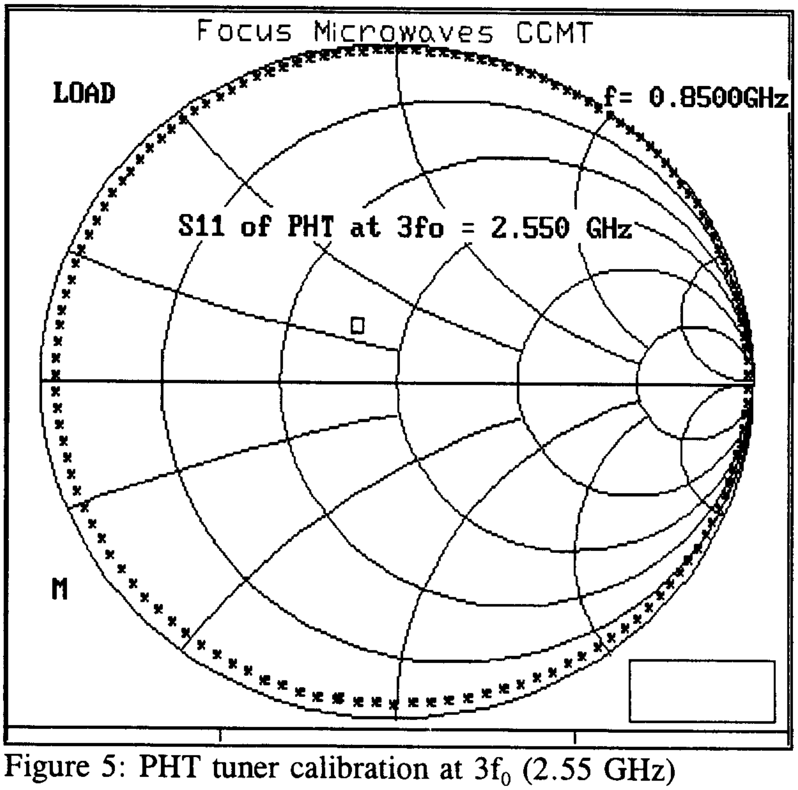


Figure 5: PHT tuner calibration at $3f_0$ (2.55 GHz)

Harmonic Tuning Menu

The harmonic operation software HASOFT offers a complete **Harmonic Tuner Control Menu** (figure 6).

This menu allows to **tune** to all three impedances at f_0, $2f_0$ and $3f_0$ using **data entry on the keyboard** (keys F1, F2 and F3 in figure 6).

It also allows to control the actual positions of the harmonic and fundamental tuners using the arrow keys (**Cursors**) and display the actual harmonic impedances deembedded to DUT reference plane (key F4 and figure 7).

Using the PgUp key in this menu (figure 7) allows to switch back and forth between harmonic and fundamental tuners. Using the 'Home' key allows to perform measurements of all parameters saved in a measurement list and display them on the screen.

```
Harmonic Tuning...
-----------------
F1  Fundamental (fo)
F2  Harmonic 2 (2fo)
F3  Harmonic 3 (3fo)
F4  Cursor Tuning
F5  Harmonic Sweep
F6  Harmonic Peak

F8  Verify CAL 2fo
F9  Verify CAL 3fo

F10 Quit...
------------------
Press F-Key...
```

Figure 6: Harmonic Control Menu

The routine **Harmonic Sweep** that can be activated using the key F5 offers the possibility to measure any of the listed parameters over a phase sweep between arbitrary start and stop phases of the harmonic 2 and 3 reflection factors and any number of equidistant steps and save it in a saturation type file (see figures 8 to 11).

```
Left-Right = Harmonic 2
Up - Down  = Harmonic 3
PgUp = 'Harm'<->'Fund'
Home=Measure (Ctrl-Home)
End  = Quit
```

Figure 7: Harmonic Cursor menu

The **Harmonic Peak** routine (key F6) allows to search the optimum harmonic phase for both harmonic frequencies and tune the harmonic tuner to it, once terminated. This routine is combined with a pre- and a past-optimization for the fundamental impedance. The result can be saved in an ASCII (HPEAK.xxx) file on the hard-disk for later processing.

