

## MODULAR LINEAR FEED-FORWARD AMPLIFIER

The invention concerns feed-forward, radio-frequency (rf) amplifiers, in which the active components are constructed of two-port modules, which remove easily, and which, being two-ports, are simple to test, using s-parameters.

### BACKGROUND OF THE INVENTION

Figure 1 illustrates a commercially available feed-forward radio-frequency amplifier. The amplifier is constructed in sections, indicated by dashed boxes, such as 3, 6, 9, and 12. When a section malfunctions, the symptoms manifest as faulty operation of the amplifier as a whole. To isolate the malfunction, a technician generally removes the individual sections from the amplifier, and tests each one.

Testing each section is not a simple task, because some of the sections are actually multi-port networks. For example, section 3 contains ports 15, 18, 21, and 24. For testing, the technician generally connects impedances to some ports of the section, but leaves two ports open. These impedances intend to (a) simulate the impedances seen by the section when installed in the amplifier and (b) create a pseudo-two-port device to test, using the unconnected two ports.

However, this simulation is an inexact procedure, and does not always replicate the actual impedances seen by the section. Thus, the section is frequently tested in an environment different from its operating environment. This difference can make diagnosis difficult.

In addition, because of the complexity of this testing procedure, it is generally done at a manufacturing site, rather than in the field at the site where the amplifier is

located. Consequently, the testing requires shipping of components to the manufacturing site, which imposes added cost.

#### **SUMMARY OF THE INVENTION**

In one form of the invention, the components of a feed-forward linear amplifier are grouped into two categories, active and passive. The passive components are highly reliable, and act as interconnections among the active components, which are all constructed as removable two-port networks, which are simple to test and maintain. Testing and maintenance can be done on-site, where the amplifier operates.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

Figure 1 illustrates a commercially available feed-forward linear amplifier.

Figure 2 is a signal flow diagram of one form of the invention.

Figure 2A illustrates removable active elements, which are two-ports.

Figure 3 is a circuit diagram of one form of the invention. The signal flow diagram of Figure 2 is based on Figure 3.

Figure 4 illustrates use of a digital bus to transmit control signals to a gain stage.

Figure 5 illustrates removability of active elements from the circuit of Figure 3.

Figure 6 illustrates another form of the invention.

Figure 7 is a modified form of Figure 3, with node numbers added.

Figure 8 illustrates a control system which issues digital signals to certain active components, in order to adjust gain and phase.

#### **DETAILED DESCRIPTION OF THE INVENTION**

##### **Highly Simplified Overview**

Figure 2 is a signal-flow diagram of one form of the invention. The active components (ie, those which consume power) are indicated as either triangles or circles. (They are explicitly listed in a later section.)

These active components are removable, as indicated in Figure 2A. Not only are they removable, but they are constructed as two-ports, as that term is used in network theory. That is, each component has an input (one port) and an output (the second port). No active component has additional ports, such as a feedback port.

Two-port networks can be tested in a straightforward manner, using commercially available equipment.

#### **More Detailed Explanation**

Figure 3 is a circuit diagram which corresponds to Figure 2. The symbols of Figure 3 are explained as follows.

MPLCP1, MPLCP2 (Main Path Linear Control Packs #1 and #2): These are gain stages, producing gain in the range of 12 dB, and which are adjustable in gain and phase, as indicated by the arrow-circle symbol 30.

LIN-LAM 1, LIN-LAM 2 (Linear Amplifier Modules #1 and #2): These are power amplifiers, having nominal gains of 20.5 dB, and have distortion characteristics which match those of the LAU, discussed below.

LCU (Linearizer Coupler Unit): This is a power divider and combiner. It consists of four rf cavities, labeled A, B, C, and D. It can be viewed as a signal splitter and summer, performing the functions of components labeled LCU A, LCU B, and so on, in the signal flow graph of Figure 2.

In the LCU of Figure 3, signal flow is in the direction indicated by the arrows.

PEDL (Pre-Emphasis Delay Line), PDDL (Pre-Distortion Delay Line), PCDL (Post Correction Delay Line), FCDL (Final Correction Delay Line): these are delay lines for generating matching loop phase delays.

DPLCP1, DPLCP2 (Distortion Path Linear Control Packs #1 and #2): in the feed-forward linearization approach, distortion signals are isolated from the information signals. The DPLCP's provide controlled gain and phase adjustment to the isolated distortion signals. Gain is 43 dB, nominal, and is adjustable, together with phase being adjustable.

