

Owning and Operating the HP 8410 Network Analyzer

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Abstract

The HP 8410 Network Analyzer offers the cheapest and most cost effective solution for network analysis (particularly scattering parameters) above 6 GHz. The paper details the various parts of the 8410 along with the various trials and tribulations of building an automated 8410 system.

1 Introduction

Kurokawa[1] introduced the generalized scattering parameter (S-parameter) in 1965. S-parameters are extremely useful for all types of microwave circuit design including amplifiers and oscillators[2]. Therefore, when the HP 8410 was introduced in 1967, it revolutionized microwave design.

It used the new 1430A sampler together with a superheterodyne receiver architecture to produce a calibrated microwave receiver. Together with the test sets, it can measure transmission and reflection coefficients for any two port device. Subsequent offerings from HP (and others) have concentrated on the lower end as shown in the following table:

As can be seen, the only analyzers that cover above 3 GHz (without internal doublers) are the 8410, the 8510A and the 8720. The 8510A/B/C and 8720A are

Model	Freq. Range(GHz)	Std. Source	Test set	Comments
8407A	0.001-0.110	8601A	none	Compatible with 8410 plugins
8410ABC	.11-18	8620C	Many: 874x	Needs display plugins
8505A	0.0005-1.3	internal	8503A	8501A normalizer
8510ABC	0.045-26	8341A	851x	The gold standard of analyzers
8712ABC	0.0003-3	internal	internal	production use
8720ABCD	0.045-26	internal	internal	“Improved” version of 8510A
8753ABCD	0.003-3	internal	85046B,47A	option 006 goes to 6 GHz
8754A	0.004-1.3	internal	850xx	H26 option goes to 2.6 GHz

Table 1: HP network analyzers

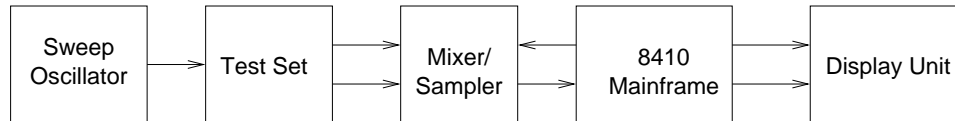


Figure 1: 8410 Block diagram

still out of the reach of all but the most well funded of amateurs. That leaves the 8410.

The paper discusses the various parts of the 8410 as well as the complications of trying to automate it. Also included is a discussion of the woes of calibration.

2 Principles of operation

Before discussing the various parts and components of the 8410, it will be useful to see how they fit into the whole scheme. The overall schematic is shown in Figure 1. Here, the swept signal source introduces an RF signal into the test set. The RF signal is divided into *test* and *reference* signals. The reference signal is passed directly to the first mixer stage. The test signal goes through the unit under test and then to the mixer. Most test sets permit the selection of a particular S-parameter set-up by engaging the RF relays inside the set. The 8411A harmonic converter (shown in Figure 2) contains a sampler for each channel. The mainframe tries to maintain phase lock between the sampler and the sweep oscillator. It also downconverts the input to a 278 KHz IF. This is given to the display unit(s).

The inside of the 8411A harmonic converter is shown in Figure 2. The first

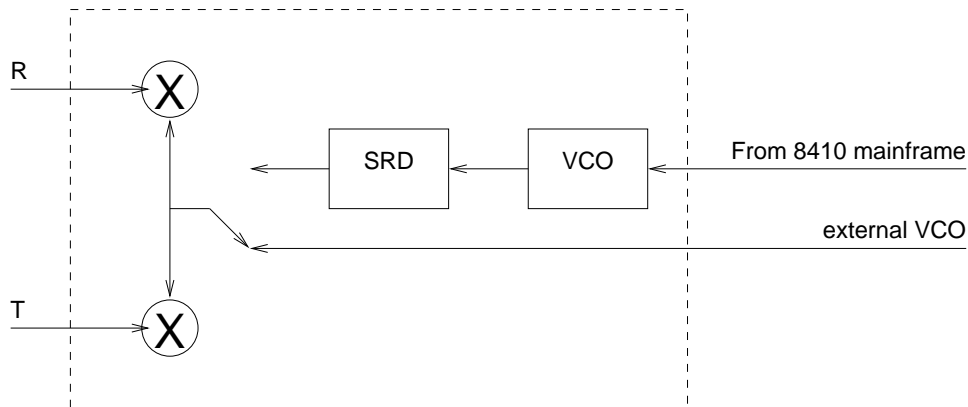


Figure 2: 8411A Block diagram

RF mixer (a Grove sampler[3]) is inside the 8411A harmonic converter; a Step Recovery Diode, driven by a VCO inside the 8411A generates harmonics which are used to down sample the input signal to 20.278 MHz. The Phase Lock Loop (PLL) inside the 8410 mainframe tries to maintain lock by controlling the VCO. The 20.278 Mhz signals are then downconverted again by heterodyning with a 20 MHz reference resulting in a 278 KHz IF. This signal is the output signal of the mainframe to the display units.