Examples of Measured Data using PHT

PHT has been used in a load pull setup, tuned and calibrated for Cellular and PCS applications including fundamental frequencies between 0.85 and 2 GHz.

The calibration procedure also involves fundamental tuner (CCMT) and setup calibration at f_0, $2f_0$ and $3f_0$ (ie: 0.85, 1.7 and 2.55 GHz or 1.85, 3.7 and 5.55 GHz etc...).
Once the data is loaded into memory, the software deembeds to DUT reference plane for all three harmonic frequencies. As a first step, the fundamental tuners are optimized to synthesize the best load and source impedances for maximum Gain / Power or Efficiency. The software can also search automatically for maximum **Compressed Gain** load and source impedances.
As a second step, the phase of the harmonic impedances at $2f_0$ and $3f_0$ are optimized.
As a last step, the fundamental impedance can be re-optimized to provide the best overall tuning conditions for the parameter selected.

The data can be saved on hard-disk in ASCII format (file extension = .SAT) and used to generated saturation type (cartesian) plots (figures 8-11).

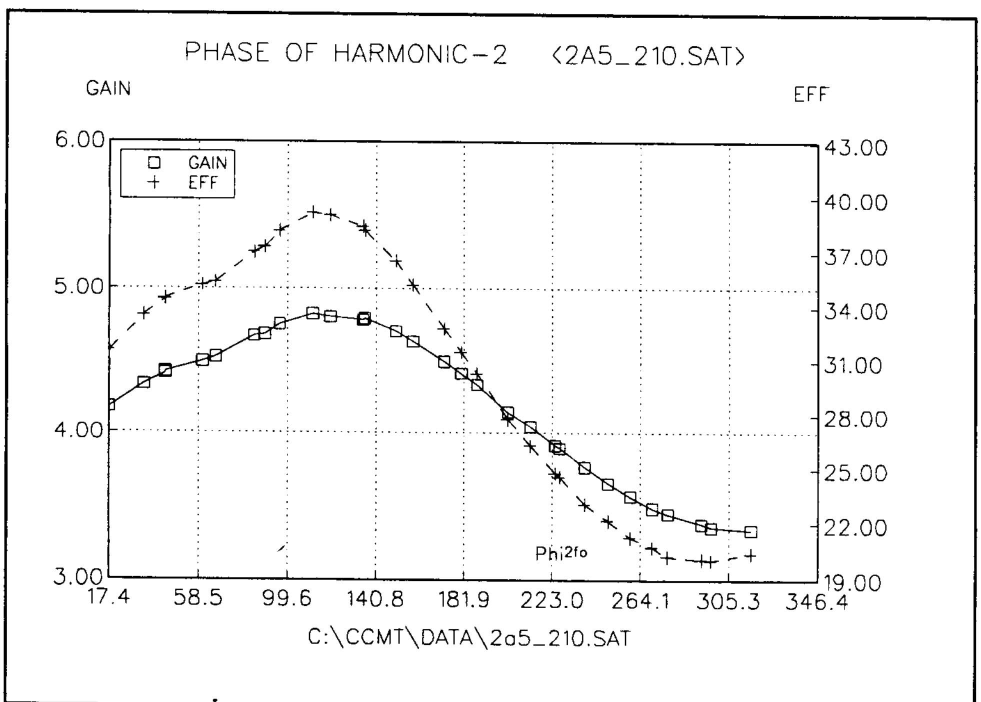


Figure 8: Dependence of Power added Efficiency and Gain from the **Phase of the Second Harmonic** reflection factor of a bipolar transistor at 3.7 GHz (f_0=1.85 GHz).