LAU (Linear Amplifier Unit): this is a power amplifier, which includes 20 individual rf amplifiers, in parallel. Gain is 19 dB, nominal. The individual rf amplifiers are sometimes called LAMs, or Linear Amplifier Modules.

LAUPD (Linear Amplifier Unit Power Distribution): this provides operating power to the LAU, and provides diagnostic functions, such as monitoring output power of the LAU.

LAUC (Linear Amplifier Unit Coupler): this isolates distortion signals generated by the LAU.

ICU (Isolator Coupler Unit): this combines the rf output of the LAU with the rf output of LINLAM2, to produce an output signal. It also contains two test ports, TC5 (Test Cable 5) and TC6. TC6 feeds a POWER MONITOR, which measures average power delivered. TC5 feeds L2T (Line 2 Test), which is discussed later.

C1, C2 (Cable 1, Cable 2), etc.: these are cables, waveguides, or striplines, as appropriate.

DIGITAL BUS: MPLCP1, MPLCP2, DPLCP1, and DPLCP2 receive a digital signal from a DIGITAL BUS. This digital signal feeds a digital-to-analog (D/A) converter, shown by example in Figure 4, which converts the digital signal to an analog signal. The analog signal controls the gain and phase of these amplifiers. The gains and phases must be periodically adjusted, because these parameters are subject to drift, and also change with input signal loading.

Figure 4 is illustrative only. Numerous different approaches can be taken to derive two analog signals (one

for gain, one for phase) from the digital signal on the digital bus. For example, if the digital signal contains 16 bits, the most significant 8 bits can be used to control gain, and the least significant 8 bits can be used to control phase. As another example, the gain/phase signals can be delivered in two steps, to two latches, one for gain and the other for phase..

The use of a digital signal has the advantage of eliminating ground loop problems. For example, if a control system measures a parameter, and, in response, applies an analog control signal to MPLCP1, then a feedback loop has been created. In general, such feedback loops are not favored.

The invention eliminates such loops, by transmitting a digital signal to the amplifiers. The digital signal path does not act as an analog transmission line, and does not create a feedback loop.

Figure 3 contains all information required to construct the amplifier indicated.

#### **Modular Aspects**

Figures 2A and 5 illustrate modular aspects of the invention. The components can be divided into two categories, active and passive:

##### **Active Components**

MPLCPs,  
LIN-LAMs,  
DPLCPs, and  
LAMs.

This list refers to active components which process signals. Power supplies, of course, are also active components, but they do not process signals.

##### **Passive Components**

LCU (including A, B, C, and D),  
PDDL,

PEDL,  
PCDL,  
FCDL,  
LAUC,  
ICU, and  
Cables and interconnects.

The active components are disconnectable from the passive components, as indicated by the CONNECTORS in Figure 5, which are standard blind mate connectors.

Further, as stated above, the active components are all constructed as two-port networks. For example, MPLCP1 contains an input port, at C1, and an output port, at C2. Two-port networks are easily diagnosed, using commercially available vector network analyzers, which analyze the s-parameter test set.

#### **Benefits**

In practice, if a malfunction occurs in the amplifier of Figure 3, it is reasonable to assume that an active component is at fault, rather than a passive component, because of the high reliability of passive components. To isolate the malfunction, a technician removes the active components, one-at-a-time, and tests them, treating them as two-port networks. S-parameter testing is a common testing method. The testing will identify the faulty active component, which is then repaired or replaced.

Alternatively, the control board, discussed below, can be instructed to run a diagnostic program or routine, to isolate the fault.

#### **Another Form of Invention**

Figure 6 is a modified form of Figure 3. In Figure 6, the active components have been deleted, and are represented by the dashed boxes. The invention of Figure 6 is the passive network illustrated. Installation of the active

components into the passive network produces a working amplifier.

#### **Prior Patent**

One type of feed-forward linear amplifier is discussed in U.S. Patent 4,879,519, issued to Robert E. Myer on November 7, 1989, and having a common assignee as the instant patent. This Myer patent is hereby incorporated by reference.

#### **Significant Features**

1. The amplifier of Figure 3 is designed to operate in a frequency range of 869 to 894 MHz, and produce an average output power of 240 Watts (at the lead labeled OUT). All of the individual components of this Figure are commercially available.

2. A CONTROL BD, in Figure 8, orders a SENSOR BOARD to sense one of four lines (Input Test, L2T, L1/4T, and L3T, also shown in Figure 3), by actuating a switch SW. If the CONTROL BD detects that the signal on the line tested is out-of-range, the CONTROL BD issues a proper digital signal, via its BUS BUFFER, to the DIGITAL BUS. The proper component (an MPLCP or a DPLCP) responds to this signal, and adjusts its gain and phase, or both, accordingly.