3 The 8410 receiver

The 8410 receiver comes in 3 models:A, B and C. The major change occurred from A to B when many changes were made to the phase lock circuits. The C model introduces the changes made to “option H17” for the B as well as placing the 8411A connector on the rear of the instrument. When it comes to trying to automate the 8410, you *must* have a B model with the H17 option or the C model. The H17 option introduces the wiring necessary to provide external injection of the RF signal for the 8411; this will be explained in the automation section.

4 The 8411A harmonic converter

The 8411A is the most tempermental unit of the 8410 components. The diodes in the sampler are delicate and sensitive to static. And of course, they are no longer available. The plug of the 8411A is a unique HP design (shared by the 4815A).

It packages several RF coax into one connector ¹. The 8411A comes with an option 018, which means that the diodes in the sampler were selected for 18 GHz operation. It must be noted that *many* early 8411s do not have the full complement of pins; these units are *unsuitable* for automation (but not for diodes!).

5 The display units

The 8410A has a half bay for the display module. There are three choices: a rectangular display for magnitude and phase, a meter and a polar display suitable for Smith charts.

5.1 The 8412A rectangular display

The 8412A comes in A and B. The B revision has a connector on the rear for connection to the 8750A storage normalizer. The test amplitude output from the 8410 mainframe is detected and then given to a log amp; this is used for dB conversion along with the test channel phase. The same operation can be applied to the reference channel. A multiplexor can choose between the two outputs.

5.2 The 8413A meter

Meter pin mashers will want the 8413A, however, it is seldom used but can be used for calibration if desired.

5.3 The 8414A polar display

The 8414A also comes in a B revision with a separate vertical blanking connector on the rear. The 8414A/B provides a sin and cos conversion for polar display.

6 The test sets

As discussed earlier, the test sets provide a way to measure reflection (S11 and S22) as well as transmission (S12 and S21) parameters. The test sets are typically controlled via a 59306A relay actuator.

¹Why didn't HP use the standard D shell?

6.1 The 8740A,41A,42A,43A reflection/transmission test sets

The 8740A, 8741A and 8742A are the earliest test sets. The 8740A is a reflection test set, the 8741A and 8742A are transmission test sets. All of these units must be considered obsolete and marginally useful because they required the user to disconnect the Device Under Test (DUT) and reverse it.

The 8743A on the other hand is a switched reflection and transmission test set. The external relay controls expect a 12 volt negative true signal. The 8743A comes in a B model and also includes an option 018 for 18 GHz operation. The 11610B was a semirigid cable designed for use with the 8743A/B.

6.2 The 8745A,46A,47A,48A S-parameter test sets

The 8745A is the low frequency (0.1 to 2 GHz) S parameter test set. It can be used with the 11600A and 11601A transistor fixtures. The 8746A is the higher frequency set (also comes with option 018) and uses the 11608A fixture. Both of these sets can be used with flexible arms (the 11604A and 11605A respectively). Also included is the 11607A small signal adapter. ²

The 8747A series are waveguide reflection and transmission test sets. The X8747A and P8747 are for X and P band respectively. The R8747A and K8747A are for R and K bands respectively. They differ from the X and P band versions since they use an external mixer and an addition CW oscillator to mix down to a lower (2-4 GHz) band. A similar set-up for V band was described by Yamaguchi et al. [4].

6.3 The 85040

The 85040A was the last test set designed for the 8410. It was part of the 8409A analyzer system. It features more modern relays and controls and is designed to be externally controlled by the 11713A relay controller.

7 Auxiliary units

These units are useful but not required.

²It must be noted that the the flexible arms have been replaced by coaxial cables made by Gore and others.

7.1 The 8418A auxiliary power unit

So what do you do if you want *both* rectangular and polar display and you don't want to keep pulling one out? You need an extra power supply: the 8418A. The 8418A may also include option 70 which adds an internal 70 dB attenuator.

7.2 The 8419 interface

Imagine a day before integrated A/D converters. The 8419A/B/C is an A/D converter and 8418A power supply rolled into one. The 8419 forms an integral part of the 8542A automated system.

7.3 The 8709A synchronizer

In order to phase lock the injected RF with the sweeper, you need an external phase lock loop to control the external synthesizer via the FM input. The 8709A synchronizer does this by duplicating the 8410 phase lock. The use of the 8709A will be discussed further in section 10.2.

7.4 The 8717A bias power supply

The 8717A is a small power supply designed expressly for the 8410A system (yes, it can be used as a standalone power supply). It is designed to be connected to the bias connectors on the S-parameter test sets. Option 001 permits external control of the voltages (via a D/A Converter).