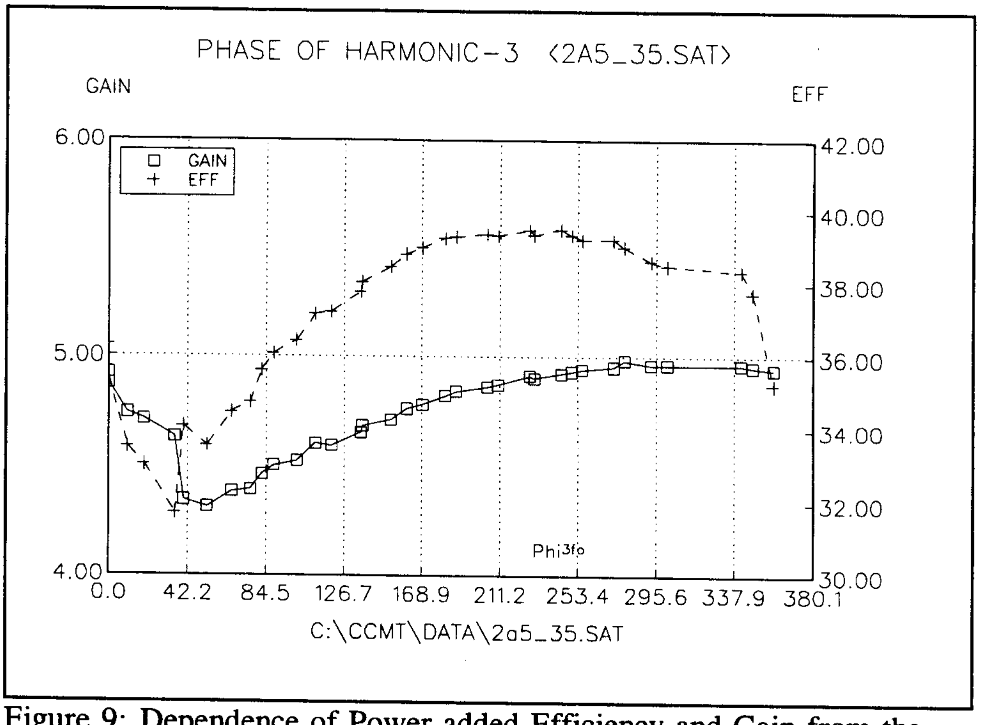


Figure 9: Dependence of Power added Efficiency and Gain from the **Phase of the Third Harmonic** reflection factor of a bipolar transistor at 5.55 GHz (f_0=1.85 GHz).

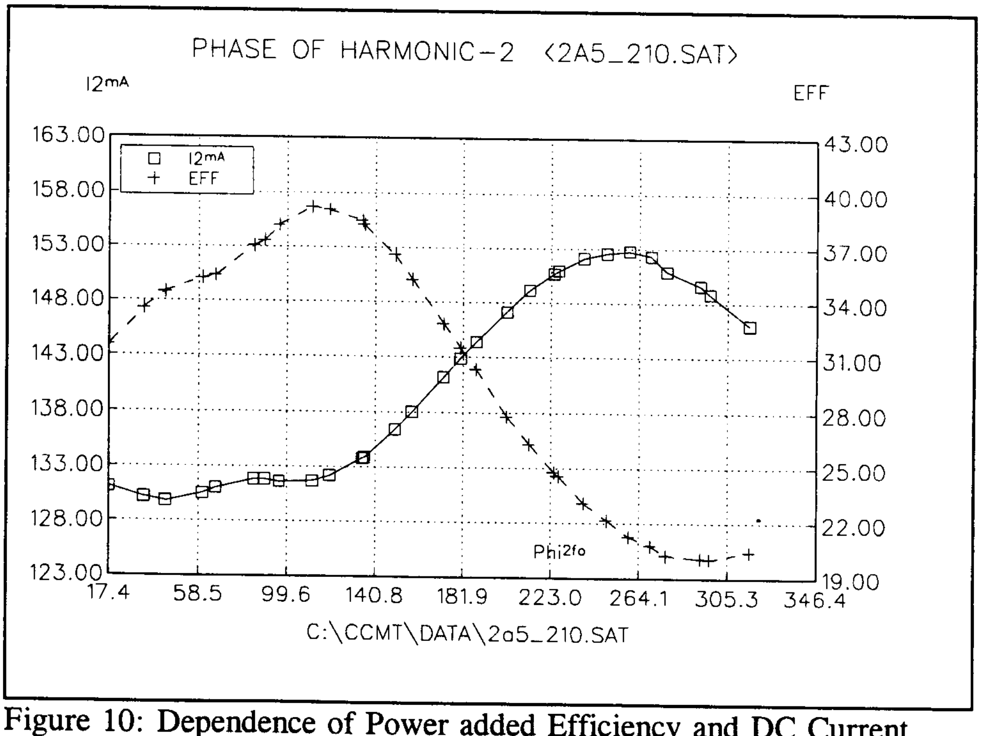


Figure 10: Dependence of Power added Efficiency and DC Current from the **Phase of the Second Harmonic** reflection factor.