These gains and phases must be adjusted in order to provide proper signal cancellation and isolation of the distortion signal, as required by known principles of feed-forward linearization using pre-distortion correction and post-distortion correction.

3. MPLCP1 and MPLCP2 are physically identical. LIN-LAM1 and LIN-LAM2 are also identical. DPLCP1 and DPLCP2 are also physical identical. (The term "identical," is, of course, subject to manufacturing tolerances.) Since these

components are identical, the types of active two-ports used by the invention of Figure 3 are limited to four in number, namely, (1) the LAM, (2) the MPLCPs, (3) the LIN LAMs, and (4) the DPLCPs. (The LIN LAMs contain a LAM circuit board.)

The use of four types of active components produces a cost saving in terms of the inventory of parts which must be maintained, both in manufacturing and for repair.

4. The amplifier of Figure 3 employs both pre-distortion correction and post-distortion correction.

5. Figure 7 resembles Figure 5, but with node numbers added for reference. It should be noted that some nodes are connected by short cables, such as nodes 22 and 23. These nodes are very close in signal amplitude and phase, and can be treated as a single node. Nodes N11 and N12 provide another example.

Numerous substitutions and modifications can be undertaken without departing from the true spirit and scope of the invention. What is desired to be secured by Letters Patent is the invention as defined in the following claims.



**CLAIMS:**

1. An amplifier, comprising:
  - a) gain stages, all of which comprise two-port devices; and
  - b) passive components which connect the gain stages into a feed-forward linear amplifier.
2. An amplifier according to claim 1, in which the gain stages comprise at least two substantially identical active two-ports.
3. An amplifier according to claim 1, in which the gain stages comprise three types of two-ports, and no more.
4. An amplifier according to claim 1, in which the gain stages comprise three pairs of active two-ports, each pair containing two substantially identical two-ports.
5. In a feed-forward amplifier which includes pre-distortion or post-distortion correction, or both, the improvement comprising:
  - a) gain stages, all of which are two-ported; and
  - b) passive components, including splitters and combiners, for connecting the gain stages into said amplifier.
6. Apparatus from which an amplifier may be constructed, comprising:
  - a) passive rf connection means, having pairs of ports, each pair for coupling to an active two-port gain stage, to produce a feed-forward linear amplifier; and
  - b) power supply means for powering the gain stages.



7. A method of testing an amplifier, comprising the following steps:

- a) removing only active two-port networks from the amplifier; and
- b) testing the active two-ports, based on an s-parameter test set, in order to identify faulty two-ports.

8. An rf amplifier, comprising:

- a) a first signal splitter (LCU A) for receiving a signal at an input (N1) and splitting it between nodes N2 and N3;
- b) a second signal splitter (LCU B) for receiving a signal at node N5 and splitting it between nodes N6 and N10;
- c) a first signal combiner (LCU C) for combining a signal at node N13 with a signal at node N7, and producing a combined signal at node N8, while passing a replica of the signal at node 13 to node 14;
- d) a second signal combiner (LCU D) for combining a signal at node N9 with a signal at node N15, and producing a combined signal at node N16;
- e) first amplifier means (MPLCP1) connecting between nodes N3 and N4, for amplifying a signal at N3;
- f) a cable connecting nodes N4 and N5;
- g) second amplifier means (MPLCP2) connecting between nodes N10 and N11, for amplifying a signal at N10;
- h) third amplifier means (LIN LAM1) connecting between nodes N11 and N13, for amplifying a signal at N11;
- i) a first delay line (PEDL), connecting between



nodes N14 and N15;

j) a second delay line (PDDL), connecting between nodes N6 and N7;

k) fourth amplifier means, (DPLCP1) connecting between nodes N8 and N9, for amplifying a signal at N8;

l) fifth amplifier means (LAU), for connecting between nodes N16 and N17, for amplifying a signal at node N16;

m) a third signal combiner (LAUC) for combining a signal at node N17 with a signal at node N18, and producing a combined signal at node N21, and producing a replica of the signal at node N17 at node N19;

n) sixth amplifier means (DPLCP2), connecting between nodes N21 and N22, for amplifying a signal at N21;

o) seventh amplifier means (LIN LAM 2), connecting between nodes N22 and N24, for amplifying a signal at node N23;

p) a third delay line (FCDL) connecting between nodes N19 and N20; and

q) a fourth signal combiner (ICU), for combining a signal at node N20 with a signal at node N24, and producing a combined signal at an output node N25.