7.5 The 8750A storage normalizer

The sweep rates generated by the 8410 can be very slow which leads to an annoying display. The 8750A permits storage of the 8412B display for redisplay. Note that the 8750A can also be used for spectrum analyzers because the 8750A has personality cards.

8 Test fixtures

For measuring coaxial components, you must use a test fixture. The 11601A and 11602A are cute fixtures designed to mount on the 8745A . They measure

transistors in the TO-18 and TO-5 packages. The fixtures also include shorts and opens, so you can calibrate the analyzer. For more complex circuits, such as SMT devices, the 11608A fixture is needed. It was designed to fit in the 8746A/B. For more complex packages, the 85041A fixtures must be considered. But for measuring “boxes” rather than components, cabling is needed.

9 Historical units

These units are of little practical use and are discussed here for completeness.

9.1 The 8327A switch

Since each test set requires an 8411A, you need multiple 8411s to cover all the bands. Or you can switch between them. That’s what an 8327A does; these are very rare.

9.2 The 8705A multiplexor and 8707A RF unit holder

The original RF source for the 8410A was the 8690A sweeper. Therefore, you needed multiple BWOs for sources. The 8707A provided a way to control multiple RF units for the sweeper mainframe. The 8705A multiplexed the outputs from the various 8690A plugins into one RF output.

9.3 The 8710A tracking filter

Due to the harmonics present in the 5105A frequency synthesizer output³, a “filter” is needed to clean up the signal. The 8710A tracks the sweeping signal and has its own clean VCO which is injected into the 8411A .

10 Automation

It would seem at first glance that just building an 8410 system would suffice to have an accurate instrument. Unfortunately, this is not the case. The test sets add additional complexity because they are part of the circuit being measured. Since

³Recall the 5105A was before the 8660A

this is no longer a lumped domain, these must be removed from the measurement. To do so requires *de-embedding*. So, to get the values for the de-embedding equations, you need to digitize the output of the 8410. Originally, HP used the 8419A/B/C discrete A/D converter as discussed earlier; subsequently, they used the 59313A A/D converter to digitize the 8414A (and also the magnitude of the 8412A due to isolation problems in the 8414A).

After de-embedding, the results need to be displayed. In the 8542A system, they are converted back to analog via a D/A and routed via the 8414. This is not really needed when you have a computer display at your service.

There are additional areas for automation besides digitization.

10.1 The source

The source for the 8410 system should ideally be broadband and controlled by the same computer. The 8620C sweep oscillator is ideal, but only if you get option 011, the GPIB/HPIB option. Or, if you have more money, you can get an HP 8350A/B. Or perhaps an EIP 931.

10.2 Phase locking and harmonic skipping

As mentioned above, the 8411A uses an SRD to generate harmonics up and down the band; it is locked via the 8410. However, the 8410A can exhibit *false locking*, i.e., lock onto the wrong harmonic. This, of course, leads to a measurement error. To eliminate this problem, HP introduced external injection of the sampler frequency controlled by an external RF synthesizer. As mentioned earlier, this synthesizer is in turn locked via the 8709A option H17. So, this is another opportunity for computer control. With computer control, the frequency accuracy will increase from ± 2.5 MHz for the 8620C to ± 5 kHz. A power amplifier may be required to raise the level of the synthesizer to drive the SRD harmonic generator (HP used the 8447 series of amplifiers).

11 Errors

In the ideal world, the perfect network analyzer would have infinite dynamic range, perfect channel isolation, coupling without loss and impedance mismatches with flat frequency response. However, we live in an inaccurate world. Random

errors can of course, not be corrected (but can be averaged). Other (repeatable) errors, such as those enumerated above, can be corrected.

These corrections can be realized by drawing the flow graph for each parameter measurement and including all the errors as well as the measurement paths. These flow graphs can be written as equations and when combined will give a set of equations for corrected measurements. Full details are given in HP's application note 221[5].

12 Calibration

In order to calibrate the 8410, you need a large collection of coaxial components including a short, a load, an open, airlines and converters from 7 mm to SMA, 7 mm to N, 7mm to 3.5 mm and so forth. A sliding load isn't harmful either.

And, as long as you're calibrating, you might consider a gage to check your 7 mm connectors...

13 Extensions

The sampling mixer of the 8411A has considerable loss. If you desire more dynamic range, you can replace the 8411A with external mixers (assuming you can take the IF and put it back into the mainframe) if you use an external LO for the mixers. This was used by a group at NASA[6] for a far field antenna range.

14 Conclusion

The 8410 is still the only network analyzer that is affordable and operational above the limit set by the 8753. This paper has related some of the trials and tribulations a system builder will encounter when building up such a system. As an indication, just consider the number of cables required...

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