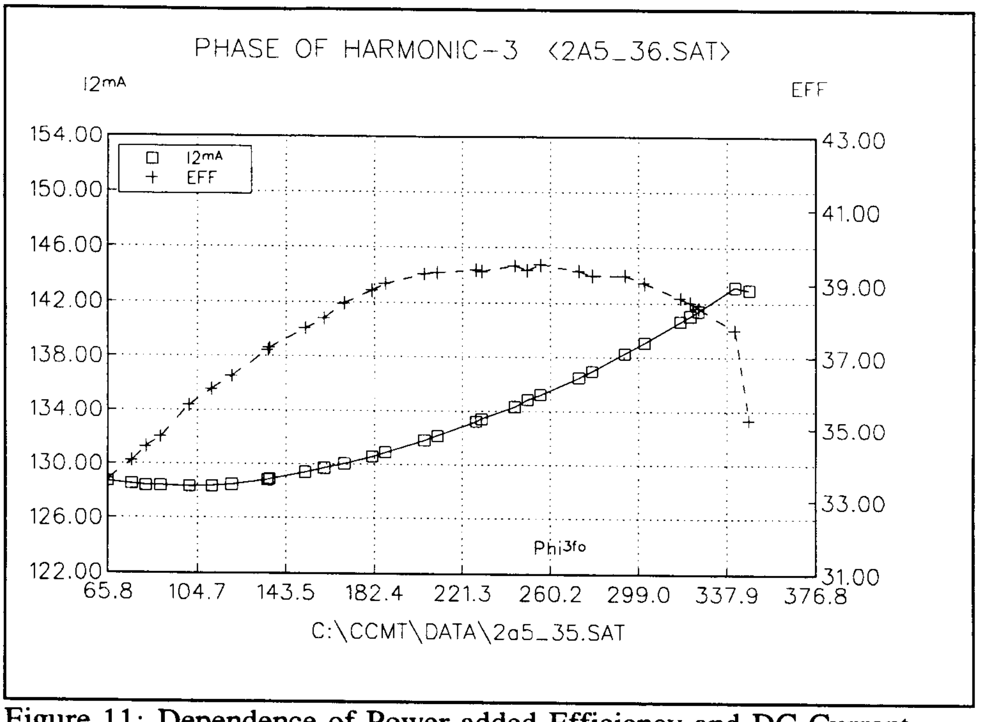


Figure 11: Dependence of Power added Efficiency and DC Current from the **Phase of the Third Harmonic** reflection factor.

Advantages of Programmable Harmonic Tuners (PHT)

Harmonic load pull systems, presently in use, are critically limited in operation frequency and either generate insufficient reflection factors at f_0, $2f_0$ and $3f_0$ and can handle limited power (electronic tuners) or require the use of complex and limited bandwidth frequency multiplexers (di- or triplexers) and complex active modules which shall compensate for the triplexer losses, but are prone to parasitic oscillations.
Compared to this, PHTs however, offer **several distinct advantages**:

- PHTs are reliable and can be simply integrated and operated in existing and new setups.
- Generate ¦**S11**¦**up to 0.98** at both harmonic frequencies.
- Can be manufactured and easily configured and tuned to handle frequencies from 400 MHz to **and beyond 18 GHz.**
- Eliminate diplexers and triplexers in the setup.
- Do not require active modules to compensate for triplexer losses, due to high ¦S11¦ and low insertion loss.
- **Reduce the risk of low frequency parasitic oscillations**, since they have low reflection factors at low frequencies.
- Handle **high power**, since they use low loss 50Ω transmission airlines and have low reflection at the fundamental frequency (where most of the power is concentrated).
- Are **compatible with existing and already operating Focus Load Pull systems**.